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World Radio History

THE PRESIDENTIAL ADDRESS

of

Professor E. E. Zepler, Ph.D.

Delivered at the 33rd Annual General Meeting of the Institution, held in London on 26th November, 1958.

My first wish, as President of the Institution, is to say how much I appreciate the honour of being elected to this high office. It is a great distinction to head one's professional Institution, and I am fully conscious of the compliment paid me.

In particular, I express my thanks to Mr. George Marriott, and to those of my predecessors under whose Presidency I have served. I know the valuable work they have done and only hope that I may come within measurable distance of their contribution to the well-being of our profession.

I spent the first part of my life in the radio industry, and the experience gained in those years has been of great help to me in my present work. For this reason, I have chosen the needs of industry and its impact on technical education as the main theme of my Address.

It seems desirable to try first to reach agreement on the definition of the term "electronics". Whilst electronics does not appear in the title of our Institution, it is nevertheless descriptive of much of our work. In my early days this new branch of engineering was known as wireless. At some later stage the better word "radio" appeared and was commonly used by the beginning of the last war. As the use of the radio valve spread rapidly to fields not connected with communication, the new term "Electronics" was coined and I first heard it when I was lecturing in Cambridge in 1943.

It may be attributed to the conservatism of age if I still do not see the need for this new description, since the word Radio does even today include this wider sphere of activity. It is, after all, the technique rather than its application which is descriptive of a man's work. A radio engineer employed by a hospital to design and improve its electronic equipment, does for this reason not become a medical man, but remains a radio engineer!

This is, of course, a personal opinion. In any event the word Electronics is with us, and is likely to remain so. In general usage, however, the term Radio is the really comprehensive one, embracing both the electronics and the telecommunications engineer. Telecommunications has become so complicated that, without the art of radio, modern telecommunication systems would not be possible—hence the term Radio equally applies to this sphere of activity.

How difficult it is clearly to define these various technical terms may be seen from one example. The term Electronics has been described as "the conduction of electricity in gases or in vacuum". Some years ago, our own Technical Committee published in the *Journal* the definition "Electronics is the radio valve, or kindred devices, at work in ways other than communications". The first definition needs the addition "or in semi-conductor devices", but our own definition is still valid. Whether it will remain so when some new invention comes along depends on how far the term "kindred devices" can be stretched in its application.*

Terminology always raises vexatious questions. Be that as it may, readers of our *Journal* can be left in no doubt that the term Radio Engineer is meant in the comprehensive sense and that the Institution represents both the telecommunications and the electronics engineer.

Policy in Education.—Having discussed the problem of terminology, I turn to the far greater, and much more urgent, problem of how best to promote scientific training in this country. Quite recently our own Prime

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* The definition in the International Electrotechnical Vocabulary Group 07 Electronics (published by the International Electrotechnical Commission) is:—

> That branch of science and technology which deals with the study of the phenomena of conduction of electricity in a vacuum, in a gas, and in semi-conductors, and with the utilization of devices based on these phenomena.

Minister emphasized that the real asset which the nation possesses lies in its people; for with them lies our national flair for enterprise, for inventiveness, and for pioneering in all branches of activity. To make the most of these assets demands, however, a wise educational policy.

It has been the concern of post-war Governments to provide the benefits of a higher technical education for the greatest number of people. There is no need for me to outline the development of our universities and technical colleges, and the increasing incentives offered to students to secure a university degree, a Dip.Tech. or a Higher National Certificate. Those are the prospects open to every student if he can find the appropriate door.

Britain introduced the education scheme which entitles everyone to free schooling until the age of 15 or 16 and now 17 or 18 years. More recently, the free schooling principle has been extended into the sphere of further education; by the grants system, more students than ever before are able to continue further education up to and including university level. It is true that there still exist a large number of people who, as I know to my personal cost, are deemed to be too rich to receive full or even partial grants, but who nevertheless cannot send their children to universities without considerable sacrifice.

Even so, it is true to say that higher education is now within the reach of every boy and girl in this country who is judged able to cope with more advanced education. This is an achievement of which we in Britain can be justly proud.

I suggest, however, that we have no reason to be complacent. We have solved one important problem—that of providing the means. Unfortunately, we have yet to devise a system of selection so foolproof as to ensure adequate opportunity and direction, so that the very best may be brought out of our young people.

The difficulty of our task is demonstrated by the fate that has befallen the 11-plus examination. An increasing number of County Authorities are abandoning this form of selection and there must be sympathy with the view that an examination at such a low age is not the ideal method of determining a child's ability and aptitude. Admittedly, machinery provides for second thoughts at the age of 13 or thereabouts, but that does not deny the fact that the result of an examination may be deceptive—especially at such a young age.

I do not offer any immediate solution to the problem of adequate selection for a grammar school education. I have stressed it, however, because much the same difficulty arises with regard to vocational training. There are few problems so difficult as that of advising a student as to the channel in which he should direct his efforts. This subject is, in fact, one which should vitally interest the President of every engineering Institution, because it affects the whole question of how to make the best use of our scientific and technical manpower.

I will not attempt to lay down hard and fast rules, for to do so would, indeed, be pretentious. But to point out the existing problems, to make suggestions as to how they might be met, and thus to throw out a challenge to all those concerned, seems to me to be a duty that must not be shirked.

The selection of young men and women, capable of fully profiting by the opportunities that now exist is, in fact, one of the thorniest problems in the whole field of education. On the one hand is the increasing need for more engineers able to measure up to professional standards and, therefore, educated to the level of a university degree, a Dip.Tech., or a Higher National Certificate with appropriate endorsements; on the other hand there is the equally great need for technicians who are best catered for by the schemes of the Radio Trades Examination Board and the City and Guilds of London Institute.

Before a General Certificate of Education was established, our professional engineering bodies had an alternative form of selection. If a man had not what we then termed "Matriculated", he had to pass the preliminary examination of his appropriate professional body before he was permitted to go on to the Graduateship Examination.

It was a very good form of selection. Bearing in mind that under the new Education Act there might still be young people unable to obtain a General Certificate of Education before the age of 18 years, many of us thought that

World Radio History

it would be a good thing for the professional bodies to continue this preliminary examination. We particularly applauded the fact that most of the professional engineering bodies joined together in conducting such an examination under the auspices of the Engineering Joint Examinations Board. This was started in 1938, and as stated in our Annual Report, it is with mixed feelings that we see it coming to an end next year.

I would, however, suggest that the Engineering Joint Examinations Board might well continue in an advisory capacity. It could be the ideal vehicle by which the professional engineering Institutions might express their views on the education best suited for entry to the engineering profession.

As things are the fact is that unless a student has obtained a General Certificate of Education at "A" level in Mathematics and Physics at least, he will not be able to proceed to a Dip.Tech. course, nor gain admission to a University; if, moreover, the student has not obtained a General Certificate of Education at "O" level in the appropriate subjects, he cannot proceed to the Graduateship Examination of any of the professional Institutions. The only method then open to the student in order to qualify as an engineer is confined to the National Certificate scheme. This is not in any way a new procedure because the majority of engineers employed in industry have hitherto qualified by means of the National Certificate courses leading to the award of a Higher National Certificate with appropriate endorsements.

Recruitment or entry to those courses is, however, by no means as clearly defined as entry to a University, admission to a Dip.Tech. course, or to a professional examination. In practice, almost any boy, after leaving his first school, can enrol for an Ordinary National Certificate course. Figures are not available to show how many of the boys who enrol for a first year Ordinary National Certificate course eventually succeed in obtaining a Higher National Certificate.

If these figures were available on a country-wide basis, they would show a tremendous wastage of student effort; the wastage is in no small measure due to the admission of far too many students whose ambition is not matched by their intellectual capacity. The fault lies perhaps not so much with the student, as with inadequate methods of selection in determining whether the student is more suited to professional engineering training or vocational training as a craftsman or technician.

I do stress this viewpoint because it is essential that the engineer engaged in industry be adequately supported by technicians and craftsmen. Our own Institution has always attached great importance to the duty of the professional engineer to encourage the proper training of craftsmen.

We may broadly regard the Higher National Certificate with endorsements as the minimum qualification for a graduate engineer. I am well aware that some may hold to the view that this standard is not high enough. If the National Certificate scheme is ignored, however, we shall be confining entry to the engineering profession to those who have been fortunate enough to get a University degree or a Dip.Tech., or to those who pass the Graduateship Examination of their appropriate professional Institution.

Now I do want to make it clear that whilst, in my view, our Institution is wise to support the principle of a National Certificate scheme, I do not consider that the scheme does, at present, provide the proper training required of a radio and electronics engineer. As members are aware, a Higher National Certificate does not, in itself, secure exemption from the Graduateship Examination. For years we have been anxious to see a far more extensive radio and electronic engineering content in the Higher National Certificate scheme.

I am happy to state that an increasing number of colleges are, in fact, now arranging their Higher National Certificate courses so that they meet with the Institution's requirements. As professional engineers we welcome this co-operation with colleges so that we may secure the radio and electronics engineers who are so greatly needed. It would be optimistic to believe that the output from the Universities or from the new Dip.Tech. courses is likely to meet the demand for electronics engineers for some years to come.

All who work in Universities are well familiar with the fact that quite a large percentage of

University students have to leave Universities at the end of their first or second year because the courses have proved too difficult for them. Although their time of study has not been without some advantage to them, they must look upon it, and rightly so, as largely wasted. They are facing the future without any recognised qualification and their career is viewed with apprehension. Such cases also involve wastage of public funds.

Surely it is not beyond our ingenuity to evolve some means of offsetting the fallibility of selection methods. I think the solution of this problem is of the greatest importance in ensuring that we make the best use of our human material, thus enabling the individual to feel competent and content in his work.

As a basis for discussion, I suggest that we should review the whole of the technical education system. It should be broken up into the various stages of qualification right from the final Degree standard down to the first year of an Ordinary National Certificate course. Each interim stage of whatever course a student is taking could then be related to another stage of an alternative course.

In this way, each step of the course on which a student has started should provide opportunity to assess his suitability for continued progress in the same course or changing into another. Thus, a student who may not be able to cope with a University course might be more profitably directed into a Higher National Certificate scheme; or, if he is already engaged on a Higher National Certificate course and is proving unsuitable, he should be directed into a technician's course. The time he has spent in his first course should naturally be taken into account when redrafting him.

Teaching Methods.—Having reviewed the problem of selection and suitability I turn now to the problem of teaching methods. I think that all educationalists are agreed that such is the expansion of knowledge in almost every field of technology that it is quite a hopeless task to cover fully even one branch of engineering. This is a fact that can no longer be overlooked. Divergence of opinion can only exist as to the extent to which this fact should affect our teaching. The question to be answered is simply this: What should be stressed most, general knowledge or depth of understanding? My own opinion is that it is the latter we should aim at above all things and we should not be dismayed if, in the process, we find that larger parts of the subject are not adequately covered. There are plenty of books from which the student can acquire a general knowledge, but the ability to think for himself critically and objectively, that is something which he will best learn from lectures and tutorials and this, therefore, should be the foremost aim of inspired teaching.

After I had drafted this Address, the latest report of the University Grants Committee on university development during the next five years came out. In dealing with the problem I have just discussed, namely the ever expanding science and the limited time for teaching it, the report stresses that the first duty of a university to a student is to "teach him how to think". I was pleased at seeing it emphasized by such an authoritative body as the University Grants Committee.

The method of thinking, the fundamental treatment and the mathematical approach are often surprisingly similar in different branches of science, so that mastery in one subject is a large step towards mastery in others.

As one example amongst many I mention the phenomenon of resonance. Whether we are dealing with the oscillation of a mechanical system or that of an electrical system, the principles and equations are the same. What, in one case, is mass, compliance and friction is inductance, capacitance and resistance in the other. Actually, it is remarkable to what extent the understanding of mechanical systems has benefited from this analogy.

Hence, my advice to those engaged on higher technological teaching would be: If you find yourself hampered by lack of time, select topics which are of fundamental importance and wide application and, preferably, in which you are particularly interested. Go to a depth well beyond the level of the general knowledge conveyed, and show the way in which the principles involved may be applied in other subjects.

Apart from depth there are other aspects in teaching which are particularly important. One of them is the fostering of what might be called sound judgement, or perhaps less ambitiously,

World Radio History

common sense. It is well known that relatively simple expressions, such as the impedance of a parallel tuned circuit, may become extremely complicated if we try to be very exact. Admittedly, there are cases where such exactness is called for, but they are comparatively rare. The simple expression:

$$Z = Z_0 / \sqrt{1 + (2Q\delta f / f_0)^2}$$

tells us with sufficient accuracy what we want to know about magnitude of the impedance in the neighbourhood of the resonant frequency. The advantage of such a simple expression is apparent in the example of Fig. 1.

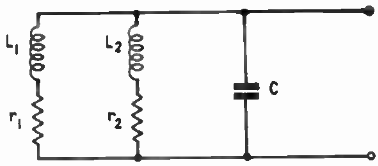

Fig. 1. Tuned circuit.

The students were asked to find, with reasonable accuracy, the resonant frequency f_0 and the impedance near f_0. I expected them to derive, by some simple means, the Q-factor of the circuit and then to write down the expression shown above. However, some students presented me with the following monstrosity:

$$Z = \frac{\dfrac{(r_1 + j\omega L_1)\,(r_2 + j\omega L_2)}{r_1 + r_2 + j\omega(L_1 + L_2)}\;\dfrac{1}{j\omega C}}{\dfrac{(r_1 + j\omega L_1)\,(r_2 + j\omega L_2)}{r_1 + r_2 + j\omega(L_1 + L_2)} + \dfrac{1}{j\omega C}}$$

Since numerical values were given you will not be surprised if these students did not get very far. They lacked, although they should not have done so, the ability to look, right from the start, for simplifications within permissible limits. This ability does not come easily and must be practised time and again.

Also of great value is the habit of looking critically at the final mathematical expressions, and finding ways of checking them. Again a simple case may serve as an example. A periodic time-base e.m.f. (Fig. 2) is applied to a series combination of R and L; the steady state current is to be found. If the e.m.f. is of form $V = at$ and if the time of repetition is T the expression for the current, taken over the time interval $0 < t < T$ is found to be:

$$i = \frac{at}{R} - \frac{aL}{R^2} + \frac{aT \exp\,(-Rt/L)}{R\{1 - \exp\,(-RT/L)\}}$$

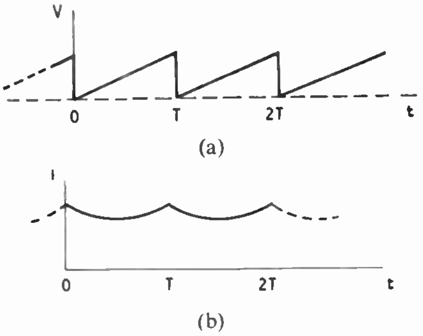

Fig. 2. (a) Saw-toothed e.m.f. (b) Current in series RL circuit to which the e.m.f. of (a) is applied.

The student, having arrived at this expression, usually does not give the problem a second thought. But he ought to satisfy himself, that the result is likely to be correct and he should find means of doing so. The first elementary method is to look at each term and see whether it is dimensionally correct.

The second, equally obvious step is to substitute for t the values 0 and T and verify that i is the same in both cases. Thirdly, since for $t = 0$ the e.m.f. is zero, $L\,\frac{di}{dt}$, having changed suddenly by $-aT$, must be at this moment equal to $-Ri$.

Finally, a little thought should tell him that the d.c. term of the current must be $aT/2R$, since $aT/2$ is the d.c. term of the e.m.f. Hence, by carrying out the simple procedure $\frac{1}{T}\int^{T} i\,dt$ the student will further strengthen his confidence in the correctness of the result.

If the graph of the steady state current is drawn it will be found to be a good deal closer to a sine curve than that of the e.m.f. The student will easily appreciate this point if he looks at the problem in the light of Fourier analysis.

Thus he has gained a deeper understanding of the transient behaviour of a single circuit. The following dialogue is typical of some such case:

World Radio History

Lecturer: "Have you derived the expression for the current in this circuit?"

Student: "Here it is."

Lecturer: "But this result cannot possibly be correct."

Student: "Why?"

Lecturer: "If the capacitance tends towards zero, the current must be zero too. That does not happen with your expression."

Student: "Oh. I hadn't thought of that."

This last phrase is symptomatic. Unless constantly urged, students have a tendency not to think beyond the immediate problem and thus they deprive themselves of a method which often enables them to see at a glance that their result must be faulty.

Accuracy of components is another item well worth our attention. I find that amongst students a lot of inaccurate thinking occurs in appreciating the function of components. I remember with amusement by own attitude when, as a student, I was faced with a grey metal case on which was printed 1μF. The fact that this might not be exactly 1μF and hence should not be used as a capacitance standard simply did not enter my head. In this I was just as wide of the mark as in another case when I used a standard resistance box as potential divider across the mains. When suddenly smoke came pouring out I began to suspect that somehow my judgement had been at fault. But then I was trained as a physicist and from the engineering point of view my training was open to criticism. It may come as a surprise that even today 3rd year students sometimes turn out to be nearly as innocent as I was in those far off days.

That electronics is not so shockingly inaccurate throughout as the normal components might lead him to believe, the student will readily appreciate when it comes to such subjects as frequency standards. Here we are in the enviable position to be able to point out that the accuracy achieved compares very favourably with any other branch of physics. At the same time the student will learn that in such cases light-hearted simplifications in the calculation, neglect of second-order effects, etc., are likely to prove fatal. So he will see that accuracy is a relative merit. Sometimes it is of paramount importance, but at other times it will be a wasted effort. If we foster this mentality which knows when to choose between perfection and compromise, we achieve something for which industry will be particularly grateful.

I have often heard it said in industry that a man who succeeds by a combination of will-power and common sense is more impressive than the man who succeeds because he is gifted. After all, any fool can get on if he is brilliant! In fact, many do!

A further point which I consider an important part of teaching is drawing attention to so-called snags or practical problems. It is very nice to read in books how the various circuits work, what their performance is, and so on. The young and innocent student, of course, takes it as gospel truth. When he works in the laboratory and finds that the circuit does not nearly behave as he expects, he is surprised, dismayed, and helpless. Here even very bright students come to grief.

The problems facing the teacher may be seen from the reactions of a highly intelligent student in one of my postgraduate Diploma courses. Within a somewhat complicated negative feedback loop which was part of a servo-mechanism, the results obtained differed substantially from those expected. The latter were based on the stage gain of a valve, recorded in the book as having a g_m of 10 mA/V. The fact that in the experiment the valve was run with an anode current of only 3 mA instead of the prescribed 12 mA in no way suggested to the student that the g_m might be substantially below the rated value. When this was pointed out to him he said: "How am I supposed to know that?". Such an example shows that things which, to the lecturer are so obvious that he forgets to hammer them in, are by no means self evident to the student.

In my opinion the student should become familiar with such problems in the course of his training at a university or technical college and not wait to learn them by bitter experience in industry. The sooner he learns his lesson the better, so that correct thinking becomes an automatic reaction with him.

While the equivalent of industrial experience cannot, and is not supposed to be, gained in a university or technical college laboratory, I strongly feel that thorough training involves good laboratory practice. What is meant by good laboratory training is clearly a matter of opinion and will, in any case, be a compromise between the time available and the ground to be covered.

Wired up and, as far as possible, foolproof experiments have their advantage. They enable the student to cover a good deal of ground, and strengthen his confidence in his ability to cope with the perversity of nature. But they should be followed up by experiments of another type, so-called projects. In these the student has to build up the whole experiment from nothing and is very much on his own. Such a project usually takes several weeks, presents the student with plenty of snags, and gives a foretaste of the type of work in industry. My experience has shown these projects to be a real success. Students appreciate their value, meet the difficulties with enthusiasm and feel afterwards that in some way they have become better engineers.

Although the rate of learning is slow in the laboratory as compared with lectures, there is much to be said in favour of giving the student maximum opportunity for practical work.

In assessing training and experience, professional Institutions might well comment on this method of teaching. I have no doubt that the qualified engineer, remembering his college days and viewing them in the light of his subsequent experience, can make a useful contribution to planning curricula in the laboratory. In my experience as an Institution representative, technical colleges appreciate any ideas which will improve the value of their courses.

Specialization.—At the beginning of my Address I stated that the vastly expanding field of knowledge in all branches of science, and the limited time available to students, are proving serious educational problems. It is this condition which has given rise to so much debate, much of it ill-informed, on the whole question of specialization.

Immediately that word "specialization" is mentioned, the critics, whatever the basis of their argument, cry "We must not give the students a narrow outlook". But narrowness of outlook need by no means result from specialization. In fact, specialization has existed for many years; we now have civil, mechanical, electrical, aeronautical, structural and many other branches of engineering, including our own.

At some universities, all engineering students cover a fairly common Part 1 syllabus where the wider issues of engineering are dealt with on a reasonably broad basis. At other universities even the common Part 1 is no longer maintained. In any case, the standard required in Part 1 of an engineering degree course is well below that required for the final parts. Thus we can fairly state that specialization of the engineer at undergraduate level is, and has been, a generally accepted fact for at least half a century. This tendency is bound to become even more prominent in the future, for obvious reasons.

There is some difference in pure science. A physicist, for example, usually takes all branches of physics up to his final examination, but even here the writing is on the wall. Besides the compulsory subjects he is given some optional ones, and the list of optional subjects seems to get longer every year. At some universities nuclear physics is taught at great length, naturally at the expense of some general physics which 50 years ago would have been considered indispensable.

Although it is easy to frown on such practice, it is, I think, both logical and sound, and in accordance with the principles stressed throughout this Address. Naturally we should avoid going too far. We would all deplore the establishment of a Bachelor of Servo-Mechanisms or of Computation.

On the other hand, Radio and Electronics, which includes most of the fundamental laws of physics, is now so vast that it has become a subject in its own right. To reach a knowledge in radio comparable with, say, that expected of a civil engineer, requires a very sound knowledge of physics and particularly of engineering and instrument techniques. A student properly covering such a course cannot be looked upon as having too narrow a scientific basis.

The same consideration applies to radio and electronic physics. Indeed, a university well known to me, and I hope to you, which can be very conservative, had no hesitation in sanctioning an honours degree in electronics, to start within the science faculty next year.

A new situation often requires new methods, and I think we should not be afraid of treading new paths. I am convinced that a university will be judged by the standard of its students, and if a high standard is achieved by unorthodox methods, then those methods are vindicated.

The question as to whether the increasing specialization forced upon us by lack of time goes hand in hand with an increasing neglect of the arts is quite a separate issue. We are all familiar with the picture of science students being barbarously uncultured, to the point of becoming morons, all of which is painted in lurid colours. Living in a technical age we might be forgiven if we felt tempted to draw the other picture of arts students whose knowledge of even the most elementary science facts is practically non-existent!

What should be done for the science student is a widely debated problem. Belonging to a university which feels very strongly on this question I do not want to take sides, but on the whole I do not share the pessimism so often expressed about our technical students. My experience has been that their interests are not as narrow as is often claimed. If, like undergraduates of all ages, they indulge in temporary crazes, this does not disturb me unduly. And some excesses of exuberance coming out on rag days seem to me, if we disregard the few really outrageous cases, no cause for despondency. Were we really so much better at that age? My own contacts with students has given me the impression that they are eager to learn, interested in many aspects of life and not as narrow as it often appears.

Indeed, it might, I think, well be argued that the undergraduate or student of today is required to work perhaps even harder than his predecessors. All of us who are concerned with drafting syllabuses know that it is a tremendous problem to keep within reasonable limits the introduction of new subjects, as the sum of human knowledge grows each year.

So even within the confines of a University Degree we have, as I have said, to allow for specialization. We have also found it in our own Institution, for although we have been considered in the past to be a rather specialized body, we have now found that the application of our particular knowledge to various industrial and commercial activities, has necessitated specialization outside our own field.

To cater for this specialized interest of our members, the Council has introduced a scheme whereby the Institution will have a number of Groups headed by Committees having special interest in the subject matter of the Group, e.g. Medical Electronics, Computers, etc. The further advantage of this work is the opening it makes for collaboration with other professional bodies which have an interest in the application of those specialized subjects. All of this could well lead to greater unanimity and understanding between the various professional bodies in the whole field of engineering. Few of us will deny that the engineering profession is by no means as closely knit as some of the older professions.

Research.—The part which research should play in technical education is a controversial question. I think, however, that industry is increasingly realizing that research enlivens and strengthens every branch of a university and can be of immense importance to industry itself. Where vigorous research is going on the students feel that their teachers speak with an air of authority, and this intangible inspiration, so important a part of good teaching, is bound to have effect. Hence, there can be little doubt that a good researcher who also has a flair for teaching will usually be better than the man who is only a good teacher. Where the real problem arises is when one has to choose between a good researcher who is a bad teacher, and a bad researcher who is a good teacher. This seems reminiscent of a captain trying to pick his best cricket team. Since it is not possible to have good all-rounders throughout, the solution is to select first-rate people of both types.

Because of its applicability to practically every branch of science, electronics as a research subject is making itself felt throughout universities. Contacts between the electronics and other departments become lively and both sides gain. The chemist, the biologist, the physicist and many others, in the course of their research, become something of an electronics engineer, while the latter frequently has to learn a good deal of the other sciences. Here the medical man should not be forgotten. To-day medical research without electronics is hard to imagine, and I would not be surprised if a good deal of medical research were to be carried out in the future in electronics departments.

The Professional Engineer.—We may ask ourselves now: "What is the function of a professional institution and how can it play an important part in the advancement of technical education?". Two responses immediately come to mind:—

> Firstly to set, by its examination, a standard considered to be adequate for the status of a professional engineer.
>
> Secondly, to give acknowledgment, by its different grades of membership, to the achievements of its members in their careers and to their position obtained.

The first of these is of considerable importance, because it defines the type of qualification which carries exemption from the Institution's Graduateship examination. It seems logical that an exempting qualification should not differ substantially from the Institution's requirements.

In the past, the percentage of those entering our Institution by way of the Graduateship examination has been high. It is to be expected, however, that with the greatly improved facilities for teaching radio at the technical colleges, and with the large increase in colleges whose courses are recognised for exemption, this percentage will go down in the near future.

The true function of a professional body does not lie in its being a means of securing qualifications. We members of the Institution should never forget that the prime object of the Institution is to advance science and knowledge. In that respect we should regard our monthly meetings, our Conventions, our Group activities and our Journal as means of postgraduate education. From those meetings and proceedings there is always something new to learn. It is therefore our function to ensure that our membership comprises the type of engineer who is eager and able to learn, and willing to exchange knowledge.

In return for the active part played by its members, the Institution, as a corporate body, becomes responsible for their prestige and well being. The Graduateship examination is one such factor of prestige. That its standard should be high is clearly understood although, as mentioned before, in fairness to those using it as an entrance door, the standard should not be unreasonable.

From my own experience in our Institution I know that in no way does it compete, nor does it try to compete, with universities or other examining bodies. Rather does it wish to contribute to their work in the field of education. Its aim is to help in the great task of utilizing to the largest possible degree the technical ability inherent in our nation.

I do not wish to suggest that the Institution's interest in education should be confined to purely engineering matters. I believe that my predecessor, Mr. Marriott, had something like this in mind when, in his Presidential Address*, he recommended that we might stimulate the provision of courses on the essential principles of industrial management and production.

Such topics play an extremely important part in the life of the engineer and of the country. I hope that we shall be able to do something during the next year in providing some platform for ventilating this question.

My last suggestion on extending Institution activities refers to books, the handmaiden of all teachers. We all know that in many branches of radio and electronic engineering there is a lack of authoritative and well written textbooks. I believe that through our membership we can provide not only advice, but actual help, and I hope to persuade our responsible Committees to initiate some action in this matter, for I believe this to be a very real way in which we can help all those engaged in teaching.

We live in an exciting scientific age. The discoveries made in our own lifetime have changed our conception of the universe. There are ample grounds for pride at our achievements, but even more grounds for humility. As our knowledge grows, so grows our admiration for the richness and complexity of nature.

As a corporate body our main purpose is to do all in our power to advance science. The gifts of nature are our heritage: to use them wisely for the benefit of mankind is our duty to God.

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* *J. Brit.I.R.E.*, **17**, pp. 5-13, January 1957.

Brit.I.R.E. Convention—July 1-5, 1959

Members have already received advice that the 1959 Institution Convention will be held in Cambridge and will have as its theme "Television Engineering in Science, Industry and Broadcasting."

Recent years have brought great strides in the engineering techniques and application of television. The papers read at the previous Institution Convention on this subject in 1951 were all concerned with television applied to broadcasting: whilst this application is still important to the radio and electronic engineering industry, both from the point of view of engineering effort and financial turnover, the techniques involved have been applied and extended over a wide field—in science, industry and in medicine. It is the Council's view that these applications will become even more important in the future, and they will therefore receive appropriate emphasis in the Convention programme.

The broad scheme of the Convention is that there will be four main Sessions, each lasting for a whole day and consisting of several groups of related papers.

The 1959 Convention Committee has already considered over forty papers and the first list of selected contributions will be published in the February *Journal*. The provisional arrangement of Sessions is given below and the final programme will be circulated to all members during March.

One particularly valuable feature of Institution Conventions in the past has been in the amount of time made available for discussion, which has been facilitated by previous distribution of preprints. Special discussion periods will again be arranged. Authors are being asked to base the presentation of their papers on demonstrations—there will of course also be a separate related display of static and working exhibits.

Residential accommodation has contributed greatly to the congenial atmosphere of previous Institution Conventions. This year, accommodation will mainly be available in four colleges—Downing, Peterhouse, Christ's and Sidney Sussex. All delegates staying for the *whole* period of the Convention can be guaranteed accommodation in one of these colleges.

Two regular features of Institution Conventions which will again find their place in the programme this year are the Clerk Maxwell Memorial Lecture and the Convention Banquet. The Clerk Maxwell Lecture will be given on the evening of Thursday, July 2nd, and the Convention Banquet will take place in the Hall of Downing College on Friday, 3rd July.

A special contribution to the Convention proceedings will be made by Dr. Vladimir F. Zworykin: it is especially appropriate that Dr. Zworykin should participate in a Convention on Television Engineering since he is so well known as an outstanding pioneer in this field.

The inclusive charge to members attending the whole period of the Convention will be £20. A form for provisional registration is enclosed with this issue of the *Journal*. It is particularly requested that members intending to be present should complete and return the form as soon as possible.

Arrangements may be made for the accommodation of members' ladies in one of the Ladies' Colleges for all or part of the Convention, if there is sufficient demand. For this reason also a quick return of registration forms will be appreciated.

PROVISIONAL PROGRAMME

Wednesday, July 1st	Session 1	Systems and Transmission.
Thursday, July 2nd	Session 2	Studio Equipment Engineering.
Friday, July 3rd	Session 3	Manufacturing Methods
Saturday, July 4th	Session 4	Industrial, Scientific and Colour Television.

World Radio History

Some Uses of Statistical Methods in the Manufacture of Radio and Television Receivers †

by

A. I. GODFREY, M.SC., A.R.C.S., D.I.C.‡

A paper read before a meeting of the Institution in London on 24th September 1958
In the Chair: Mr. D. W. Heightman (Member)

Summary: Statistical methods are described which help to reduce variation in the successive stages of receiver manufacture, assisting in the control of quality. The use of index numbers to indicate production quality is described, and the need for statistically designed experiments is outlined. It is shown that factory administration can sometimes be improved with statistical help.

Introduction

Statistics is the science which studies objects as groups rather than as individuals, paying special attention to the differences between groups. For example, not only are the thousands of receivers of any particular model different as a group from all the receivers of another model, but the individual receivers of one kind are different from each other, covering a whole range of sensitivities, band-widths, and so on. Statistics involves the mathematical study of variations within and between such groups. It is based on the fact that the variations observed in nature occur in patterns which are often very similar in quite different cases. Such patterns are called Distributions and are studied by using the theory of Probability (the "laws of chance"). Appendix 1 gives a brief outline of the probability theory used in receiver production.

Engineers have long used tolerances to accommodate the differences between receivers that should be identical. A small proportion of receivers is usually outside the specifications, but the manufacturing process itself has always been considered satisfactory so long as the proportion of defective sets was not too large. The pressure for greater efficiency has led to the study of behaviour within tolerances, in order to obtain early warning of impending trouble. Statistical methods are clearly suited to such studies, and have been adopted as the core of the "early warning system".

Statistical techniques are now widely used in industry. This paper attempts to summarize some of the aspects particularly suited to radio and television manufacture, but does not cover the general fundamentals. Reference should be made to any of the excellent books[1] on statistics and statistical quality control for these matters.

Although it is a highly mathematical science, statistics can be applied on the shop-floor apparently without mathematics. The technique is to observe the variations that are actually occurring, recording them on "control charts" which are effectively pieces of graph paper calibrated with the appropriate distribution. Deviations from an established pattern show up very quickly, and give early warning of a change in the production process. Corrective action on the process, as well as to individual products, may therefore be taken before many defective parts have been made.

Applications of Statistical Methods

Statistics may be applied at all stages from market research, which assesses future commercial requirements, through development, production and sales to the service department, which assesses problems in the field. Applications in the factory are mainly in the fields of quality control during manufacture, experimental design in development and production, and operations research in administration. These three fields will be treated separately.

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† Manuscript first received 8th August, 1958 and in final form on 13th October, 1958. (Paper No. 484.)

‡ Formerly Philips Croydon Works Ltd., now with Casablancas High Draft Co., Ltd.

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World Radio History

1. Quality Control in Production

The term "Quality Control" covers all aspects of ensuring the manufacture of uniform and acceptable products. The problems involved are purely technical, but statistics is a new and powerful weapon to help the engineer solve them. The statistician, who will handle the specialized mathematics, must subordinate his work to suit technical conditions. The philosophy of engineer and statistician when working at Quality Control will be "Prevention of trouble is better than cure".

The usual sequence in receiver production is:

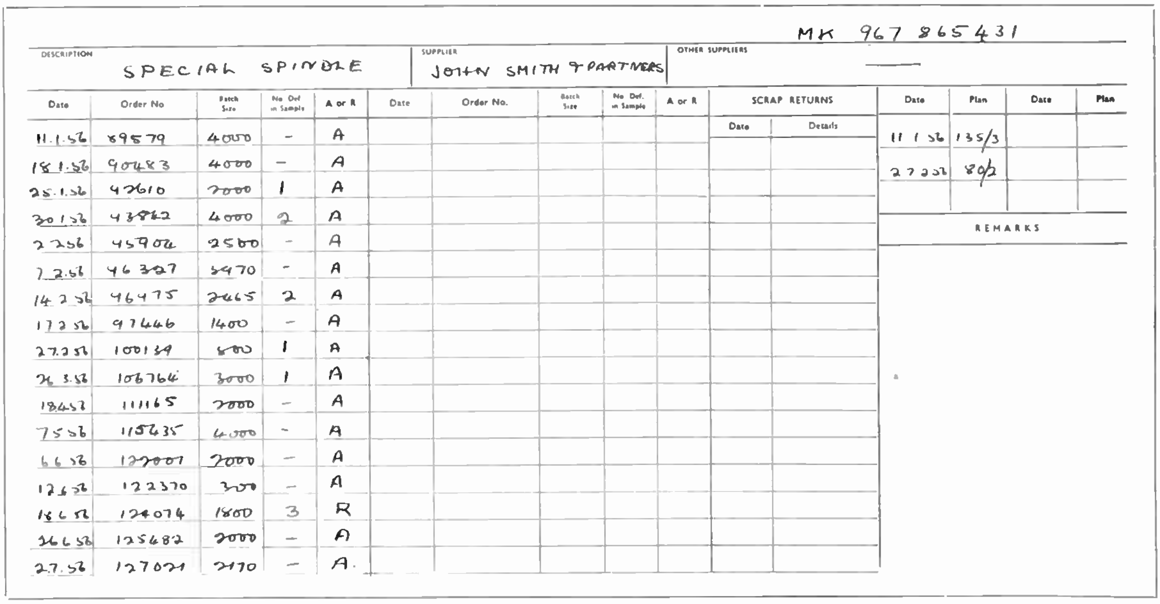
Purchase of raw materials
↓
Manufacture of components and sub-assemblies
↓
Assembly of chassis
↓
Casing and polishing
↓
Final inspection
↓
Despatch

Designers, of course, do not shed their responsibilities once production has begun; they remain vitally interested. The appropriate statistical aids to manufacture at all these stages also throw up information useful to the design engineers.

1.1. *Control of Raw Materials*

As in other industries, purchased goods usually arrive in batches. Despite the constant call from production departments for perfect raw material, the majority of processes can tolerate a small proportion of defective components. How large this proportion can be will depend on circumstances, but it must in any case be remembered that perfection is usually unobtainable; where it can be achieved, it is extremely costly. The inspection problem at this stage is therefore not to sort good items from bad, but to separate usable batches from those which are unacceptable through containing too high a proportion of defective items. The inspection of samples allows this distinction to be made quickly and cheaply, but with the risks of error always present when only samples are inspected.

It must be emphasized that the keeping of effective records is particularly vital in radio and television manufacture, where so high a proportion of the many different components is



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DESCRIPTION SPECIAL SPINDLE

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OTHER SUPPLIERS ——

Date	Order No	Batch Size	No Def in Sample	A or R	Date	Order No.	Batch Size	No. Def. in Sample	A or R
11.1.56	89579	4000	–	A					
18.1.56	90483	4000	–	A					
25.1.56	92610	2000	1	A					
30.1.56	93842	4000	2	A					
2.2.56	95902	2500	–	A					
7.2.56	96327	5470	–	A					
14.2.56	96475	2465	2	A					
17.2.56	97446	1400	–	A					
27.2.56	100134	800	1	A					
26.3.56	106764	3000	1	A					
18.4.56	111165	2000	–	A					
7.5.56	115635	4000	–	A					
6.6.56	122001	2000	–	A					
12.6.56	122370	300	–	A					
18.6.56	124074	1800	3	R					
26.6.56	125482	2000	–	A					
2.7.56	127021	2110	–	A.					

SCRAP RETURNS

Date	Details

Date	Plan	Date	Plan
11.1.56	135/3		
27.2.56	80/2		

REMARKS

Fig. 1. Record Card used with Sampling Plans for checking raw material.

normally purchased from outside suppliers. An effective and easily administered system for checking batches of raw materials is the use of appropriate Sampling Plans from Table 1, coupled with record cards similar to Fig. 1. The Acceptable Quality Level or AQL for each item is the batch quality (the percentage of defectives), which is declared "usable" by arrangement with the supplier; all batches of this quality or better should be accepted. This does not mean that all batches of worse quality than the AQL must be rejected, for slightly worse batches should be tolerable so long as they do not arrive too often. The poorer the quality, the less frequently it can be tolerated, and there will be qualities so bad as to be unacceptable at any time. The Lot Tolerance is a percentage of defectives chosen by the factory as the "upper limit" of unacceptable quality; all batches of this quality or worse should be rejected.

The use of sampling plans will nearly always involve:

(*a*) the acceptance of batches of better quality than the AQL,

(*b*) the rejection of batches worse than the Lot Tolerance.

Batches between the two qualities will sometimes be accepted and sometimes rejected, depending on the "luck of the draw" in choosing the sample. The factory requirements will lead to the choice of these two qualities, and the record cards will provide commentaries on the correct choice of plan and on the supplier. Purchasing policy may therefore be based on sound information. Moreover, the cost of the few

Table 1

Sampling Plans

AQL ½%				AQL 1%				AQL 2%			
Sample Size	Accept	Reject	Lot Tolerance	Sample Size	Accept	Reject	Lot Tolerance	Sample Size	Accept	Reject	Lot Tolerance
10	0	1	20·3%	5	0	1	37·0%	18	1	2	19·8%
70	1	2	5·6%	35	1	2	10·8%	40	2	3	12·7%
160	2	3	3·3%	80	2	3	6·6%	70	3	4	9·3%
270	3	4	2·5%	140	3	4	4·8%	100	4	5	8·0%
390	4	5	2·0%	200	4	5	4·0%	130	5	6	7·1%
520	5	6	1·8%	260	5	6	3·6%	160	6	7	6·6%
660	6	7	1·6%	330	6	7	3·2%	200	7	8	5·9%
800	7	8	1·5%	400	7	8	2·9%	230	8	9	5·6%
940	8	9	1·4%	470	8	9	2·8%	270	9	10	5·3%
1100	9	10	1·3%	540	9	10	2·6%	310	10	11	5·0%
1250	10	11	1·2%	620	10	11	2·5%				

AQL 3%				AQL 4%				AQL 5%			
Sample Size	Accept	Reject	Lot Tolerance	Sample Size	Accept	Reject	Lot Tolerance	Sample Size	Accept	Reject	Lot Tolerance
12	1	2	29·0%	9	1	2	37·0%	7	1	2	45·0%
25	2	3	19·5%	20	2	3	24·3%	16	2	3	29·7%
45	3	4	14·1%	35	3	4	18·0%	25	3	4	24·6%
65	4	5	11·9%	50	4	5	15·4%	40	4	5	19·0%
85	5	6	10·5%	65	5	6	13·8%	50	5	6	17·8%
110	6	7	9·5%	80	6	7	12·8%	65	6	7	15·7%
130	7	8	9·1%	100	7	8	11·5%	80	7	8	14·2%
160	8	9	8·1%	120	8	9	10·6%	95	8	9	13·1%
180	9	10	7·8%	140	9	10	10·1%	110	9	10	12·5%
210	10	11	7·3%	150	10	11	10·0%	125	10	11	12·0%

World Radio History

wrong decisions occurring when suitable plans are used will be far outweighed by the savings due to efficient inspection and a soundly based purchasing policy.

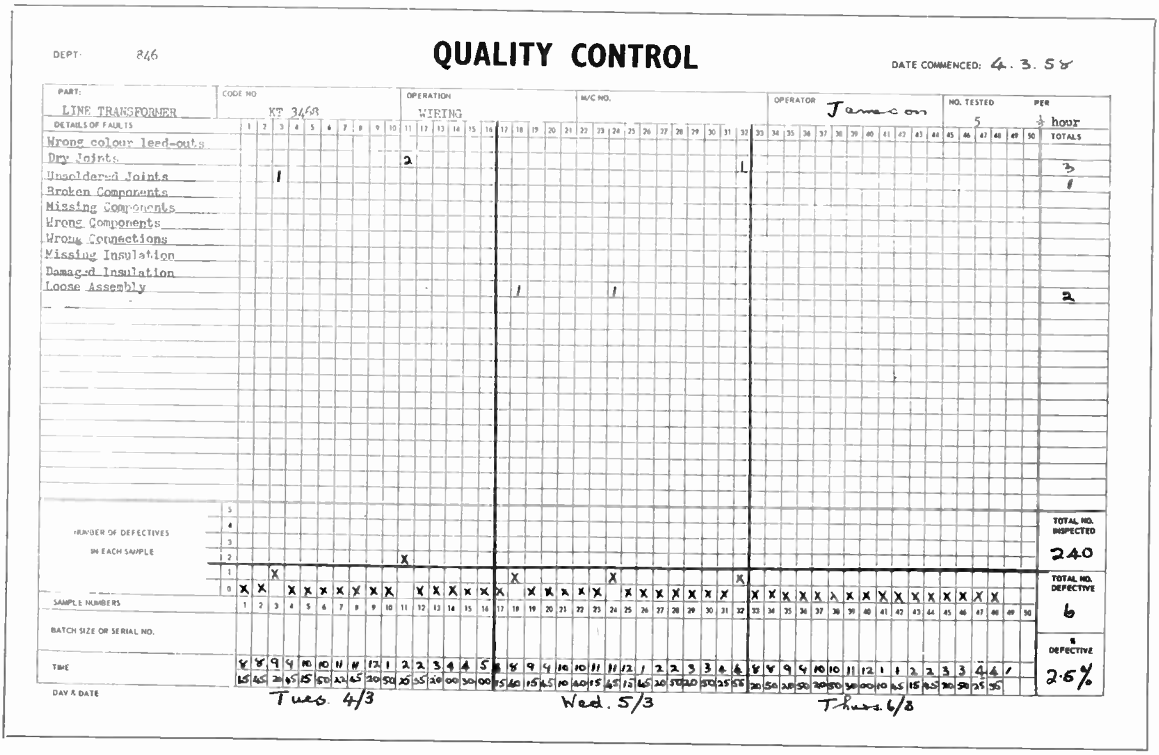
The theory behind sampling inspection is outlined in Appendix 2.

1.2. *Manufacture of Components and Sub-Assemblies*

The machine-shop methods used in the radio industry are identical with those used elsewhere, and the well-known techniques of control charts, patrol inspection and acceptance sampling are appropriate.

Coil-winding, loudspeaker assembly, tag-strip assembly and so on, are still largely manual work, although automatic methods are increasingly being used. Defective components may be produced either through faulty materials or through bad workmanship, and in either case the faults may appear either spasmodically or systematically. The quality control problems here are therefore very similar to those of the machine-shop, and similar techniques may be used for their solution.

Control may be maintained by patrol inspection at regular, suitably short intervals (e.g. half-hourly). Small samples (e.g. 5 components), are drawn at random from those made since the last visit, but for automatic processes the sample should include the last component made, to check that the machine has not just gone wrong. The samples are inspected and the inspection results recorded on a Control Chart as in Figs. 2(a) and 2(b). In either case the usual number of defectives is soon found from the charts, and once this has been brought down to a satisfactory level by suitable action, a "Control Line" is calculated and drawn on the chart to indicate the normal maximum number of defectives to be expected in any sample. A worse sample than this indicates that a systematic cause of faults has arisen, which should immediately be investigated. Thus the Control Chart distinguishes between the random variations that will always occur, and any systematic variation that may appear, and the number of defectives produced is minimised. Nevertheless, some defectives will still be produced, and as each batch of components is completed, a check is made to



QUALITY CONTROL

DEPT. 846

DATE COMMENCED: 4. 3. 58

PART: LINE TRANSFORMER

CODE NO KT 3468

OPERATION WIRING

M/C NO.

OPERATOR Jameson

NO. TESTED 5 PER ½ hour

DETAILS OF FAULTS	3	11	18	24	32	TOTALS
Wrong colour lead-outs						
Dry Joints		2			1	3
Unsoldered Joints	1					1
Broken Components						
Missing Components						
Wrong Components						
Wrong Connections						
Missing Insulation						
Damaged Insulation						
Loose Assembly			1	1		2

SAMPLE NUMBERS	NUMBER OF DEFECTIVES IN EACH SAMPLE	TIME	DAY & DATE
1	0	8 15	Tues. 4/3
2	0	8 45	
3	1	9 20	
4	0	9 45	
5	0	10 15	
6	0	10 50	
7	0	11 22	
8	0	11 45	
9	0	12 20	
10	0	1 50	
11	2	2 25	
12	0	2 55	
13	0	3 20	
14	0	4 00	
15	0	4 30	
16	0	5 00	
17	0	8 15	Wed. 5/3
18	1	8 40	
19	0	9 15	
20	0	9 45	
21	0	10 10	
22	0	10 40	
23	0	11 15	
24	1	11 45	
25	0	12 15	
26	0	1 45	
27	0	2 20	
28	0	2 50	
29	0	3 20	
30	0	3 50	
31	0	4 25	
32	1	4 55	
33	0	8 20	Thurs. 6/3
34	0	8 50	
35	0	9 20	
36	0	9 50	
37	0	10 20	
38	0	10 50	
39	0	11 30	
40	0	12 00	
41	0	1 10	
42	0	1 45	
43	0	2 15	
44	0	2 45	
45	0	3 20	
46	0	3 50	
47	0	4 25	
48	0	4 55	
49		/	
50			

BATCH SIZE OR SERIAL NO.

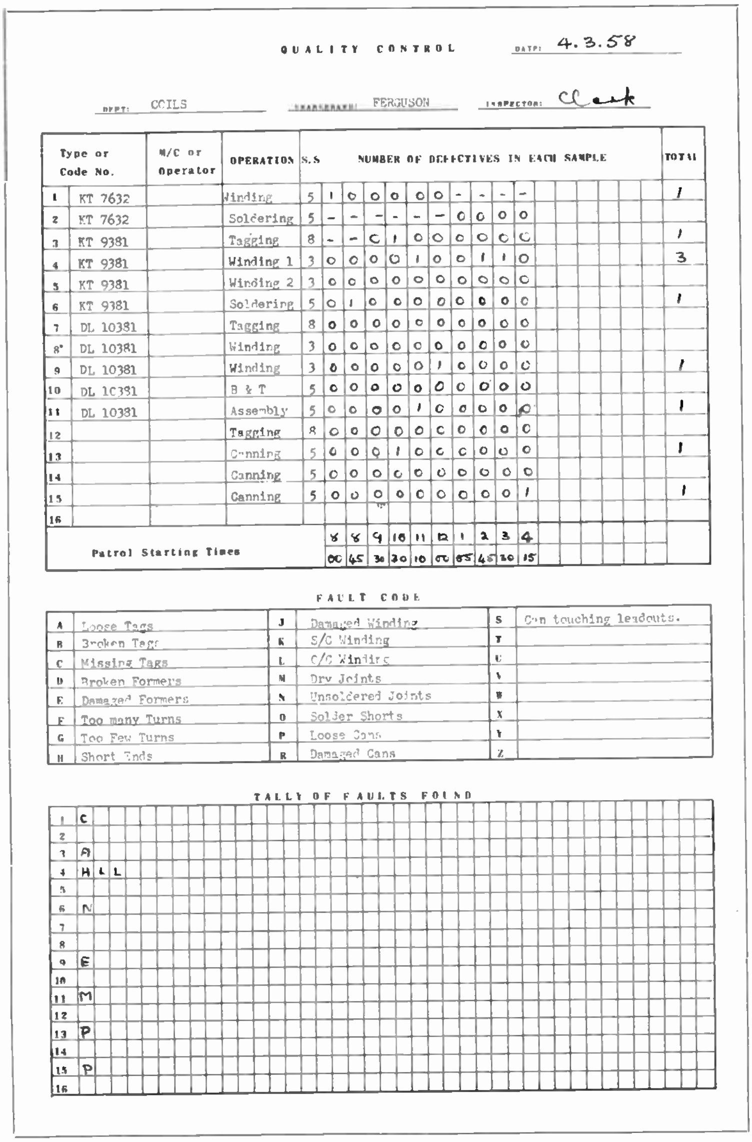
TOTAL NO. INSPECTED 240

TOTAL NO. DEFECTIVE 6

% DEFECTIVE 2·5%

Fig. 2. (a) Quality Control chart for individual working position.

World Radio History



QUALITY CONTROL DATE: 4.3.58

DEPT: COILS CHARGEHAND: FERGUSON INSPECTOR: Clark

Type or Code No.		M/C or Operator	OPERATION	S.S	NUMBER OF DEFECTIVES IN EACH SAMPLE																TOTAL
1	KT 7632		Winding	5	1	0	0	0	0	0	-	-	-	-							1
2	KT 7632		Soldering	5	-	-	-	-	-	-	0	0	0	0							
3	KT 9381		Tagging	8	-	-	0	1	0	0	0	0	0	0							1
4	KT 9381		Winding 1	3	0	0	0	0	1	0	0	1	1	0							3
5	KT 9381		Winding 2	3	0	0	0	0	0	0	0	0	0	0							
6	KT 9381		Soldering	5	0	1	0	0	0	0	0	0	0	0							1
7	DL 10381		Tagging	8	0	0	0	0	0	0	0	0	0	0							
8	DL 10381		Winding	3	0	0	0	0	0	0	0	0	0	0							
9	DL 10381		Winding	3	0	0	0	0	0	1	0	0	0	0							1
10	DL 10381		B & T	5	0	0	0	0	0	0	0	0	0	0							
11	DL 10381		Assembly	5	0	0	0	0	1	0	0	0	0	0							1
12			Tagging	8	0	0	0	0	0	0	0	0	0	0							
13			Canning	5	0	0	0	1	0	0	0	0	0	0							1
14			Canning	5	0	0	0	0	0	0	0	0	0	0							
15			Canning	5	0	0	0	0	0	0	0	0	0	1							1
16																					
Patrol Starting Times					8	8	9	10	11	12	1	2	3	4							
					00	45	30	30	10	00	05	45	30	15							

FAULT CODE

A	Loose Tags	J	Damaged Winding	S	Can touching leadouts.
B	Broken Tags	K	S/C Winding	T	
C	Missing Tags	L	C/C Winding	U	
D	Broken Formers	M	Dry Joints	V	
E	Damaged Formers	N	Unsoldered Joints	W	
F	Too many Turns	O	Solder Shorts	X	
G	Too Few Turns	P	Loose Cans	Y	
H	Short Ends	R	Damaged Cans	Z	

TALLY OF FAULTS FOUND

1	C		
2			
3	A		
4	H	L	L
5			
6	N		
7			
8			
9	E		
10			
11	M		
12			
13	P		
14			
15	P		
16			

Fig. 2. (b) Quality Control chart for group of working positions.

ensure that overall quality is adequate by a sample inspection on the lines of those used on raw materials.

Figure 2(a) illustrates the use of a chart at an individual working position and Fig. 2(b) its use over a group of working positions, the chart in this case being carried by the patrolling inspector. Both charts contain the technical analysis of any faults found, which is of enormous help in curing trouble.

Daily summaries of the numbers of defectives produced may be made for each group, and passed upwards to more senior supervision. This enables them to keep a watch on quality, and it has been found in practice that awareness of the upward movement of this information causes improved quality effort on the shop floor.

The size of samples to be inspected, and the frequency of the patrols, will depend on circumstances; no rigid rules can be laid down. The amount of inspection used will be a compromise between the cost of inspection and the cost of faulty production that might be permitted through insufficient inspection.

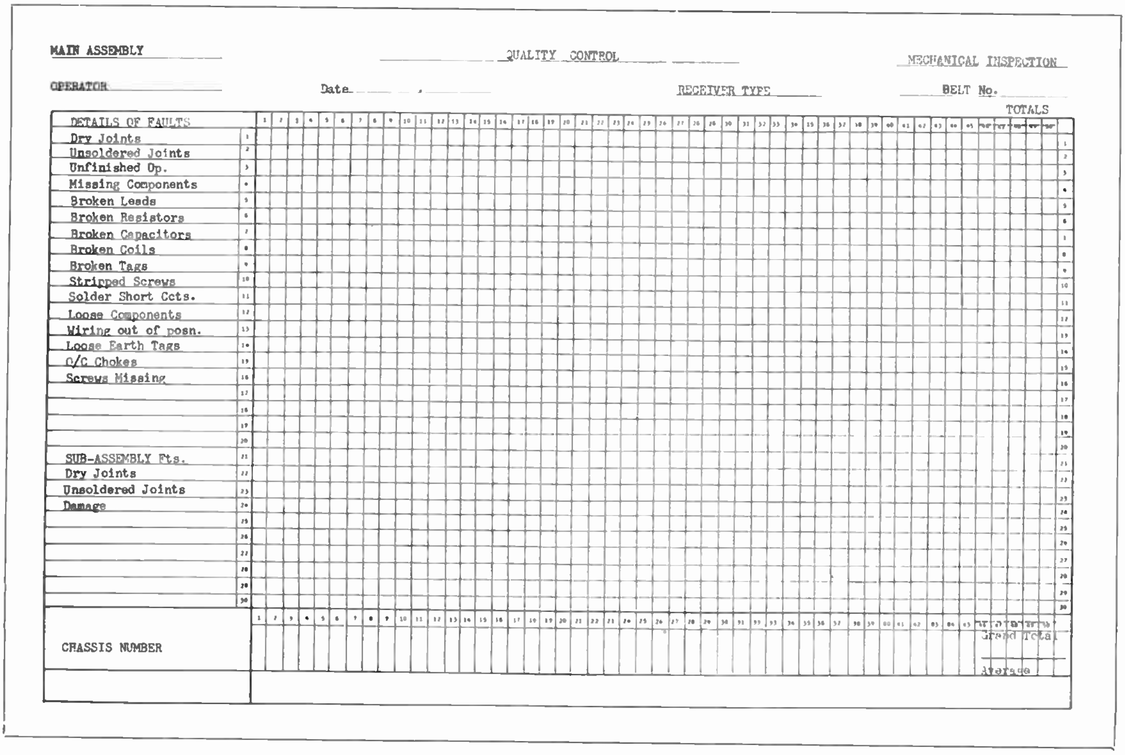
1.3. *Assembly of Chassis*

Because each chassis should function correctly on leaving the factory, sampling methods are no longer adequate. There are normally three inspection stages: mechanical inspection of the wired chassis, electrical inspection of its functioning, and final inspection covering both the appearance and operation of the finished receiver. There will usually be a number of inspectors performing identical work at each stage, and two quality control problems are

(a) the rapid correction of the causes of systematic faults, and

(b) the maintenance of uniform quality standards at the right quality level.

If the inspectors record their observations on suitable charts, any upsurge of a particular fault can be seen at once, and at the same time differences between inspectors' standards will be exposed. Production chargehands, by keeping an eye on faults recorded, can very quickly take whatever corrective action is necessary. A suit-



MAIN ASSEMBLY QUALITY CONTROL MECHANICAL INSPECTION

OPERATOR Date , RECEIVER TYPE BELT No.

TOTALS

DETAILS OF FAULTS

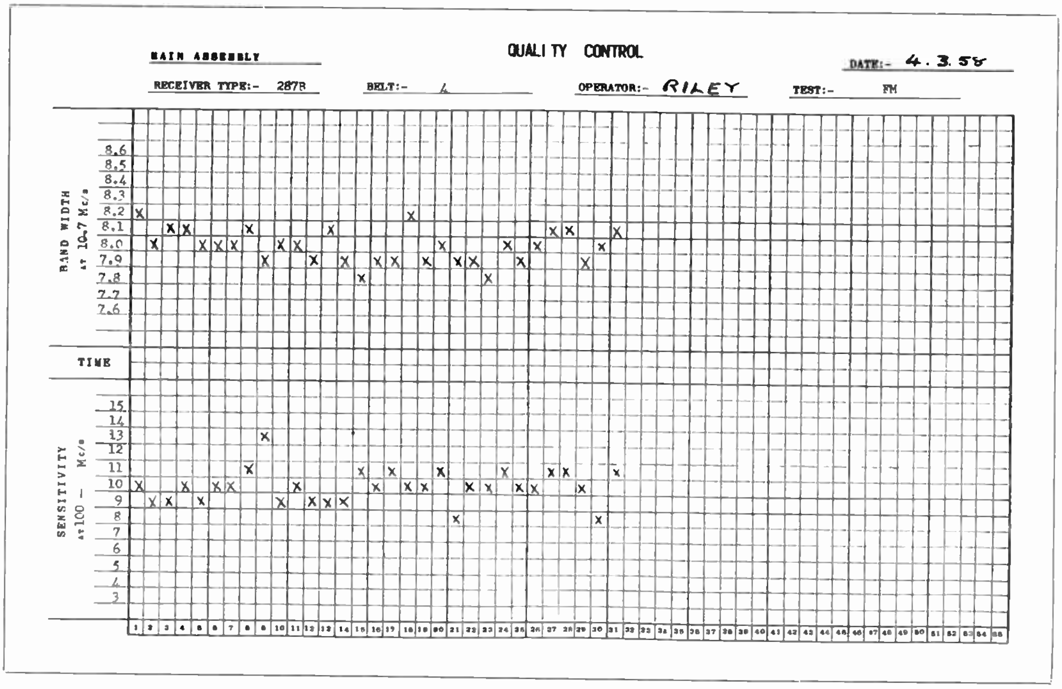
1 Dry Joints
2 Unsoldered Joints
3 Unfinished Op.
4 Missing Components
5 Broken Leads
6 Broken Resistors
7 Broken Capacitors
8 Broken Coils
9 Broken Tags
10 Stripped Screws
11 Solder Short Ccts.
12 Loose Components
13 Wiring out of posn.
14 Loose Earth Tags
15 O/C Chokes
16 Screws Missing
17
18
19
20
21 SUB-ASSEMBLY Fts.
22 Dry Joints
23 Unsoldered Joints
24 Damage
25
26
27
28
29
30

CHASSIS NUMBER

Grand Total

Average

Fig. 3. Chart for mechanical inspection.



MAIN ASSEMBLY QUALITY CONTROL DATE:- 4.3.58

RECEIVER TYPE:- 287B BELT:- 4 OPERATOR:- RILEY TEST:- FM

Fig. 4. (a) Chart for recording the electrical performance of radio receiver production.

able chart for mechanical inspection is shown in Fig. 3. A similar chart, but with room for many more faults, could be used at the final inspection stage, but it may be considered unwieldy. Faults could, of course, be grouped at final inspection, in order to pin-point their origin and so provide a check on earlier inspection.

While such action is not statistical in nature, it is a simplification of a statistical technique—the "defects-per-unit" chart. These charts are used to record the total numbers of faults in each unit of complicated product (e.g. each chassis), without regard to their nature. Control limits may be applied, as in the charts described in Section 1.2, to distinguish between random and systematic defects. Although very powerful, this technique is not always advisable on the assembly floor. It has been found that, because it labels the faults, the simplified version is more readily applied and understood by mechanical inspectors and their local supervision.

Electrical testing involves taking measurements of receiver performance. While it would be unnecessary to keep records of all these measurements, certain critical ones can provide an invaluable commentary on current production and on the equipment used to measure it. Figs. 4(a) and 4(b) show simple charts used respectively for radio and television alignment, and illustrate typical patterns of variation found in practice. Every set has these measurements recorded, and as there is no reason why a particular inspector should receive unusually good or bad chassis, the charts of all the inspectors should show similar patterns. Widely scattered patterns indicate careless alignment, and narrow patterns careful work. A chart showing different average levels from the rest indicates test-gear deviations, so that continuous commentaries on both work and test-gear are provided. Simultaneous drifts of average level on all charts point to a change in the production as a whole, and even such simple records as those illustrated here are very sensitive to drifts. When these occur, technical assistance can be called in before the change has caused a large accumulation of defective receivers; even an hour's early warning can save large sums of money. It has been found that inspectors and supervisors are familiarized with normal conditions by a few days' working, and they are quick to spot any change from the norm. Provision on the chart for details of rejection faults helps the overall administration, as well as providing further checks on the earlier assembly and mechanical inspection stages.

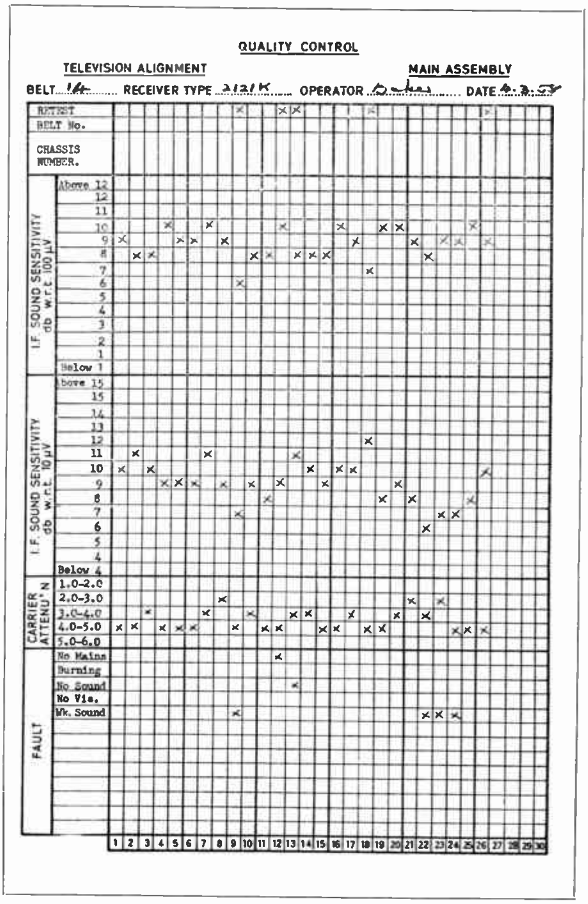


Fig. 4. (b) Chart for recording the electrical performance of television receiver production.

It is possible, if required, to fit control limits directly to the measurement records. This amounts to fixing the standard distribution pattern with which future production will be compared. However, it has been found in practice that the measurement records, without the limits, are usually sufficient for quality control purposes. An automatic inspection machine incorporating a built-in reference distribution has been described in this *Journal*[3].

A most useful by-product of the measurement records is the information they provide for

World Radio History

designers, who must predict, from very few prototypes, the performance of their designs in the factory. While past production measurements cannot help at the inception of a completely new design, it remains true that most receivers are derived more or less closely from earlier types. The relation between prototype and production performances on the earlier sets can therefore give some guidance to designers working on the derivatives.

Another by-product is that the measurements made as routine on the first few production chassis of a new design can help in fixing production test limits. Practical limits should satisfy both commercial requirements and the factory demand for a small reject rate; these are not necessarily compatible, and any discrepancies must be noticed as quickly as possible. By fitting a theoretical distribution pattern to the first few production measurements recorded, the whole range of future measurements can be accurately predicted, even if the ends of the range have not been included in the receivers so far made. Moreover, the proportion of sets showing extreme behaviour will be accurately known. By this means, those responsible for setting limits can confidently take appropriate action at the earliest possible moment.

1.4. *Using index numbers in overall factory control*

Senior management should not be burdened with too much detail of the factory quality situation, yet must be fed with up-to-date information. Giving a "Customer Test" to a sample of finished receivers can provide information which is both a detailed check on all factory work and a means of supplying accurate, but undetailed quality information to management. This sample customer test may be carried out by a department which "represents" the consumer and remains reasonably independent of the factory organization. Reports on each 100 tested sets of a type could be used by the factory as part of its quality control procedure. In addition, if the faults reported are graded according to severity, an index number may be constructed which is presented to Management as a "Quality Number".

The index number is constructed by allocating "penalty points" according to the severity of each fault. After, say, 10 sets of a kind have been checked, the total number of penalty points in them is subtracted from, say, 100, leaving a "Quality Number" for that sample. In this way, perfect quality, i.e. no faults, will have a Quality Number of 100, and poorer qualities will be represented by smaller numbers. There will be separate quality numbers for each type of receiver being made.

Naturally, there will be wide fluctuations of quality number from one sample of sets to another of the same type, even if the overall production quality is constant. These fluctuations must be smoothed out if a true picture is to be presented to Management. In any case, managers will instinctively apply mental smoothing if none is included in their figures. A simple smoothing device is an average over a period of time. If this average is taken from the beginning of a production run, the early history of the receiver (often bad), will weight the average quality number, but the average over the last, say, 10 samples of 10 sets will not vary as much, and will be a better index of current quality. The numbers will now be based on the last 100 sets tested, and a new figure will be available for each type of receiver after every 10 sets of the type have been tested.

The fluctuations from one number to another will now be reasonably small, but will still be there, even if production quality is constant.

By using a technique similar to that of control charts on measurements, the Quality Number quoted may be constant, except when there is a real change of quality. In this method, simple statistical calculations provide boundaries for the area of random fluctuation, and a true change of quality is indicated by a 10-set sample whose Quality Number oversteps the boundary. The Quality Numbers quoted to Management will be the averages for 10 samples of 10 sets of each type of receiver, and will be altered only when there is evidence of a quality change. The new numbers will be the averages for the last 10 samples of 10 sets.

It has been found in practice that Quality Numbers have provided a useful stimulus to the factory, for efforts by the workers to better the current Quality Number show immediate results, and an interest in *quality* is maintained at little cost.

World Radio History

2. Analysis of Field Returns

The true test of a design is not in the factory, but in the field. After some months of use faults may appear that call for design changes, and it is vital to introduce such changes at the earliest possible moment. Therefore, information from the field must be analysed both rapidly and accurately, separating systematic faults that call for design changes from the random faults due to bad components. Engineering judgement has always been used in making this distinction, and must so continue, but statistical "tests of significance" can be used as rapid and simple mathematical aids to judgement. They are more sensitive than human estimation, and give quantitative answers to the question "How likely is it that the relatively high frequency of a given fault is merely due to chance?" When this likelihood is low, the fault probably calls for a design change.

Where punched card installations are available, service returns may rapidly be punched into cards and analysed automatically by the machine. Even the statistical calculations may be performed automatically, and the machines can supply the engineer with printed lists of items calling for decisions; items not on this list may be ignored. It must again be emphasized that statistical methods do not replace engineering. They are an additional weapon to help the engineer, who must still have the last word.

3. The Design of Experiments

Experimentation in the radio and television industry has hitherto been used mostly in development work. Experiments in the factory have been limited to testing the gradual introduction of new techniques as they were developed, and the flexibility of human labour allowed gradual, tested changes, with retractions when necessary. The use of more automatic production methods involves much loss of flexibility, and it will be necessary to carry out all experimental work before a change of technique is introduced. Indeed, it will be necessary to experiment initially in order to find the most efficient production process, e.g. to establish the conditions of time, temperature and so on, which will yield receivers needing the minimum of manual repair work. For example, the solder bath, which can produce good or faulty joints, illustrates the need to find optimal conditions.

Where many variables operate simultaneously, the most effective form of experimentation is that which lends itself to comprehensive statistical analysis. This is because the sources of error that are always present in a process may mask an effect being studied, unless care is taken to separate the random variations they cause from the main effect. It has already been seen how statistical techniques distinguish random from systematic variation in production; they perform the same task in experimentation. Traditionally. experimentation involved eliminating unwanted variations from the tests, but statistically designed experiments are more realistic in that they try to reproduce normal conditions during the experiments. The practical effect of whatever is being tested can therefore be assessed in its true light. In the near future, the pilot production runs will have to be experiments on a scale far more lavish than anything at present carried out in a receiver factory, with the statistician as the inseparable ally of the methods engineer.

It may well be that the best manufacturing conditions change with time, because some of the uncontrolled variables have altered. A process which began efficiently may therefore become less so, since the constant, controlled conditions then need to be changed. Continuous experimentation during production, involving very small changes of the controlled conditions around the original standard, will detect any drift of the optimum without involving significant changes of efficiency. This continuous experimentation will be incorporated in the automatic production process, thereby allowing "evolutionary development", in which the process will follow the most efficient conditions wherever they wander[4].

Experiments leading to evolutionary development may be applied equally to the present systems of manual assembly. For instance, it may be that the best production factors, even with human labour, change in time. The kind of experiments already carried out by production and work study engineers could be extended to allow for evolutionary development. In any case, the transition to the automatic factory is gradual, and the time is already here

World Radio History

when parts of the production process are mechanized. Dip-soldering is an example.

Design and development engineers will, of course, continue to experiment as in the past. Statistically designed experiments will therefore continue to be of value to them.

4. Operations Research

Management techniques, as well as production techniques, can always be improved, but it is only recently that scientific attention has been concentrated on the interactions between production and management. Attempts are now being made to express quantitatively the effects of management decisions on production. For example, the amount of raw material and components held as stock will affect the quality and quantity of receiver production, especially if stocks are low. A stock policy is an attempt to balance the capital cost of stocks against the cost of poor quality and lost production caused by shortage of material. Because of the random element in both the delivery of raw materials and their consumption by the factory, the problem of finding the optimum stock of an item is partly statistical. An "Operations Research" team (which studies the operation of a factory). will therefore include a statistician as well as other specialists in tackling such problems of factory administration.

Many problems that seem unconnected with production may nevertheless have a strong bearing on it, and may be tackled quantitatively by the methods of operations research, including statistics. Wages, the provision of amenities, the flow of material through a factory, and so on, all of which are complicated by random elements, can be tackled with the help of statistics, and solutions found.

5. Conclusion

It will be apparent that the statistical techniques discussed can be applied far more widely than to radio and television receiver production. They are well established in practically every industry, and similar papers have been written on the applications in other industries. Radio and television production, one of the most recent industries, has not been bound by tradition, and has been one of the leaders in the adoption of statistics, yet there is still the fear of "mumbo-jumbo" in some sections of the industry. It is hoped that this paper will dispel some of these fears by showing that, although statistics can be a heavily mathematical topic, its industrial applications are merely common sense made scientific. The factory floor supervision can be provided with statistical methods in forms which are at once understood and appreciated, while more high-powered mathematics can be applied to rather involved problems of design and administration.

6. Acknowledgments

The author wishes to thank Philips Electrical Industries Ltd. for permission to use much material, and Messrs. S. H. Perry and R. H. S. Lesser for their helpful criticism.

7. References

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O. L. Davies (ed.), "Statistical Methods in Research and Production" (1947), and "The Design and Analysis of Industrial Experiments" (1954). Published by Oliver & Boyd, London.
2. Some of the uses of statistical quality control in industry are described in a pamphlet "BPC Case Studies: No. 3—Quality Control," published by the British Productivity Council.
3. P. Huggins, "Statistical computers as applied to industrial control." *J.Brit.I.R.E.*, **14**, p. 309, July 1954.
4. The so-called "evolutionary development" technique was perfected in chemical production at I.C.I. by Dr. G. E. P. Box. It is described in more detail in "The Design and Analysis of Industrial Experiments" above.

8. Appendix 1: An Outline of Basic Theory

8.1. *Probability Theory. (The Laws of Chance.)*

The throw of a die can give only one of the numbers 1 to 6. In any throw of an unbiased die, there is therefore one chance in six of the occurrence of a specified number in the range 1 to 6. Putting it another way, the *probability* is 1/6, or 0·166 . . . , of seeing this number in the next throw. This statement has been made merely from the prior knowledge that all the numbers have equal chances of occurring.

We have been led to the idea of measuring a probability (or chance), and a little thought will show that the scale of measurement ranges from 0, which represents "impossibility", to 1, corresponding to "certainty". It will further be noticed that the probability of a particular num-

World Radio History

ber being observed at the next throw is the same as the proportion of throws in which it will occur in the long run. Putting it in the language of statistics, "probability" is identified with "relative frequency."

In other situations, where the possible observations do not all have equal chances of occurring, the same rules apply. For example, if a sack contains 10,000 red, 8,000 green and 5,000 blue marbles, well mixed, then a single marble chosen at random will have a probability

10,000/23,000 or 0·435 of being red,
8,000/23,000 or 0·348 of being green,
5,000/23,000 or 0·217 of being blue.

The total probability of obtaining either red, green or blue is 0·435 + 0·348 + 0·217, which is, of course, 1, for we are certain to have one of these colours.

In more complicated cases, the proportions will still be the appropriate probabilities, but may not be so easy to calculate. Very often recourse must be made to the theory of permutations and combinations, in order to find

(1) the number of ways in which the desired event occurs (this will be the numerator in the probability fraction), and
(2) the total number of possible observations (the denominator of the fraction).

When several events, to each of which a probability can be assigned, occur simultaneously, we must MULTIPLY their separate probabilities in order to obtain the probability of all events occurring together. For example, if we throw 3 unbiased dice, the combined probability of three sixes is $1/6 \times 1/6 \times 1/6$, or 1/216, since the probability of a six from each die is 1/6.

The addition of probabilities has already been illustrated above. Probabilities are ADDED when there are several alternative events (say A, B, C . . .), only one of which can appear at a time; the probability of (EITHER A, OR B OR C . . .) is equal to (Probability of A) + (Probability of B) + (Probability of C). . . .

8.2. *Frequency Distributions*

In nature it is very often impossible to calculate probabilities from first principles, as can be done with dice. Statements of probability must therefore depend on large numbers of observations; the probability of a single event is associated with the proportion of times it has occurred. (This assumes that there is safety in numbers, so that the large number of observations accurately represents the truth.) The statement of the observed frequencies of all events is thus the pattern of probabilities, and is called the Frequency Distribution.

Some patterns occur in widely different circumstances, and appear so frequently that they have been found worthy of mathematical study. An example of this is the so-called Gaussian or Normal Distribution, which tends to occur when large numbers of individual measurements can be made. For example, the heights, or the weights, or leg-lengths, etc., of a group of people will all tend to have Normal Distribution patterns of occurrence, as will measurements connected with repetition machined parts, valve anode currents, and so on. A mathematical knowledge of the Normal Distribution, and the knowledge that it applies in a certain case, will therefore allow the calculation of any individual probabilities in that instance. The Normal Distribution underlies Quality Control charts based on measurements of items; the control limits are calculated on the assumption that the product's characteristics obey the Normal law.

Other types of distribution apply when samples of individual items are drawn from batches. These are the basis of the Quality Control charts that involve the classification of inspected items as "good" or "bad". Many distributions, including these and the Normal law, can be derived from first principles on mathematical grounds, and so have more than empirical justification.

9. Appendix 2:

The Mathematics of Sampling Inspection

The principles of acceptance sampling will be found in the textbooks on statistical quality control, but a simple outline is given here in order to help in understanding how to choose a sampling plan.

The purpose of sampling is to test the acceptability of a batch. Very good and very bad batch qualities will usually be clearly recognized from the samples, but medium qualities will sometimes give good samples, and sometimes bad. Incorrect decisions are therefore possible, but larger samples will give better discrimination than smaller ones, although at greater cost.

World Radio History

It is necessary to know the chance of accepting a batch of any quality with a given sampling plan, and the laws of chance may be used to calculate it. How they are used will be shown by an example.

Consider the sampling plan
"Sample Size = 100; Acceptance No. = 1".

This means that a sample of 100 items is to be chosen *at random* from each batch; batches having 1 or less defectives in their samples will be accepted, and those having more than 1 defective will be rejected. A batch containing, say, 5% defectives will average 5 defectives per sample, but some other number may be found in practice. The chance of accepting such a batch is the chance of having 1 or 0 defectives in a sample; this is the sum of the separate chances for one defective and no defectives, which are found as follows:

Chance of 0 defectives: Each of the 100 chosen items must be good, and the chance of a randomly chosen individual being good is 95% or 0·95. The chance of all 100 being simultaneously good is therefore $(0{\cdot}95)^{100}$, which is 0·006.

Chance of 1 defective: The chance of a randomly chosen individual being defective is 5% or 0·05, while the chance of the other 99 individuals being good is $(0{\cdot}95)^{99}$. The combined chance is therefore $(0{\cdot}05).(0{\cdot}95)^{99}$. But any of the 100 could be the good item, so that 1 defective will occur 100 times more frequently than the expression $(0{\cdot}05).(0{\cdot}95)^{99}$ indicates. The true chance of 1 defective is therefore $100.(0{\cdot}05).(0{\cdot}95)^{99}$, which is 0·031.

The total chance of either 1 or 0 defectives is therefore 0·031 + 0·006, or 0·037. In other words, 3·7% of submitted batches containing 5% defectives will be accepted by this plan.

The chance of accepting any other batch quality with this plan may be similarly found, so that the risk of

(*a*) accepting poor qualities, and

(*b*) rejecting usable qualities

may be judged. It is helpful to plot a graph of "Chance of Acceptance" against "Batch Quality"; the curve obtained is called the "Operating Characteristic" for the plan. The AQL and Lot Tolerance are suitably defined "good" and "bad" qualities on the curve, and are measures for the two risks mentioned above. A suitable plan for any item may therefore be chosen from a table calibrated in AQL's and Lot Tolerances.

DISCUSSION

V. H. Piddington (Associate Member): Today in the radio industry, with the coming of new and more complex techniques, costs must be kept down in order to realise the full possibilities that exist. The use of statistical methods is one of the ways in which this end can be achieved.

I believe that very few people today have any doubts about quality control, as such. Every manufacturer tries to control quality in more or less an effective way. It is not, however, generally realized that in these days of large batch or mass production, and flow line manufacturing techniques, statistical methods are by far the most effective way of obtaining information about quality trends. This lack of realization does, of course, imply a lack of knowledge of what statistics can or cannot do. Although the day will come when statistics is as integral a part of an engineer's training as mathematics, that day hasn't come yet. In the meantime we have to contend with not only a lack of knowledge, but some mistaken beliefs too.

Some of the blame for this must be attributed to the way in which statistics are presented in certain cases. One sees, for example, case histories given in which it is shown what large variations exist in a process and how small they become after the application of statistical methods. The implication is there that the application of statistical methods have by themselves brought about this very beneficial change, which is not quite true.

Statistics is, I think, a tool which will show whether or not there are variations in a process which are not ascribable to chance and which it is therefore economically profitable to seek out and eliminate, but statistics will not tell you to what a given variation is due.

Statistical methods will give information that a fault is developing in a process before that fault has gone so far as to actually produce the production of unacceptable articles. It will not tell what that fault is, although it can be designed to give useful pointers, as Mr. Godfrey has shown us, but you still have to go and look for the trouble yourself.

T. H. Beech: It seems to me that a "minimum programme" on statistics that every radio engineer would find it useful to achieve would comprise three items:

(a) A general appreciation of what the various branches of the subject are concerned with and the types of problem they can help to solve;

(b) Ability to manipulate the simpler tests and estimates based on the normal (Gaussian) distribution:

(c) Some appreciation of the assumptions (e.g. normality, random sampling, independance of observations) on which the techniques are based.

With regard to (a) Mr. Godfrey's paper goes a long way to meeting the need; on (b) I suspect that many of those present will have this knowledge or are in process of acquiring it.

It is on (c) that I would like to inject a note of caution. When reading a statistical textbook one tends to skip the constantly reiterated remarks on the assumptions underlying the various tests, merely murmuring "of course" and proceeding rapidly to the magic formulae. Fortunately it is often the case that the practical result is not seriously jeopardized even when some of the assumptions are not strictly justified. This is so in many situations, but not all.

I recall a government valve specification which incorporated a tolerance of 2pF on an inter-electrode capacitance. In view of the geometry and construction of the valve I thought this unnecessarily wide and measured up a sample of 12; all were within a range of 0·2pF. When I raised the question of tightening the specification so that this unexpected consistency could legitimately be utilized by designers, it was pointed out to me that the specification was framed to accept, under the same Service type number, the products of several manufacturers. Each of them was working to a tolerance of about ±0·1pF but about widely differing mean values! You may say I should have taken my sample in a random manner. Very true, but however I had taken a sample from the valves in my establishment store, I should still have reached the same (wrong) conclusion, for all were from the same manufacturer. Even if a sample is drawn correctly in a random manner, if it is taken from a sub-group (in this case a particular bin) of the total population then conclusions derived from that sample only hold true for the sub-group sampled, unless the items comprising the sub-group are themselves a random sample of the total population.

A branch of statistics of increasing importance to the radio industry is the compounding of tolerances, whereby knowledge of the tolerances on various individual components (and their distribution within their respective limits) may be used to derive the tolerance of one or more output parameters (gain, power, frequency, etc.) that may be expected from ostensibly "identical" models in a production run. It is often assumed that if a number of sources of variation are simultaneously present, the total variation will follow the Normal Law fairly closely, even if the separate sources of variation are individually far from "normal". This is only true provided that these sources are all of the same order of magnitude, or at least that one or two sources do not swamp the others in their contribution to the total variation. It is also important that the various sources of error should operate independently.

Closely allied to the topic of compounding of tolerances is the matter of "optimum design". In its simplest form, this consists of choosing the tolerances on each of those components affecting a major output parameter so that each has roughly the same influence on the tolerance of the output parameter. This principle, or a more sophisticated development of the same idea, usually leads to the most economical design. Too often one finds designers demanding close tolerances (which are usually costly) on *all* components even though only a limited number can significantly affect the output tolerance of the unit. By suitably balancing the tolerances of the various items it is possible to achieve closer-tolerance performance for the same cost (by using cheaper wide-tolerance components in the less significant positions, and applying the saving to get the closest possible tolerance components in one or two critical posi-

World Radio History

tions), or alternatively to achieve the same performance at a lower cost. A disadvantage of "optimum design" on these lines is that if there is a sudden "crash" demand for a closer tolerance performance than was originally asked for, there is nothing for it but a major redesign. For this reason the economic advantages can only be realized if the performance specification has been carefully drawn up and is not liable to sudden tightening. The method is particularly applicable to instrument design.

Reliability and maintenance problems occupy a central position to-day and in this field it is worth noting that the techniques used by actuaries in connection with mortality tables and life contingencies have a part to play. There is in fact some analogy between the mortality and sickness of human populations and the breakdown and out-of-action time of components or units, and in some instances the actuarial and statistical methods developed for dealing with the former situation may with suitable modification be applied to the latter.

Major J. K. V. Lee (Associate): It seems to me that another of the uses of statisticians in production control could be to assist the designer or producer to assess the percentage of rejects which might occur due to an adverse combination of tolerances. I call to mind the case of a certain precision-built machine which suffered from an abnormally high percentage of rejects. A reason frequently levelled against the designer was the addition of tolerances in an adverse direction. Given the necessary data could not a statistician calculate the likely percentage of rejects due to such a cause?

E. R. Friedlaender (Member): Turning from the problem of a small unit in a large factory, I would like to draw attention to the small factory with up to about 100 employees which cannot count on a full-time statistician. Every manager in such a firm will employ some statistics. Others are introduced only as emergency measures and their evaluation is often faulty. I consider it important that engineers should have some training in statistics and their evaluation before attaining executive position.

Author's Reply

I agree entirely with Mr. Piddington that statistical methods are merely aids, (although sensitive ones), to warn engineers of trouble, (if we are lucky, of impending trouble), of an unspecified nature. These methods cannot be properly used unless and until engineers have some understanding of them.

Naturally, I approve of Mr. Beech's warning about taking care when making assumptions. I am grateful to him for amplifying my remarks on the role of statistics in design work: it is vital to help designers as much as possible.

The question raised by Major Lee is one of the most fundamental in Quality Control. If all the components used in receiver assembly had stable qualities, (i.e. if the percentage of defectives per batch for each component remained reasonably constant over a long period), then the expected proportion of reject receivers would be predictable. Unfortunately, such stability cannot usually be obtained, and the many schemes of raw material inspection are eloquent acknowledgments of this fact.

I am sure Major Lee will agree that it is better to keep rejects down rather than merely to calculate their expected proportion: the quality control techniques I have illustrated have this aim. Moreover, the final quality is a property of the particular quality schemes used, and can be calculated. Naturally, the output quality will depend on the corresponding input, and so will fluctuate, but a graph of "average outgoing quality" against "input quality" is all that is normally required, and this can be plotted. Incidentally, there will be an upper limit to the proportion of defectives in any particular circumstances, and this can be calculated, too. If necessary, the quality control schemes can be chosen by reference to their "average outgoing quality limits."

Finally, I agree unreservedly with Mr. Friedlaender's suggestions.

World Radio History

Recommended Method of Expressing Electronic Measuring Instrument Characteristics

2. CATHODE-RAY OSCILLOSCOPES

Prepared by the Technical Committee of the Institution and based on a report compiled by G. Hersee (Associate Member)

Introduction

This is the second set of recommendations issued by the Institution to assist users in the selection and comparative assessment of the various instruments available. As explained in the first of the series, which dealt with Signal Generators and was published in the *Journal* for January 1958, they are intended as guides to the information required by the user, giving a standard form for its presentation.

Cathode-ray Oscilloscopes find uses in a very wide field, with many instruments designed for specific applications (television, radar, computers, etc.). Although many of the characteristics of specialized instruments are covered by these recommendations, they deal primarily with the general purpose laboratory instrument.

A number of parameters involve subjective assessment, e.g. contrast of trace with background, interaction of controls, etc. Therefore, it is extremely difficult to assess them objectively, and no attempt has been made to do so. It is considered that a practical trial will be made whenever a special need exists.

In the case of double-beam or multi-gun tubes, the relevant sections should be repeated for each beam. Here again interaction cannot readily be assessed quantitatively and must be considered on the working instrument.

Table of Contents

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* Approved by the Council for publication on 17th September, 1958. (Report No. 15.)
U.D.C. No. 621.317.755

World Radio History

Part 1—GENERAL DATA

Feature	Method of Expression	Remarks
1.1. **Power supply requirements**	.. volts d.c./a.c. ... c/s .. watts	Maximum supply voltage variation for which stated performance holds good.
(Voltage change	± .. %)	
1.2. **Temperature range**	.. °C to .. °C	Maximum ambient temperature range for which stated performance holds good.
1.3. **Tube**		
1.3.1. Type and face diameter	.. in. (.. cm)	If choice of types available give data for them all.
Is the tube flat-faced?	YES/NO	
1.3.2. Phosphor type, colour, and decay time		
1.3.3. Recommended usable size if less than full face area	.. in. (.. cm) × .. in. (.. cm)	
1.3.4. E.h.t. used	.. kV	
Range (if variable)	max. & min. .. kV	State type of control.
1.3.5. If direct connections to plates available state sensitivities and input impedances	.. V/cm .. ohms	State if shifts are still operative.
1.4. **Graticule**		
1.4.1. Fixed or removable		
1.4.2. Rotatable	YES/NO	To permit alignment with scan.
1.4.3. Illumination provided	YES/NO	
„ variable	YES/NO	
1.4.4. Size and engravings		
1.5. **Accessories**		
1.5.1. Probes		
(*a*) Type		Is power supply in main oscilloscope?
(*b*) Alteration to transmission characteristics of Y-amplifier	Bandwidth or rise time	
(*c*) Input impedance	.. ohms shunted by .. pF	
(*d*) Attenuation or gain	.. ×	State accuracy.
(*e*) Dimensions and weight	.. in. (.. cm); .. lb (.. kg)	Include length of connection cable.
1.5.2. Cameras		
Recommended types and fittings (e.g. 4 screw, bayonet)		
1.5.3. Stand or trolley		
(*a*) Dimensions and weight	.. in. (.. cm); .. lb (.. kg)	
(*b*) Angle of tilt	.. deg	If variable give details.
(*c*) Castor diameter	.. in. (.. cm)	
(*d*) Space for additional units		
(*e*) Drawers		Give details.
1.6. **Plugs and sockets**	Types used for all connections.	State whether mating connectors are provided for all plugs/sockets.

World Radio History

	Feature	Method of Expression	Remarks
1.7.	**Intensity modulation**		
1.7.1.	Input voltage and polarity required for full brightness	.. V d.c. or pk-pk	From extinction to defocusing point.
1.7.2.	Input impedance	.. MΩ shunted by .. pF	
1.7.3.	Amplifier characteristics		
	Frequency response		To 70% points.
	Shape of response	e.g. maximally flat/critically - damped / Gaussian / over-compensated	
1.7.4.	D.c. coupled	YES/NO	If NO, state time constant.
1.7.5.	If method other than amplifier used		Give details (e.g. h.f. oscillator).
1.8.	**Shifts**		
1.8.1.	X-shift	.. % max. deflection	*See* 1.3.3.
1.8.2.	Y-shift	.. % max. deflection	
1.8.3.	D.c. coupled	YES/NO	If NO state time constants of couplings
1.9.	**Cooling**		
1.9.1.	Natural or forced extraction or induction		
1.9.2.	Location of louvres		
1.9.3.	Air filters	YES/NO	
1.9.4.	Any special methods or special mounting requirements		
1.10.	**Construction and finish**		Where the construction conforms to a particular specification, the latter should be named.
1.11.	**Valve complement**		
1.12.	**Dimensions**	.. in. (.. cm)	Over projections.
1.13.	**Weight**	.. lb. (.. kg)	With all accessories normally supplied.

Part 2—Y-AXIS

2.1.	**Deflection factor**		
	Maximum	.. V/cm	If e.h.t. is variable state values at various e.h.t. settings.
	Minimum	.. V/cm	
	For a.c. coupling state maximum permissible d.c.	.. V	
	State input required in each position of gain control to overload amplifier (see 2.5.)	.. V	
2.2.	**Impedance**		
	Input impedance	.. MΩ shunted by .. pF	If variable or differential give details.
2.3.	**Response**		
2.3.1.	Frequencies at which response is 30% down		

World Radio History

	Feature	Method of Expression	Remarks
2.3.2.	Shape of decrement characteristic	e.g. maximally flat/critically damped/Gaussian/best *k*-factor	Alternatively give frequencies at 10%, 30%, 50% down. *See* Appendix 6.1.
2.3.3.	Any variation in 2.3.1 and 2.3.2 caused by the gain control		
2.3.4.	Response to 50 c/s square wave	.. % tilt	*See* Appendix 6.2.
2.3.5.	Response to high frequency edge	Show photograph	*See* Appendix 6.3. (a) and (b).
2.4.	**Linearity**		
	For a signal giving the full rated deflection amplitude, the deflection caused by any 10% portion of the input signal shall not differ from the deflection caused by any other 10% portion by more than stated amount.	.. % of full deflection	*See* 1.3.3.
2.5.	**Gain control**		
2.5.1.	Type (*a*) Continuously variable (*b*) Step		
2.5.2.	Accuracy	.. %	
2.5.3.	Compensation		*See* Appendix 6.4.
2.6.	**D.c. drift**	.. % in. .. hr.	*See* Appendix 6.5.
2.7.	**Pre-amplifiers**		To be tested as part of the oscilloscope, i.e. when measuring 2.1 and 2.3.
2.7.1.	Built-in power supply	YES/NO	
2.7.2.	Dimensions and weight	.. in. (.. cm); .. lb. (.. kg)	
2.7.3.	Connectors (plug in or external unit)		
2.7.4.	Bandwidth	.. Mc/s (70% points)	} of complete equipment.
2.7.5.	Gain	× ..	
2.7.6.	Differential input and input impedance	YES/NO	State if impedance is to ground or between inputs.
	State in-phase rejection	.. db	
2.7.7.	Beam switching		State number of beams.
(*a*)	Triggered or free running	.. μ sec	
(*b*)	Time to switch over, and max. repetition rate	.. /sec	
(*c*)	Slow change of gain	.. %	*See* 2.6.
2.8.	**Signal delay**		
2.8.1.	State where the delay line is situated in the circuit, and whether it can be switched out of circuit		
2.8.2.	State delay time and time of rise of line	.. μ sec	*See* Appendix 6.3.(*b*).

World Radio History

	Feature	Method of Expression	Remarks
2.8.3.	Indicate any defects to the wave front caused by the delay line	Show photograph	*See* Appendix 6.3.(*b*).
2.8.4.	Amplitude of the echo of the signal at 3 times delay time	.. %	Caused by mismatch.
2.9.	**Signal output**		
2.9.1.	Amplitude	.. V	
2.9.2.	Permissible loading of circuit	.. ohms and .. pF	
2.10.	**Mains surges**		
	Deflection	.. cm.	Effect of sudden 5% change. *See* Appendix 6.6.

Part 3—TIME-BASE or X-AXIS

	Feature	Method of Expression	Remarks
3.1.	**Linear sweep velocities**		
3.1.1.	Ranges	.. cm/sec to .. cm/sec in .. ranges	State whether under expanded conditions, and if expansion affects the calibration.
3.1.2.	Calibrated	YES/NO	
3.2.	**Operating modes**		
3.2.1.	Repetitive	YES/NO	
3.2.2.	Triggered	YES/NO	
3.2.3.	Triggered single shot	YES/NO	State if manual or electronic reset.
3.2.4.	Delayed single shot	YES/NO	
3.2.5.	Built in mains trigger	YES/NO	
3.2.6.	Auto-lock trigger	YES/NO	Is base-line present in absence of signal?
3.3.	**Linearity**		
	For a signal giving the full rated deflection amplitude, the deflection caused by any 10% of the scan time shall not differ from the deflection caused by any other 10% portion by more than the stated amount.	.. % of nominal full deflection	*See* 1.3.3.
3.4.	**External output of generator**		
3.4.1.	Amplitude	.. V	State if gate pulse instead of saw tooth.
3.4.2.	Permissible loading of circuit	.. ohms and .. pF	
3.5.	**Trace expansion**		
3.5.1.	Values available	.. × normal and accuracy	State if continuously variable or switched.
3.5.2.	Does expansion work from centre of trace?	YES/NO	
3.5.3.	Can selected section of trace be expanded?	YES/NO	

World Radio History

Feature	Method of Expression	Remarks
3.6. **Triggering**		
3.6.1. Internal		
(*a*) Deflection of trace required when using		
(i) sine-wave (and max. freq.)	.. mm .. Mc/s	For all conditions under 2 above. State polarity required.
(ii) Pulse (give mark/space ratio, time of rise, width)	.. mm	
(*b*) Loading on Y-axis signal	.. % amplitude reduction	
(*c*) Trigger window		i.e. pulse clipping levels.
(i) Amplitude of window (min. and max.)	.. V	
(ii) Range of movement relative to signal	.. %	
(*d*) Input d.c. coupled or d.c. restored	YES/NO YES/NO	If NO, give time constant.
(*e*) Time for trace to start	.. μ sec after trigger edge	
(*f*) Line/frame pulse separator from composite signal	YES/NO	For television work. State if line selector incorporated.
3.6.2. External If any values given in Section 3.6.1. are no longer valid state new ones		
3.6.3. Delay		
(*a*) Range (min.-max.)	.. μ sec in. .. ranges	
(*b*) Variable	YES/NO	
(*c*) Internal connection to time base	YES/NO	
(*d*) Output available	YES/NO	Specify waveform.
(*e*) Level and impedance-loading	.. V .. ohms and .. pF	
(*f*) Calibration and accuracy		
(*g*) If a pulse type of delay state trigger requirements		Similar to Sections 3.6.1. and 3.6.2. above.
(*h*) Is main trace triggered by end of delaying pulse *OR* by signal after end of delaying pulse gate?	YES/NO YES/NO	
(*i*) Jitter at maximum delay when main trace is fired by end of delaying pulse	.. parts per 1,000 of delay time	
3.7. **External input**		
3.7.1. Input required for full deflection	.. V	Is attenuation available?
3.7.2. Input impedance	.. MΩ shunted by .. pF	
3.7.3. Bandwidth	.. kc/s	To 70% points.

Part 4—VOLTAGE MEASUREMENT

Feature		Method of Expression	Remarks
4.1.	**Type**		
4.1.1.	Meter		
	Measurement ranges		
	Accuracy (including meter)	.. % of actual reading	
4.1.2.	Graticule		
	Type of ruling		
	Accuracy of measurement	.. % of actual reading	
4.1.3.	Dial		
	Ranges engraved		
	Accuracy of measurement	.. % of actual reading	
4.1.4.	Other methods		
4.2.	**Zero setting**		
4.2.1.	Max. shift as % of max. deflection	.. %	
4.2.2.	Resetting accuracy	.. mm	Error of trace position when resetting to value.
4.3.	**Earth/earthy**		
	Maximum rated voltage of insulation	.. V	
4.4.	**Calibration and checking**		
4.4.1.	Internal or available as external unit		State type of signal, e.g. d.c., sine wave, square wave.
4.4.2.	Can all ranges be calibrated directly?	YES/NO	
4.4.3.	Range and accuracy	.. V and .. %	

Part 5—TIME MEASUREMENT

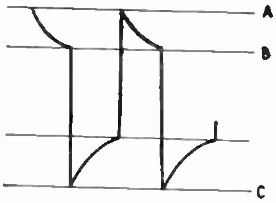
Feature		Method of Expression	Remarks
5.1.	**Type**		
5.1.1.	Meter		
	Measurement ranges		
	Overall accuracy (including meter)	.. % of full scale range	
5.1.2.	Graticule		
	Type of ruling		
	Overall accuracy of measurement	.. % of actual reading	*See* 1.3.3.
5.1.3.	Dial		
	Ranges engraved		
	Overall accuracy of measurement	.. % of actual reading	*See* 1.3.3.
5.1.4.	Marker pips		
(*a*)	Modulation	Y or Z	State if bright-up or black-out and if for use with repetitive, triggered or single stroke time base.
(*b*)	Repetition rates and accuracy	.. /sec and .. %	
(*c*)	Phasing control	YES/NO	
(*d*)	Amplitude control	YES/NO	
(*e*)	Rise time	.. μ sec	

Feature		Method of Expression	Remarks
5.2.	**Zero setting**		
5.2.1.	Max. shift as % of max. deflection	.. %	
5.2.2.	Resetting accuracy	.. mm	Error of trace position when resetting to value.
5.3.	**Calibration and checking**		
5.3.1.	Internal or available as external unit		
5.3.2.	Can all ranges be calibrated directly?	YES/NO	
5.3.3.	Range and accuracy	.. V and .. %	

Part 6—Appendix: Explanatory Notes

6.1. The linear waveform distortion of links and equipment used for television purposes can conveniently be expressed numerically as a *k*-rating factor which is obtained from the response to a set of standardized test signals. These include narrow pulses of sine-squared shape, a half-line bar and a 50 c/s square wave. Naturally the waveform display should not introduce any distortion of the test signals; this may require a different adjustment of the Y-amplifier response to that required for other purposes*.

6.2. Apply a 100% deflection of a 50 c/s square wave, and state the distortion as a percentage of the undistorted wave, i.e. $\frac{AB}{BC} \times 100\%$.



Any coupling, which may be either a.c. or d.c., should be in the a.c. position.

6.3. (*a*) Apply a waveform which has a time of rise less than one-third of the fastest which the instrument is designed to display. The amplitude should be such as to give 100% of the rated maximum deflection. The time-base should be adjusted so that the edge occupies not less than 10% of the horizontal scan (or the maximum if less than 10%). State time of rise used, and input level, maximum % overshoot, and time for overshoot to reduce to 1% of signal amplitude.

(*b*) Repeat with two cycles showing, and pulse width not less than 10 times delay in line (or distributed amplifier). The time of rise to be that for which the circuit is designed. State pulse width in μ sec.

6.4. The gain control should be tested by stating the percentage tilt of the following square waves:—

(*a*) 50 c/s

(*b*) 10 kc/s or 1/10th bandwidth, whichever is larger.

(*c*) Periodic time approximately 40 times the attenuator time constants at each setting of the gain control.

6.5. The d.c. drift should be the maximum change of the trace from a reference line during a specified period. The amplifier should be d.c. coupled throughout, and at maximum sensitivity. The drift should be expressed as

$$\frac{\text{change in position} \times 100}{\text{maximum deflection}} \%$$

6.6 Artificial mains surges can be produced by shorting a resistor in series with the mains input. The value should be such that it causes a 5% drop in volts. The distance moved by the trace at maximum sensitivity should be stated.

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* See N. W. Lewis, "Waveform responses of television links," *Proc. Instn Elect. Engrs*, **101**, Part III, p. 258, 1954; and "An introduction to the sine-squared pulse," *J. Telev. Soc.*, 7, p. 49, 1953.

Digital Techniques for Small Computations †

by

YNGVAR LUNDH, M.SC.‡

Summary: A special digital method of computation of simple algebraic functions of 1 to 4 variables is described and analysed. The system is programmed by interconnection of units according to a block diagram formulation of the problem. The calculation speed is relatively low, but the logical design is very simple.

1. Introduction

Digital techniques have become increasingly important, not only for pure computing, but also more and more in special applications for control and measurement purposes. This has given rise to a demand for simple means of performing algebraic operations automatically. The ordinary computer concept with storage-, arithmetic- and control-units makes possible large-scale, very flexible and powerful machines. But a certain minimum of equipment is required, which will be relatively large when only a few operations are required. There exists, however, a quite different system of computation which, though not strictly *digital* throughout, maintains the basic advantages of digital techniques, namely high accuracy in spite of low component precision requirements. For less complex operations, this concept promises economical solutions. It has appeared in the literature several times during the past years[1, 2, 3].

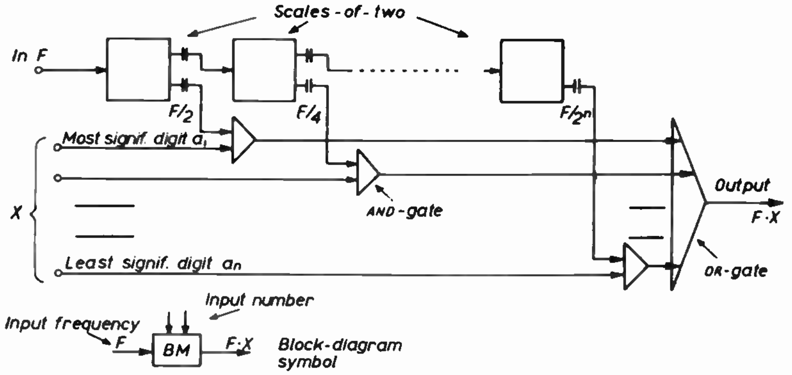

Fig. 1. Binary multiplier (BM). Logical diagram.

The Norwegian Defence Research Establishment has undertaken a somewhat more extensive investigation of the system than reported by the references above. It is the purpose of this paper to report on the work of N.D.R.E. and to record the main conclusions reached.

2. The Basic Concept

The system consists of two different types of elements, namely the binary multiplier (BM), and the bidirectional counter (BDC).

Figure 1 shows the binary multiplier. There are two input quantities: a frequency F, and a number X in parallel binary form. The frequency F is lead to a binary scaler, from which the frequencies $F/2$, $F/4$, $F/8 \ldots$, $F/2^n$ pass to AND gates controlled by the digit signals of the input number X. (n = number of scales-of-two = number of digits in X). As the frequencies $F/2$, $F/4 \ldots$ are derived as pulses at the non-carry change-over times of the scales-of-two, none of these pulse frequencies have coincident pulses (see Fig. 2). The frequencies that pass the AND gates therefore may simply be added in the OR-gate, thus:

If $$X = a_1 . \frac{1}{2} + a_2 . \frac{1}{2^2} + \; . \; . \; . \; a_n . \frac{1}{2^n} \ldots\ldots(1)$$

$a_1, a_2 \; . \; . \; .$ being binary coefficients of value 0 or 1, the frequency $F/2^\nu$ will pass its AND gate if the corresponding digit $a^\nu = 1$. Therefore, the output frequency will become:

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† Manuscript received 5th November, 1958. (Paper No. 485.)

‡ Norwegian Defence Research Establishment, Lillestrøm, Norway.

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World Radio History

$$f = a_1 . \frac{F}{2} + a_2 . \frac{F}{2^n} + \ . \ . \ . \ + a_n . \frac{F}{2^n} = F.X \qquad \ldots\ldots.(2)$$

The multiplier performs the operation

$$f = F.X$$

Here $0 \leqq X < 1$, hence $f < F$.

The frequencies that occur are apparently analogue representations of quantities. But it will later be understood that they may be more exactly regarded as quantized representations.

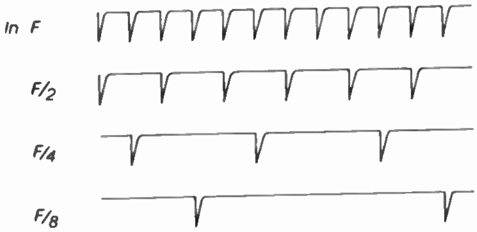

Fig. 2. Timing of pulses in the BM.

The other main element is the bidirectional counter (BDC), shown in Fig. 3. Pulses entering the "+" input are counted ordinarily in the binary counter, and pulses entering the "–" input make it count backwards. The total number indicated by the multivibrators in the counter is the sum of plus-pulses minus the sum of minus-pulses.

Table 1 shows the logical requirements of backwards counting. Going forward, the carry signal to the next higher digit should be derived at the transition from 1 to 0. In backwards counting the carries should be derived at transition from 0 to 1.

Table 1

one	001
two	010
three	011
four	100
five	101
six	110
seven	111

In Fig. 3 the position of the direction multivibrator determines which of the transitions the carry signals are derived from by opening and closing AND gates. The time delay T is short compared to the interval between pulses. It is seen that plus-and minus-pulses coming every second time will only trigger the BM, back and forth, and will not affect the position of the counter itself. Pulses on the plus and minus inputs must be non-coincident.

Figure 4 shows two examples of how such units may be connected to perform calculations. The pulse repetition frequency F is constant. F and F' are equal in magnitude, but out of phase (non-coincident). In Fig. 4(a) we assume that the number in the BDC, Z, at first is 0. The frequency coming through the two lower multipliers will then be: $F.Z.Y = 0$. The plus input frequency to the BDC, however, will be $F.X \neq 0$, and the counter will start to count forwards. Now Z will increase and the minus input frequency will increase until

$$F.X = F.Z.Y \qquad \ldots\ldots\ldots(3)$$

Plus and minus pulses now occur every second time, and Z stays unaltered. Hence, the system will reach an equilibrium where the two input frequencies to the bidirectional counter are alike. From eqn. (3).

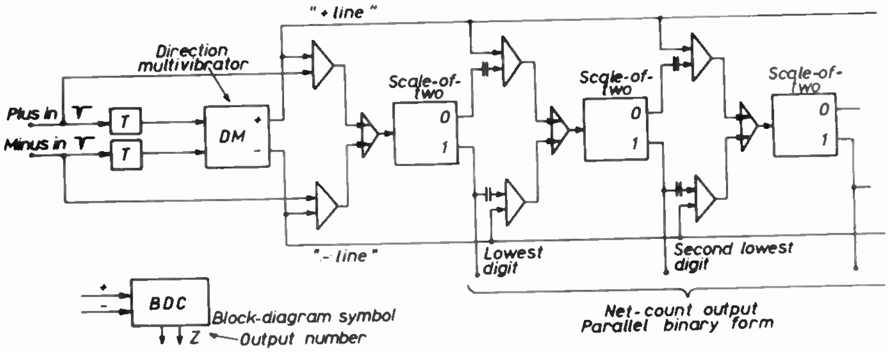

Fig. 3. Bidirectional counter (BDC). Logical diagram.

$$Z=\frac{X}{Y} \qquad \text{.........(4)}$$

X and Y were independent variables. Thus the system performs a division.

A similar reasoning in the case of Fig. 4(b) leads to

$$F.X=F.Z^2$$

$$Z=\sqrt{X} \qquad \text{.........(5)}$$

One more BM in the minus-branch would give the cube root, and so on.

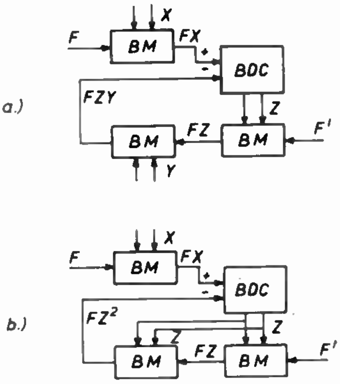

Fig. 4. Units connected for (a) division; (b) square root extraction.

3. Dynamic Analysis of the System

The number Z in the bidirectional counter reaches the equilibrium value after a certain time. Considering Fig. 4(a), the net number of pulses entering the BDC during the time t is

$$\int_0^t F.X\,dt-\int_0^t FZY\,dt$$

2^n pulses correspond to $Z=1$, therefore

$$2^n.Z=F[\int_0^t (X-ZY)\,dt] \qquad \text{.........(6)}$$

which has the solution

$$Z=\frac{X}{Y}+[Z_0-\frac{X}{Y}]\exp(-\frac{FY}{2^n}t) \qquad \text{....(7)}$$

Z varies from the initial value Z_0 towards the asymptote $Z=X/Y$ through an exponential transient. During the transient, X and Y are assumed constant. X, Y and Z are quantities between 0 and 1.

In fact, Z does not vary continuously, but in steps of $1/2^n$. Equations (6) and (7) are therefore approximate. The greatest accuracy that can be obtained is therefore in general within $\pm 1/2^n$ of the exact answer.

The time required for a calculation may thus be defined as the time from when the new set of variables (X, Y) are put in until the error is $\pm 1/2^n$.

Substituting $Z=\frac{X}{Y}-1/2^n$ in eqn. (7) gives

$$t=t_d=\frac{2^n}{FY}.\ln[2^n(\frac{X}{Y}-Z_0)] \qquad \text{........(8)}$$

t_d is defined as "division time".

The example of Fig. 4(b), for calculating the square root may be analysed in a similar manner:

The number of pulses to the BDC is given by

$$2^n.Z=\int_0^t FX\,dt-\int_0^t FZ^2\,dt \qquad \text{.........(9)}$$

which when integrated gives

$$Z=\sqrt{X}.\tanh\left[\frac{F\sqrt{X}}{2^n}t+\tanh^{-1}\frac{Z_0}{\sqrt{X}}\right] \qquad \text{.......(10)}$$

The time t_r until the error is $1/2^n$ is found by substitution of $Z=\sqrt{X}-\frac{1}{2^n}$ in eqn. (10):

$$t_r=\frac{2^{n-1}}{F\sqrt{X}}\ln\frac{(2^{n+1}\sqrt{X}-1)(\sqrt{X}-Z_0)}{(\sqrt{X}+Z_0)} \qquad \text{.....(11)}$$

If $Z_0=0$:

$$t_r=\frac{2^{n-1}}{F\sqrt{X}}\ln[2^{n+1}\sqrt{X}-1] \qquad \text{.........(12)}$$

t_r is defined as the required time for root extracting.

Figure 5 shows two examples of root extraction. In the lower curve, the answer is exactly ½. In the upper curve, the answer is irrational, and can therefore not be expressed exactly. This will lead to a persistent irregular oscillation in the value of Z between the two nearest steps 45/64 and 46/64. The experiments in Fig. 5 were made with a 6 digit model, thus $1/2^n=1/64$.

4. Frequency Fluctuations

In the dynamic analysis so far, the frequencies which come out of the binary multipliers have been assumed to be constant if the input quanti-

World Radio History

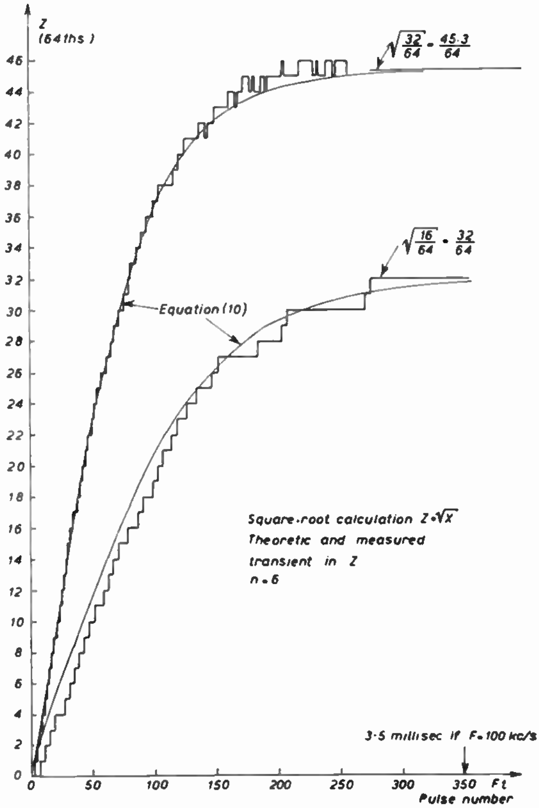

Fig. 5. Typical calculation performance.

ties are constant. On looking closer into the function of the BM, this is seen to be true only for average values. Figure 6 shows the output of a BM when F is constant, and $X=\frac{3}{4}=\frac{1}{2}+\frac{1}{4}$. For other values of X, the pulse pattern may even be more complicated. For times very much greater than $1/F$ the mean output frequency is exactly $F.X$, but there occur fluctuations which will conflict with an assumption made earlier. In considering Fig. 4, at equilibrium plus and minus pulses were coming every second time to the inputs of the BDC. Now all we may say is that the plus and minus frequencies are alike *on the average*. But because of the fluctuations, Z may be expected to vary some steps up and down around the equilibrium value. There will be oscillations in Z which are often very irregular.

Another case when oscillations occur is when the answer to the calculation is such that it cannot be expressed by n digits, as for example in the upper curve of Fig. 5.

Oscillations in Z also cause a secondary error in the function of the BM which has Z as its digital input. Figure 7 illustrates this by a three-digit example. Here the input to the BM ($=Z$ of the system) oscillates between $\frac{1}{2}$ (for τ seconds) and $\frac{3}{8}=\frac{1}{4}+\frac{1}{8}$ (also for τ seconds). During the time $T=2\tau$ there may be two cases, namely the output from the BM will be

or	pulses No. 7, 9, 10, 12	i.e. 4 pulses
	pulse No. 11	i.e. 1 pulse

Both these cases are nominally the same. It is thus seen that the oscillations of Z should be very slow compared to the pulse-repetition frequencies handled by the BMs, in order that erroneous function of the BMs may be prevented.

There seems to be a serious reason for closer investigation of the accuracy. First, there will be oscillations of Z between more than two values. Second, there may occur erroneous functioning of the multiplier when there are oscillations at all. Both these difficulties are caused by the binary multiplier which makes irregular pulse patterns (Figs. 6 and 7). We therefore call errors introduced in this way "multiplier-errors".

Oscillations will in the general case be present even if there are no multiplier-errors. This is because only very few of the possible calculations have answers that may be expressed exactly. We therefore must tolerate oscillations, but if possible they should be restricted to two adjacent steps (of $1/2^n$), namely the nearest step over and under the exact solution. In this case, the oscillations would always be within the error-limit, which is $\pm 1/2^n$.

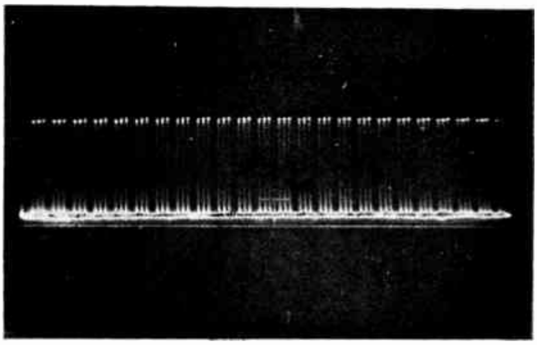

Fig. 6. Output $F.X$ from BM. F=constant (not fluctuating) $X=\frac{3}{4}$. Such fluctuations as are illustrated here lead to some difficulties.

Fortunately there is a good chance that we may cure the multiplier-errors. Figure 8 shows a device called "backlash-unit" which is inserted before the bidirectional counter.

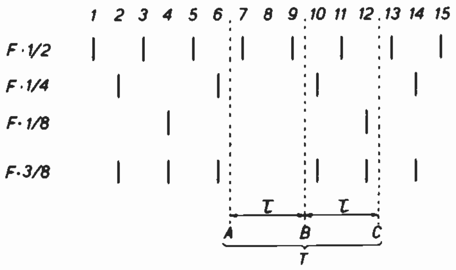

Fig. 7. Timing of output frequencies from BM. If the digital input to the BM oscillates, inaccuracies may result.

Assume first that the multivibrator is in the "−" state, and a plus-pulse is received. The pulse will be stopped by the gate, but after a short delay T, it will trigger the multivibrator to "+" and thus open the plus-gate. If the next pulse is another plus-pulse, it will be transmitted. If plus and minus pulses arrive alternately, nothing will be emitted.

Obviously, if we put such a unit before a BDC, we thereby increase the "backlash" to two pulses in either direction before the number held by the counter is affected. By adding more backlash units, we may increase the backlash arbitrarily. It is seen that this backlash "swallows" frequency fluctuations so long as the averages of the two frequencies are alike. Differences in the mean values, however, will pass the backlash units correctly.

Moreover, the backlash unit will decrease the frequency of all oscillations, and thereby further reduce the possibilities of error.

5. Experimental Verification of Theories

The theories of the system performance outlined in the preceding paragraphs, have been tested and verified by experiments on a six-digit laboratory model[4, 5].

The analysis of the transient calculation process itself leads to eqns. (7)-(12) which give a fairly instructive picture of the performance of the fundamental functions. A series of experiments has been carried out to verify these equations and all confirm that although approximate, the equations are fundamentally right.

A record of the transient from a calculation like Fig. 5 would not necessarily be identically the same if it was repeated with exactly the same variables and initial values. This is again because of the mechanism of the BMs. Obviously, the initial conditions are not exactly the same unless all the stages of all the BMs in the system were also put to the same state. If this is not done, one may expect divergences from one test to another. But as we are not interested in the transient itself, these irregularities are not significant. The only effect is that there is introduced a certain tolerance in the determination of the required computing time. In fact we have found from experiments that the times defined by eqns. (8) and (11) vary up and down by approximately a factor of 1·5. This is of no other significance than as an increase in maximum computing time over that calculated from eqns. (8) and (11).

Unfortunately, it has not been possible to develop mathematical tools which have been practical for the investigation of frequency fluctuations and related problems arising from the method of function of the binary multiplier. The examinations of the mechanism have therefore been restricted to experiments.

Oscillations of the number Z in the BDC between as many as 3 and 4 different values are observed. Observations of the mean value of Z during the oscillations have indicated serious inaccuracies in the mean value also (due to the multiplier error illustrated in Fig. 7). The fears outlined in the last paragraph thus are supported by experiments.

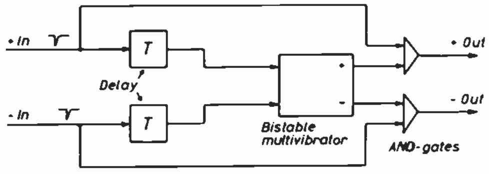

Fig. 8. "Backlash unit" is inserted before the BDC to reduce errors caused by frequency fluctuations.

However, the introduction of the backlash unit has proved very promising. It has been possible to reduce and slow down the oscillations to a degree which gives good hope of keeping the errors within the limit $\pm 1/2^n$ in all cases. This has unfortunately not quite been proved. Neither can it at present be stated how many

World Radio History

backlash units will be needed in a given case for a general reduction of oscillations to two values. As mentioned before, no useful mathematical method has been found, and the scale of the experiments hitherto does not permit derivation of general laws for this important question. However, the experiments with backlash units give hope that the frequency fluctuations do not make the system useless. Backlash units mean of course, a little additional equipment, but as far as has been observed, they do not affect the dynamic performance in any other way than already stated. (There is a delay in the transient, but too small to be of significance.)

6. Functions of Several Variables

The system is not restricted to the simple operations described in Fig. 4. By introducing a few additional BMs, more complex functions may be calculated by interconnecting the units according to a block diagram formulation of the problem. The principles are best described by an example. The problem solved will be given by the equilibrium equation, which says that the plus and minus frequencies to the BDC are alike.

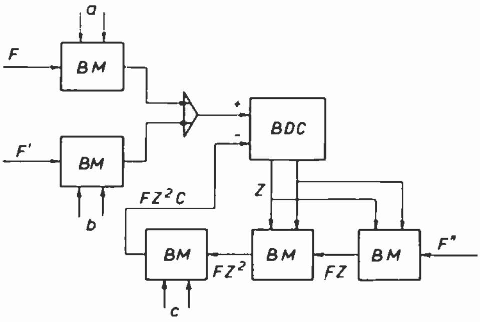

Fig. 9. Interconnection program for the solution of $Z=\sqrt{\frac{a+b}{c}}$

Thus in Fig. 9:

$$F.a+F.b=F.Z^2.c \qquad \ldots\ldots\ldots(13)$$

$$Z=\sqrt{\frac{a+b}{c}} \qquad \ldots\ldots\ldots(14)$$

The frequencies F, F' and F'' in Fig. 9 are coherent, but non-coincident pulse frequencies of the value F. Backlash units should be introduced before the BDC to secure the accuracy of the system.

In a similar manner other algebraic problems may be solved by the appropriate connections of units. A dynamic analysis of such systems of several variables often leads to formulae which may be reduced to eqns. (7)-(12) with very small modifications. These equations are, in other words, easily extended to a general analysis.

An interesting feature is that in many cases a complicated expression takes the same time as a simple one. For example, a division of two sums takes the same time as a division of two single numbers.

Any problem which is to be solved is set up on the computer by interconnecting BMs and BDCs, the frequency numbers by single lines, and the digital numbers by n-way plugs.

7. The Computer in a Closed Loop Control System

The ability to keep two quantities (the plus and minus frequencies) equal, makes the system useful as an integral part of a control system. Figure 10 shows the basic principle. The number Z is converted into the position of a valve or setting point of other power amplification gear which governs the process. The transducer should preferably give a frequency proportional to the measured quantity. Such transducers exist for some physical quantities. A digital transducer might also be used together with a binary multiplier. The possibility also exists of using an analogue transducer and a standard analogue-to-digital converter.

The reference is inserted in the form of a frequency. It will be seen that this system contains one integration within the loop (in addition to what might be inside the process).

A system of this kind is, in general, more expensive than a conventional analogue control system, and it is attractive only in special cases. For example when the system is distributed over great geographical distances and there is thus a demand for special data transfer media. In particular it might be desirable to introduce corrections into the loop automatically. This may easily be done in some cases. For example by inserting a BM in the measured variable line of Fig. 10 we could multiply this variable by a factor. Other more elaborate corrections are also possible. These corrections may also be regarded as taking several of the process variables into account at the same time. Some successful experiments have been done with a simple, simulated system of this kind[5]. The dynamic properties of a closed-loop control system containing digital frequency elements are more difficult to analyse than a pure analogue system.

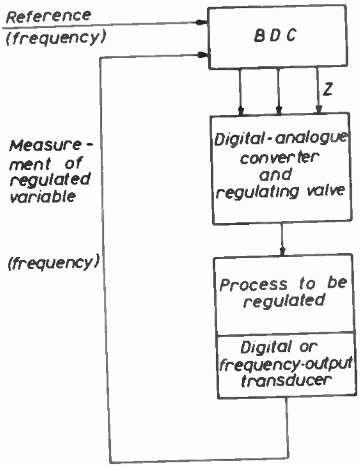

Fig. 10. Process control. A correction factor might here, for instance, be introduced by cascading a BM into the "regulated variable" line.

8. Integration and Differentiation

The bidirectional counter may be regarded as an integrator—it counts pulses, that is, integrates frequency over time. The pulses are a quantized expression of physical quantities.

The pulse frequency which appears in the bidirectional counter (Fig. 3) after the first OR-gate, triggering the lowest digit of the scaler, may be regarded as the time derivative of the number Z being held in the counter.

However, in general, it has proved very difficult to interconnect these units for solving differential equations in a similar manner to that used in classical analogue computers. This is due mainly to two reasons: (1) the problem of compatibility between the time scales of the different units; (2) the tendency to inaccuracy caused by the mechanism of the BM, in fact the same as the reason for frequency fluctuations.

Nicola[3] describes a neat concept for the generation of sine and cosine. He does not mention however that there will be inaccuracies, for the reasons mentioned above, even if steps are taken to reset both the BDCs and BMs every quadrant. However, this method of sine and cosine generation may prove useful in many cases because the pulse source on the shaft which is used is a very much simpler device than the coded disks which would be an alternative solution.

Another application of this concept might be for the generation of very slow sine waves by using a digital-to-analogue converter. Such sine waves are useful for testing of control systems. It is also possible to introduce very accurate phase delays in such a generator.

9. Comments on the System

In the previous Sections the digital frequency system has been described and analysed, and some of its possibilities have been illustrated by examples. An attempt will now be made to place it in its proper place in the pattern of already-existing computing systems.

9.1. *Speed*

The speed of the system may be investigated by the formulae (8), (11) and (12). First of all, it is seen that the quantities of the calculation (X, Y and Z_0) have influence on the computing time. It is the factor $2^n/FY$ ($2^{n-1}/F\sqrt{X}$ for square root) which is of greatest importance. The logarithm varies relatively less. It is seen that the computing time increases exponentially with increasing number of digits n. *Accuracy can only be improved at the expense of computing speed, at a given clock frequency.*

The time is longer as Y is less. To find the slowest case when n and F are given, Y should be minimal and X maximal. X/Y is always kept less than 1, thus $X < Y$, and $Y_{\min} = 2/2^n$. Thus, to maximize the logarithm, Z_0 should be maximized, that is

$$Z_{0\,\max} = \frac{2^{n-1}}{2^n}$$

Then

$$\ln\left|2^n\left(\frac{X}{Y} - Z_0\right)\right|_{\max} = \ln 2^n = n \ln 2 = 0{\cdot}693n \qquad \text{.........(15)}$$

The maximum division time, therefore, is (from eqn. (8))

$$t_{d\,\max} = \frac{2^n}{F.2/2^n}\,.0{\cdot}693n = \frac{0{\cdot}347n\,.\,2^{2n}}{F} \qquad \text{........(16)}$$

As a practical example, take $F = 1$ Mc/s and $n = 9$ (which means a maximum error of 0·2%). $t_{d\ \max} = 0{\cdot}82$ sec. With a factor of 1·5 for uncertainty due to frequency fluctuations, the maximum division time is a little over one second. Square root and other functions take computing times of the same order. This is, of course, extremely slow compared to other digital computers. But this example was the worst possible case. Every other problem is solved more rapidly—down to a few microseconds—and if Y is restricted by a lower limit, a very large improvement may be achieved. Thus, with a lower limit for Y of $\frac{1}{2}$, the *maximum* division time is reduced to about 10 millisec. Though the system is still slow compared to other digital computers, it has about the same speed as, or better than, most analogue computers.

9.2. *Accuracy*

On conventional computers calculations may be made with a precision down to 0·1 per cent. by the use of precision components and stabilizing techniques. In the digital frequency system this accuracy and better may be achieved without the use of precision components, and at speeds which are expected to be adequate for many applications.

9.3. *Complexity*

The feature which contributes most to making the system attractive is the very simple design. It consists almost exclusively of two different types of elements, the binary multiplier and the bidirectional counter. Both of these are also very simple, consisting of a number of identical stages. These units may with advantage be designed using transistors and magnetic cores. By using potting and etched circuit techniques, it is expected that the system may prove very economical and be easily adapted to difficult working conditions such as those encountered in industrial and military applications. Fig. 11 shows an example.

10. Conclusion

The concept of digital computing discussed here is expected to offer favourable solutions to some special automatic computation problems. The functions best suited are simple algebraic functions of one to four variables, especially divisions and root extraction. The accuracy is better than that of conventional analogue systems when the speed requirements are moderate. The system may be used as an integral part of control systems, and then makes possible the automatic introduction of correction factors. The logical design is remarkably simple.

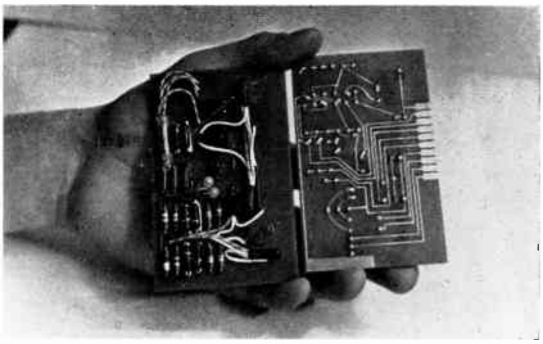

Fig. 11. Bidirectional counter stage in modular design, using etched circuit technique. There are 4 transistors (OC 45) and 6 germanium diodes (OA 70) per stage. Resolution time 1 microsec. Indication by subminiature "magic eye" (DM 160).

11. Acknowledgments

The author wishes to thank the Norwegian Defence Research Establishment for permission to publish this paper, and Karl Holberg, Superintendent of Telecommunications Department for his interest and encouragement.

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World Radio History

Subscriber Trunk Dialling in the British Post Office

Last month Her Majesty the Queen visited Bristol to inaugurate the first installation for completely automatic dialling of trunk telephone numbers by subscribers. At a conference on the previous day to which an Institution representative was invited, the Postmaster General stated that there were now seven million telephones in the U.K. This is more than in any other country with the exception of the U.S.A.* The worth of capital equipment currently in use was over £1,000 millions, whilst replacement costs at to-day's prices would be nearer £1,200 millions. One-quarter of this related to equipment in the Exchanges, and Mr. Marples said that a much more intensive use of all this very costly gear was needed.

Two changes have therefore been proposed to obtain greater efficiency, namely, group charging, introduced on the 1st January 1958, and standard charge units. In the past some 6,000 Exchanges have been responsible for call charging, whereas since the 1st January only 600 Exchanges have been used, as the extension of the areas in which standard charges are levied makes their task more simple. Now, under Subscriber Trunk Dialling (S.T.D.) trunk charges will be twopence for each twelve-second period. The local charge of Exchanges having S.T.D. will be twopence for three-minute units.

One development which has permitted more intensive use of the telephone system is the v.f. apparatus and associated coaxial cable. Previously, with repeaters every six miles, 960 channels were available, but now, with repeaters every six miles, 2,000 channels are possible. Lower charges which promote more calls and subscribers ought to bring a pressure for even more channels on the same cable—development here could have implications for more intensive use of international cables.

Technical Details†

The opening of Subscriber Trunk Dialling system at Bristol brings into service the first installation of GRACE—*G*roup *R*outing *A*nd *C*harging *E*quipment. This automatic apparatus takes over the functions of the operator setting up trunk calls. It notes the number required, selects the correct route to that number and charges for the call at the appropriate rate.

The equipment is constructed on a unit principle so that its size can be readily suited to the needs of a particular exchange and can easily be enlarged to meet growth in telephone traffic. The Bristol installation is capable of completing over 6,000 calls per hour.

To obtain connection to GRACE, and to present the required exchange and number to the equipment in a suitable form, the subscriber dials the national number of the subscriber he requires. The national number consists of a series of figures and letters to identify the required exchange, followed by the called subscriber's local number. All national numbers start with 0 and dialling 0 connects the call to GRACE.

Call Charger.—Initial connection is made to a Register Access Relay Set or Call Charger. The Call Charger remains associated with the call throughout its duration, its main function being to start charging at the appropriate rate when the call is answered and to continue charging until the calling subscriber hangs up.

For setting up the call and selecting the correct charging rate, two further items of equipment, a Register and Translator, are called into use.

Registers, which are used only during the setting-up of a call, are provided in a common pool which can handle 66 calls simultaneously. A Call Charger taken into use by a call associates itself immediately with any available free Register. The Registers are of electronic design based on the use of cold-cathode tubes interconnected by miniature selenium rectifier gates.*

The number dialled by the subscriber is received by the Register, counted and coded electronically and stored on cold-cathode tubes in "2-out-of-5" code. A total of 45 tubes per

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* These figures must not be confused with the number of telephones per hundred of the population. In 1957, the U.K., with 14·04 telephones per hundred population came seventh in order of "telephone density."

† For a fuller description of the new system, reference should be made to the comprehensive series of papers published in the "Subscriber Trunk Dialling" issue of *The Post Office Electrical Engineers Journal* (**51**, Part 4, January 1959).

Register is provided for this purpose giving a capacity for nine digits.

Translator's Functions.—The first one, two or three digits received by the Register identify the charging group of the wanted exchange. It is the function of the Translator to inspect these digits and deduce from them the route and charge rate for the call. The Translator is in effect and brain of the system, incorporating a permanent memory of the route and charge rate for all calls that can be made by Bristol subscribers.

The Translator is also of electronic design and can deal with a Register in a few milliseconds. This high speed of operation permits it to control up to 40 Registers, to each of which it is connected sequentially by electronic gates once every two-third second. Each time it is connected to a Register it decides what action if any is required and sets the Register to perform this action.

While the Translator is dealing with its other Registers, the Register carries out this action and when this is completed receives a further instruction on its next connection to the Translator. This meter control arrangement permits a relatively simple design of Register since it is called upon in the main to carry out only similar and simple operations.

Instructions to Registers.—The first instruction given to the Register is a signal representing the charge rate for the call. This is passed by the Register to the Call Charger, where it sets an electromechanical switch to select the appropriate metering rate ready to start charging when the call is answered. Subsequent instructions cause the Register to send suitable signals to the automatic switches in the local and distant exchanges to route the call to the required exchange. These are followed by the digits of the called subscriber's number which have been stored in Register and select the required line. When the connection is complete, the Register releases from the Call Charger and is free to set up further calls.

When the call is answered the Call Charger operates the calling subscriber's meter once and then periodically throughout the call at intervals of time depending on the distance.

Metering.—The meter on which the call charge is recorded is the one previously used only for recording local call charges. It is an extremely reliable mechanism of the Veeder type and each line in the exchange has its own meter.

If, however, a subscriber must know the cost of a dialled call at the time it is made to charge it to the user (e.g. in a hotel), a meter can be installed at his premises to work in step with his meter at the exchange.

Operation of this meter is controlled by an equipment in the exchange which responds to the charge units received by the subscriber's exchange meter and connects a pulse of 50 c/s alternating current to the line. This signal passes over the two wires of the line in parallel, via the meter at the subscriber's premises to an earth return. By applying the signal in this balanced manner no interference to the subscriber's conversation is caused.

The meter has a sensitive moving iron movement tuned to 50 c/s to prevent misoperation by ringing current or dialling surges. It is equipped with three hands which move over a graduated scale, taking one step for each pulse of current received. Two of these hands indicate the total number of 2d. charge units used while the third indicates the number of units used on individual calls and can be set to zero after each call.

Future Developments

At present only one of the Bristol exchanges (Central) is equipped with S.T.D. but the others in the city will be provided with the new facility during 1959. The G.P.O. expects that Bodmin and Evesham will have S.T.D. during the year 1960. By 1970 it is intended that three-quarters of all trunk calls will be dialled by subscribers.

The provision of Subscriber Trunk Dialling facilities in metropolitan areas (such as London, Birmingham, Liverpool, Manchester, and Glasgow) introduces difficulties which have not been solved by the Register Translator equipment designed for Bristol. Accordingly a storage and translating device based on the magnetic drum has been designed and is currently undergoing trials in service at a London telephone exchange.

W. C. HENSHAW.

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* J. H. Beesley, "Cold-cathode voltage transfer circuits." To be published in the *Journal* in 1959.

World Radio History

Some Aspects of Permeability Tuning †

by

W. D. MEEWEZEN, DIPL.ING.‡

This paper, first published in the Proceedings of the Institution of Radio Engineers, Australia, was awarded the Norman W. V. Hayes Memorial Medal for 1957 at the recommendation of the Brit.I.R.E.

Summary: In the first part of the paper, permeability tuned circuits are analysed and compared with capacitance tuned circuits. Attention is given mainly to aerial circuits for the broadcast band. The second part of the paper deals with the construction of permeability tuners. The causes of law and tracking errors are discussed and an indication is given of the manner in which these errors can be reduced and corrected. Finally, a tuner is described which features an adjustable tuning law, as well as approaching the ideal linear frequency law more closely than do most of the commercially used tuning capacitors.

1. Introduction

A general trend towards the replacement of capacitance tuning by permeability or inductive tuning may become the most radical change in radio receiver design since the introduction of the superheterodyne. A major reason for this change is the reduction in the cost of the receiver. Unfortunately, however, this has sometimes been achieved only by accepting a lowered standard of performance from the set. This is particularly so in the case of the domestic broadcast band receiver where the design is made more difficult by virtue of the high ratio of maximum to minimum frequency to be covered.

However, some of the best communications receivers available to-day use permeability tuning and there is no reason why a permeability tuned domestic receiver should be inferior to a capacitance tuned one.

The introduction of permeability tuning poses two separate problems to the receiver designer. Firstly, there is the design and performance of the circuits affected by the change from capacitance tuning; secondly, there is the construction of the permeability tuning elements.

The most important circuit problem is that of the broadcast band aerial coupling circuit. This is discussed in Section 2, where the step-up factors and image rejection ratios of the different types of circuit suitable for capacitance and permeability tuning are compared. With capacitance tuning, the mutually coupled aerial circuits may be used while for permeability tuning a type of capacitively coupled circuit gives the best results.

Other circuit considerations covering the effect of aerial losses, the signal-to-noise ratio, the short-wave aerial circuits, r.f. interstage coupling and the local oscillator circuit are discussed in Sections 3 to 6.

The major problem in the construction of a permeability tuner—dealt with in Section 7—is the realization, in production, of an accurate adjustable and linear tuning law. The use of a high permeability ferrite core and an adjustable inductance in series with the tuning coil makes this quite straightforward.

2. Broadcast Band Aerial Circuits

The aerial coupling circuit is designed to satisfy the following requirements:

(*a*) Maximum voltage step-up factor, G, between the aerial and the grid of the first valve.

(*b*) Maximum attenuation at image frequencies.

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World Radio History

(*c*) Adequate adjacent channel selectivity as a protection against intermodulation.

In this section the performance of the various circuits which may be used with capacitance tuning and permeability tuning, and with different types of aerial, are compared on the basis of the above requirements.

2.1. *Mutually Coupled Aerial Circuit*

Perhaps the most common aerial circuit is the mutual inductance coupled circuit Fig. 1(a) designed to be used with capacitance tuning and with an external aerial which is almost purely capacitive for the broadcast band. Figure 1(b) is obtained from Fig. 1(a) by replacing the transformer by its equivalent inductive T-network, and the aerial by a generator e_a in series with the aerial capacitance C_a. The equivalent circuit of Fig. 1(c) may then be obtained by replacing the capacitance input voltage divider C_a, C_2 and the generator with the equivalent series arrangement and by subsequently modifying the inductive T-network.

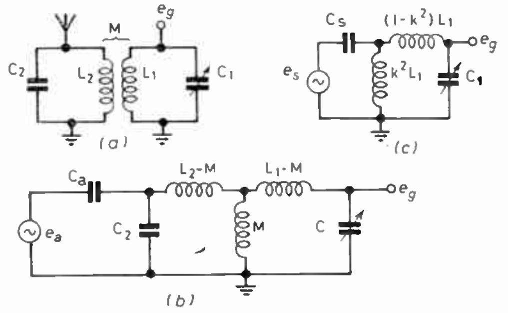

Fig. 1. (a) Mutually coupled aerial circuit using capacitance tuning. (b) and (c) Equivalent circuits of (a)

$$\frac{e_s}{e_a} = \frac{C_a k\sqrt{L_1/L_2}}{(C_a+C_2)}$$

$$C_s = \frac{(C_a+C_2)\,L_2}{k^2 L_1}$$

$$G = \frac{Qe_s}{e_a} = \frac{QkC_a\sqrt{L_1/L_2}}{(C_a+C_2)}$$

$$G_0 = \frac{QK\sqrt{L_1/L_2}}{2} \text{ for } C_2=C_a$$

$$R_i = Q\ [(f_i/f_0)^2-1]$$

The primary inductance L_2 and its minimum parallel capacitance C_2 are made to resonate at a frequency lower than the lowest frequency in the band, and in the case of 455 kc/s i.f., lower than the intermediate frequency. Therefore the influence of C_s and k^2L_1 in Fig. 1(c) can be neglected in first approximations for frequencies within the broadcast band. The loop current at resonance causes a voltage across either reactance $L_1(1-k^2)$ and C_1, which is Q times as high as the generator voltage e_s if Q is the quality factor of the equivalent loop of Fig. 1(c). In practice, Q approaches the quality factor of the secondary circuit.

2.1.1. Step-up factor

From the equivalent circuit the step-up factor may be written down.

$$G = \frac{e_g}{e_a} = Q\frac{e_s}{e_a} = kQ\sqrt{\frac{L_1}{L_2}}\,\frac{C_a}{C_a+C_2} \quad \text{.........(1)}$$

Since the primary circuit L_2 and C_2 is required to resonate below the intermediate frequency, L_2 and C_2 are inversely proportional. L_1 also is determined by the value of the tuning capacitor C_1. Thus for a given tuning capacitor and a given value of k (usually about 0·2) it is possible to plot G/Q as a function of the aerial capacitance $L_1(1-k^2)$ and C_1, which is Q times as high from such curves (Fig. 2) that the value of L_1/L_2 which provides the optimum step-up factor G_0 varies with the aerial length (C_a).

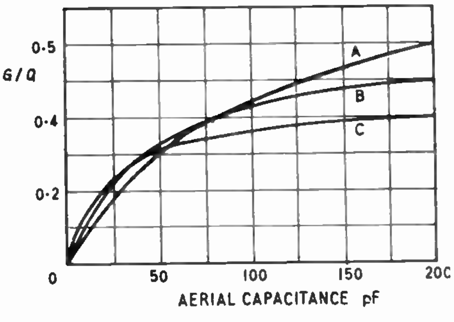

Fig. 2. Step-up factor ratio G/Q of a capacitance tuned mutually coupled aerial circuit ($k=0{\cdot}2$) as a function of the aerial capacitance with the following parameter values:

A, C_2 = 100 pF, L_2/L_1 = 5.
B, C_2 = 50 pF, L_2/L_1 = 10.
C, C_2 = 25 pF, L_2/L_1 = 20.

For a given value of the aerial capacitance the value of C_2 for optimum step-up is found by differentiation of eqn. (1) with respect to C_2 and equating to zero. This gives $C_2 = C_a$, and so

$$G_0 = Q \frac{k}{2} \sqrt{\frac{L_1}{L_2}} \qquad \text{.........(2)}$$

For an average indoor aerial with a capacitance of 80 pF and a coil Q-factor of 100, the value of G will be about 4.

2.1.2. Image ratio

The image ratio can also be calculated fairly accurately from the equivalent circuit of Fig. 1(c). If f_0 is the resonant frequency of this circuit, then for a frequency $f_1 = \alpha f_0$ the total loop reactance of the circuit will be $(\alpha - 1/\alpha)\ X$, where X is the reactance of C_1 at resonance.

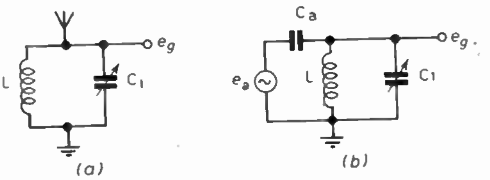

Fig. 3. (a) Top capacitance aerial coupling circuit using capacitance tuning. (b) Equivalent circuit of (a).

$$G = Q\ C_a/(C_a + C_1)$$
$$R_i = Q\ [1 - (f_0/f_i)^2]$$

This loop reactance will determine the loop current for frequencies not too close to f_0 and since the voltage e_g across C_1 is X/α times the loop current then, off resonance

$$(e_g/e_s)_{f1} = (X/\alpha)/X(\alpha - 1/\alpha) = 1/(\alpha^2 - 1) \qquad \text{......(3)}$$

But since at resonance $(e_g/e_s)_{f0} = Q$, the voltage ratio is

$$(e_g)_{f0}/(e_g)_{f1} = (\alpha^2 - 1)\ Q \qquad \text{.........(4)}$$

With an intermediate frequency of 455 kc/s, the image frequency is $f_i = f_0 + 910$ kc/s.

For the lower limit of the broadcast band f_0 is 530 kc/s and so α_i is 2·7; the upper limit of the band is 1620 kc/s which gives an α_i of 1·56. Again assuming a coil Q-factor of 100, equation (4) gives image ratios of

$$R_i\ (530\ \text{kc/s}) = 6{\cdot}3Q = 630$$
$$R_i\ (1620\ \text{kc/s}) = 1{\cdot}43Q = 143 \qquad \text{.........(5)}$$

2.2. *Top Capacitance Aerial Coupling*

Sometimes very short aerials, such as built-in plates, are used and connected directly to the top of the tuned circuit as shown in Fig. 3(a). Figure 3(b) shows the equivalent circuit from which it can be seen that $G = QC_a/(C_a + C_1)$.

Assuming a 30-400 pF tuning capacitance and a 10 pF aerial, the step-up factor will vary from $Q/41$ at the low frequency end of the band to $Q/4$ at the high frequency end. This variation of G of more than 10 is, of course, most undesirable.

The image ratio R_i is now determined by the voltage across the inductance L at the image frequency $f_i = \alpha_i f_0$, so that

$$R_i = Q\ \{(\alpha_i^2 - 1)/\alpha_i^2\} = Q\ (1 - 1/\alpha_i^2)$$
$$R_i\ (530\ \text{kc/s}) = 0{\cdot}86Q$$
$$R_i\ (1620\ \text{kc/s}) = 0{\cdot}59Q \qquad \text{.........(6)}$$

A comparison with eqn. (5) shows the inferiority of top coupling.

For the above reasons, top capacitance aerial coupling has been abandoned. Very often, however, a small amount of top coupling is used in combination with mutual coupling to correct a decrease in step-up factor at the high frequency end of the band, due to secondary effects. In such cases the image ratio will have an intermediate value between the figures indicated by eqns. (5) and (6) and dependent on the amount of top coupling used.

2.3. *Capacitive Aerial Coupling*

When permeability tuning is used the capacitive leg of the tuned circuit consists of fixed components and it therefore seems more logical to use capacitive coupling rather than inductive coupling. An aerial transformer is then necessary only when a balanced aerial is used.

The capacitive aerial coupling circuit and its equivalent circuits are shown in Fig. 4. Before determining the step-up factor we must discuss the requirement which limit the amount of detuning caused by the use of different aerials. This requirement determines the values of the capacitor ratios C_1/C_t, C_2/C_t and C_3/C_t, where C_t is the equivalent total tuning capacitance.

2.3.1. Limited detuning requirement

From Fig. 4(c) we find

$$C_t = \frac{C_1\{C_2 + C_aC_3/(C_a + C_3)\}}{C_1 + C_2 + C_aC_3/(C_a + C_3)}$$

C_t is a function of the aerial capacitance C_a which may take values between 0 and ∞. The circuit must be designed so that the resultant detuning $(\Delta f/f_0)$ is limited to a predetermined amount.

C_t will vary between the values

$$C_{t\,\min} = C_1C_2/(C_1+C_2) \quad C_a = 0 \qquad \text{.........(7a)}$$

$$C_{t\,\max} = C_1(C_2+C_3)/(C_1+C_2+C_3) \quad C_a = \infty \qquad \text{(7b)}$$

Putting $\gamma = \dfrac{C_{t\,\max} - C_{t\,\min}}{C_{t\,\min}}$,

or $\dfrac{C_{t\,\max}}{C_{t\,\min}} = 1+\gamma$, ...(8)

it follows that for small values of γ the maximum detuning resulting from connection to different aerials will be $(\Delta f/f_0)_{\max} = \pm\gamma/4 \quad \gamma \ll 1$ If the maximum permissible detuning is ±1%, the corresponding value of γ will be 0·04.

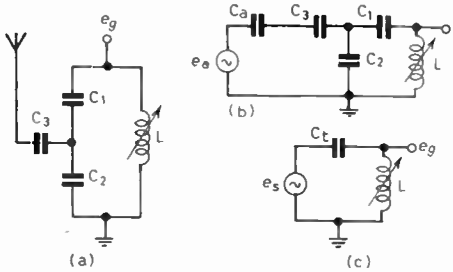

Fig. 4. (a) Capacitive aerial coupling circuit using permeability tuning. (b) and (c) Equivalent circuits of (a).

$$\frac{e_s}{e_a} = 1/[1+(C_2/C_a)+(C_2/C_3)]$$

$$C_t = \frac{C_1[C_2+C_aC_3/(C_a+C_3)]}{C_1+C_2+C_aC_3/(C_a+C_3)}$$

$$G = Q\frac{e_s}{e_a}$$

2.3.2. Capacitor values

Having decided on a value of γ and knowing the required value of C_t, the values of the capacitors C_1, C_2 and C_3 may be found.

From eqns. (7) and (8),

$$\frac{C_{t\,\max}}{C_{t\,\min}} = \frac{(C_2+C_3)\;(C_1+C_2)}{C_2\;(C_1+C_2+C_3)} = 1+\gamma$$

$$\frac{1}{\gamma} = \frac{C_2}{C_3} + \frac{C_2}{C_1}\left(1+\frac{C_2}{C_3}\right)$$

$$C_2/C_1 = (1/\gamma - C_2/C_3)/(1+C_2/C_3) \qquad \text{........(9)}$$

It should be noted that eqn. (9) does not apply if $(C_2/C_3) > 1/\gamma$, but in this case the maximum possible detuning is automatically limited to less than the permissible amount. Putting

$$Z = 1+C_2/C_3 \qquad \text{.........(10)}$$

$$C_2/C_1 = \{(1+1/\gamma)-Z\}/Z \qquad \text{.........(11)}$$

and using the minimum value of C_t given in equation (7a), so that

$$C_1 = C_2C_t/(C_2-C_t)$$

$$C_2/C_t = (1+1/\gamma)/Z \qquad \text{.........(12a)}$$

$$C_1/C_t = (1+1/\gamma)/\{(1+1/\gamma)-Z\} \qquad \text{......(12b)}$$

$$C_3/C_t = (1+1/\gamma)/Z\,(Z-1) \qquad \text{.........(12c)}$$

eqns. (12) give the relationship between the circuit capacitances which satisfy the requirement of limited detuning due to aerial capacitances.

It will be shown in Section 2.3.3 that the optimum step-up occurs when

$$Z = \sqrt{(1+1/\gamma)\,C_t/C_a}$$

Substitution in eqn. (12) then gives for the capacitor values,

$$C_1/C_t = \sqrt{(1+1/\gamma)\,C_a/C_t}/\{\sqrt{(1+1/\gamma)\,C_a/C_t}\} - 1 \qquad \text{(13a)}$$

$$C_2/C_t = \sqrt{(1+1/\gamma)\,C_a/C_t} \qquad \text{.........(13b)}$$

$$C_3/C_t = \sqrt{(1+1/\gamma)\,C_a/C_t}/\{\sqrt{(1+1/\gamma)\,C_t/C_a}\} - 1 \qquad \text{(13c)}$$

For small values of γ these formulae reduce to the form

$$C_2/C_t = \sqrt{C_a/\gamma C_t} \qquad \text{.........(14a)}$$

$$C_1/C_t = 1/(1-\sqrt{\gamma C_t/C_a}) \qquad \text{.........(14b)}$$

$$C_3/C_t = C_a/C_t\;(1-\sqrt{\gamma C_a/C_t}) \qquad \text{.........(14c)}$$

2.3.3. Step-up factor

The step-up factor, G, with the capacitive coupling, Fig. 4(c) is the ratio of the voltage across L to the aerial voltage e_a. Again the voltage across L at resonance is Q times the equivalent generator voltage e_s, so

$$G = Qe_s/e_a = Q/\{1+(C_2/C_a)+(C_2/C_3)\}$$
$$= Q/(Z+C_2/C_a) \qquad \text{.........(15)}$$

Substituting for C_2 from eqn. (12a),

$$G = Q/\{Z+(1+1/\gamma)\,C_t/ZC_a\} \qquad \text{.........(16)}$$

Taking Z as a variable, G will be a maximum when the derivative of the denominator is zero, i.e. when

$$Z^2 = (1+1/\gamma)\,C_t/C_a$$

or, since Z must be positive,

$$Z = \sqrt{(1+1/\gamma)\,C_t/C_a} \qquad \text{.........(17)}$$

This equation is applicable only over a limited range of values for the ratio C_a/C_t. As pointed out in connection with eqn. (9) the foregoing analysis assumes that $C_2/C_3 < 1/\gamma$, therefore eqn. (10) gives $Z < (1 + 1/\gamma)$ and so eqn. (17) can only hold if $C_t/C_a < (1 + 1/\gamma)$. Again, inspection of eqn. (12c) shows that if C_3 is not to become infinite, $Z > 1$, so that $C_a/C_t < (1 + 1/\gamma)$. Hence, with $1/\gamma \gg 1$,

$$\gamma < C_a/C_t < 1/\gamma.$$

Within this range, substitution of eqn. (17) in eqn. (16) gives

$$G_0 = Q/2\sqrt{(1 + 1/\gamma)\,C_t/C_a} \quad \text{.........(18)}$$

$$= Q/2Z \quad \text{.........(19)}$$

For the small values of γ generally required, a sufficiently accurate estimate of G_0 can be obtained from

$$G_0 = \tfrac{1}{2}Q\sqrt{\gamma\,C_a/C_t} \quad \text{.........(20)}$$

A comparison between eqns. (19) and (16) shows that G_0 is one half the maximum obtainable step-up factor with a comparatively long (high capacitance) aerial connected to the same circuit, since as $C_a \to \infty$, $G \to Q/Z$.

Equation (18) gives the relationship between G_0, Q, the L/C ratio (tuning capacitance C_t) and the maximum permissible detuning due to different aerial capacitances. A high value of Q and a low value of C_t will provide a high step-up factor and, since γ must be inversely proportional to Q, a maximum value of Q/C_t will give the highest possible step-up factor. It is generally advisable to select C_1, C_2 and C_3 for optimum step-up from the shortest aerial which is likely to be used. The step-up factor will then be greater for higher capacitance aerials.

2.3.4. Built-in aerial

If a built-in aerial is used, the capacitance C_a is known and so C_3 and C_1 may be omitted. The aerial capacitance may then be placed in parallel with a suitable fixed capacitor (with or without a trimmer) directly across the tuned circuit. The step-up is in this case

$$G = QC_a/(C_a + C_2) = QC_a/C_t \quad \text{.........(21)}$$

A small 10 pF plate aerial with a total tuning capacitance of 50 pF will give a G of $0{\cdot}2Q$ which even with a Q-factor as small as 50 provides a step-up of 10 times. This step-up is constant throughout the band (cf. Section 2.2.).

2.3.5. Image ratio

The image ratio for the capacitive aerial coupling is just as poor as for the case described in Section 2.2. For this reason it is often better to make use of the circuit discussed in the next section.

2.4. *Reversed Capacitive Aerial Coupling*

In the reversed capacitive aerial coupling circuit, shown in Fig. 5(a), the output is taken across part of the tuned circuit so that the output voltage, e_g, is reduced in the ratio C_t/C_1 compared with the circuit of Fig. 4. The equivalent circuit is shown in Fig. 5(b).

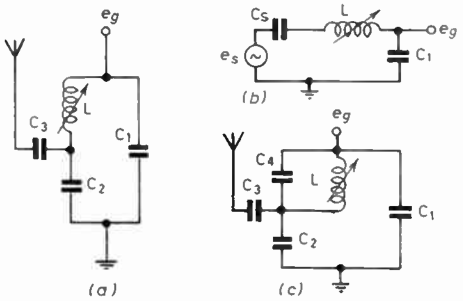

Fig. 5. (a) Reversed capacitive aerial coupling circuit. (b) Equivalent circuit of (a). (c) Modified reversed capacitive aerial circuit.

$$\frac{e_s}{e_a} = 1/[1 + (C_2/C_a) + (C_2/C_3)]$$

$$C_s = C_2 + C_aC_3/(C_a + C_3)$$

$$C_t = C_1C_s/(C_1 + C_s)$$

$$G = \frac{C_t}{C_1}\cdot\frac{Qe_s}{e_a}$$

2.4.1. Step-up factor

$$G = \frac{QC_t}{C_1\left(1 + \dfrac{C_2}{C_a} + \dfrac{C_2}{C_3}\right)} \quad \text{.........(22)}$$

Using eqns. (7a) and (11), which still hold,

$$G = \frac{Q}{\left\{1 + \dfrac{Z}{(1 + 1/\gamma) - Z}\right\}\left\{Z + \dfrac{(1 + 1/\gamma)\,C_t}{Z\quad C_a}\right\}} \quad \text{.........(23)}$$

which is a maximum when

$$Z = -\frac{C_t}{C_a} + \sqrt{\left(\frac{C_t}{C_a}\right)^2 + \left(1 + \frac{1}{\gamma}\right)\frac{C_t}{C_a}} \quad \text{.......(24)}$$

Substituting from eqn. (24) in eqn. (23), then for the optimum step-up factor G_0

$$G_0 = \tfrac{1}{2}Q/\{Z + 2\,(C_t/C_a)\} \quad \text{.........(25)}$$

or

$$G_0 = \frac{\tfrac{1}{2}Q}{\dfrac{C_t}{C_a} + \sqrt{\left(\dfrac{C_t}{C_a}\right)^2 + \left(1 + \dfrac{1}{\gamma}\right)\dfrac{C_t}{C_a}}} \quad \text{......(26)}$$

The expression (26) has been plotted for various values of C_2/C_3 and for $\gamma = 0{\cdot}04$, in Fig. 6. One of the curves of Fig. 2 has also been included (dotted line). Since the two tuning systems can be compared only for a given value of C_t of the permeability tuner, a value of 50 pF has been assumed. A check on Fig. 2 shows that for a short 50 pF aerial the curve $L_2/L_1 = 10$ gives optimum step-up. This same curve in Fig. 6, however, shows that higher step-up factors are obtained, with the same aerial length ($C_a/C_t = 1$) and reversed aerial coupling, from a permeability tuner, even if allowance is made for a lower Q-factor. Of course, a lower value of C_t would make the difference even greater whereas a higher value of C_t would bring the dotted line closer to the curves for the permeability tuner.

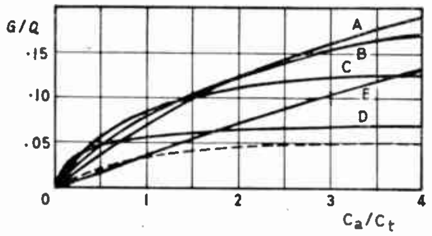

Fig. 6. Step-up factor ratio G/Q of the reversed capacitive coupled aerial circuit as a function of the capacitance ratio C_a/C_t with the parameter values:

E, $C_3/C_2 = 1$, $\gamma = {\cdot}04$.
D, $C_3/C_2 = \frac{1}{2}$, $\gamma = {\cdot}04$.
C, $C_3/C_2 = \frac{1}{4}$, $\gamma = {\cdot}04$.
B, $C_3/C_2 = \frac{1}{8}$, $\gamma = {\cdot}04$.
A, $C_3/C_2 = \infty$, $\gamma = {\cdot}04$.

Curve B of Fig. 2 is also shown (dotted) for comparison.

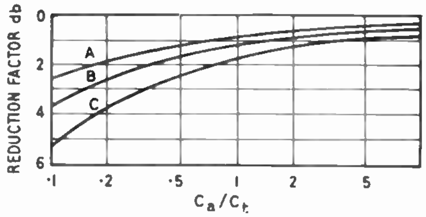

Fig. 7. Reduction in the optimum step-up factor G_0 for the circuit of Fig. 5(a) compared with the circuit of Fig. 4(a) as a function of C_a/C_t.

The loss of optimum gain due to grid tapping is given in Fig. 7 for various values of γ.

Obviously this difference between the performance of the circuits in Figs. 4 and 5 is only of minor importance provided C_a/C_t is not too small and γ not too high. For a circuit with a moderate quality factor of 50, a sensible value of γ is 0·04 resulting in a gain reduction of not more than 3 db as long as $C_a/C_t > 1/3$ (17 pF aerial when $C_t = 50$ pF). The curves of Fig. 7 indicate that when very short aerials are used the reduction of C_t to a minimum (tuned circuit with high L/C ratio) is even more important for the reversed capacitive coupled aerial circuit of Fig. 5 than for the direct capacitive circuit of Fig. 4.

2.4.2. Capacitor values

The values of C_1, C_2 and C_3 for optimum step-up factor may be found by substituting the value of Z in eqn. (24) into eqn. (12). These optimum capacitor values are shown in Fig. 8 as a function of the ratio C_a/C_t.

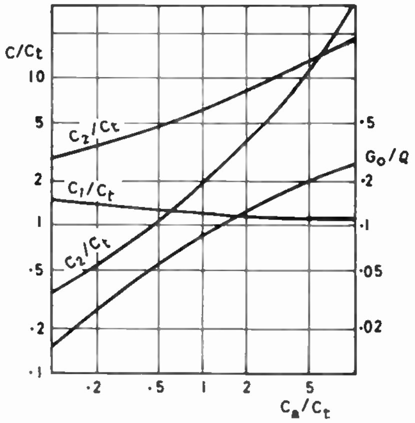

Fig. 8. Optimum capacitor ratios for the circuit of Fig. 5(a) as a function of the ratio C_a/C_t.

2.4.3. Built-in aerials

Again consider a low-capacitance built-in aerial plate, directly connected to the tuned circuit ($C_3 \to \infty$) in which case the optimum value of C_2/C_t (disregarding γ) can be found from

$$G = QC_t/C_a(1 + C_2/C_a) \quad \text{(compare equation 22)} \qquad \ldots\ldots\ldots(27)$$

With $C_t = C_1(C_2 + C_a)/(C_1 + C_2 + C_a)$,

$$G = Q(C_2 + C_a - C_t)/(C_2 + C_a)^2 \qquad \ldots\ldots\ldots(28)$$

which shows a maximum for

$$C_2/C_t = 2 - (C_a/C_t) \qquad \ldots\ldots\ldots(29)$$

consequently,

$$C_1/C_t = 2 \qquad \ldots\ldots\ldots(30)$$

and $$G_0 = Q\,C_a/4C_t \qquad \ldots\ldots\ldots(31)$$

A comparison with eqn. (21) shows a 12 db drop in gain, but nevertheless a 10 pF aerial gives a step-up factor of 2·5 if Q is 50 and C_t is 50 pF.

2.4.4. Image ratio

The image response of the circuit in Fig. 5a will follow the same law as that in Fig. 1, but, in general, the Q-factor of a permeability tuned circuit will be lower. With $Q = 50$ the image rejection will be approximately

$$R_i\ (530\ \text{kc/s}) = 300$$
$$R_i\ (1620\ \text{kc/s}) = 70$$

These figures are approximately the same as would be obtained from a mutually coupled tuned circuit which has additional top-capacitance coupling. The image rejection can be improved by a modification of the circuit, discussed in the next Section.

2.5. *Modified Reversed Capacitive Aerial Coupling*

The modified circuit shown in Fig. 5(c) places part of the tuning capacitor across the inductance L. If the value of the capacitor C_4 is made one quarter of the total tuning capacitance C_t, the step-up factor will show a minimum at a frequency of $2f_0$, where f_0 is the resonant frequency of the entire tuned circuit. Then, in the centre of the broadcast band where $f_0 = 910$ kc/s, G will be a minimum at 1820 kc/s which is also the image frequency. Thus the image rejection is increased relative to the circuit of Fig. 5(a). This improvement in image rejection decreases away from the centre of the band.

Assuming the circuit losses to be mainly concentrated in the inductance L (equivalent series resistance r_L), the voltage across C_1 is in this case given by

$$\frac{e_g}{e_s} = \left(\frac{C_2}{C_1 + C_2}\right) \cdot \left(\frac{1 - \omega^2 LC_4 + j\omega r_L C_4}{1 - \omega^2 LC_t + j\omega r_L C_4}\right) \ldots(32)$$

For series resonance at the frequency f_0, this becomes approximately

$$\left(\frac{e_g}{e_s}\right)_{f_0} = \left(\frac{C_2}{C_1 + C_2}\right) \cdot \left(\frac{1 - \omega_0^2 LC_4}{j\omega_0 r_L C_t}\right)$$
$$= \frac{Q_s C_2\ (1 - \omega_0^2 LC_4)}{C_1 + C_2}$$
$$= \frac{(1 - C_4/C_t)\,Q_s\ C_2}{C_1 + C_2} \qquad \ldots\ldots\ldots(33)$$
$$= \frac{3/4\ Q_s C_2}{C_1 + C_2} \quad \text{for } C_4/C_t = 1/4$$

$Q_s = 1/\omega_0 r_L C_t$ is the Q-factor of the coil at the frequency f_0. Equation (33) appears to indicate a reduction in G of 2·5 db for $C_4/C_t = 1/4$, or an equivalent modified circuit $Q_m = 3/4\ Q_s$.

However, that part of the total tuning capacitance contributed by C_1 and C_2 now only needs to be

$$C_{tm} = C_t - C_4 = 3/4\,C_t$$

and, since C_4 is constant, a variation of $\gamma_m = 3/4\gamma$ in C_{tm} will still satisfy the requirement for limited detuning. Consequently equation (20) gives for this modified circuit

$$G_{0m} = \frac{Q_m}{2}\sqrt{\frac{C_a\gamma_m}{C_{tm}}}$$
$$= \frac{3/4Q}{2}\sqrt{\left(\frac{4}{3}\gamma\right)\left(\frac{4\,C_a}{3\,C_t}\right)} = G_0 \ldots\ldots(34)$$

i.e., G_0 is unaltered.

In determining the values of the capacitors C_1, C_2 and C_3 from eqn. (12), etc., C_a/C_{tm} should be used instead of C_a/C_t.

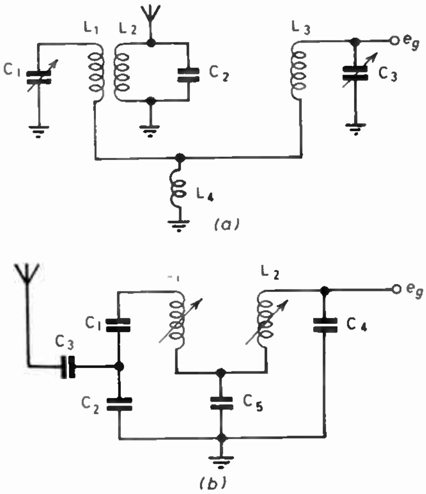

Fig. 9. Bandpass aerial circuits. (a) Capacitance tuned. (b) Permeability tuned.

2.6. *Bandpass Aerial Circuit*

A bandpass capacitance tuned aerial circuit, shown in Fig. 9(a) gives a much higher image rejection than do other aerial circuits. With permeability tuning the bottom capacitance coupled circuit of Fig. 9(b) should be used when-

World Radio History

ever the unwanted frequencies are higher than the wanted frequencies.

For the broadcast band and a 455 kc/s i.f. the image rejection for the circuit in Fig. 9(b) is 12 db better than that of Fig. 9(a); i.e., a permeability tuned circuit with only half the Q-factor of a capacitance tuned one will give comparable image rejection.

Again, the step-up factor for the circuit of Fig. 9(b) is much greater than that for the circuit of Fig. 9(a).

Despite their better performance, these circuits are seldom used nowadays because of the additional expense of the extra tuning elements required.

2.7. *Summary*

The results of the preceding sections are summarized in Figs. 10 and 11. The former shows the optimum step-up factor ratios G_a/Q for the various circuits as a function of the ratio of aerial to tuning capacitances. The best factors are obtained with the top capacitance coupled circuits. They are, in fact, the maximum possible.

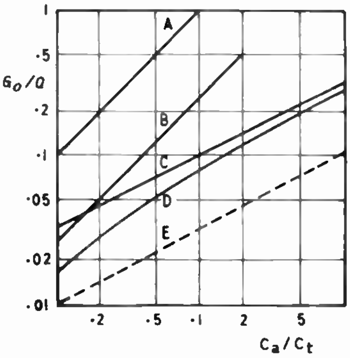

Fig. 10. Optimum step-up factor ratio G_0/Q as a function of the capacitance ratio C_a/C_t for the following aerial coupling circuits:

- *A* Top capacitance coupled circuit.
- *B* Top reversed capacitance coupled circuit.
- *C* Capacitance coupled circuit with $\gamma = \cdot 04$.
- *D* Reversed capacitance coupled circuit with $\gamma = \cdot 04$.
- *E* Mutually coupled capacitance tuned circuit.

The lowest step-up factor is obtained from the mutual coupled circuit (capacitance tuning), while the capacitance coupled and reversed capacitance coupled circuits (with $\gamma = 0{\cdot}04$) give intermediate results.

The image rejection ratios throughout the broadcast band are compared in Fig. 11. The top capacitance coupled circuits have been omitted because of their poor performance. For the capacitance tuned circuits a Q-factor of 100 has been assumed whereas for the permeability tuned circuits $Q = 50$. It can be seen that the modified reversed capacitive coupled circuit (Fig. 5(c)) produces a better average result than the conventional mutually coupled circuit (Fig. 1).

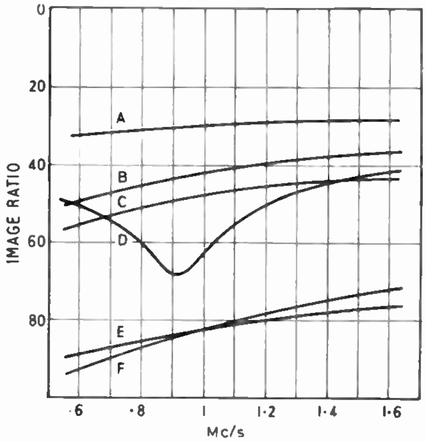

Fig. 11. Image rejection ratios throughout the broadcast band (i.f. = 455 kc/s) for the following aerial coupling circuits:

- *A* Capacitance coupled circuit ($Q = 50$).
- *B* Reversed capacitance coupled ($Q = 50$).
- *C* Mutually coupled capacitance tuned circuit ($Q = 100$).
- *D* Modified reversed capacitance coupled circuit ($Q = 50$).
- *E* Bandpass capacitance tuned circuit ($Q = 100$).
- *F* Bandpass permeability tuned circuit ($Q = 50$).

From the above it is clear that for the broadcast band a permeability tuner using the aerial coupling circuit of Fig. 5(c) can give a higher step-up factor and a better image rejection than a capacitance tuner with a much higher Q-factor. However, there will be a slight decrease in adjacent channel selectivity due to lower Q.

3. The Influence of Aerial Losses on the Aerial Circuit

So far, only purely capacitive aerials have been considered. In practice, the aerial capacitance does not only vary throughout the broadcast band but it also has a limited Q-factor.

The variation of aerial capacitance is generally not important, since a well designed aerial stage allows for considerable variations. The variation throughout the broadcast band is seldom more than 10% (depending on the type of the aerial used).

There is, however, a resistive component of the aerial impedance which tends to vary with frequency in such a manner that the Q-factor of the aerial is roughly constant. To determine what effect the Q-factor of the aerial capacitance has on the effective Q of the aerial circuit, assume that all the other capacitances in the circuit have infinite Q-factors and, for the circuits of Figs. 4(a) and 5(a), put

$$C_s = C_a C_3/(C_a+C_3) \text{ with } Q\text{-factor } Q_s$$

and

$$C_b = C_2+C_s \qquad \text{with } Q\text{-factor } Q_b$$

We now have

$$Q_s/Q_a = (C_a+C_3)/C_3 = C_a/C_s$$
$$Q_b/Q_s = (C_2+C_s)/C_s = C_b/C_s$$
$$Q_t/Q_b = (C_b+C_1)/C_1 = C_b/C_t$$

if Q_t is the resulting Q-factor of C_t. Consequently,

$$Q_t/Q_a = (C_b/C_s)^2 . C_a/C_t \qquad \text{.........(35)}$$

or, also,

$$\frac{Q_t}{Q_a} = \left\{1 + \frac{C_2(C_a+C_3)}{C_a C_3}\right\}^2 \frac{C_a}{C_t} = \left(\frac{C_2}{C_a} + Z\right)^2 \cdot \frac{C_a}{C_t}$$

which shows a minimum when

$$C_a = C_2/Z = (1+1/\gamma)\ C_t/Z^2 \qquad \text{.........(36)}$$

This minimum appears to be

$$(Q_t/Q_a)_{\min} = 4C_2 Z/C_t = 4(1+1/\gamma) \qquad \text{.........(37)}$$

For a γ of 0·04, then $(Q_t/Q_a)_{\min}$ is 104. In other words, as long as the Q-factor of the aerial is not extremely bad it will hardly influence the Q-factor of the aerial circuit at all for low values of γ. For indoor aerials a Q-factor of the order of 50 is normal throughout the broadcast band, but even values as low as 10 will barely influence the performance of the receiver, provided γ is low.

It should be mentioned that in the case of direct capacitive aerial coupling, Fig. 4(a), the minimum value of Q_t with a given aerial occurs when $G=G_0$.

When a top-connected aerial is used,

$$Q_t/Q_a = (C_t+C_a)/C_a \text{ and } Q_r = Q_t Q_2/(Q_t+Q_2), \qquad \text{.........(38)}$$

if Q_r is the resultant Q-factor of the aerial circuit and Q_2 is the Q-factor of the circuit disregarding the aerial losses.

For an aerial directly connected to the reversed capacitive aerial circuit of Fig. 5(a) $(C_3=\infty)$,

$$Q_t/Q_a = (C_2+C_a) \quad (C_2+C_a+C_t)/C_a C_t$$

Under optimum step-up conditions, eqns. (29) and (30) give

$$Q_t/Q_a = 4C_t/C_a \text{ and again } Q_r = Q_t Q_2/(Q_t+Q_2) \qquad \text{.........(39)}$$

4. Signal-to-Noise Ratio

No attention has been paid so far, to the signal-to-noise ratio. The parallel impedance of the aerial circuit is $R_p = Q.X(C_t)$, where $X(C_t)$ is the reactance of the total tuning capacitance at resonance. This parallel impedance will be highest at the low frequency end of the band when C_t is constant. If an input circuit is to be designed for optimum signal-to-noise ratio, however, this can be done at only one point in the band and it appears logical to take the geometric mean frequency $f_s = \sqrt{(f_{\max}.\ f_{\min}.)}$. For the broadcast band, $f_s = 930$ kc/s. At this frequency, with $Q=50$ and $C_t=50$ pF, $R_p =$ 170,000 ohms. This is considerably higher than the equivalent noise resistance of a good frequency converter valve.

A capacitance tuned circuit using 100 pF tuning capacitance at 930 kc/s, and with a Q-factor of 100, will also have a parallel impedance of 170,000 ohms. Since under practically all circumstances the capacitive aerial coupling gives a better step-up ratio, the permeability tuner will generally give a slightly better signal-to-noise ratio.

5. Aerial Circuits for Short-Wave Reception

Obviously, for additional s.w. reception, a second aerial coil will have to be added to the receiver. Since, however, the one drive mechanism can be used for all coils, the increase in cost need not be much more than for a capacitance tuned receiver and may be offset by simplified circuitry.

For the s.w. bands, the aerial characteristics are generally more or less resistive. On the other hand, a permeability tuned aerial coil for the higher frequencies of the s.w. bands can be made with a higher Q-factor than can be obtained for the broadcast band. In other words, the aerial circuit can be loaded to a certain extent with the aerial and still give a reasonable step-up factor. With the circuit of Fig. 4(a) step-up factors of the order of four are obtainable from a 400 ohm aerial.

Much depends on how the short-wave range is split up. Since in any case special aerial and oscillator coils will have to be used for s.w. reception, these coils can be designed for a lower maximum to minimum frequency ratio than for the broadcast coils, thus easing the tuning of the s.w. range (bandspread). There are many different ways of covering the range from 6 to 18 Mc/s in a number of tuning ranges, and the behaviour of the aerial circuit varies accordingly. The main change from capacitance tuning is that electrically the tuning device is used for the s.w. band only and therefore simpler and better circuits may be designed for whatever band is involved.

6. R.F. and Oscillator Stages

The main difference between the behaviour of a capacitance tuned and a permeability tuned r.f. interstage coupling circuit is that whereas for the former the parallel impedance tends to increase towards the high frequency end of the tuning range, the permeability tuned circuit will show the opposite effect. This is an advantage as far as the stability of the r.f. stage is concerned. If gain correction is required, a small coupling capacitor and not too high a value of gridleak for the following stage will generally be sufficient.

Although in principle a multitude of oscillator circuits can be adapted to permeability tuning, the Colpitt's oscillator, which avoids tapping of coils is probably the most straightforward arrangement. This circuit gives good results for high maximum to minimum frequency ratios.

7. The Construction of Permeability Tuners

The problems involved in the construction of permeability tuners are mainly tolerance problems brought about by the tracking requirements. This is not altogether surprising in view of the required accuracy (of the order of 1%) and the rather elaborate measures taken to obtain this accuracy with conventional tuning capacitors. One of the main problems is, in other words, to produce an accurate law and unless this is done a permeability tuner will never be completely successful.

Very often, only two adjustments are used—the positioning of the moving (tuning) core in the coil and the adjustment of the tuning capacitance. It should be realised, however, that the tuning capacitance has nothing to do with the tuning law of the permeability tuner, since throughout the range all frequencies are affected proportionately. The adjustment of the tuning capacitance gives a constant multiplication factor for all frequencies in the band, but cannot alter the maximum to minimum frequency ratio of the tuner or the tuning law. This leaves only the positioning of the tuning core to correct for law errors. When a linear drive system is used this correction of the core position is virtually the same thing as shifting the pointer along the dial, so that it does not provide much freedom. Let us, therefore, investigate what can be done electrically to improve this situation. The electrical remedies for this situation will therefore be considered.

7.1. *Core Permeability and the Tuning Law*

The minimum permeability of the core material to be used is determined by the required maximum to minimum frequency ratio of the frequency range to be covered. Since the maximum inductance of the coil varies proportionally with the maximum effective permeability of the core, and since furthermore the inductance ratio, required is the square of the required frequency ratio, the maximum effective permeability will have to be at least as high as the square of the frequency ratio of the range to be covered. It is for this reason, and the fact that the effective permeability of a core inserted in a coil tends to be considerably lower than the true permeability of the core material, that permeability tuning of the broadcast band with its high maximum to minimum frequency ratio was practically impossible until high permeability materials suitable for use at high frequencies became available.

The effective permeability of a core of given dimensions, inserted in a coil (coil permeability μ_c) depends not only on the true permeability of the core material μ_t but also on the shape of the coil and the core. It is highest when the coil is wound as a single layer solenoid, close to the core and of the same length as the core. Under these circumstances,

$$\mu_{c\ \max} \cong 0{\cdot}7\ \mu_{\text{rod}}\ ,$$

where μ_{rod} is the ratio of the maximum flux density in the core compared with the original flux density when the core is placed in a uniform field[†]. μ_{rod} now is a figure which does not depend on the coil any more. It is determined by the length to diameter ratio of the core and the true permeability of the core material.

In Fig. 12 the value of μ_{rod} has been plotted as a function of the l/d ratio of the core for various values of the true permeability μ_t. A given value of μ_{rod} can be obtained with a multitude of combinations from a high μ_t, with a low l/d ratio, to a low value of μ_t with a high l/d ratio. For example, a μ_{rod} of 10 can be obtained with a μ_t of 20 or less, in which case l/d is not very critical but for any variation in μ_t the variation in μ_{rod} approaches half this variation in μ_t, or more. In general, for a variation $\Delta\mu_t$ in μ_t, the variation $\Delta\mu_{\text{rod}}$ in μ_{rod} is given by

$$\frac{\Delta\mu_{\text{rod}}}{\mu_{\text{rod}}} = \left(\frac{\mu_{\text{rod}} - 1}{\mu_t}\right) \cdot \frac{\Delta\mu_t}{\mu_t} \quad \ldots\ldots\ldots(40)$$

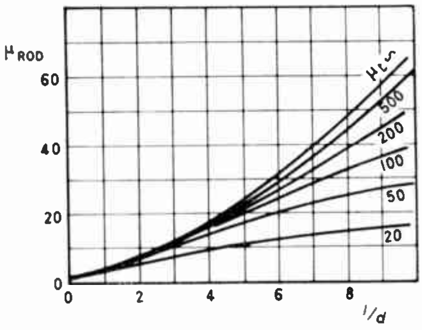

Fig. 12. Rod permeability as a function of the length/diameter ratio with the core material permeability as a parameter. (After Bozorth and Chapin‡.)

A rod permeability of 10, however, can also be obtained with a μ_t of 1000 and a l/d of 2·5, in which case a considerable variation in μ_t will hardly influence μ_{rod}.

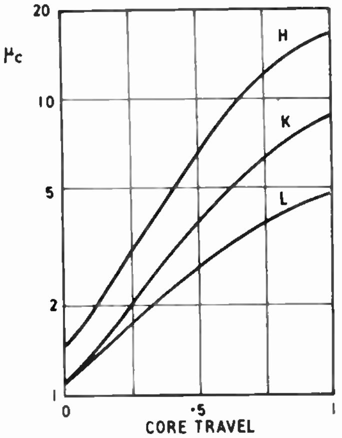

Fig. 13. Effective coil permeability as a function of the core position for a 0·2 in. diameter solenoid, 1 in. long, with the following cores, all 1 in. long:

H, core diameter 0·16 in., μ_t = 800
K, core diameter 0·06 in., μ_t = 800
L, core diameter 0·16 in., μ_t = 10

Of course, μ_{rod} is only a direct measure of the effectiveness of the core under the conditions stated. One can say, however, that the value of μ_c at any core setting depends on the l/d ratio of that part of the coil which is affected by the core, and the rod permeability of that part of the core which affects it.

When a low permeability core is inserted in a coil, the coil permeability will for the first part of the travel be determined by the increasing number of turns affected and secondly by the increase in μ_{rod} for the growing fraction of the core length inserted in the coil. When, however, μ_{rod} approaches μ_t, any further increase in μ_c can be obtained only due to the increasing number of turns affected, whereas for a high permeability core the further increase in μ_{rod} helps all along to build up a higher inductance. Consequently, there is a difference in "law" between the two. This is illustrated in Fig. 13, where curve H gives the tuning law of a high permeability core ($\mu_t = 800$) of diameter 0·16 in. and 1 in. long in a solenoid 1 in. long and of 0·2 in. diameter. Curve L is the tuning law for

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[†] H. van Suchteien, "Ferroxcube rod aerials", *Electronic Appl. Bull.*, **13**, pp. 88-100, June 1952.

[‡] R. M. Bozorth, and D. M. Chapin, "Demagnetizing factors of rods", *J. Appl. Phys.*, **13**, p. 321, 1942.

World Radio History

a low permeability core of the same dimensions. It can be seen that the high permeability core tends to provide a more nearly linear tuning law. Curve K is the tuning law for a high permeability core ($\mu_t = 800$) of smaller diameter (0·06 in.). The tuning capacitance remained unaltered in all cases.

For the core of curve K, the reduced effective permeability due to the smaller cross section (proportional to the square of the diameter) is counteracted by the increased μ_{rod} resulting in an effective (coil) permeability which for small variations in the diameter is approximately proportional to the diameter. Curve K is generally similar to curve H, differing only by an almost constant multiplying factor. This ratio of permeability of the two cores changes radically only at the extreme high frequency end of the band. There the core is practically out of the coil, so that the total inductance is mainly controlled by the coil without the core. This is shown clearly in Fig. 14, where the ratio of the coil permeabilities for the three cores has been plotted as a function of core travel. Since the ratio-error in the tuning system can be corrected with the tuning capacitance, it is obvious that the diameter error is not as serious as the true permeability error, especially if one can afford to keep the minimum coil permeability (at the highest working frequency) high. Generally, it is more easy to control core sizes than the true permeability of the core material.

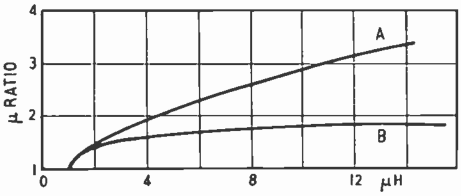

Fig. 14. Ratios of the effective permeabilities shown in Fig. 13, μ_H/μ_L (curve A) and μ_H/μ_K (curve B) as a function of μH_t showing the influence of core diameter and permeability on the tuning law.

From the foregoing it can be seen that for optimum performance in a production permeability tuner the core material should have a high permeability. The most suitable materials are the ferrites. It is true that ferrites have a high temperature coefficient, but since the effective permeability is many times lower than the true permeability, the temperature effects are reduced almost proportionally (eqn. 40) and will generally not cause any difficulty.

7.2. *Law Adjustment*

Although the selection of proper materials and proper construction will help us considerably towards a repeatable tuning law, production difficulties can be reduced to a great extent if the tuning law can be adjusted. With high permeability core materials the parallel capacitance allows for the correction of diameter errors apart from the very high frequency end of the tuning range (Fig. 14). A separate control of the law for this part of the tuning range may be obtained using a series connected adjustable fixed inductance. This fixed series coil, the inductance of which can be small compared with the minimum inductance of the variable coil, will mainly affect the high frequency end of the tuning range since for those frequencies the tuning coil has the lowest inductance and therefore the series inductance makes up a larger fraction of the total inductance in the circuit. It follows that the series inductance will alter the tuning law, especially when the maximum to minimum frequency ratio of the band is high.

Including this series coil, there are three variables in the tuned circuit which provide for adjustment of the tuner at three frequencies in the range. In many cases this will be sufficient. For higher accuracy, however, a parallel fixed inductance may be introduced. This will influence mainly the low frequency end of the tuning range, since at those frequencies the tuned inductance is a maximum. The inductance of the parallel coil should be high compared with this maximum inductance of the tuned coil. Thus with four controls the tuning law can be corrected at four points in the range.

When series inductance is used it should be used for law correction at the high frequency end of the band. The core position can then be adjusted at the low frequency end of the band, whereas the parallel capacitance is to be adjusted at some intermediate frequency. Similarly, a parallel coil should be used for correction of the low frequency end of the tuning range.

7.3. *Tuning Law*

The tuning law of a permeability tuner should, from an operational point of view, be as close to linear as possible. Only a linear tuning law gives a constant rate of frequency change. Also, from a mechanical viewpoint, a linear law is an advantage in that it optimizes the permissible tolerance in the drive mechanism. However, the law obtained from a core moved into a solenoid is far from linear, the deviation from linearity depending on the core and coil sizes, true permeability of the core material and also the maximum to minimum frequency ratio in the range to be tuned. Even the law for a high permeability core is far from linear when the maximum to minimum frequency ratio is high, as for the broadcast band.

In a superheterodyne receiver, the frequency ratio for the r.f. and oscillator circuits are entirely different. It is therefore not possible to use regularly wound coils for both and in order to satisfy the requirement of a high L/C ratio for the aerial circuit the aerial coil is frequently wound as a progressive pie-winding. The oscillator law is then experimentally found with a variable pitch coil. The drawback to this arrangement is that the non-linear law of a tuner of this type causes a considerably higher rate of frequency change at the higher end of the band than that obtained for the lower frequencies in the band and that, therefore, the tolerance requirements are more difficult than is necessary. Furthermore, where the spacing of a variable pitch coil is not always easy to control, part of the saving obtained with a basically inexpensive tuner is lost due to the unavoidably tight control which must be exercised in production. Therefore a slightly more complicated tuner with an easily adjustable tuning law may prove a better proposition in that it gives better and more reliable results for approximately the same cost price. An example of such a tuner is the Straight Line Frequency tuner described in Section 7·4.

Tracking problems are very dependent on the maximum to minimum frequency ratio of the band covered. For a low ratio a low effective permeability will suffice, hence variations in true permeability will be of comparatively little consequence. Also, the relative frequency change per unit of core travel will be lower. Consequently, larger mechanical errors may be tolerated. This is the case with the short-wave range which can be split up with considerable operational advantage. However, the broadcast band must be covered in one range. This is much more difficult and requires better control of the tuner law. Provision should therefore be made for law adjustment, especially in the case of the broadcast band.

7.4. *Series Inductance Tuner*

A tuner has been constructed in which the series inductance used for law adjustment was wound on the same former as the tuning coil. An ordinary solenoid could be used, with the tuning core entering from one end and with an additional "fixed" core inserted at the other end.

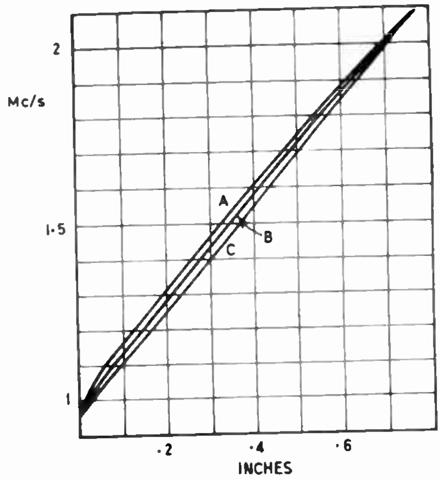

Fig. 15. Tuning law of oscillator coil for three values of the parallel capacitance: *A* 85 pF; *B* 90 pF; *C* 95 pF.

The "fixed" core has a number of effects. First, when the tuning core is moved into the coil the tuning law is affected for the last part of the core travel where proximity of the two cores tends to increase the mutual coupling between parts of the coil. Hence the rate of frequency change is increased at the low frequency end of the tuning range (where an increase is needed. As a result, a more linear law is obtained. Secondly, adjustment of the fixed core can be compared with adjustment of a series inductance (law correction). Thirdly, the Q-factor of the total inductance, when the tuning core is almost removed (high frequency end) is considerably better.

World Radio History

There is no real need for that part of the coil which contains only the fixed core to be wound as a solenoid. In fact, the tuner can be made smaller, and the Q-factor further increased, if that part is wound as a concentrated winding. In Fig. 15 the tuning curves are shown for such a composite coil wound on a 0·2 in. former and using a 0·16 in. tuning core and fixed core. The coil was surrounded by 0·06 in. ferrite rods and mounted in an aluminium can, 0·4 × 0·5 in. The total core travel was 0·75 in. The coil consisted of a close wound single layer solenoid with a wild winding as a "fixed series coil" at one end.

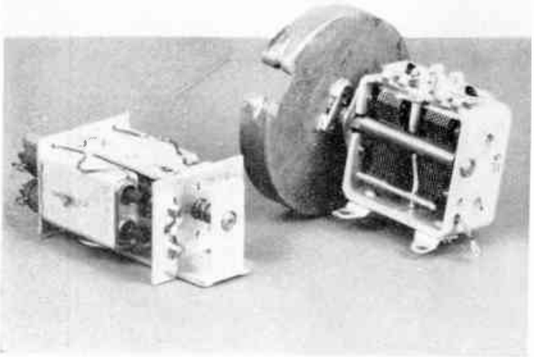

Fig. 16. Multi-band permeability tuner alongside conventional small tuning capacitor.

With this construction, the wire size may be selected for optimum L/C ratio and Q-factor. The l/d ratio of the solenoid and the turns ratio of the "fixed" and "variable" coil can be selected for optimum linearity. There are three adjustments on this tuner, the fixed core for the high frequency end, the variable core for the low frequency end and the parallel capacity for the middle of the tuning range. Fig. 15 shows clearly what is meant by a "flexible" tuning law. For these curves the tuner was adjusted to cover a given frequency range with three different values of parallel capacitance.

This coil was used as an oscillator coil for the broadcast band, with an i.f. of 455 kc/s. The associated aerial coil was constructed in the same manner, using identical former and cores. It gave almost perfect tracking.

A multi-band tuner of this type is shown in Fig. 16 beside a "small" tuning capacitor. The tuner shown is complete with its linear drive mechanism and requires only the tuning knob to be attached to the spindle at the rear end. It carries two double coil cans for the two aerial coils and the two oscillator coils used. In Fig. 17 the law of this S.L.F. tuner is compared with the law of a tuning system using the variable capacitor shown in Fig. 16 for the broadcast band.

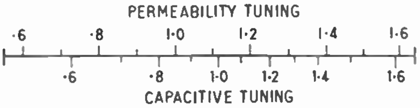

Fig. 17. A comparison of the tuning dial calibrations for the Straight Line Frequency tuner and the tuning capacitor as shown in Figure 16.

8. Conclusion

It would appear from the foregoing that permeability tuning, when compared with capacitance tuning, can offer better aerial step-up factors with comparable or superior image rejection figures, even when the Q-factor of the permeability tuned aerial coil is considerably lower than that of the fixed coil used with capacitance tuning.

The adjustment and control of the law of a permeability tuner to a pattern which very closely approaches the ideal Straight Line Frequency law is quite straightforward. There appears to be no reason why the application of permeability tuning should be restricted to cheaper class equipment only. The advantage of permeability tuning when applied to Short Wave reception is that it permits the design of bandspread receivers without the use of complicated circuitry. This indicates the potentialities of permeability tuning in general.

News from the Sections

SCOTTISH SECTION

At the November meetings of both the Glasgow and Edinburgh branches two papers were read on industrial applications of electronics.

Mr. G. F. Norman (Associate Member) described "An Electronic Engine Indicator" which he defined as a device for plotting combustion chamber pressures. He pointed out that various mechanical methods existed but that these were totally unsuitable for the high speed of modern engines. The three major requirements were:

1. A pressure transducer giving a linear output.
2. A frequency response adequate for the steep wave fronts encountered when the engine "pinks."
3. The operation of the engine must in no way be affected.

A number of suitable materials for the transducer element were described, and Mr. Norman discussed their advantages and disadvantages. Barium titanate was eventually chosen and used in the form of a ring inside a special sparking plug. In an engine under test this replaces the normal sparking plug. A selection of nine different combinations of heat range and reach have been found to cover most requirements. The output of the transducer is coupled to a d.c. amplifier with a top response of 10 kc/s and an input impedance of 20 megohms. This operates a cathode-ray oscilloscope in which the controls have been simplified for the benefit of non-technical personnel, e.g. the time base is calibrated in engine speed. A reliable triggered time-base is necessary and ways of achieving this were described.

The transducer is also applicable to the more difficult case of the diesel engine for which it is incorporated in the glow-plug. A barium titanate element can also be incorporated as part of the fuel line for measuring injection pressure.

In the discussion which followed Dr. D. Gordon referred to the Farnborough Indicator. Mr. Norman stated that the main objection was its inability to show up "detonation spikes." Calibration of the new transducer was discussed at some length and although it was shown how this could be done it was pointed out that the transducer was intended more for qualitative than quantitative measurement.

The second paper was read by Mr. D. Goodwin and was entitled "An Electronic Pin Hole Detector for Tin Plate Inspection." The author explained that in the production of tinplate pinholes are normally due to blowholes in the parent ingot and may be smaller than $0{\cdot}5 \times 10^{-3}$ in. in diameter. The tinplate normally runs at up to 800 ft./min. but detection was required at up to 1,500 ft./min.

In the method finally adopted the tinplate is exposed to the light from a 4 ft. mercury vapour strip lamp modulated at 4 kc/s. If a pinhole is present the light passes through, is dispersed by a suitable screen, and directed by a multiple lens system on to one of nine type 27 M1 photomultiplier cells. The output of these cells, after amplification and rectification, eventually operates the reject mechanism at the appropriate moment to reject the defective sheet of tinplate.

The cost of a breakdown in a strip mill was stated by Mr. Goodwin to be up to £6,000 per hour and elaborate steps must therefore be taken to ensure reliability including automatic monitoring of the correct functioning of the equipment.

W.R.E.

SOUTH WESTERN SECTION

A very comprehensive paper on "Electronic Transducers" was read in Bristol on November 25th by Mr. G. F. N. Knewstub (Associate Member). Commencing by describing the simple d.c.-excited, resistive strain gauge, Mr. Knewstub used this to illustrate the many possible sources of error. These included thermal e.m.fs which may be of the same order as those expected from the bridge, variations between calibration and test conditions, variations in type and thickness of bonding material, etc. He then went on to develop a symmetrical circuit by which most of the errors could be eliminated or minimized. The problems and advantages of a.c. excitation were then investigated.

Having stressed the pitfalls awaiting the unwary user, the paper introduced the many other types of "circuit element transducer," giving the basic circuits used to illustrate their applications.

Piezo-electric, photo-electric, thermo-electric and other generator types of transducers were then considered with basic circuitry, and some theory where necessary, to illustrate the very many ways in which they may be used. The author concluded with a reference to the possible future use of the "Hall" and other physical effects.

The paper was followed by working demonstrations of resistive strain gauges, crystal accelerometers and differential transformers.

In the discussion which followed, condenser microphones having responses up to 150 kc/s were suggested for recording insect noises in the ultrasonic range, while "string" and "viscosity" accelerometers were discussed in relation to inertial navigation problems; sensitivities of 10^{-5}_{g} were quoted for these types. The problem of strain gauge measurements on aero-engine turbine blades also aroused much interest but, unfortunately, lack of time prevented this subject being fully explored. E.G.D.

SOUTH WALES SECTION

The need for an Ordinary National Certificate and Higher National Certificate education scheme for radio and electronics engineers was warmly advocated in a discussion on training which followed the Section's Annual General Meeting on December 10th.

The first speaker in the discussion was Mr. C. T. Lamping who outlined the training facilities available in the telecommunications engineering branches of the British Post Office. A representative of a local electronics firm, Mr. G. F. Lawrence, appealed for a part time training scheme at Higher National level to cater for late entrants into the industry. He felt, too, that day release courses were far too long and too technical for the majority of students. He stressed that the number of jobs open to technologists was limited, and such key posts had to be supported by a number of more junior positions. The greatest difficulty was experienced in filling these posts because the five years course was widely regarded as a waste of time. People who took the full course and qualified were discouraged at finding that they were in the same kind of work as before taking the course. He considered there was a need for a shorter course of, say, two or three years.

The Section Chairman, Mr. J. Cotterell, stressed the need for a working partnership between industry and the technical colleges. He considered it was absurd that Post Office trainees should have to break off their training at the age of 18 years in order to fulfil national service commitments.

Mr. Cotterell said that he could not agree with criticisms of the technical colleges and the results they obtained, since the critics apparently did not appreciate that the colleges were trying to do the impossible. Teachers were expected to teach for two-and-a-half hours per subject each week for 36 weeks a year for five years, and he wondered sometimes how students managed to obtain a pass degree by this method. Discussing the training of craftsmen, Mr. Cotterell said that this had to be carried out both on the shop floor and in the technical college. He was of the opinion that after the first year suitable trainees should be allowed to attend a technical college in the block course scheme for at least one month full time. This would give both trainee and teacher a fair chance.

Professor Emrys Williams was firmly of the opinion that the development of radio and electronic engineering should be recognized. "I believe that a major dis-service to the cause of technological education is being done by adhering to the idea that electrical engineering is one and indivisible," he said. "Electronic engineering can be shown to be rather more than one half of electrical engineering at present. It is quite apparent that it is not only a subject in its own right, but is one which before long is going to be faced with the process of splitting in two. There should be specialized training at all levels in radio and electronic engineering."

The first social event organized by the Section took place on November 21st when the Chairman held a reception at the Angel Hotel, Cardiff. This preceded a visit to the Pontcanna studios of the television programme company for Wales and the West Country, T.W.W. Ltd. Members and their ladies were able to see rehearsals in progress for a programme which was broadcast later in the evening. C.T.L.

Coupling Coefficients of Ladder Networks with Maximally Flat Amplitude Response†

by

R. A. WALDRON, B.A.(CANTAB.), ASSOCIATE MEMBER‡

Summary: The problem solved in the present paper is that of expressing the coupling coefficients of a ladder network with maximally flat amplitude response in terms of the dissipations of the input and output branches. Green has already found one set of values; the present paper gives the generalized theory of Green's method of solution, and shows how to obtain all sets of values. These are given for networks containing up to five branches, together with the values of dissipation for which they are valid.

1. Notation

Following Green(1, 2) we number the branches of the network as in Fig. 1, and each inductance or capacitance is then referred to as L_r or C_r, where r is the number of the branch. We then define the following quantities:

$\omega_b =$ frequency at edge of pass-band. This is fixed arbitrarily by the designer, but will usually be the 3db point.

$d = G/\omega_b C_1 =$ decrement of the first branch, containing the load, which has conductance G.

$D =$ ratio of the decrement of the nth branch (containing the generator) to that of the first branch. Thus Dd is the decrement of the nth branch, and is given by $R_g/L_n\omega_b$ (n even), $1/R_g\omega_b C_n$ (n odd), according as the input branch contains an inductance or a capacitance.

$K_{r,\,r+1} =$ coupling factor between the rth and $(r+1)$th branches, given by

$$\frac{1}{\omega_b\sqrt{L_{r+1}C_r}}\ (r\text{ odd}),\quad \frac{1}{\omega_b\sqrt{L_rC_{r+1}}}\ (r\text{ even}).$$

$V_b =$ output voltage at frequency ω_b.

$V_0 =$ output voltage at peak of amplitude response curve ($\omega = 0$).

$p = j\omega/\omega_b$.

$$\gamma_n = \left\{\left|\frac{V_0}{V_b}\right|^2 - 1\right\}^{-1/2n}$$

2. Introduction

The present paper is prompted by a recent paper by Weinberg[3], who considers a second solution for the coupling coefficients of the three-branch ladder network. The problem of finding alternative solutions to the normal solution was solved generally by the present author in 1953, but not published then. Some of the results were, however, included in a paper by Green[2] published in January 1954. There is evidently still some interest in these alternative solutions, and the present paper now gives details of the general solution.

We confine ourselves to the case of a low-pass filter in which there is dissipation only in the first and last branches, i.e. in the generator and the load. Reactive components in the generator and load may, by suitable transformations, be regarded as part of the network, so that we need consider only a purely resistive generator, connected via a purely reactive network to a purely resistive load. A suitable frequency transformation will enable the results to be applied to a band-pass or high-pass filter, so that there is no loss of generality in considering the network we have described. Such a network is illustrated in Fig. 1. Since it is intended to be a low-pass filter, all the series elements are inductances and all the shunt elements capacitances. In general there will be n branches in the network. The higher the value of n, the flatter will be the response in the pass-band. We may now state our problem thus: given the generator and load resistances, connected by a low-pass ladder network of n branches, what are the values of the capacitances and induc-

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World Radio History

tances in order that the amplitude response function shall be maximally flat?

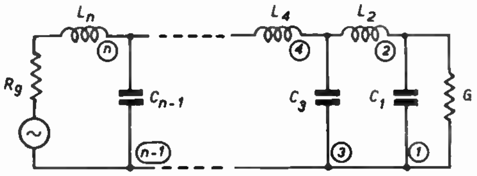

Fig. 1. The network considered in the paper.

It will be seen from the definitions in Section 1 that if we know any one of the L_r or C_r, and all the $K_{r,\,r+1}$, we can find all the other L_r and C_r. Also, if we know either d or D, R_g and G being given, we know the reactance of the first or last element. Thus if we can express the $K_{r,\,r+1}$ as functions of d and D, we shall regard these functions as solutions of the problem.

A partial solution to the problem has been given by Green[1], in the form of a general expression for networks of any number of branches; however, except for networks of one or two branches, it is not the only possible solution.

3. Green's Solution for the Coupling Coefficients

Green[1], Wallman[4], and Dishal[5] have shown that the output voltage V, at frequency ω, is given by

$$\frac{V_0}{V}=\frac{1}{\Upsilon^n_n}\prod_{k=1}^{q}\left\{[p-(-r_k+\mathrm{j}i_k)]\,[p-(-r_k-\mathrm{j}i_k)]\right\} \qquad \ldots\ldots\ldots(1)$$

where $q=n/2$ (n even), $q=(n+1)/2$ (n odd) $\qquad\ldots\ldots\ldots(2)$

$$r_k=\Upsilon_n \sin\left(\frac{2k-1}{n}\cdot\frac{\pi}{2}\right)$$

$$i_k=\Upsilon_n \cos\left(\frac{2k-1}{n}\cdot\frac{\pi}{2}\right)$$

Equation (1) may be written

$$\frac{V_0}{V}=\prod_{k=1}^{n}\left\{\frac{p}{\Upsilon_n}-\mathrm{j}\exp\left[\mathrm{j}(2k-1)\pi/2n\right]\right\} \qquad \ldots\ldots\ldots(3)$$

Bosse[6] has given a method of reducing this expression to a polynomial. Writing

$${}_nE_1=\frac{V_0}{V}=\sum_{r=0}^{n}{}_nA_r\,p^r/\Upsilon^r_n \qquad \ldots\ldots\ldots(4)$$

we find, following Bosse,

$$\frac{{}_nA_r}{{}_nA_{r-1}}=\frac{\cos(r-1)\theta}{\sin r\theta} \qquad \ldots\ldots\ldots(5)$$

where $\theta=\pi/2n$.

It is evident from eqn. (3) that ${}_nA_0=1$. Thus ${}_nA_r$ may be evaluated, and we find

$${}_nE_1 = 1+\frac{1}{\sin\theta}\frac{p}{\Upsilon_n}+\frac{\cos\theta}{\sin\theta\sin 2\theta}\frac{p^2}{\Upsilon^2_n}+\ldots\ldots$$
$$\ldots\ldots+\frac{\cos\theta.\cos 2\theta\ \ldots\ \cos(n-1)\theta}{\sin\theta.\sin 2\theta\ \ldots\ \sin n\theta}\;.\frac{p^n}{\Upsilon^n_n} \qquad \ldots\ldots\ldots(6)$$

This polynomial in p expresses the response of the network. A similar polynomial may be found, in terms of the inductances, capacitances, and decrements present in the network, generator, and load. In this way, Green[1] and Skwirzynski (unpublished) have shown that

$$\left.\begin{array}{lllll}
{}_nA_n & = 1 & & & \\
{}_nA_{n-1} & = {}_{n-1}A_{n-2} & +\,dD & & \\
{}_nA_{n-2} & = {}_{n-1}A_{n-3} & +\,dD_{n-1}A_{n-2} & +\,K^2_{n-1,\,n}\,.\,{}_{n-2}A_{n-2} & \\
\cdot & \cdot & \cdot & \cdot & \\
\cdot & \cdot & \cdot & \cdot & \\
\cdot & \cdot & \cdot & \cdot & \\
{}_nA_{n-r} & = {}_{n-1}A_{n-r-1} & +\,dD_{n-1}A_{n-r} & +\,K^2_{n-1,\,n}\,.\,{}_{n-2}A_{n-r} & \\
\cdot & \cdot & \cdot & \cdot & \\
\cdot & \cdot & \cdot & \cdot & \\
\cdot & \cdot & \cdot & \cdot & \\
{}_nA_0 & = \quad 0 & +\,dD_{n-1}A_0 & +\,K^2_{n-1,\,n}\,.\,{}_{n-2}A_0 &
\end{array}\right\} \qquad \ldots\ldots\ldots(7)$$

From eqn. (7), we can obtain

$$\left.\begin{aligned}
{}_nA_n &= 1\\
{}_nA_{n-1} &= d(1+D)\\
{}_nA_{n-2} &= Dd^2+\sum_{r=1}^{n-1}K^2_{r,\,r+1}\\
{}_nA_{n-3} &= Dd\sum_{r=1}^{n-2}K^2_{r,\,r+1}+d\sum_{r=2}^{n-1}K^2_{r,\,r+1}\\
{}_nA_{n-4} &= Dd^2\sum_{r=2}^{n-2}K^2_{r,\,r+1}+\frac{1}{2}\sum_{r=1}^{n-1}K^2_{r,\,r+1}\sum_{s=1}^{n-1}K^2_{s,\,s+1}\\
&\quad -\frac{1}{2}\sum_{r=1}^{n-1}K^4_{r,\,r+1}-\frac{1}{2}\sum_{r=1}^{n-2}K^2_{r,\,r+1}\cdot K^2_{r+1,\,r+2}\\
{}_nA_{n-5} &= \frac{Dd}{2}\sum_{r=1}^{n-2}K^2_{r,\,r+1}\cdot\sum_{s=1}^{n-2}K^2_{s,\,s+1}-\frac{Dd}{2}\sum_{r=1}^{n-2}K^4_{r,\,r+1}\\
&\quad -\frac{Dd}{2}\sum_{r=1}^{n-3}K^2_{r,\,r+1}\cdot K^2_{r+1,\,r+2}-\frac{d}{2}\sum_{r=2}^{n-1}K^4_{r,\,r+1}\\
&\quad +\frac{d}{2}\sum_{r=2}^{n-1}K^2_{r,\,r+1}\cdot\sum_{s=2}^{n-1}K^2_{s,\,s+1}-\frac{d}{2}\sum_{r=2}^{n-2}K^2_{r,\,r+1}\cdot K^2_{r+1,\,r+2}
\end{aligned}\right\}\quad\dots\dots\dots(8)$$

These relations hold for all n; further coefficients become increasingly complicated. One further coefficient for the case $n=6$ is

$${}_6A_0=Dd^2K^2_{23}K^2_{45}+K^2_{12}K^2_{34}K^2_{56}\qquad\dots\dots\dots(9)$$

From eqns. (7) or (8) it is possible to solve for the $K^2_{r,\,r+1}$. Green[1] gives

$$K^2_{r,\,r+1}=\frac{d^2\sin^2\theta(\cos^2 r\theta+D^2\sin^2 r\theta)}{\sin(2r-1)\theta\,.\,\sin(2r+1)\theta}\dots\dots\dots(10)$$

($\theta=\pi/2n$). An equivalent formula was obtained by Skwirzynski, but not published. Equivalent results for the special cases $D=0$, $D=1$, have been found by Norton[7] and Bennett[8]. For physical realizability, $K_{r,\,r+1}$ must be real and positive for all r. It follows that the only restrictions on d and D are that they are real. Thus for any d and D that may be specified, eqn. (10) will give a solution to the problem, since physically d and D must be real and positive.

Green[2] has given another method of solving for the coupling coefficients, based on the reflection coefficients. It is by generalizing this method that the present author found the method of obtaining all possible solutions. Green's method is as follows:

If we write

$${}_nE_1(p)=\varphi_1(D)\qquad\dots\dots\dots(11)$$

the reflection coefficient is

$$\rho=\varphi_1'/\varphi_1\qquad\dots\dots\dots(12)$$

where

$$\varphi_1'(D)=\varphi_1(-D)\qquad\dots\dots\dots(13)$$

Thus to obtain the reflection coefficient, we take the response polynomial ${}_nE_1$, replace D by $-D$ throughout, and form the quotient.

Consider eqns. (8) and (9). If in these D is replaced by $-D$, the values of ${}_nA_{n-r}$ so obtained may be equated to the coefficients of ${}_nE_1$ given in equation (6). From the coefficient of p in equations (6), and using the second of equations (8), we obtain

$$\lambda_n=\frac{d(1-D)}{\sin\theta}\qquad\dots\dots\dots(14)$$

where λ_n is related to φ_1' in the same way as γ_n is related to φ_1. Thus a set of equations is obtained from which the $K_{r,\,r+1}$ may be evaluated. We now have two sets of equations, one from φ_1, one from φ_1', which are mutually consistent. The simplification arises from the fact that only half of the equations are necessary to give a solution, so that the simplest equations may be chosen from each of the two sets.

The physical significance of Green's method is that it makes use of the fact that the reflection coefficient must be physically realizable, i.e. the solutions for the $K_{r,\,r+1}$ satisfy not only φ_1, but also the reflection coefficient, and hence φ_1'. Thus from φ_1' we may obtain this second set of equations. Mathematically, there is nothing in eqn. (10) to limit D to positive values, so that solutions found in terms of D should be valid for all real D. Thus it is legitimate to change the sign of D in eqns. (8); the truth of the equations is not altered. Having solved for the $K_{r,\,r+1}$ in terms of D, the restrictions on D necessary to make the $K_{r,\,r+1}$ physically realizable can again be imposed.

4. General Solutions for the Coupling Coefficients

Green's reflection coefficient method of solution is a special case of the general method to be developed here. The method is to determine all the physically possible reflection coefficients, and hence to obtain alternative functions φ_i', one of which is φ_1'. However, we shall find that these alternative solutions are not valid for all values of D, so that after obtaining a solution it is necessary to determine the range of values of D for which the $K_{r,\,r+1}$ are physically realizable.

Let us consider eqns. (3) and (6). The factors on the right-hand side of eqn. (3) will, if individually equated to zero, give the roots of the equation

$$\varphi_1 \equiv {}_nE_1 = 0 \qquad \text{.........(15)}$$

Thus the zeros of φ_1 are given by

$$p = j\gamma_n \exp\left[j(2k-1)\theta\right] \qquad \text{.........(16)}$$

and lie on a circle of radius γ_n, at angular distances $\frac{1}{2}\pi + (2k-1)(\pi/2n)$ from the real axis, measured anticlockwise. This is shown in Fig. 2 for the case $n=6$, the values of k from 1 to 6 being marked beside each zero.

Now, the maximally flat response is defined by

$$\left|\frac{V}{V_0}\right|^2 = \frac{V}{V_0}\left(\frac{V}{V_0}\right)^* = \frac{1}{1+\left|\dfrac{p}{\gamma_n}\right|^2} \qquad \text{.......(17)}$$

But $\dfrac{V}{V_0} = \dfrac{1}{\varphi_1(p)}$ and $\left(\dfrac{V}{V_0}\right)^* = \dfrac{1}{\varphi_1(-p)}$

Thus to obtain V/V_0, we pick from the denominator of eqn. (17) the factors which are zero for values of p in the left half-plane, giving rise to eqn. (1) and thence eqn. (3). The factors which are zero for values of p in the right half-plane belong to $\varphi_1(-p)$, and are given by eqn. (16) when k takes the values $(n+1)$, $(n+2)$, . . . $2n$. These values are also shown in Fig. 2 for the case $n=6$.

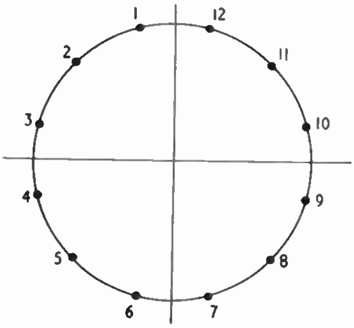

Fig. 2. Zeroes of φ_1

For the zeroes of the reflection coefficient, we are not limited to the left half-plane, but we must have the product of n factors of the type given in eqn. (16), with n different values of k lying between 1 and $2n$ inclusive. For $\varphi_1(p)$ we have $k=1, 2, 3 \ldots n$, and correspondingly $\varphi_1(-p)$ has $k=(n+1), (n+2) \ldots 2n$. Let us now consider what other sets of values of k may be chosen.

Green (page 10 of reference 1) shows that the reflection coefficient may be written

$$\rho = \frac{\varphi_1'(p)}{\varphi_1(p)}$$

Thus $$|\rho|^2 = \rho\rho^* = \frac{\varphi_1'(p)\,.\,\varphi_1'(-p)}{\varphi_1(p)\,.\,\varphi_1(-p)} \qquad \text{.........(18)}$$

The numerator on the right-hand side of eqn. (18) contains all factors of the type of the right-hand side of eqn. (3). We may thus write

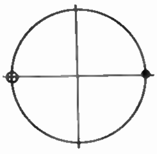

Fig. 3. Zeroes of ${}_1F_1$

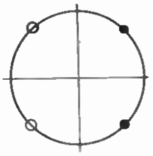

Fig. 4 Zeroes of ${}_2F_1$

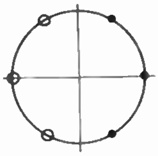

Fig. 5. Zeroes of ${}_3F_1$

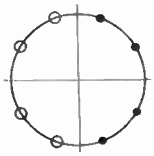

Fig. 6. Zeroes of ${}_4F_1$

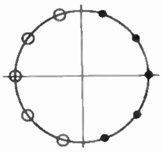

Fig. 7 Zeroes of ${}_5F_1$

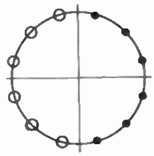

Fig. 8. Zeroes of ${}_6F_1$

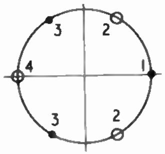

Fig. 9. Zeroes of ${}_3F_2$

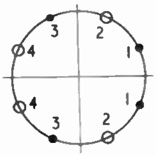

Fig. 10. Zeroes of ${}_4F_2$

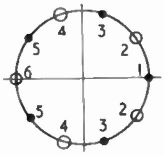

Fig. 11. Zeroes of ${}_5F_2$

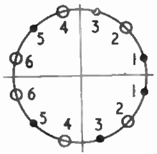

Fig. 12. Zeroes of ${}_6F_2$

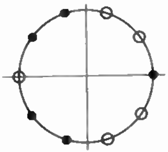

Fig. 13. Zeroes of ${}_5F_3$

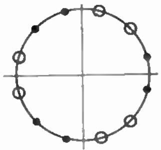

Fig. 14. Zeroes of ${}_6F_3$

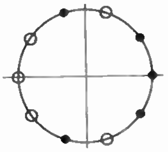

Fig. 15. Zeroes of ${}_5F_4$

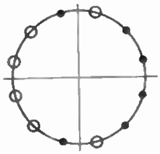

Fig. 16. Zeroes of ${}_6F_4$

$$|\rho|^2 = \rho\rho^* = \frac{\varphi_i'(p)\,.\,\varphi_i'(-p)}{\varphi_1(p)\,.\,\varphi_1(-p)} \qquad \ldots\ldots\ldots(19)$$

where again the numerator contains all possible factors, but arranged differently. This has no effect on $|\rho|^2$, i.e. on the amplitude response, but will lead to a different phase response when $i \neq 1$. Note that in the denominator φ_1 is retained since the poles of the reflection coefficient must lie in the left half-plane.

Selection Rules

We may choose factors of the φ_i by choosing n of the $2n$ zeros of $\rho\rho^*$. The first rule to be observed in making the choice is that if a certain zero is chosen, the zero at the opposite end of the diameter belongs to $\varphi_i'(-p)$ and so cannot be chosen for $\varphi_i'(p)$.

If the reflection coefficient is to be realizable physically, the phase response must have only odd powers of p in the numerator and only even powers in the denominator. This leads to the requirement that on expressing $\varphi_i'(p)$ as a polynomial in p, all the coefficients of p^r ($r = 0, 1, 2 \ldots n$) are real. Thus our second rule is that the zeros of $\varphi_i'(p)$ in the p-plane are chosen in conjugate pairs.

The number of sets of solutions for the $K_{r,\,r+1}$ is equal to the number of ways of choosing zeros of φ_i', subject to the rules given above. Clearly, the choice of zeros in any one quadrant is free, but, once made, fixes the zeros in the other three quadrants by virtue of the selection rules, so that the number of sets of solutions is the number of ways of choosing or not choosing zeros out of q zeros, i.e. 2^q, q being given by eqns. (2). For values of n up to 6, the possible combinations of zeros are shown in Figs. 3-16, where the circles represent zeros of $\varphi_i'(p)$, and the dots zeroes of $\varphi_i'(-p)$. Since a given $\varphi_i'(p)$ is identical with some $\varphi_j'(-p)$, where $j \neq i$, all cases are covered by the dots and circles together. Thus we need only 2^{q-1} definitions for the φ_i'; 2^{q-1} more functions are given by replacing p by $-p$ in these.

If a solution is found in the form

$$K^2_{r,\,r+1} = f(d, D)$$

when $\varphi_1(p)$ and $\varphi_i'(p)$ are used, then on using $\varphi_1(p)$ and $\varphi_i'(-p)$, a solution is obtained in the form

$$K^2_{(n-r)\,,\,(n-r+1)} = f(d, D)$$

for all r. Thus the use of $\varphi_i'(-p)$ leads only to solutions which are readily inferred from those obtained by the use of $\varphi_i'(p)$, and we do not regard the $\varphi_i'(-p)$ as distinct solutions. We shall in future refer only to the $\varphi_i'(p)$.

We shall now give geometrical definitions of the functions $\varphi_i(p)$; later we shall give equivalent algebraic definitions which will enable us to express the $\varphi_i(p)$ as polynomials by methods analogous to Bosse's method for $\varphi_1(p)$. It will be observed that while all definitions given are applicable for all values of n, as n decreases certain of the definitions become equivalent, so

World Radio History

that the number of distinct functions φ_i decreases. Just as Green[1, 2] wrote ${}_nE_1 \equiv \varphi_1$, we shall write ${}_nE_i \equiv \varphi_i$.

${}_nE_1$:

Take all zeroes in the left half-plane. This is Green's function and is defined for all n (see Figs. 3-8).

${}_nE_2$:

Starting with the zeros having the largest positive real part, number them 1, 2 . . . $2q$ in both the upper and lower half-planes (Figs. 9-12). When n is odd, the same zero, that on the real axis, is taken as starting-point for both half-planes. For n even, there are two zeros having the same (highest) real part, and each of these is taken as starting point for its own half-plane. Take all zeros to which even numbers have been assigned. This function becomes identical with ${}_nE_1$ for $n \leqslant 2$.

${}_nE_3$:

Numbering the zeros as for ${}_nE_2$, take those numbered 2, 3, 4 . . . q, and $2q$ (Figs. 13, 14). This function becomes identical with ${}_nE_2$ for $n \leqslant 4$.

${}_nE_4$:

Take the zeroes numbered 1, 2, 3 . . . $(q-1)$ and $(q+1)$. (Figs. 15, 16.) This function becomes identical with ${}_nE_2$ for $n \leqslant 4$.

These definitions hold for all values of n, and cover all possibilities for $n \leqslant 6$. For higher values of n, further definitions may be readily formulated.

Algebraically, we may write, for n even,

$$ {}_nE_i = \prod_{k=1}^{q} \left\{ \frac{p}{\gamma_n} - \exp\left[j\pi\left(f_i + \frac{2k-1}{2n} \right) \right] \right\} \left\{ \frac{p}{\gamma_n} - \exp\left[j\pi\left(f_i - \frac{2k-1}{2n} \right) \right] \right\} \qquad \text{.........(20)} $$

where

$$ \left. \begin{aligned} f_1 &= 1 \\ f_2 &= k \\ f_3 &= 2^{k-1} \\ f_4 &= 2^{q-k} \end{aligned} \right\} \qquad \text{.........(21)} $$

Other functions f_5, f_6, etc., may be defined to give ${}_nE_5$, ${}_nE_6$, etc. The f_i hold for all values of n. When n is odd, we must avoid using the zero on the negative real axis twice, and we write

$$ {}_nE_i = \frac{ \prod_{k=1}^{q} \left\{ \frac{p}{\gamma_n} - \exp\left[j\pi\left(f_1 + \frac{k-1}{n} \right) \right] \right\} \left\{ \frac{p}{\gamma_n} - \exp\left[j\pi\left(f_i - \frac{k-1}{n} \right) \right] \right\} }{ \left[\frac{p}{\gamma_n} - \exp(j\pi f_i) \right] } \qquad \text{.........(22)} $$

The terms $2k-1$, $k-1$, in eqns. (20) and (22) respectively, arise from the general expression $(2k+n-2q-1)$. Now write

$$ \left. \begin{aligned} {}_nE_1 &= \sum_{r=0}^{n} {}_nA_r \frac{p^r}{\gamma^r_n} \\ {}_nE_2 &= \sum_{r=0}^{n} {}_nB_r \frac{p^r}{\gamma^r_n} \\ {}_nE_3 &= \sum_{r=0}^{n} {}_nC_r \frac{p^r}{\gamma^r_n} \\ {}_nE_4 &= \sum_{r=0}^{n} {}_nD_r \frac{p^r}{\gamma^r_n} \end{aligned} \right\} \qquad \text{.........(23)} $$

The ${}_nE_i$ may now be expressed as polynomials by methods analogous to that of Bosse[6]. We then find, putting $\pi/2n = \theta$,

$$ \frac{{}_nA_r}{{}_nA_{r-1}} = \frac{\cos(n-1)\theta}{\sin n\theta} \qquad \text{.........(5)} $$

This equation has already been given in Section 3.

$$ \left. \begin{aligned} &\frac{{}_nB_r}{{}_nB_{r-1}} = \frac{\cos[(k-1)(\theta+\pi/2)]}{\cos[k\theta+(k-1)\pi/2]} \quad (n \text{ even}) \\ &\left. \begin{aligned} {}_nB_0 &= {}_nB_n = 1 \\ {}_nB_r &= 0 \;\; [r=1, 2 \;.\;.\;.\; (n-1)] \end{aligned} \right\} \quad (n \text{ odd}) \end{aligned} \right\} $$

$$ \text{.........(24)} $$

$$ \left. \begin{aligned} &{}_nC_r - 2\cos\theta . {}_nC_{r-1} + {}_nC_{r-2} \\ &\quad = (-1)^r \{ {}_nA_r - 2\cos\theta . {}_nA_{r-1} + {}_nA_{r-2} \} \; (n \text{ even}) \\ &{}_nC_r - {}_nC_{r-1} = (-1)^r \{ {}_nA_r - {}_nA_{r-1} \} \quad (n \text{ odd}) \end{aligned} \right\} $$

$$ \text{.........(25)} $$

$$ \begin{aligned} &{}_nD_r - 2\sin\theta . {}_nD_{r-1} + {}_nD_{r-2} \\ &\quad = (-1)^r \{ {}_nA_r - 2\sin\theta . {}_nA_{r-1} + {}_nA_{r-2} \} \; (\text{all } n) \end{aligned} $$

From eqns. (24), we obtain ....(26)

$$ {}_nE_2 = 1 + \frac{1}{\cos\theta} . \frac{p}{\gamma_n} + \frac{\sin\theta}{\cos\theta . \sin 2\theta} . \frac{p^2}{\gamma^2_n} + \text{.........} + \frac{p^n}{\gamma^n_n} $$

$$ \text{.........(27)} $$

for n even, and

$$ {}_nE_2 = 1 + (p/\gamma_n)^n \qquad \ldots\ldots\ldots(28) $$

for n odd. The expressions for ${}_nE_3$ and ${}_nE_4$ are not so simple, and are best derived individually for given values of n. By substituting the values of $\sin\theta$ and $\cos\theta$, the coefficients of $(p/\gamma_n)^r$ take fairly simple forms involving surds. These coefficients are given in Table 1 for the ${}_nE_i$, $1 \leqslant n \leqslant 6$, $1 \leqslant i \leqslant 4$.

Using these values, the coupling coefficients have been determined for $2 \leqslant n \leqslant 5$, and are given in Tables 2 (*a*)-(*d*). These are valid if they are real, i.e. if their squares are real and positive, which limits the values of D for which solutions may be derived from the ${}_nE_i$, with $i \geqslant 2$. The ranges of values of D for which the solutions are valid are also stated in Tables 2 (*a*)-(*d*). In particular, it may be noted that when n is odd, solutions from ${}_nE_2$ are only valid for $D=1$. But when $D=1$, the coupling coefficients derived from all values of i become identical, so that a distinct set of physically realizable coupling coefficients cannot be derived from the ${}_nE_2$ when n is odd.

Green[2], quoting the work described in this paper, gives the pole distributions and coupling coefficients for all cases with $n=4$ or 5, and also extends the results to the Chebyshev case.

5. Conclusion

For a ladder network containing n branches, with maximally flat amplitude response, there are 2^q possible choices of solution for the coupling coefficients, half of which may be easily derived from the other half. Here $q=n/2$ (n even), $q=(n+1)/2$ (n odd). The normal solution is valid for all ratios, D, of the dissipations, while the other solutions are only valid for limited ranges of D. Values of coupling coefficients are given in Tables 2 (*a*)-(*d*) for values of n up to 5, and it has been shown in the course

Table 1

Coefficients of p^r/γ^r_n in the ${}_nE_i$.

Function	$r=0$	$r=1$	$r=2$	$r=3$	$r=4$	$r=5$	$r=6$
${}_1E_1$	1	1					
${}_2E_1$	1	$\sqrt{2}$	1				
${}_3E_1$	1	2	2	1			
${}_3E_2$	1	0	0	1			
${}_4E_1$	1	$\sqrt{2(2+\sqrt{2})}$	$2+\sqrt{2}$	$\sqrt{2(2+\sqrt{2})}$	1		
${}_4E_2$	1	$\sqrt{2(2-\sqrt{2})}$	$2-\sqrt{2}$	$\sqrt{2(2-\sqrt{2})}$	1		
${}_5E_1$	1	$1+\sqrt{5}$	$3+\sqrt{5}$	$3+\sqrt{5}$	$1+\sqrt{5}$	1	
${}_5E_2$	1	0	0	0	0	1	
${}_5E_3$	1	$1-\sqrt{5}$	$3-\sqrt{5}$	$3-\sqrt{5}$	$1-\sqrt{5}$	1	
${}_5E_4$	1	2	2	2	2	1	
${}_6E_1$	1	$2\sqrt{2+\sqrt{3}}$	$2(2+\sqrt{3})$	$2\sqrt{6}+3\sqrt{2}$	$2(2+\sqrt{3})$	$2\sqrt{2+\sqrt{3}}$	1
${}_6E_2$	1	$2\sqrt{2-\sqrt{3}}$	$2(2-\sqrt{3})$	$2\sqrt{6}-3\sqrt{2}$	$2(2-\sqrt{3})$	$2\sqrt{2-\sqrt{3}}$	1
${}_6E_3$	1	0	0	$\sqrt{2}$	0	0	1
${}_6E_4$	1	$2\sqrt{2}$	4	$3\sqrt{2}$	4	$2\sqrt{2}$	1

World Radio History

Table 2

Coupling Coefficients

(a): $n = 2$.

Coefficient	Value	Range of Validity
K^2_{12}	$\frac{d^2}{2}(1+D^2)$	$D \geqslant 0$

(b): $n = 3$.

Coefficient	Value Using ${}_3E_1$	Value Using ${}_3E_2$
K^2_{12}	$\frac{d^2}{8}(3+D^2)$	$d^2/2$
K^2_{23}	$\frac{d^2}{8}(1+3D^2)$	$d^2/2$
Range of Validity	$D \geqslant 0$	$D = 1$

(c): $n = 4$.

Coefficient	Value Using ${}_4E_1$	Value Using ${}_4E_2$
K^2_{12}	$\frac{d^2}{4}\left\{\sqrt{2}+(3\sqrt{2}-4)D^2\right\}$	$\frac{d^2}{4D}\left\{3\sqrt{2}D^2-4D^3+\sqrt{2}D^4\right\}$
K^2_{23}	$\frac{d^2}{2}(3-2\sqrt{2})(1+D^2)$	$\frac{d^2}{4D}\left\{\begin{array}{l}-\sqrt{2}D^4+6D^3-6\sqrt{2}D^2\\ +6D-\sqrt{2}\end{array}\right\}$
K^2_{34}	$\frac{d^2}{4}\left\{(3\sqrt{2}-4)+\sqrt{2}D^2\right\}$	$\frac{d^2}{4D}\left\{\sqrt{2}-4D+3\sqrt{2}D^2\right\}$
Range of Validity	$D \geqslant 0$	$(\sqrt{2}-1) \leqslant D \leqslant (\sqrt{2}+1)$

of the work how the solutions may be extended to any value of n.

6. Acknowledgments

I should like to express my thanks to Messrs. E. Green and J. K. Skwirzynski for much encouragement and many helpful discussions, and to the Chief Engineer of Marconi's Wireless Telegraph Company for permission to publish this paper.

7. References

1. E. Green, "Amplitude-Frequency Characteristics of Ladder Networks" (Marconi's Wireless Telegraph Co., Ltd., Chelmsford, 1954).
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3. L. Weinberg, "Explicit formulas for Tschebyscheff and Butterworth ladder networks", *Journal of Applied Physics*, **28**, pp. 1155-1160, October 1957.
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6. G. Bosse, "Filter networks without oscillatory attenuation characteristics in the pass band ('power-law chains')", *Frequenz*, **5**, pp. 279-284, October 1951.
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8. W. R. Bennett, U.S. Patent 1,849,656 (March 1932).

World Radio History

(d): $n=5$. **Table 2** (contd.)

Coefficient	Value Using ${}_5E_1$	Value Using ${}_5E_2$	Value Using ${}_5E_3$	Value Using ${}_5E_4$
K^2_{12}	$\frac{d^2}{8}(\sqrt{5}-1)[\sqrt{5}+(\sqrt{5}-2)D^2]$	$\frac{d^2}{2}(3-\sqrt{5})$	$\frac{d^2}{8}(\sqrt{5}-D)[\sqrt{5}D^2-2D+\sqrt{5}]$	$\frac{d^2}{32}(\sqrt{5}-1)(1+D)[(\sqrt{5}-1)D^2-4D+(3\sqrt{5}+1)]$
K^2_{23}	$\frac{d^2}{16}(\sqrt{5}-1)[1+\sqrt{5}(\sqrt{5}-2)D^2]$	$\frac{d^2}{2}(\sqrt{5}-2)$	$\dfrac{\frac{d^2D}{8}\left\{\begin{array}{l}5D^4-10\sqrt{5}D^3+40D^2- \\ \quad -14\sqrt{5}D+11\end{array}\right\}}{(\sqrt{5}D^2-2D+\sqrt{5})}$	$\frac{d^2D[D-(\sqrt{5}+2)]}{16(1+D)}\left\{\begin{array}{l}(\sqrt{5}-3)D^2+4(\sqrt{5}-2)D+ \\ \quad +(7\sqrt{5}-17)\end{array}\right\}$
K^2_{34}	$\frac{d^2}{16}(\sqrt{5}-1)[\sqrt{5}(\sqrt{5}-2)+D^2]$	$\frac{d^2}{2}(\sqrt{5}-2)$	$\dfrac{\frac{d^2D}{8}\left\{\begin{array}{l}5-10\sqrt{5}D+40D^2- \\ -14\sqrt{5}D^3+11D^4\end{array}\right\}}{(\sqrt{5}D^2-2D+\sqrt{5})}$	$\frac{d^2[1-D(\sqrt{5}+2)]}{16D(1+D)}\left\{\begin{array}{l}(\sqrt{5}-3)+4(\sqrt{5}-2)D+ \\ \quad +(7\sqrt{5}-17)D^2\end{array}\right\}$
K^2_{45}	$\frac{d^2}{8}(\sqrt{5}-1)[(\sqrt{5}-2)+\sqrt{5}D^2]$	$\frac{d^2}{2}(3-\sqrt{5})$	$\frac{d^2}{8D}(\sqrt{5}-1)[\sqrt{5}D^2-2D+\sqrt{5}]$	$\frac{d^2}{32}(\sqrt{5}-1)(1+D)\left\{\begin{array}{l}(\sqrt{5}-1)-4D+ \\ +(3\sqrt{5}+1)D^2\end{array}\right\}$
Range of Validity	$D \geqslant 0$	$D=1$	$1/\sqrt{5} \leqslant D \leqslant \sqrt{5}$	$(\sqrt{5}-2) \leqslant D \leqslant (\sqrt{5}+2)$

World Radio History

APPLICANTS FOR ELECTION AND TRANSFER

As a result of its December meeting the Membership Committee recommended to the Council the following elections and transfers.

In accordance with a resolution of Council, and in the absence of any objections, the election and transfer of the candidates to the class indicated will be confined fourteen days after the date of circulation of this list. Any objections or communications concerning these elections should be addressed to the General Secretary for submission to the Council.

Direct Election to Full Member

COX, Frank. *Hayes, Middlesex.*

Transfer from Associate Member to Member

BETTRIDGE, Bernard Robert Arthur. *Beckenham.*
JAQUEMET, Albert Edward, O.B.E. *Hemel Hempstead.*

Direct Election to Associate Member

BOURNE, Wg. Cdr. Walter John, R.A.F. *Henlow.*
GATENBY, Donald, B.Sc.(Eng.). *Chelmsford.*
INDIRESAN, Pavagada, B.Sc.(Hons.). Venkata. *Birmingham.*
MAZUR, Stanislaw. *London, N.W.2.*
SANCHEZ, Fernando. *London, W.12.*
SEBESTYEN, Laszlo Gabor, M.Sc., B.Sc., Dip.El. *London, W.6.*
WEBSTER, Norman William, B.Sc. *Reading.*

Transfer from Associate to Associate Member

COOKE, William Henry. *Whaley Bridge.*

Transfer from Graduate to Associate Member

ASHMAN, Roy John. *St. Albans.*
EVANS, Hugh Maitland. *Newbridge.*
GOODINGS, Harry Arthur. *Ilford.*
HOWICK, Douglas William. *Chelmsford.*
JACKSON, Michael Rex. *Pinner.*
LAWTON, Sqdn. Ldr. Samuel Derek. R.A.F. *Hemel Hempstead.*
LAYTON, Gunter. *London, N.W.9.*
LOCKWOOD, Peter. *Luton.*
MILLS, Samuel John. *Crawley.*
MORRIS, Brian Percival, B.Sc. *Bristol.*
MURRAY, Patrick Joseph. *Stockport.*
PARKER, Frederick Gordon, B.Sc. *Pinner.*
SECKER, George William. *Harrow.*
SEYMOUR, Frank Daniel. *Henley-on-Thames.*
THOMAS, Sqdn. Ldr. Caradog, R.A.F. *Nicosia.*
WHITEWAY, Frank Ernest, B.Sc.(Eng.). *Woodley.*
ZAKRZEWSKI, Jan Tadewsz. *London, N.W.2.*

Transfer from Student to Associate Member

de BRUYNE, Pieter. *Leidschendam, Holand.*
HALL, Kenneth James, B.A.(Hons.). *London, N.13.*

Direct Election to Associate

ALLINGHAM, Herbert Stanley. *Weymouth.*
de LARNY, James Donald Nelson. *London, W.14.*
DINGLEY, James Thomas. *Upper Belvedere.*
HARRIS, Hubert. *Dartford.*
LITTLE, John Richard. *Bracknell.*
NEWLAND, Henry Arthur Frederick. *London, N.W.11.*
NORWOOD, Peter Douglas. *Watford.*
SOLOMIDES, Louis Michael Zenon. *London, S.W.16.*

Transfer from Student to Associate

BULL, Maurice Philip Goodwin. *Shoeburyness.*
YOUNG, Wiliam Arthur. *Tripoli, Libya.*

Direct Election to Graduate

ALLEN, Stanley George. *Hornchurch.*
ANDREWS, Plt. Off. John Burpitt, R.A.F. *Taunton.*
BEGLEY, James Anthony Gerard. *New Malden.*
BOULTON, Robert Alan. *Liverpool.*
EDGE, Gordon Malcolm, Dip.El. *Cambridge.*
HELY-HUTCHINSON, John Richard, B.Sc. *St. Albans.*
JACKSON, Robin Malcolm Bushe. *London, W.11.*
MILLS, Jacob Lamquaye. *London, N.W.6.*
REEVE, Peter Joseph. *Kenilworth.*
SKELTON, Colin John, B.Sc. *Guildford.*
THIRD, Sinclair Matthew. *Wantage.*
WILSON, John Douglas, B.Sc. *Bristol.*

Transfer from Student to Graduate

WHITEHILL, William Kenneth. *Newport, Mon.*

STUDENTSHIP REGISTRATIONS

The following 46 Students were registered at the meeting held in November; the names of the other remaining 31 Students registered at that meeting, and those registered in January will be published later.

ABRAHAM, V. T., B.Sc. *Kottayam.*
AJIT SINGH, Professor Seahra, M.Sc., B.A. *Bundala.*
ALEXANDER, Vaidian T. M., B.Sc. *Thevalakara.*
ALLMAN, Royston Anthony. *Woodford Green.*
AVULA, Nageswararao, B.Sc. *Guntur.*
BERGER, Israel. *Kiryat Yam.*
BHANU PRAKASH, B.V., B.Sc. *Bangalore.*
BURKI, Nagarajarao, B.Sc. *Bangalore.*
BUTT, Peter Jackson. *Ilford.*
CHANDLER, Michael Henry A., B.A. (Hons.). *Farnham.*
CHAWLA, Hari Krishan, B.A. *Tambram.*
CLAYTON, Robert Alexander Alfred. *Northwood.*
COLLINS, Brian. *Blackburn.*
da SILVA, Eduuardo F. *Coventry.*
de SOUZA, Joseph Fianian. *Singapore.*
DOWLING, Patrick Joseph. *Limerick.*
DU PUGET PUSZET, Edward. *Reading.*
GANESAN, Harihara Iyer. *Ambala.*
GAVANKAR, Pushpahas Ganesh, B.Sc. *Bombay.*
GUNDU RAO, Alalaghatta N. *Jalahalli.*
HARDCASTLE, John Andrew. *Liverpool.*
HOSANGDI, Rabindranath, R., B.Sc. *Bombay, 16, India.*
HUBALDUS, Joshua, B.Sc. *Ernakulam.*
HURST, Leslie. *Manchester.*
ISAAC, Ponnaghath Varghese, B.Sc. *Shertally.*
JOHN, K. P., B.Sc. *Trichur.*
JOHN, M. T., B.Sc. *Gothuruthy.*
JOHN, Stewart Morris. *Hounslow West.*
JOSEPH, C. Devasia, B.Sc. *Erumeli.*
JOSEPH, K. T., B.Sc. *Shertally.*
KANDASWAMY, C. *Madras.*
KASTURI RANGAN, Ganapathi, B.Sc. *Ernakulam.*
KAUL, Mohan Kishen, B.A. *New Delhi.*
KERVELL, Michael George. *Cambridge.*
KUMAR, Ravi K., B.Sc. *Venmony.*
LAMBERT, Keith Walter. *Cardiff.*
LEWIS, Colin Roy. *Braunton.*
LIMAYE, Madhav Achyut, B.Sc. *Bombay.*
LING, Yup Too. *Hong Kong.*
MARDEN, Frederick James. *Plymouth.*
MATHEW, K. Jacob. *Chirakadavu.*
MENON, M. P. Sethu Madhava, B.Sc. *Ernakulam.*
MURALEEDHARAN, K. Venkata R., B.Sc. *Ernakulam.*
NABI, Tajul Islam M. N. *Karachi.*
NAGARAJ, Havanur, B.Sc. *Bangalore.*

INSTITUTION NOTICES

Mr. Eric K. Cole

The Council announces with pleasure that Mr. Eric K. Cole, C.B.E., is to be elected an Honorary Member of the Institution in recognition of his services to the radio and electronics industry and profession.

Mr. Cole, who is Chairman and Managing Director of the firm bearing his name, which he founded in 1926, has for many years taken a prominent part in the work of the Radio Industry Council and other industry bodies. He has participated in several Institution functions, and his addition to the Roll of distinguished Honorary Members has been widely acclaimed.

Subscriptions from Members Overseas

Members abroad should note that annual subscriptions for the year 1959/60 should be received by the Institution on April 1st.

Members may remit either direct to London or, where more convenient, to the Institution's local bankers; in the latter case they should specify that the amount paid is for the credit of "The British Institution of Radio Engineers." The Institution's bankers overseas are as follows:—

Australia:	Bank of New South Wales, Head Office, Sydney.
Canada & U.S.A.:	Imperial Bank of Canada, King & Bay Street, Toronto.
France:	Barclays Bank, Rue de Septembre Quatre, Paris.
India:	State Bank of India, 40 St. Mark's Road, Bangalore, 6.
Pakistan:	National Bank of Pakistan, P.M.A. Building, Nicol Road, Karachi, 1.
New Zealand:	Bank of New South Wales, Auckland.
South Africa:	Barclays Bank D.C.O., 40 Simmonds Street, Johannesburg.

Separate advice should be sent to the London Office of the Institution immediately payment is made to the local bank.

Institution Visits

On December 4th last sixty members took part in the visit arranged by the Technical Committee to the Luton works of Vauxhall Motors Ltd. This factory is stated to be the most up-to-date of its kind in Europe, and members had the opportunity to see the latest techniques in automation applied to such operations as the machining of cylinder blocks.

Applications for the visit greatly exceeded the number of places available, and the party had to be restricted to members only. A further visit has therefore been agreed to by Vauxhall Motors, and this will take place on Tuesday, April 7th. Members wishing to take part in the visit should send in their names to the Institution as soon as possible; guests' names may also be included on the understanding that preference will be given to members in the event of the number of applications exceeding the places available.

Applications will be acknowledged, but it will not be possible to give confirmation in respect of guests until a fortnight before the visit is due to take place.

Students' Essay Competition

The Council announces that the subject for the Students' Essay Competition for 1959 will be:—

"The Future of Electronics in Industry."

Entries are now invited from registered Students of the Institution as well as from Graduates who are under the age of 23 at the closing date of the competition. Essays, which should be between three thousand and five thousand words in length, should preferably be submitted in typed form, using one side of the paper only. The closing date for both home and overseas competitors is 30th June 1959.

A prize of £10 10s. will be awarded for the best essay; additional prizes may be awarded at Council's discretion for essays which are highly commended. The Council reserves the right to publish the prize-winning essay in the *Journal*.

Graduateship Examination

A total of 918 candidates entered for the Graduateship Examinations during 1958; the results of the November 1958 examination will be published in the February issue of the *Journal*.

Entries from home candidates for the May 1959 examination must be received by 1st April. Overseas candidates should ensure that their entries for the November 1959 examination reach the Institution by 1st May.

World Radio History

Radio Engineering Overseas . . .

The following abstracts are taken from European and Commonwealth journals received in the Library of the Institution. Members who wish to borrow any of these journals should apply to the Librarian, stating full bibliographical details, i.e. title, author, journal and date, of the paper required. All papers are in the language of the country of origin of the Journal unless otherwise stated. The Institution regrets that translations cannot be supplied.

EDUCATION

Methods of teaching electronics to undergraduates are discussed in a recent paper by two senior lecturers at the University of Sydney. The importance of experimental work is emphasized, and alternative systems of handling large numbers of students are considered. A method of construction of experiments is given which superimposes circuit diagram and physical construction, eliminating the need for constant reference to the circuit and simplifying the problems involved in identifying components and tracing wiring. The "Serial" as against "Parallel" operation of experiments is discussed, and the authors conclude that for large numbers of students parallel operation of experiments is preferable, particularly in the early stages of a course where basic ideas are concerned. The type of equipment necessary for control of multiple, parallel-operated experiments is considered and specific designs outlined. Equipment needed for individual groups carrying out basic and advanced experiments on vacuum tube and transistor circuits is discussed. Details are given of the experience obtained over the last five years and methods for use in supplementary experimental work are also considered.

"The teaching of electronics," R. E. Aitchison and C. T. Murray. *The Journal of the Institution of Engineers, Australia*, **30**, pp. 263-267, September 1958.

PHYSICS OF THE IONOSPHERE

A method of computation of the electron production rate in the F2-layer has been put forward which leads to a regular consistent diurnal variation of the rate with a single peak at about half an hour before noon time. It is stated that the method eliminates the anomalous results that are sometimes obtained when other methods of computation are employed. A column of unit cross-section of the F2-region extending from the "bottom" to the height of its maximum electron density is divided into four columns of equal length, and the mean production rate in each of the columns is calculated. For this purpose, diurnal variation of the total number of electrons in each of the columns and the height variation of the attachment coefficient suggested by Ratcliffe *et al* (1956) are utilized.

"On the electron production rate in the F2-region of the ionosphere," S. Datta. *Indian Journal of Physics*, **32**, pp. 483-491, October 1958.

COMPONENT DESIGN

The problem of heat conduction is encountered when a carbon film resistor attached to supporting material is exposed to a temporary load. A recent paper determines the temperature distribution in a finite cylinder, whose one front comes into contact with a hot disc from the time $t=0$ onward. Also calculated is the temperature distribution in a finite cylinder whose jacket comes into contact with a hot surface at the time $t=0$. This corresponds to the temporary loading of carbon film resistors held at their front by the supporting material. For a solution of the problems the unidimensional Laplace transformation is used to advantage.

"The solution of the problem of heat conduction in electrical technique by means of a unidimensional Laplace transform." R. Hofmann. *Archiv der Elektrischen Ubertragung*, **12**, pp. 472-478, October 1958.

MOLECULAR AMPLIFIERS

In a review of recent developments in amplification obtained by the interaction of an electromagnetic field and the internal energies of a gaseous molecular system, some of the basic properties of the "maser" amplifier such as gain, bandwidth, noise figure, etc., are discussed. It is concluded that the performance of such an amplifier is superior from the point of view of noise but inferior from the standpoint of bandwidth and power handling capacity when compared with the performance of existing microwave amplifiers. A brief discussion of the basic properties of the molecular system used is also included.

"A new method of microwave amplification," S. K. Chatterjee. *Journal of The Institution of Engineers (India)*, **38**, No. 11, Part 2, pp. 1081-1088, July 1958.

PHOTOCELLS

In an automatic curve follower developed in the Laboratory for Automation and Remote Control of the Czechoslovak Academy of Sciences in Prague for use with an electro-mechanical differential analyser, the tracer can follow the edge of a 1 mm black line with a precision of ±0·1 mm. The follower head contains a germanium photodiode with light modulation by a rotating mirror. The tracer amplifier is electronic with a magnetic final stage, the servo-motor is d.c. with permanent magnets.

"Photoelectric curve follower," J. Tomasek. *Slaboproudy Obzor, Prague*, **19**, pp. 574-580, September 1958.

World Radio History

PRODUCTION TECHNIQUES IN WIRE INSULATION

The length of the water trough used for cooling p.v.c. coated wires in the production process depends mainly on the speed of the process and on the type of conductor. The required cooling period can be determined experimentally in two different ways. In the first case, the period for cooling a conductor from 160° C is determined by means of a measurement of the electrical resistance in the copper. On the other hand, the maximum velocity beyond which the insulation is flattened can be determined for each type of wire when the length of the water trough is given. The permissible final temperature has been determined to be 90-100° C. The length of the water trough required for any speed of processing and for any type of wire can be determined from the result of these measurements.

"The cooling of p.v.c.-coated conductors during the production process," B. Buhmann. *Nachrichtentechnische Zeitschrift*, **11**, pp. 557-560, November 1958.

WAVEGUIDES

In bends of a waveguide with dimensions relatively large compared with the operating wavelengths, part of the energy of a mode to be transmitted is converted into other modes capable of propagation and inimical to wideband transmission. To minimize the amplitudes of the undesirable modes excited at the curved section, discontinuities of the curvature must be avoided. The most favourable bending curve for a specified maximum of energy conversion into a specific undesirable mode is derived in a recently published paper. Particular emphasis is placed on the coupling between the fundamental modes of circular and square waveguides and the higher modes with the lowest cutoff frequencies. As compared to a waveguide bent with constant curvature the excitation of the higher modes is stated to be considerably reduced.

"Syntheses of bent waveguides with continuous curvature," M. G. Andreasen. *Archiv der Elektrischen Ubertragung*, **12**, pp. 463-471, October 1958.

Waveguides with rectangular cross-sections are frequently used as transmission lines in radio links. Reflections occur at the flange connections due to production tolerances and unavoidable assembly deviations, even when the flanges are provided with dowel pins or precision shank bolts. It is shown in a German paper that in general the discontinuities in cross-section due to aperture tolerances at the waveguide ends produce greater reflections than the error occurring during the assembly due to an offset or a twist of both cross-sections. With the aid of diagrams illustrating the field distribution it is shown that the electrical effect of an offset has a close similarity to an appropriate iris. Consequently the offset between two apertures can be treated with the aid of equations published in available literature. The results are confirmed by measurements. The final part of the paper contains an estimate of the maximum reflections which can occur when the waveguides comply with proposed standards.

"Reflections at waveguide flange connections," U. v. Kienlin and A. Kurzl. *Nachrichtentechnische Zeitschrift*, **11**, pp. 561-564, November 1958.

RADIO COMMUNICATION

The development of future communications technique depends upon two conditions: on the requirements of the communications traffic and its subscribers on one hand and the progress made in the technique of the communications elements on the other. Two of the most important elements are the transistor and the travelling wave tube, and the possibilities of their application in various frequency ranges are discussed in a recent Dutch newspaper. This paper deals also with the question of economics and considers the development which is feasible in the future. Some possibilities of solving future problems, for instance by the linearization of the amplitude characteristic and by the pre-emphasis and amplitude compression of speech, are indicated.

"On the considerations for future developments in communications techniques," K. O. Schmidt. *Tijdschrift van het Nederlands Radiogenootschap*, **23**, No. 5, pp. 201-223, 1958.

INTERFERENCE

Radio reception is sometimes subject to interference from high-frequency oscillations generated in fluorescent lamps and entering the receiver via the mains. Quantitative information on this irregular phenomenon has been obtained with the C.I.S.P.R. standard test arrangement, and the results analysed statistically. The symmetrical and asymmetrical components of the interference voltage were measured in this way on various types of lamps and ballasts. The usual upper limit is specified as 1 mV, and it is found that this limit is appreciably exceeded only when TLS lamps are used in series with an incandescent lamp and with no suppressor capacitor. This interference can be largely suppressed by means of a delta filter. In the authors' view, the principal intereference is caused by oscillations of positive ions in the potential minimum in front of the cathode.

"Radio interference from fluorescent lamps," H. J. J. van Boort, M. Klerk and A. A. Kruithof. *Philips Technical Review*, **20**, No. 5, pp. 135-144, November 1958. (In English.)

TRANSIT-TIME DEVICES

A beam tube with two anodes controlled by magnetic field has been described which is convenient for the measurement of magnetic-field intensity or, in connection with a reactance coil, for the measurement of current. Its advantage is that the meter is reliably protected against overload in short-circuiting of the metered circuit.

"Vacuum tube with magnetic-field control," J. Katscher. *Slaboproudy Obzor, Prague*, **19**, pp. 658-660, October 1958.

PROPAGATION

The transatlantic reception of short-waves is compared with the activity of the F2-layer and with earth-magnetic disturbances in a recent paper. The evaluation of the test results has led to the allocation of propagation codes for characterizing the prevailing propagation conditions of the ionosphere close to and in the zone of Aurora. Special statements are made for the path Europe to U.S.A. and various values for this code are discussed. Proposals are made for scatter tests on the F2-layer in the waveband 35-50 Mc/s and over distances of 3,000 to 4,000 km.

"Propagation conditions between Europe and North America in the frequency band 40 to 52 Mc/s during a maximum of sun-spot activity," H. Wisbar. *Nachrichtentechnische Zeitschrift*, **11**, pp. 586-590, November 1958.

BROADCASTING

The serious disadvantages of common-channel operation with independent transmitters and programmes are well-known. If the sharing stations radiate the same programme, a considerable improvement is obtainable by synchronizing the transmitter frequencies within a fraction of a cycle. A recent paper has described two experiments by the P.M.G.'s Department in such synchronized operation, chosen to suit the special conditions of Australian broadcasting. In the first, a low-power "booster" at Bendigo, Victoria, was locked to the main high-power station (3AR Melbourne) for some months, deriving both carrier-frequency and programme from the received signal. This produced an area of about seven miles radius wherein the greatly increased signal strength was adequate to overcome the urban noise level and provide good service day and night. Surrounding this area was a belt out to 20 miles radius, containing at intervals narrow zones of distortion. In the second experiment, two high-power stations in Queensland, separated by 600 miles, were operated on 630 kc/s for three months by independent crystal oscillators synchronized once nightly. Their daytime and night-time primary service areas were unaffected; at night conditions in their separate fading zones deteriorated, with additional distortion. Beyond these zones, the combined night-time secondary service area was effectively the sum of those of the two stations separately, although some care was necessary with receiving aerials in the region of near-equal signal strength. Modulation delay affects were small, and did not limit the service area.

"Common channel common programme operation of medium-wave broadcasting stations," S. F. Brownless. *Proceedings of the Institution of Radio Engineers Australia*, **19**, No. 10, pp. 529-541, October 1958.

COLOUR TELEVISION

The problems arising from the adaptation of the N.T.S.C. system to the European 625-line standards as far as the frequency of the chrominance carrier, the choice of the colour information and the bandwidth of these signals are concerned have recently been dealt with in a German paper. The effects of bandwidth reduction in the colour channels and of the choice of the sub-carrier frequency in the video band on the reproduction of luminance and chrominance details as well as on the cross-talk between luminance and chrominance information are discussed and evaluated with the aid of suitable tests. Finally, the problem of selecting the broad-band axis in the chromaticity diagram is discussed.

"Experiments concerning the adaptation of the N.T.S.C. colour television system to the European 625-line standards," J. Davidse. *Nachrichtentechnische Zeitschrift*, **11**, pp. 461-466, September 1958.

COMPUTERS

The selection and routing of pulses, before the computing processes, can be considered as the essential operations which are most frequently required for industrial programme panels set up for machine tools, welding, etc. For these same practical operations in computers there is usually no need to have appreciable amounts of power available at each intermediate stage of a selector-computer group. A French paper points out that the situation is quite different with industrial electronic control apparatus where computing is not an end in itself but a means of exercising diverse controls either at intervals or simultaneously. With these practical requirements in mind, logic circuits for medium speed computing using diodes are followed by pre-ionized cold cathode thyratrons. The calculations involved in their operation are described and a description given of the main logic circuits.

"Computers and logic circuits using cold cathode thyratrons," R. Arronssohn. *L'Onde Electrique*, **38**, pp. 724-729, October 1958.

World Radio History