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WARTIME ENGINEERING

By

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***Foreword**—The rapid expansion of wartime radio manufacture has created a corresponding need for greatly enlarged engineering staffs. Thus many engineers working in new fields have been faced with difficult, novel, and urgent problems. Hence it was thought desirable to assemble in compressed form the guiding principles of engineering ethics, a list of the primary beneficial engineering traits, a study of engineering methods of attacking research and development problems, and a descriptive analysis of design procedure for manufacturing.*

The resulting material has been presented before groups composed principally of junior engineers of the RCA Manufacturing Company at its plants at Camden, New Jersey, Indianapolis and Bloomington, Indiana, and Harrison, New Jersey. While the lectures were prepared with the radio engineering aspects principally in mind, it is believed that the included information is transferable to, and helpful in, other fields of engineering. It is accordingly hoped that it will constitute a conveniently available guide and summary of the art and practice of engineering.

WHILE every skilled engineer, to a considerable extent, develops certain methods of his own and successfully applies them, yet there are some general rules which long experience in the engineering field has shown to be safe guides. It is with this thought that I am laying before you in these talks a number of suggestions which, I hope, will prove helpful and constructive. You may not wish to adopt some of them for your own work but, in any case, the suggestions will be before you.

In these trying days, the very essence of success is to work at highest efficiency and to accomplish a maximum of results in the shortest possible time. This is a test period for every engineer, just as it is for our country. I need hardly point out how important it is for us to plunge wholeheartedly into the wartime efforts of the United States. Loyalty to our country, to the organization for which we work, to our fellow engineers, and to ourselves must alike prompt us to make the best possible use of every minute of time and to produce the maximum possible output of high quality.

In normal times a moderate degree of indulgence in certain personal limitations or weaknesses might occasionally be tolerated. I do not mean that such indulgence is ever desirable, but in calm days it can sometimes be pardoned. But in these days of terrific emergency and extreme stress, grim necessity urgently compels the stern repression *by each man within himself* of carelessness, of laziness, of thoughtlessness, and of uncooperativeness.

I hope I shall avoid seeming to "preach" in these talks. I assure you it is not my desire to do anything more than to offer, as one engineer to another, some suggestions that may help each of us and our country. I shall try to give practical advice, frankly expressed, and based on the needs of the present emergency. If occasionally my candor seems somewhat harsh, I know you will understand that these are no times for "pussy-footing" and that my only object is an attempt at genuinely friendly helpfulness.

I shall start with the more general considerations and pass into details as we go along. But in these particular talks I shall not go into intimate technical details of your daily jobs. They are too diverse for adequate discussion in any reasonably available time even were any one man qualified to discuss each of them completely and intelligently. But I am sure you can get help on the questions that arise in your daily work from other sources or from smaller conferences in which you may participate. So I shall here restrict myself to those questions and methods which are of broader use to you and which may help you in tackling the jobs which you face.

Engineering Ethics

As an engineer, each of us is a member of a *profession* and not a trade. That is, we are members of an intellectual fellowship rather than a competitive commercial group. It is important always to remember this in determining our attitude toward our work, our fellows, our company, and our country. As professional men, we have been highly trained over a long period of years. The knowledge of the past has been placed before us in clean-cut form. Carefully written text books, painstakingly prepared lectures, the facilities of a university, and all the experience of a great organization have been put at our disposal. Thus you and I owe a great deal to our engineering predecessors, to our families, and to ourselves. And we have the heavy obligation of achieving thorough effectiveness in our work and maintaining unusually high personal standards of conduct and performance. While it would be well if all men were to live up to such standards, yet in our case particularly is it essential that we shall maintain high professional and personal standing.

Under the conditions which we now face, we will find that we have specifically the following loyalties:

First, we owe a great debt to the United States, our own country, which is now engaged in a life-and-death struggle with destructive and ruinous forces stemming backward from stark savagery and barbarism. These forces represent a viewpoint which is the antithesis of freedom of thought, integrity and dignity of the individual, and the granting of opportunity to each of us for self-advancement and personal growth. They would represent the stultification and destruction of all that we have been taught to accept as the basis of an ordered, calm, and ambitious life.

The emergency we face is indeed a serious one. Through a combination of incredulity on our part that such violent and unscrupulous aims could exist in our modern world, and through a lack of foresight, "it is much later than we think." Thus time must now be compressed, and extraordinarily much must be accomplished in a brief space. What has been done by our opponents during a decade must be equalled and surpassed by us within a few years. But we have no alternative to accomplishing something which will be almost a miracle. For we shall "hang together or hang separately."

But this does not in the least mean that we must hasten hysterically, fall into a panic, or rush into disorganization. Quite the contrary. It means only that we must face our jobs and the future with steadfast bravery, a cool acceptance of conditions, and a stubborn determination which will overcome all obstacles. Given these qualities, our success and the victory of our country is assured.

While we engineers are conscious that we are members of a profession rather than a trade, we sometimes fail to remember the corresponding distinctions and obligations. A brief consideration of definitions is worthwhile. A trade may be regarded as a business, a special form of handicraft, or a pursuit or activity of a fairly skilled but usual or customary type. There are generally many people capable of following a given trade. Success in a trade does not customarily require outstanding or unusual talents. A profession is an occupation, calling, or activity which necessarily does require exceptional mental attainments and other qualities and involves special discipline, both during the training period and during later professional life. Relatively few persons are provided by nature with the mental and moral equipment to succeed in a profession.

When we examine the differences between a profession and a trade still more closely, we are impressed by the gap between the two—perhaps a wider gap than most of us have realized. The length of time required for training and the scope and demands of the training are both greater for a profession than for a trade. The training of the professional man is indeed long, arduous, and costly. For many years he must acquire knowledge of numerous facts, of methods and procedure, and in many instances must achieve manual dexterity. He must develop habits of thought characterized by exactitude, careful reasoning, and willingness to face the facts, no matter how discouraging or unflattering to himself personally this process may be. A combination of knowledge *and* wisdom is necessary. And these are very different assets, for knowledge, by itself, may be far removed from that skill in its selection, and that judgment as to its timeliness and suitability of application, which are a part of wisdom.

Accordingly the professional man must pass through many years of severe training and must develop a broad viewpoint as to his work and a willingness to serve humanity in the practice of his profession which are less requisite in other paths of life.

The mental qualifications of the competent professional man are numerous and severe. He must be thoughtful, analytic, thorough, honest in his appraisals, and considerably above the average in his mental capabilities.

The character requirements of the true professional man are also numerous. Pre-eminently, he must have high ethical concepts, for it has been found that men who think obliquely and evasively are poor professional material. The professional man is also distinguished by a sense of his commitments to society, to his professional colleagues, and to his own standing. He usually has a feeling of solidarity with his fellows—and this is more on mental, moral, and social bases than from a purely material standpoint. The professional man is self-disciplined. He has a sense of restraint which prevents him from acting precipitately or thoughtlessly or from rushing to hasty conclusions. He has the strength of character to view himself as nearly impersonally as possible and to appraise alike his weaknesses and his elements of strength. At his best, the professional man has a loftiness of attitude which ensures the progress of his field and of himself. He should be more controlled than most men by such ethical concepts as fairness, justice, cooperativeness, and honesty of purpose in his actions.

It may seem to some of us that these ideals are almost unrealizable and perhaps largely theoretical. Yet such is not the case. The viewpoints just expressed have been developed during the long experience of the professions through the centuries and have been found necessary in practice if those professions are to endure and their practitioners are to prosper in high repute.

Professional men are set somewhat aside from the remainder of humanity by their specialized skills, and are accordingly not too well understood. They are also attractive targets for criticism from demogogic politicians, muddled reasoners, and other parasitic or controversy-seeking elements in the community. Against attacks from such groups the professional man has only his own standing and the repute in which he is held in the community as a shield against injury or destruction. It is therefore particularly incumbent upon him to practice so far as he can the qualities which have just been outlined. These needs are not mere idle imaginings. These characteristics of the true professional man are rather the results of experience through the ages. They may even be regarded as proven empirically necessary. They have certainly been shown by pragmatic tests to be part of the outlook and code of successful professional men. The pragmatic test is merely finding the answer to the question: "Does it work?" We may be assured that the highest professional standards *do* work—and indeed, their absence is a fatal defect in the case of the would-be engineer. I have not dwelt on the inner satisfaction that the better type of man achieves in living a finer sort of life along the lines of his chosen profession. Yet as the years pass, each one of us finds an inner satisfaction and strength in having pursued, sometimes in the face of discouraging difficulties, a pathway which followed the code of his profession.

I would not have you believe that I am depreciating trades or those who work in them. To the extent that men in commerce or trades elevate their standards, they too can share in the fine standing, worthy accomplishments, and inner pleasure that come to the true professional man. But those standards, which are perhaps only permissive (though preferable) in the present stage of our civilization when applied to men in general, must be regarded as mandatory for us in the engineering field. To that extent we may be harbingers of a future mankind in a happier world. And we may be proud if we keep the torch of honesty of purpose and pride in constructive accomplishment lit during the occasional darker ages through which humanity may pass.

Toward our own profession, every one of us owes the duty of carrying on a high tradition. Remember that we have inherited the knowledge and experience of the past, accumulated by painful toil, courage in the face of obstacles, and hard and straight thinking over the centuries. It is stimulating to recall that men have endured disbelief, scorn, poverty, intolerance, and even death so that your heritage and mine of knowledge and the capability of mastery over the forces of nature might exist. The least we can now do is to show our appreciation of that priceless heritage. We must forever realize that we are members of a fraternity of intellectual workers.

Toward our own company we owe much the same loyalty as each man on a college team owes to his fellows. Enlightened executives—and there are many of them—have a deep interest in the engineer and abiding faith in his capabilities. These industrial leaders plan the help that can be given to our country through engineering skill. They then promise the Government definite accomplishments based on their faith in what we can do. We owe it to the country and to these men to make good.

As I have said, we are members of a fraternity of professional men. Toward our colleagues we owe frankness, true cooperation, clarity of expression, and unselfish teamwork. The major difference between an army and a mob is in its spirit and direction. Given capable direction and the spirit of unity, an army may confidently look toward victory. Each of you is no less in the front line of defense and offense than the soldier or sailor. We all know well that it takes considerable strength of character and broadness of viewpoint to suppress our little personal weaknesses and petty reactions. Yet it must be done, and this is the very time to resolve that it shall be done. The great engineer is he who does this job of real cooperation the best.

The Engineering Virtues

Every engineer from time to time should try to assess himself frankly and honestly. Self-analysis and self-judgment are stepping stones to greater strength and wider achievement. In wartime or peacetime, the esteem of our fellows and our success in a worldly sense will largely depend on the extent to which we possess and practice certain qualities and methods. There is no use in refusing to analyze ourselves. Our fellow workers and directors will do so in any case, and there is no purpose in trying the ostrich trick of hiding one's head in the sand. Better to determine one's limitations, vigorously try to remove them, and then to walk with our heads high.

The following are some of the major engineering virtues:

Initiative—Life may almost be defined as self-willed motion. When motion stops, life dwindles. Unless a man is ready to "start something" he will get nowhere. Lethargy, uncertainty, indifference, delay, and fear are paralyzing. Enterprise and keen thinking and fast action are the keys to success. Don't be too conservative in trying things out. Remember that a conservative has been humorously defined, with an undertone of indictment, as "a man who doesn't believe anything should be tried the first time." The great rewards of history, as well as inner satisfaction, often spring from trying it the first time.

Application—Steady work is an amazing instrument for achieving results. Sweat is the best possible lubricant to keep the wheels rotating. Mere ideas in the abstract lead hardly anywhere. To get results, it is necessary to keep going, and planning, and working even when one is very weary and there is a great temptation to sit back and "take it easy." This last is a fatal fault in an engineer. It is inconsistent with our dignity, our loyalties, and our future success.

There is no good reason for worrying too much about toil. Relatively few people have been ruined by hard work but many have failed through laziness. Lack of application is a costly national or personal luxury. Maybe we have had too much of it in the past; but certainly now is not the time for it.

Originality—Doing the same thing over and over is well enough in its way, but it is not enough during times of stress when unusual results are necessary. Then originality becomes particularly important. Practice imaginative thinking. If you have an idea, carefully cultivate it in detail. Then try to find flaws in it, viewing it with real detachment and in a critical mood. Try to think up numerous alternative ways of accomplishing the same thing. Then compare the various ideas which occur to you as to their respective and comparative merits and faults. Such comparisons lead to a wise and practical decision. Learn to think creatively and in a prolific way. Any man can expand his capabilities in these directions by trying, just as he can develop stronger muscles by exercise. Never be afraid to discard ideas which seem inappropriate or faulty, or to accept new ideas, even though radical, if they seem necessary and practical.

Frankness—One of the worst faults that an engineer can have is vagueness, the concealment of facts, or the lack of courage to face facts. Avoid silence where the communication of information is required. And avoid loose or incomplete information where definite statements are needed. We should try to tell the whole story. Science and engineering need the "truth, the whole truth, and nothing but the truth." Substitute candor for double talk, which latter is alike the bane of engineering, politics, and many another field. Engineering does not need "verbal glamor boys"; it demands really creative workers with a genuine output.

Personal Relations—As we all know only too well, it is easy to develop the fault of seeing no good in the ideas or work of the other man. We engineers should keep an open mind. Let us listen very calmly, coolly, and judicially to the other man's ideas. Think how you yourself would react to a scornful, unfriendly, or close-minded reaction to your own ideas. Try to find something valuable in the other man's proposals, for your own sake as well as his. If you must disagree, after careful consideration, do so courteously and clearly. Explain exactly why you disagree and how far you disagree, and give the other man a full opportunity to convince you with his arguments and reasoning. There is relatively little danger in being open-minded but much hazard in keeping our minds shut.

To get on in life, we must always remember that we are part of a community made up of many diverse elements. Think as well as possible of the other man and of his ideas. And, above all, avoid backbiting.

It may be easy to injure the reputation and standing of the other fellow and (with regret and shame be it admitted) there is occasionally a human temptation to play tricks of this kind. But remember that it is probably equally easy for him to hurt your standing. It may be stressed that men generally do not admire the engineer who selfishly depreciates his fellow workers and their accomplishments. This is the easy way to lose friends, standing, and self-respect. Such attacks hurt his fellows, himself, and the general standing of his profession. Our careers depend in part on convincing the executives and others with whom we deal that engineers are broadminded, capable men who can do things, who are willing to do things, who think well of each other, and who can work together efficiently.

Relations with Your Chief

You may safely take it for granted that those who are directing or supervising your work have been selected because they have had wide experience, have shown an unusual grasp and mastery of their subjects, and have proven that they know how to deal with emergencies and to appreciate good work. Give them your respect and loyal cooperation just as you will wish to receive such help and will need it in the future when you are in charge. Remember that, in the aggregate, they will be sternly judged by what you have accomplished; your company itself will be appraised by the sum total of the efforts of its members; and our country will rise or fall on the integrated efforts and cooperation of all individuals and organizations in the United States.

Engineering Methods in General

In order to reach a certain desired result, as engineers you may apply inductive methods, deductive methods, or both. Let us consider each of these and their most useful applications or scope.

Inductive Method—This is the method where we reason from particular facts or observations to general rules or guiding principles. To carry out such a method it is first necessary to try various experiments. Thus, a number of specific or detailed things are done or methods tried or devices built. Then the results of the experiments or the performance of the devices are carefully studied (preferably with sufficiently exact measurement and test) to see if any underlying rule, law, or more general relationship can be detected.

There are many sorts of relationships from the simplest to the most complex. There are algebraic relationships, exponential or logarithmic relationships, trigonometric relationships, or even unclassified graphic relationships. Sometimes we will find that we must work by the "cut and try" method, determining by trial and error whether we have found a simple relationship between two or more quantities or elements in an experiment. It takes a good deal of skill and some experience to separate the essential from the unessential in such work and to discover whether some unforeseen or undesired factor is affecting the results and obscuring an otherwise simple or definite relationship. This is a case where we will find that there is no substitute for patience, thoughtfulness, and experience.

If it is thought finally that such a law or relationship has been found by the inductive method, it is checked again and again (though not necessarily immediately) by trying out experiments which develop from those which we have already completed, endeavoring to predict in advance the anticipated results by application of the supposed law; and then noting whether the facts and the theory still agree. If they do not agree, either the theory is wrong, or it is inapplicable to the particular case for some reason that must generally be determined speedily if further progress is to be made; or else the theory is incomplete. In the last-mentioned case, some important and contributing or controlling factor or factors have been omitted from consideration. These must be discovered if the law is to be expanded into a reliable guide. There is at least one other group of possibilities, namely that the experiment has been incorrectly performed or its results wrongly set down or its meaning misinterpreted.

In other words, if the relation which we have derived does not work out, we must not be content to say that theory and practice seem to disagree—we must try to find out *why* they disagree. A correct and complete theory cannot disagree with practice, although an incorrect or incomplete law will not be a useful guide. Often in finding out why theory and practice do not agree, you and I will learn valuable and helpful facts.

The inductive method is principally used by scientists and engineers in major or minor research projects where the experimenter is working at or near the boundaries of available knowledge and is trying to discover really new physical or chemical facts, methods, or laws.

Deductive Method—In applying this method we reason from the general law to the particular instance. Thus we start with a supposed law, which has been found to be correctly applicable in the past and sufficiently complete and wide in scope to cover the assumed special instance under consideration. We then apply this law and predict a result or effect.

After the experiment is tried, we see whether the desired and predicted results are actually obtained. If so, we have another apparent strengthening of the law, and we have added confidence in its usefulness. If, however, the desired and predicted results are not obtained, we must make every attempt to find out why the law has seemingly failed. Merely abandoning the quest is generally insufficient. Perhaps the law was incorrectly applied. Maybe some other factors vitally affecting the results were omitted from consideration. Possibly the equipment under test was not correctly built or did not operate in the manner assumed by the designer. Or, finally, there may be a flaw or exception or limitation to the supposedly controlling law.

We should try to find out which is the case, for this will enable us to try the experiment the next time with a better chance of success or to determine how the law had best be modified or replaced in order to make it a safe and reliable guide.

Deductive methods, as might be anticipated, apply more usually in development work. Sometimes, when laws are well established as to their validity, scope, and completeness deductive work runs smoothly and to the satisfaction of the experimenter. However, this is usually the case only in long-established and well-covered fields. In general, even clever deductive reasoning requires caution and keen analysis at each stage.

Sometimes both inductive and deductive methods are used or mixed in handling the same problem. It generally takes an experienced worker with a wide knowledge of his subject, much experience, keen faculties of observation, and something of what we call (for want of a better term) "intuition" to handle such a problem by the use of the mixed methods. But it can be done and it frequently saves a great deal of time and effort. Intuition seems to be a sort of inner guidance or inspiration, dependent upon accumulated knowledge of a subject, and stimulated by the need for accomplishment and the urgent requirements of a situation.

It is a good idea in determining our methods to study carefully our own capabilities and preferences. As a general rule, the man who is most at home in research work and does it most naturally and best, is not so capable a development man as he likes to think he is. Similarly, the skilled development or design man who by instinct and experience develops equipment and methods readily may be a less effective pure research worker than he believes himself to be. For these reasons, every experimenter or designer should study his own capabilities carefully and impartially, if that is possible, and find out what type of work he does best. He should then endeavor to be assigned to that sort of work.

Further, if a man finds that he does his best work in a given sphere of activity, after he has carried any job to the point where it is about to pass out of that sphere into the next region, he should willingly turn it over to the next man for further work or completion. To speak in a blunt but friendly way, don't try to hog the development road—you may merely block traffic. Many a good research man has stuck to a job long after a development man should have taken it over and turned it into a commercially useful article. Often enough a development man has gone further into detailed design or manufacturing problems than is desirable or, on the other hand, has slipped back into research work where it would have been better to refer the unsolved problem again to a research specialist.

The advice I have just given does not mean that we should be without interest in any type of work other than our own. Quite the contrary, for it is an excellent idea to know something of the type of job which is done by the men who handle a problem before and after it reaches us. In that way we can best understand what is meant by the data or model or plan which reaches us and we can somewhat shape our own work to give our results or models to the next men in a form which will mean the most to them and will help them to carry on speedily. But avoid contracting that prevalent and contagious disease: "designer's itch." This grave ailment will make us satisfied with nothing that reaches us and will force us to try to change or re-design almost anything that passes before us. A little healthy appreciation of the other man's work and a broad attitude, applied daily to the mind, will be an effective remedy for this disease.

Engineering Methods of Attacking Problems

Let us suppose that a problem has been submitted to us or a job assigned to us. What should be done next? While there are no general rules in the nature of a universal panacea that cures all ills, here are a few hints. In a long experience in such matters, they have proven to be sometimes useful.

In general, it is very helpful to start out by finding out *what is known*. That is, search for and thoroughly study the existing information on the subject. Don't depend too much on your memory for facts, figures, or methods. Even the most experienced engineers can easily enough forget very pertinent facts. I cannot too strongly stress the thought that it is no disgrace to have to seek information. Quite the contrary; for the search for information betokens the open and inquiring mind and the resolution to accomplish the desired results. As a matter of fact, it is sheer folly to insulate ourselves from sources of valuable data. Conversely, when anyone approaches us for information, let us try to help him patiently, remembering that we shall probably be in the same boat, and for the same good reason, before much time has passed.

There are a number of ways of finding out what is known which may prove useful to us. The simplest and most obvious one is first to go to the best available *text books*. We may get some general or specific data that way. The more nearly routine the problem, the more likely we are to find help in available texts. It is advisable to make notes at each stage of our study so that, when we have completed our investigation, our notes can be digested, summarized, and used as a guide. Great care and some patience is necessary in making notes. It does little harm to make notes too complete or elaborate, but it does a great deal of damage to have them so incomplete or brief that we have difficulty in interpreting them at a later date.

Let us see if the engineering *handbooks* have any available information on the devices or methods in which we are interested. If so, we shall make notes of them, entering a specific reference with each note so that we can re-locate the full information in the handbook or text book if we so desire. In fact, it is a good idea to give definite information as to where we located *any* data, in the form of a specific reference in our notes.

To get more reference material than is obtainable by the above methods, we should resort to the *published papers* in the major engineering journals. It is sometimes difficult to locate the desired references in an engineering journal. However, the annual or other indices of these journals will be of some help. The card index system of an engineering library may also assist us. If we know the names of the engineers who have worked in a given field, we should look them up in the index or file so as to locate their papers which may bear on the subject at hand.

It is usually possible to accumulate a fairly full list of references on a given subject by a process of aggregation. One good reference article may give us a number of other references dealing with the same subject, which latter articles, in turn, will provide additional references. Thus we may soon accumulate a good *bibliography* of the subject and, in the process, a detailed knowledge of the particular field. The *reports* of our own organization's engineering staff are often helpful, and should be liberally consulted. They will usually contain more detailed and practical information than can be found in the average publication. *Standards reports* of the manufacturing associations (for example, the Radio Manufacturers Association or the National Electrical Manufacturers Association) or of engineering bodies (for example, the Institute of Radio Engineers, the American Institute of Electrical Engineers and the American Standards Association) may prove helpful. Now and then issued *patents or* accessible patent *applications* will also be instructive. But we should keep in mind that patents and patent applications are not necessarily completely scientific presentations in some cases nor will they always furnish the most useful forms of technical data. They should therefore be taken as interesting and suggestive but not necessarily final in every instance.

Speaking of reports, the technical reports prepared by you should be carefully written and in such detail as will enable others to understand fully what you have found and described. Technical report writing is a real art, and it is well to read and assimilate good books on the subject for your guidance.

It has been found that home study in the evenings, or even during part of the day, is sometimes not a bad idea at this stage of a new project. Frequently the change in surroundings or the quiet of the home may prove helpful in accomplishing a good deal in the assembly of data and in getting new ideas. It is usually a helpful plan to have loose-leaf note books for the data we shall accumulate or even to use a card index for particular subjects or fields in which we steadily work. These are useful tools for the engineer.

Continuing our process of finding out what is known, we must not hesitate to call on our *fellow engineers* (but try to avoid interrupting them at a particularly busy moment). There is no odium or loss of standing involved in asking questions. Nobody knows everything about a subject. Then too, we may be able to help the other fellow a little later on and he should be willing to give us what assistance he can at each stage.

In trying to get a definitely new idea, "hunch" or inspiration, don't force the issue too hard. Over-straining in an attempt to get a new idea may have the opposite effect. One can become stale or over-tired in that way. There are no rules governing the arrival of an inspiration. Some men get their best ideas in the early morning working hours, others in the late afternoon, and still others say they tend to get their new ideas during their normal hours of sleep, perhaps waking up with the answer to the problem which has been bothering them. It is not a bad idea to study your own reactions and to see into which of these classes you may fall. You can then try to arrange some of your work so that you can sit back and think intensely and take notes of your ideas at those times when experience shows you are most likely to "find the answer." It is thoroughly in order to make a great number of sketches and to jot down a considerable group of alternative ideas on any subject without analyzing each of these too thoroughly. Thus you will have a number of alternative plans in your notes, secured when you were in an "original mood." You can always analyze each of these later for its advantages and defects thus choosing at last the one that seems most hopeful and likely to work out in practice.

Occasionally it is a good plan (if conditions permit) to lay aside work on a particular problem for awhile, and instead work for a spell on some other job. A return to the original problem in due course will sometimes show that considerable progress toward its solution has somehow been made in the intervening period.

And now, suppose that we have found what looks like a plausible or probable solution, method, or design. We shall then be ready to start putting our ideas into equipment, such as an experimental, functional, or "bread-board" model, or even what we hope will be the final manufacturing form. If we wish to make only a functional and experimental model we need consider only the requirement that it shall produce the desired result regardless of its adaptability to manufacture. But, if we are tackling the even more difficult job of making a manufacturing design—and this, it must be stressed, is an entirely different matter—we shall have to consider many additional problems of design as well as factory methods and limitations and economic controls. But in either case, this is the time to plan the model, of whatever type, very carefully. Consider in detail just what the model must accomplish. How can it be made most simply, and from the least possible number of parts? What parts are already available? Be sure to utilize these as a matter of economy of time and money. Even in building a purely experimental model, let us try to imagine as far as we can what the final and manufactured form will ultimately be like and then make our model as much like that as possible (unless we are in so early a stage of a development that it is not practical to visualize the final commercial form of the device). Keep our set-up as simple, complete, and reliable as possible; but let us not waste time on unimportant details. Cultivated good judgment along these lines is an important asset to the development and design engineers.

In making tests and observations on our set-up, we must watch not only for the desired results but also for any odd, or unexpected or undesirable effects or performances. Very close observation is important at this stage. A great many new things can be learned in that way and many future "headaches," or "bugs" in the apparatus, can be avoided. Your general slogan should be "watch closely and think hard." Avoid distractions and try not to hear or see what is going on around you unless it directly concerns your work. Develop, if you can, "earlids"—they are as useful in shutting out undesired sounds as are eyelids in keeping out intrusive scenes. Stop, look, and think!

There is another thought which may be particularly important to us in wartime development and design. It may sometimes seem to the engineer that the requirements of the Army, Navy, or Air Force are unnecessarily stringent or detailed. But it is well to remember that, while the customer may not be invariably right, it is an excellent idea to give him every benefit of the doubt. This is particularly the case in connection with military divisions of the government in wartime. They are closest to the actual use of the equipment under the stringent and grueling field conditions. They have had experience in the difficulties which arise in its use; they must live with it; and they generally will have a more complete and clear conception of service conditions which must be met than designers who have not been active in the field for a long time. Accordingly it is wise to keep an open mind on specifications even if they look too stiff. However, it is in order to ask questions as to the reasons for them. And if we have unusual difficulty in meeting them, perhaps the specifying group may be able to suggest a solution or even to provide for us a model of something fairly similar to what we are supposed to produce and thus help us to "make the grade." Don't hesitate to ask for help in such directions, particularly under the present emergency conditions. It is readily possible to be too "dignified" in such matters. You will often find that the customer can be a helpful friend.

Engineering Factors Guiding Design

All products logically start with a clear concept of their purpose, general construction, and mode of use. It is a difficult task then to translate them from the mental field into the world of physical things. This process involves the element of skilled design.

Design itself may be regarded as a means to a certain end. Its procedure is controlled by the function or use to which the product is to be put, the availability and suitability of the materials which go into the product, and the methods of construction and test which are at hand.

The use to which a product is to be put necessarily determines its functional design. That is, unless the design from the very beginning is such that the device will produce the desired practical result, no progress is possible.

Nevertheless, a merely functional design, however interesting and encouraging, is usually not in itself of major practical importance. It must be possible to manufacture the desired article readily, at a reasonable cost, and within acceptable limits of time. The availability of suitable materials, and of methods of handling such materials, determine whether the proposed design is manufacturable and economic. There may be many methods of translating a functional design into a manufacturing design, but some of these will be too complicated, too costly, or too slow to meet the requirements.

There is no substitute for good judgment and careful analysis. Accordingly designers should avoid plunging hastily in a direction which, for the moment, seems attractive. They should rather carefully analyze a number of possible methods of passing from a functional design to a manufacturing design. They should then select that particular method which best fits the current conditions.

One of the worst mistakes an engineer can make is to start design work without carefully considering the numerous guiding factors governing the nature and use of the desired product and then translating these factors, perhaps in tabular fashion, into corresponding physical embodiments. This should be followed by a thoughtful comparison of the various possibilities and the selection of that one which, on the whole, offers the maximum advantages and the minimum disadvantages. Rarely, if ever, will any decision be free from disadvantages—but good judgment and the relative appraisal of advantages and disadvantages will go far toward contributing to the success of the engineer. It is natural enough to be impatient with delay and to desire to get started on a job immediately. But yielding to these natural desires is frequently costly in time and money, for the later rectification of early mistakes is a sorry and trying job. "A thought in time saves nine."

There are a great number of factors which markedly control or influence the design of a given piece of equipment. Some of the most important factors are the following.

Nature of Specifications—Specifications are a sort of bible to the designing and planning engineer. Many an engineer has invited—and encountered—serious trouble by not reading the specifications sufficiently closely and then checking on reliable methods of meeting each and every feature of the "specs." Take the specifications very seriously. If you don't expect to be able to meet them, it is better to say so in advance and try to have them modified or else secure such help as will enable you to meet them.

It is important to be sure that every element in the specs can be met before the job is started. Once the design is well advanced, it often becomes an appalling task to change even one element without scrambling many of the others. Delays and changes in the later stages of the work are extremely costly and time-consuming. And it must be remembered that now, more than in any other period in our history, time is of the essence. Peacetime standards may not be adequate for wartime needs. To repeat, let us take the specifications seriously, plan meeting them in advance, be sure that each element can be met before we start, if that is at all possible, and make every effort to avoid changes in the latter part of the development or design.

Conditions of Use—Obviously it makes a great difference under what conditions equipment is to be used since these conditions will vitally affect its design and required performance. Such questions as the following arise. Will the device be subjected to marked temperature changes? And with what effects on the materials and operation of the device? Or to wide changes in barometric pressure (with possible consequent high-voltage insulation problems)? Or to high humidity? Or to heavy jars and violent vibrations? Or to sudden accelerations? Will it be used continuously or only intermittently? Must it stand up under frequent and even prolonged overload? Must it be handled in the dark, and how? How noisy are the likely locations of its use? Must the operating personnel wear heavy gloves? Is it fixed, portable, or transportable equipment? Is it required to work in any position? Will many assemblies of the device be made, or only a limited number? Must it fit into a given space, or pass through openings of a limited size? From which side or sides must it be operated? How shall it be installed or removed? How is it associated with adjacent or nearby equipment? Is it a well-standardized type or is it likely to be changed shortly? Are weight considerations of prime importance? How skilled are the personnel who are likely to use the equipment? What service problems must be met in advance?

We should try to accumulate as complete a list as we can of such working conditions, and then to give them major consideration in design and construction, as well as subsequent test. These requirements are of interest even in experimental models but are of course vital in the manufacturing model and design.

Servicing—Every piece of equipment may develop some trouble sooner or later, and often enough at an entirely inopportune or dangerous time. Hence it is generally necessary that servicing problems shall be reduced to a minimum. Breakdown might occur at a tragically wrong time and place. Accordingly parts should be as far as possible conveniently accessible, easily removed, and readily replaceable (if there is any likelihood of their failure). Appearance is generally less important in wartime equipment than great convenience of use and reliability. The training and methods of the personnel who will probably do this servicing must be considered in each instance. Let us not hesitate to ask questions in these regards if we do not have the facts. A question is less embarrassing than an apparatus breakdown.

Cost—It is obviously necessary that the designer of equipment which is to be manufactured from his plans must be thoroughly acquainted not only with the design processes but their capabilities, limitations, and costs. It takes years of experience to become a master in this field but everyone should make a good start. As apparently simple a factor as the permissible tolerance set by the designer for a given dimension, or the reference point or plane of such a tolerance, may make a device either practical or impractical from the viewpoint of the factory expert. Further, it may make the product economic, or, on the other hand, unsalable. The same comment holds for specification of materials, finishes, and fittings. Thus there must be very close cooperation between the designer and the factory men if there is to be speedy, uninterrupted, and economic production.

Drawings—Most large plants have specifications for standard drafting practice. Such practice may differ from plant to plant, and it is necessary to be thoroughly acquainted with the practice in our own company and systematically to adhere to it. Not only the designer but also those engaged in development work should become thoroughly acquainted with this material since it dictates a line of thought and procedure which is useful to all and which may short-circuit otherwise costly and unnecessary misunderstandings or errors. It is extremely wasteful and dangerous to make "off-standard" drawings.

Interchangeability and Economy—Most modern manufacturing, particularly on a mass-production basis, depends on some form of interchangeability. Interchangeability, in its most complete form, enables the assembly of a complete device from component parts selected at random from lots of each of such component parts. That is, an operative device will result from the assembly of any available components. The advantages of such a possibility, both at the plant and under servicing and replacement conditions, are obvious.

In some forms of interchangeability only the sub-assemblies can be assembled at random to form an operative whole. These sub-assemblies form normal groups or combinations of parts. Sometimes the same sub-assemblies can be used as parts of a whole group of devices, which again increases economy in manufacture.

Selective interchangeability is another type in which all component parts are classified or graded into groups. A selected group of one component will then combine with a correlated selected group of another component, and so on. The advantage of selective interchangeability is mainly the broader tolerance in manufacturing each component which then becomes acceptable. On the other hand, the components must be classified or graded, and complete interchangeability in servicing may no longer be possible (that is, a certain amount of modification or machine work may be required from the service men).

Economy and speed in manufacture are largely associated with a wise and corresponding degree of interchangeability. Very careful design of the manufacturing model is involved in interchangeability. As previously indicated, the manufacturing model will generally differ markedly from a merely experimental or functional model. The functional model need only carry out a purpose or requirement and perform a certain job. However, it may be in a form inappropriate for manufacture or normal use in practice. Needless to say, manufacturing models should be designed with the help of the factory men. The construction of such models, their assembly, and their performance should be checked systematically in the factory throughout the manufacturing process. Any errors in the manufacturing design or in the process specifications can thus be corrected, the records made complete and instructive, and the lessons thus learned can be embodied as improvements, or in the avoidance of errors in later designs.

In the modern plant, fixtures, specialized machine tools, and cleverly contrived gauges, all play their part in economical production and in the obtaining of that precision which is required for the desired type of interchangeability.

Materials, Processes, Finishes—In his selection of these factors, the development man and the designer can prove himself to be either a skilled and valuable man or the opposite. The designer should ask himself many and searching questions as to the available choices in each case, the advantages and disadvantages of each of them from the manufacturing and customer viewpoint, the relation between each of them and the corresponding saving of time in production (with particular reference to the needs of war production), and the cost and labor requirements of each. Minimizing the demand for highly skilled and experienced labor is important at this time.

Unusual materials, processes, or finishes are strenuously to be avoided because of the delays, chances of error, and high costs they introduce. Only where they can be proven to be absolutely indispensable should they be considered.

There are usually available in any large factory assembled data on standard shop practice. Here again we have material which is of great value to the practical development or design engineer and which should be thoroughly understood and applied by him.

Overall Reliability—One of the characteristics of most adequate designs is that they are "balanced." That is, every part of the device is designed from a given viewpoint as to cost, performance, and reliability—and the criteria apply alike to each part of the design (except perhaps a few parts which, for some special reason, require unusual precision or particular care or better materials than the rest). Designing for an overall equalized reliability permits the user to judge more accurately what will be the probable life of the device in actual use. It contributes to economy in manufacture. Further, it prevents some one weakness from unfavorably controlling or limiting the useful life of the device. It requires considerable experience and good judgment, however, to design equipment so that it will run something like the "one-horse shay."

In closing, I would like to suggest that we all go through a mental over-haul, so to speak, every few months. It is astonishingly easy to get into a rut, or to drift behind the times. Let us review the thoughts which have been laid before us, and the experience we have gained. We shall decide whether we have used both of these to the full. We should keep notes of our own on the experiences we have had and draw conclusions from them which will serve as further guiding ideas for our own use in the future.

And, if you have any suggestions which you think might be useful to others (and I am sure you will have), I hope that you will convey them to your directors (or even send them to me) so that they may be made more generally available. We have a tough job ahead of us, so let's all pull together and get it done promptly.

And we should always remember that our work is being increasingly appreciated and judged to be of paramount national importance. In its leading editorial on December 26, 1941 "The New York Times" said:

> "As this war develops we can be increasingly thankful that we need no 'propaganda' to convince ourselves of the necessity and justice of what we are doing. All argument was silenced at Pearl Harbor. More and more this nation will value the gifts of certainty and of unity which our enemies bestowed upon us by their very act of aggression. Few causes and few wars are as simple as this one has become. The defeat of the Axis Powers has become as well-defined and essential an objective as was, a generation ago, the completion of the Panama Canal.
>
> "We suspect that it arouses a not wholly dissimilar emotion. We have grown up since 1898, when we looked for 'glory' in our brief and one-sided war with Spain; and even since 1917, when an exalted and Utopian mood seemed necessary. *Today's war requires the industrial and engineering type of heroism and fortitude. It requires planning, patience and exactness.*
>
> "We know that war itself is not glorious, though there is glory in some of the qualities which it reveals and utilizes. We shall give praise to every American, soldier, sailor or civilian, who forgets risk and hardship and does his duty, or more than his duty. But principally the mood of this nation at this moment, if we may judge by what is said, written and done, is reflected in a desire *to get on with the job, and get done with it*. One may well believe that this is a

frame of mind more dangerous to our enemies than the fanaticism of Berlin, Rome or Tokyo is dangerous to us. For, after all, the fanatical phase passes and is always limited to a minority in any nation, whereas the sober determination to finish what has been begun will engage a majority to the end.

"We think there prevails in this country a grim resentment at the necessity of devoting wealth, ingenuity, labor, courage and precious human lives to the ugly task of sanitation which the Axis has, by its existence, created. We have been interrupted at our work. We want no more such interruptions, and, God helping us, we will have no more."

Fellow engineers, we are in the first line of defense and offense. Let us then *think straight, plan well and work hard* to bring for all of us a brighter tomorrow.

LOW-FREQUENCY CHARACTERISTICS OF THE COUPLING CIRCUITS OF SINGLE AND MULTI-STAGE VIDEO AMPLIFIERS

By

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Summary—*Low-frequency amplitude and phase characteristics are given for a wide range of circuit constants of single-stage compensated video amplifiers.*

Curves are given showing the low-frequency transient response of single and multistage amplifiers with various degrees of compensation. For purposes of comparison the transient response of two to five identical uncompensated amplifiers is included.

In order to increase their range of application the curves are plotted in terms of dimensionless variables. The range of circuit constants covered should be sufficient, in most practical cases, for audio resistance-coupled amplifiers as well as video amplifiers.

Expressions are given for the above cases and, in addition, for the case of any number of identical stages where the grid time constant equals the filter time constant.

Introduction

As is well known, the ordinary resistance-coupled amplifier does not faithfully reproduce the lower frequencies (frequencies below about 200 cycles). The form of compensation usually employed to improve the low-frequency response of the amplifier is the plate-filter circuit $R_F C_F$ as shown in Figure 1.

The lack of sufficient design data on the low-frequency characteristics of the circuit of Figure 1 prompted the authors to calculate curves which show the effects on the response to unit function and the steady-state characteristics produced by changes in the circuit constants. A series of such curves which apply to multistage as well as single-stage amplifiers enables the designer to determine with a minimum of effort the values of the circuit constants necessary to meet a specified low-frequency requirement. This requirement may be over or under compensation, as perfect compensation as possible, a definite phase characteristic, amplitude characteristic, or transient response.

The results as presented here are valid for a pentode amplifier tube with fixed bias and screen-grid voltage. No attempt has been made to account for the effects of a cathode self-biasing circuit.

The transient response of multistage amplifiers has been limited to the case of identical stages in which the grid resistor value is large in comparison with the plate resistor value. Non-identical stages have not been included, since they were considered to be of less practical importance and are of considerably greater complexity than the identical stage amplifier.

In the following discussion, the individual steps in the analysis will be omitted; merely, the end equations will be stated, sufficient data will be presented in the form of curves or equations to be of value in the design of audio resistance-coupled amplifiers as well as video amplifiers.

I. Single-Stage Amplifiers—Steady-State Characteristics

(1) *General Equation*

With the assumption of a constant-current generator, the expression for the gain as deduced from the equivalent circuit of Figure 1 can be written as:

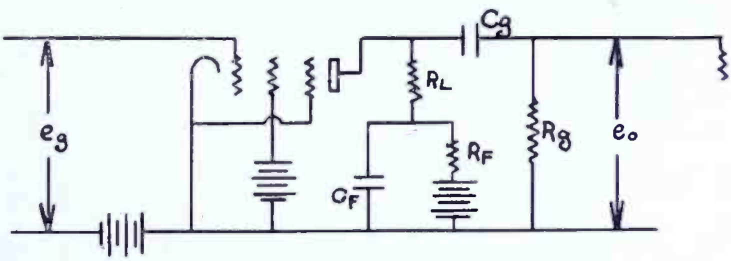


Fig. 1

Low Frequency Circuit, Video Amplifier Stage

$$\left|\frac{\text{gain}}{g_m R_L}\right| = \left[\frac{(\omega T_g)^4 + a^2(1+b)^2(\omega T_g)^2}{(1+\alpha)^2(\omega T_g)^4 + \{(1+a\alpha+ab\alpha+a)^2 - 2a(1+\alpha)\}(\omega T_g)^2 + a^2}\right]^{\frac{1}{2}}$$

where ω = angular frequency; $T_g = R_g C_g$; $T_F = R_F C_F$; $\alpha = R_L/R_g$; $a = T_g/T_F$; and $b = R_F/R_L$.

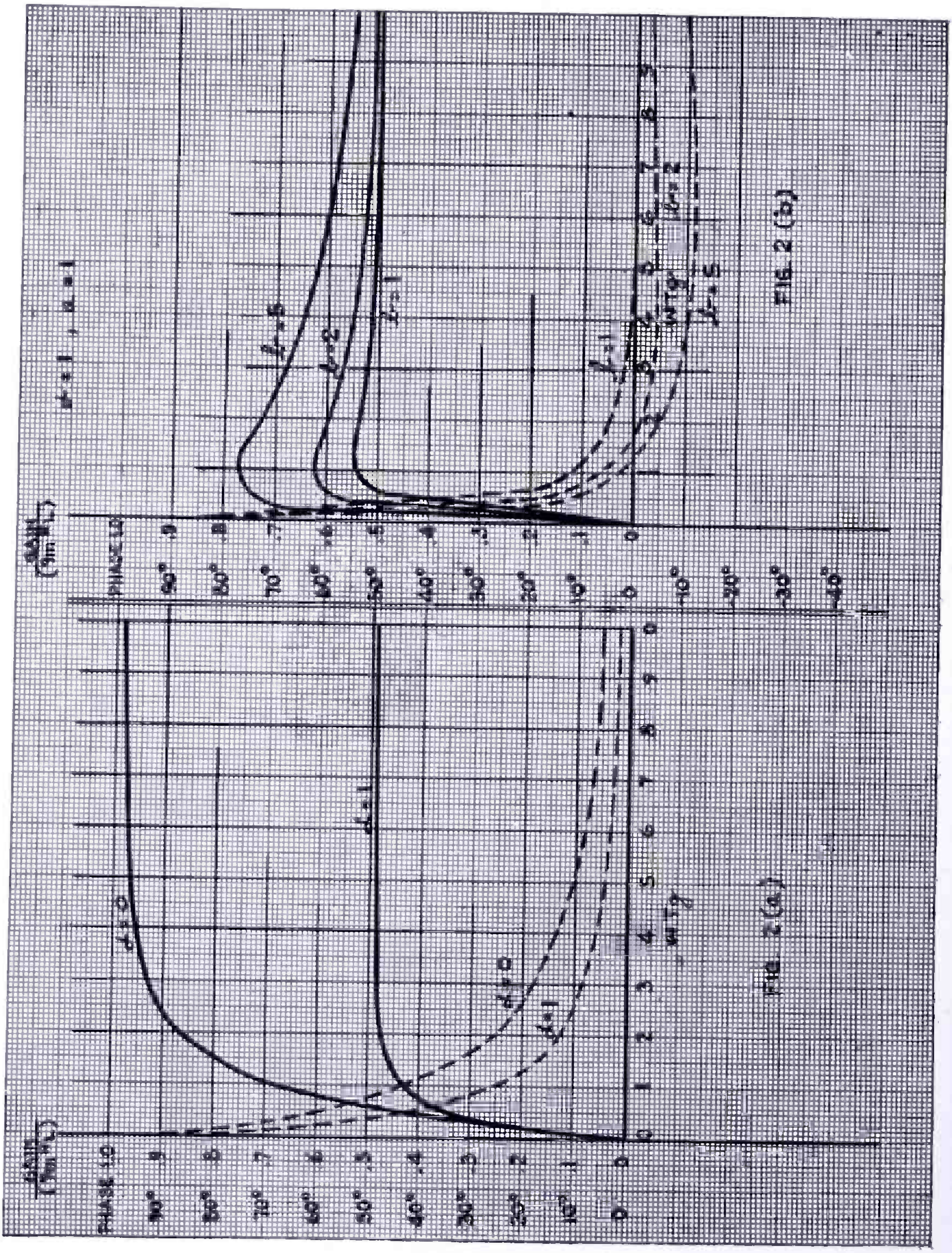
In terms of this same notation the phase angle is given by

$$\varphi = \tan^{-1}\left[\frac{(1-ab)(\omega T_g)^2 + a^2(1+b)}{(1+\alpha)(\omega T_g)^3 + \{a(1+b)(1+a\alpha+ab\alpha+a) - a\}\,\omega T_g}\right] \quad (2)$$

(2) *Particular Equation*

In the usual amplifier stage the resistance of the gridleak R_g is considerably larger than that of the plate resistor R_L, i.e., $\alpha = 0$. In this case Equations (1) and (2) become

$$\left|\frac{\text{gain}}{g_m R_L}\right| = \left[\frac{(\omega T_g)^4 + a^2(1+b)^2(\omega T_g)^2}{(\omega T_g)^4 + (1+a^2)(\omega T_g)^2 + a^2}\right]^{\frac{1}{2}} \quad (3)$$



and

$$\varphi = \tan^{-1}\left[\frac{(1-ab)(\omega T_g)^2 + a^2(1+b)}{(\omega T_g)^3 + a(a+ab+b)\omega T_g}\right] \tag{4}$$

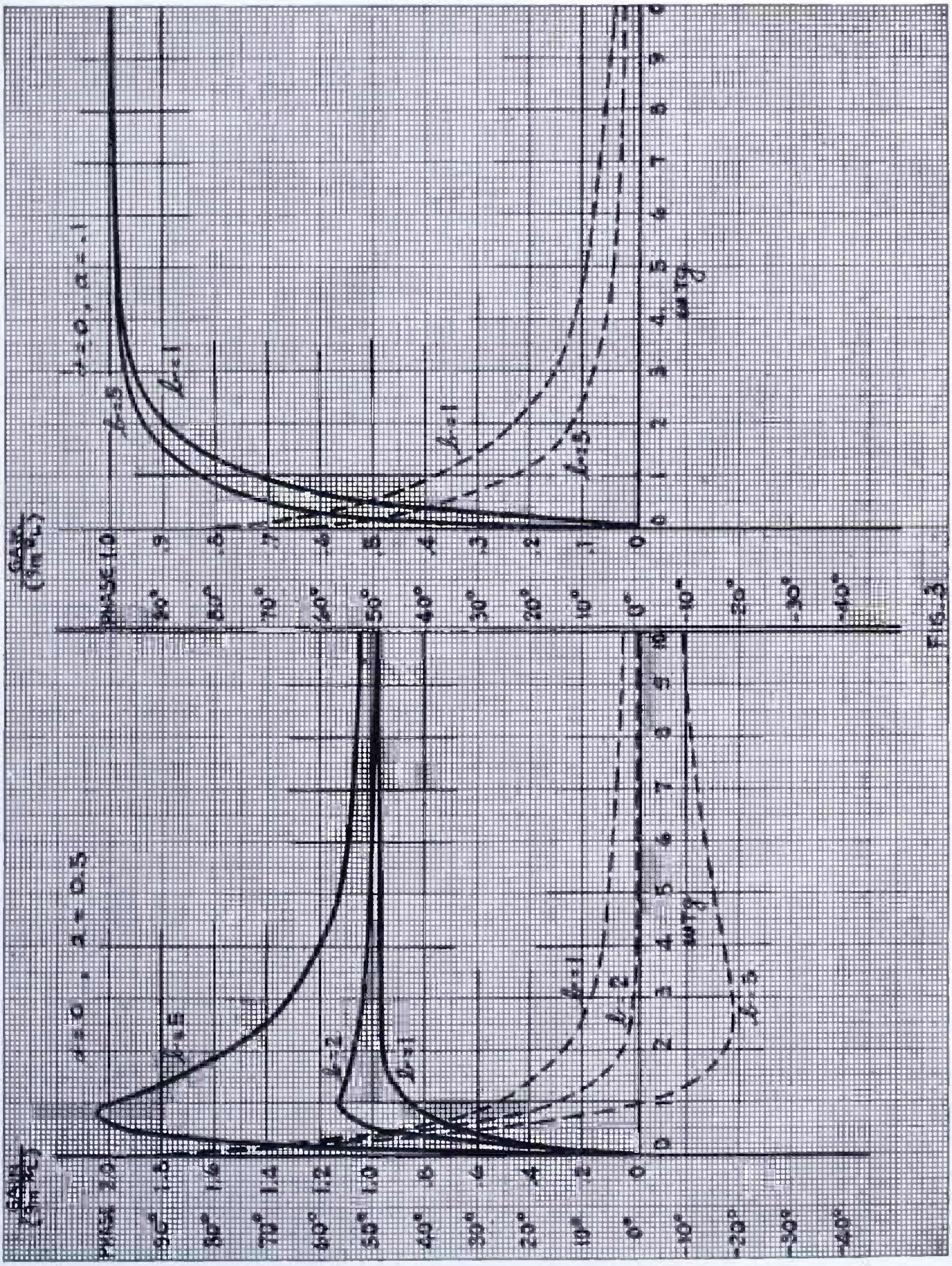


FIG. 3

(3) *Gain Curves*

By the use of Equation (3), gain/$g_m R_L$ was plotted as a function of ωT_g for various values of a and b.

The solid curves in Figures 3, 4, and 2(b) give the amplitude characteristics for different values of the circuit constants. For purposes of comparison, the solid curves of Figure 2(a) show the amplitude char-

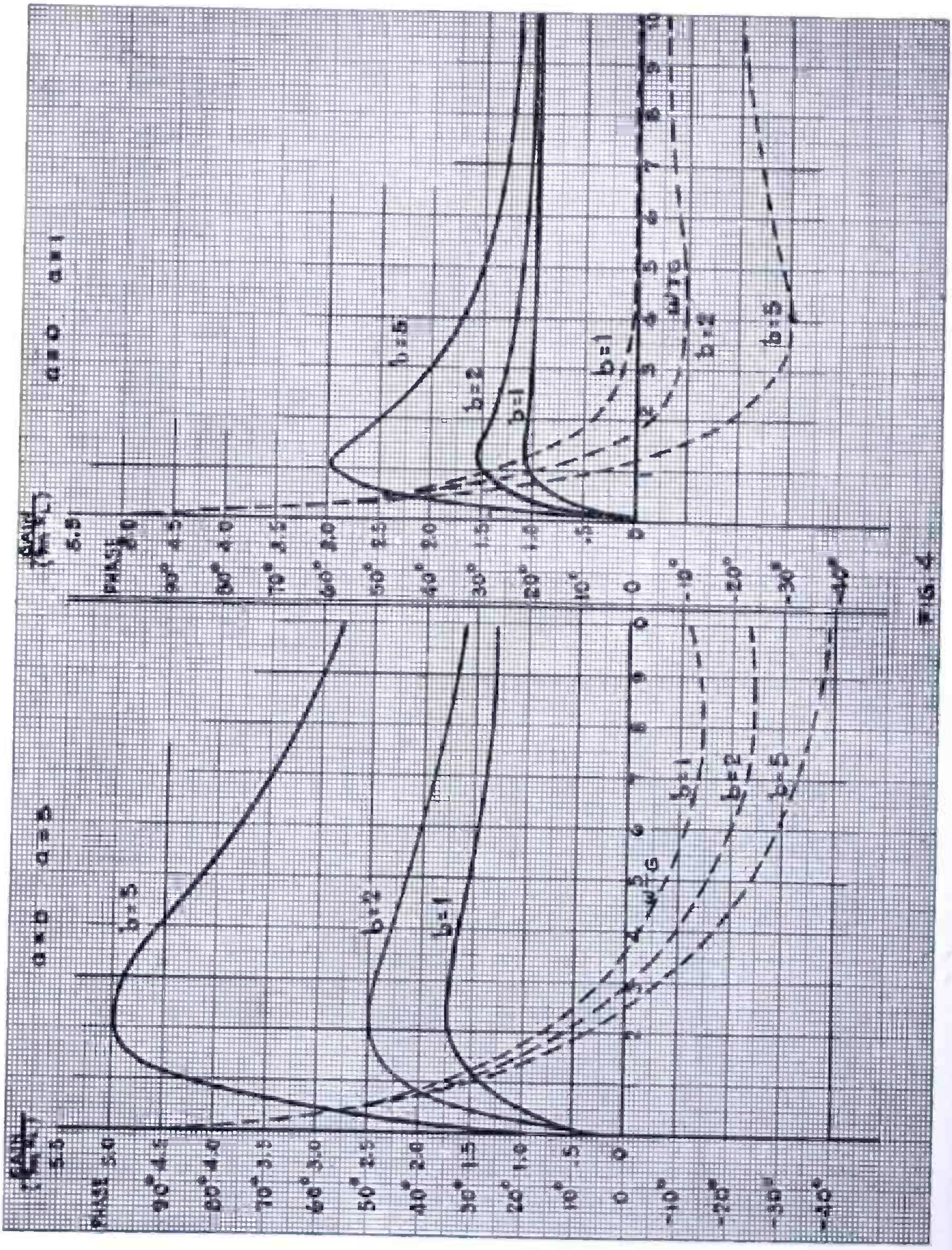


FIG. 4

acteristic of the straight resistance-coupled amplifier for the cases $\alpha = 0$ and 1. Obviously, to show the effect of various values of α as the parameters a and b are varied would require a large number of curves. Thus, only the characteristics for $R_g >> R_L$ ($\alpha = 0$) and the case of $R_g = R_L$ with $T_g = T_F$ are shown.

In the plot of the amplitude characteristics, gain/$g_m R_L$ was chosen as the dependent variable rather than say gain/g_m because in the usual case of high gridleak ($\alpha = 0$), the value of R_L is determined by the high-frequency considerations of minimum shunt capacitance and the highest frequency to be amplified. In the comparison of the curves for $\alpha = 1$ with $\alpha = 0$, it must be emphasized that for $\alpha = 1$ it is not R_L but rather R_L and R_g in parallel which are determined by high-frequency requirements. Hence, the high-frequency gain for $\alpha > 0$ can equal that for $\alpha = 0$ if R_L is accordingly increased with α. Hence gain/$g_m R = (1 + \alpha)$ gain/$g_m R_L$ where R is the resistance of R_L and R_g in parallel. Thus, for direct comparison of curves for $\alpha = 1$ with those for $\alpha = 0$ it is only necessary to multiply the ordinates of the former curves by 2.

The family of curves for the same α are, of course, directly comparable. In general, for given values of α and a ($= T_g/T_F$) the amplitude response becomes flatter as b is decreased, i.e., as R_F decreases, since R_L is fixed as pointed out above. If flattest response is the criterion, then for any value of α, the value of a should be about 0.5 and b should be between 1 and 2. In general, the conditions on R_F to fulfill a specific low-frequency requirement must be consistent with good filtering action which is a maximum value for R_F. This maximum value, however, will be fixed by the allowable voltage drop which determines the d-c voltage at the plate of the tube.

The inclusion of the curves for $\alpha = 1$ and $a = 1$ in the characteristics permits their comparison with the corresponding curves for $\alpha = 0$ to see roughly the effect of an increase in α. By multiplying the curve values for $\alpha = 1$ by the appropriate factor 2, it is seen that the gain and phase in the two cases are considerably different. From other curves not presented, it has been found that this difference in gain does not become pronounced until α exceeds 0.1 or 0.2.

It is obvious that by multiplication of the amplitude values given in these curves, the steady-state low-frequency response of a multistage amplifier can readily be found.

(4) *Phase Curves*

The phase curves accompanying the corresponding amplitude characteristics are shown dashed in Figures 2(a), 2(b), 3, and 4. These curves can all be compared directly since R_L appears only in α and b.

From the standpoint of the least possible phase shift at the lowest possible frequency, the curves indicate that a should be about 0.5 and b should be about 2 for any value of α, i.e., $T_F = 2T_g$ and $R_F = 2R_L$. These conditions are somewhat different from the optimum conditions for flattest amplitude response.

II. Single-Stage Amplifiers—Transient Characteristics

(5) *General Equation*

The response to unit function for the circuit of Figure 1 is given by the following equation:

$$\frac{\text{gain}}{g_m R_L} = \frac{1}{\sqrt{A^2 - 4a(1+\alpha)}}$$

$$\left[\left\{ \frac{\sqrt{A^2 - 4a(1+\alpha)} - A}{2(1+\alpha)} + a(1+b) \right\} e^{\dfrac{-A+\sqrt{A^2-4a(1+\alpha)}}{2(1+\alpha)} \dfrac{t}{T_g}} \right.$$

$$\left. + \left\{ \frac{\sqrt{A^2 - 4a(1+\alpha)} + A}{2(1+\alpha)} - a(1+b) \right\} e^{\dfrac{-A-\sqrt{A^2-4a(1+\alpha)}}{2(1+\alpha)} \dfrac{t}{T_g}} \right] \quad (5)$$

where $A = 1 + a + a\alpha + ab\alpha$; $a = T_g/T_F$; $b = R_F/R_L$; $\alpha = R_L/R_g$; $T_g = R_g C_g$; $T_F = R_F C_F$ as defined in connection with Equations (1) and (2).

(6) *Particular Equation*

The case of most interest is when $\alpha = 0$, in which case Equation (5) reduces to

$$\frac{\text{gain}}{g_m R_L} = \frac{1}{a-1} \left[(a + ab - 1)\, e^{-t/T_g} - ab\, e^{-a\,t/T_g} \right] \quad (6)$$

and for the particular case $a = 1$, Equation (6) further reduces to

$$\frac{\text{gain}}{g_m R_L} = \left(1 + b \frac{t}{T_g} \right) e^{-t/T_g} \quad (7)$$

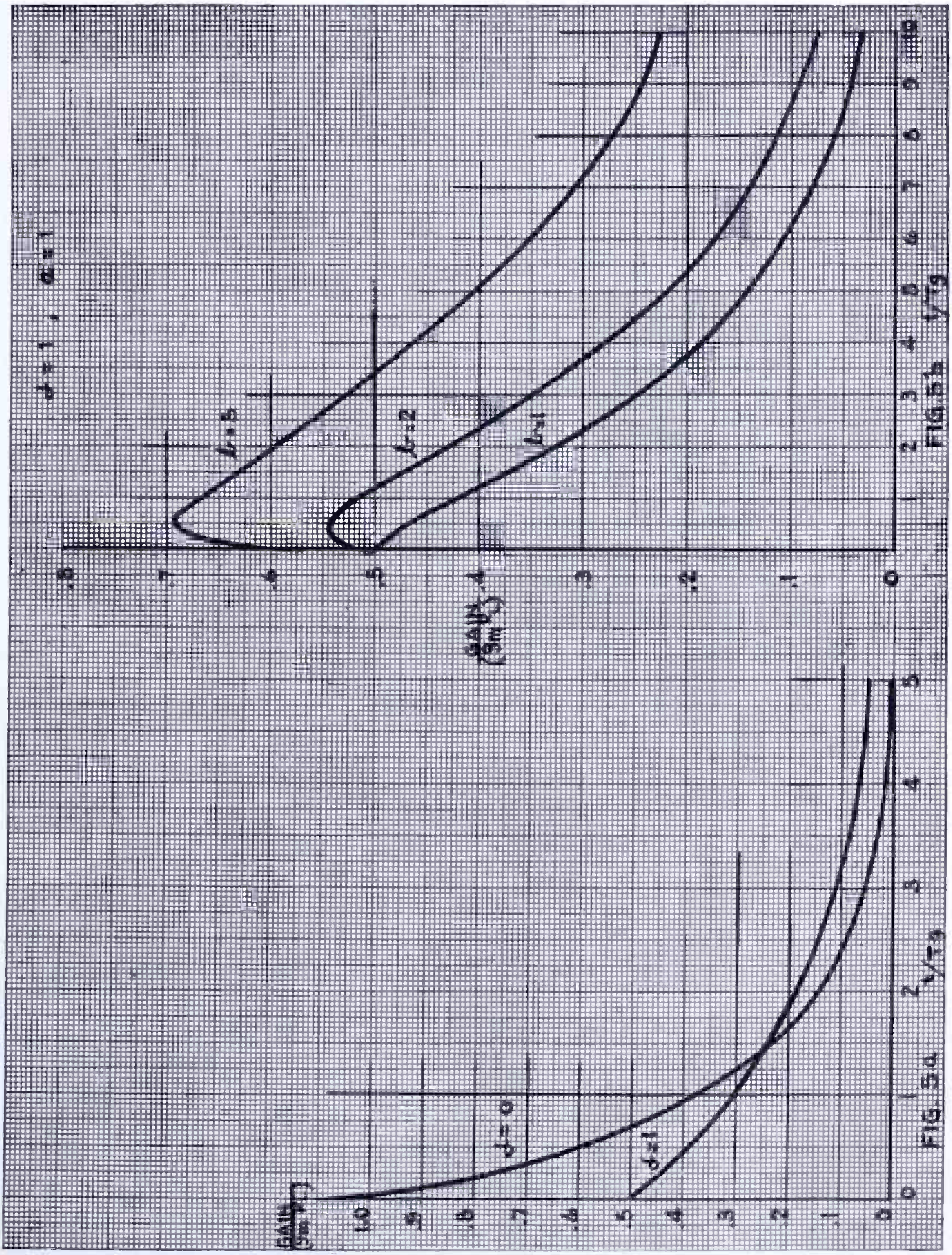
(7) *Transient-Response Curves*

Figures 5(b), 6, and 7 give the transient characteristics for the same range of circuit constants used in the calculation of the steady-state curves. The transient response for $\alpha = 0$ or 1 of the uncompensated resistance-coupled amplifier is shown in Figure 5(a).

The same remarks made in the case of the amplitude characteristic curves of differing α's apply to the curves of Figures 5(a), 5(b), 6, and 7.

(8) *Use of Curves*

The use of the curves can perhaps be emphasized best by means of a simple example. Suppose the characteristics of flat amplitude response



within 10 per cent with a maximum phase shift of 5 degrees at 10 cycles is desired. From the curve for $\alpha = 0$, $a = 1$, $b = 1$ (Figure 4) the phase characteristic determines the lowest ωT_g as 2.6. Since $\omega T_g = 2.6$ and $\omega = 62.8$, $T_g = 0.042$. From the requirement that $a = b = 1$, $(R_F = R_L,\ T_g = T_F)$ then $T_F = T_g = 0.042$. From this last relation a suitable C_g can be chosen since R_F is known and C_F is also

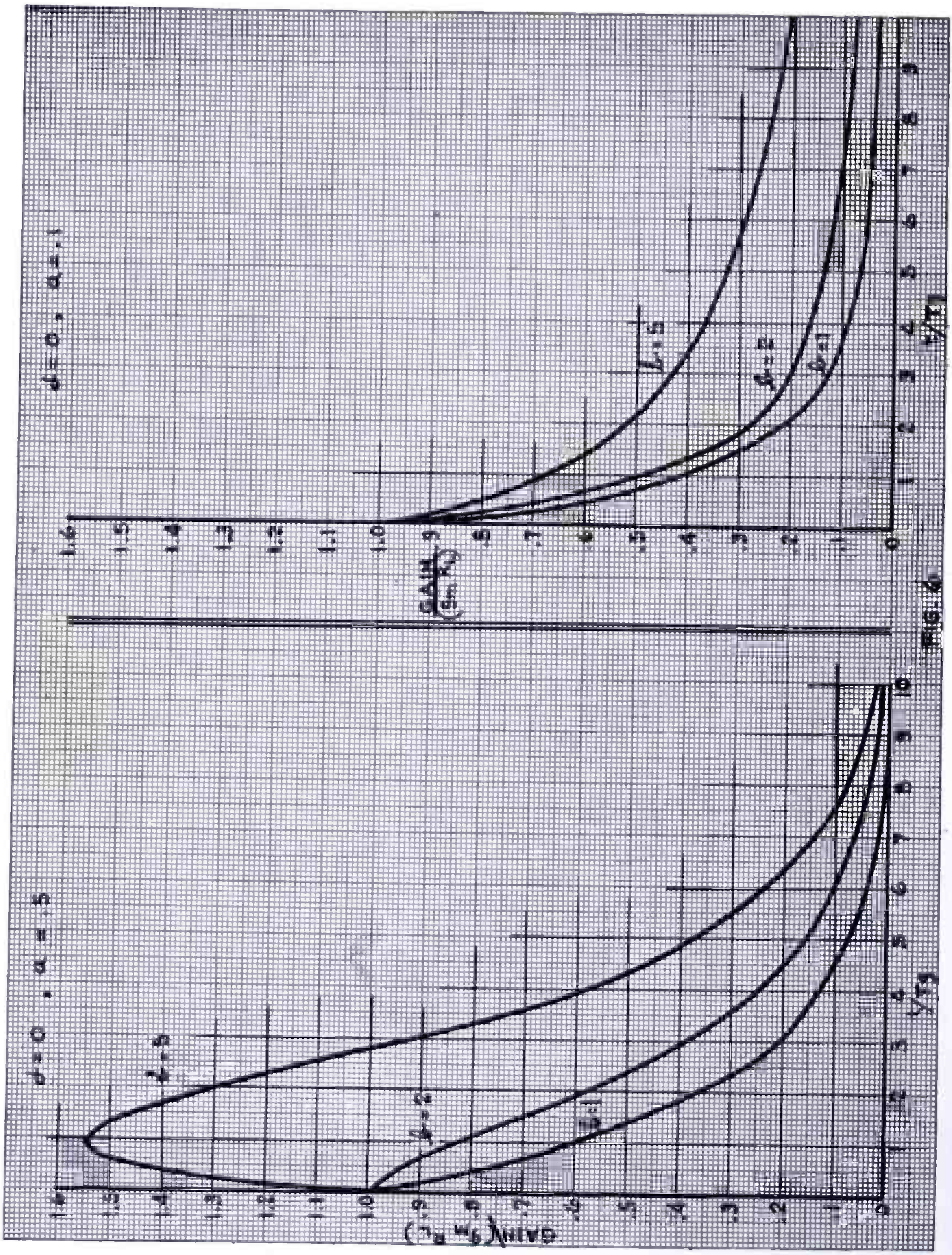
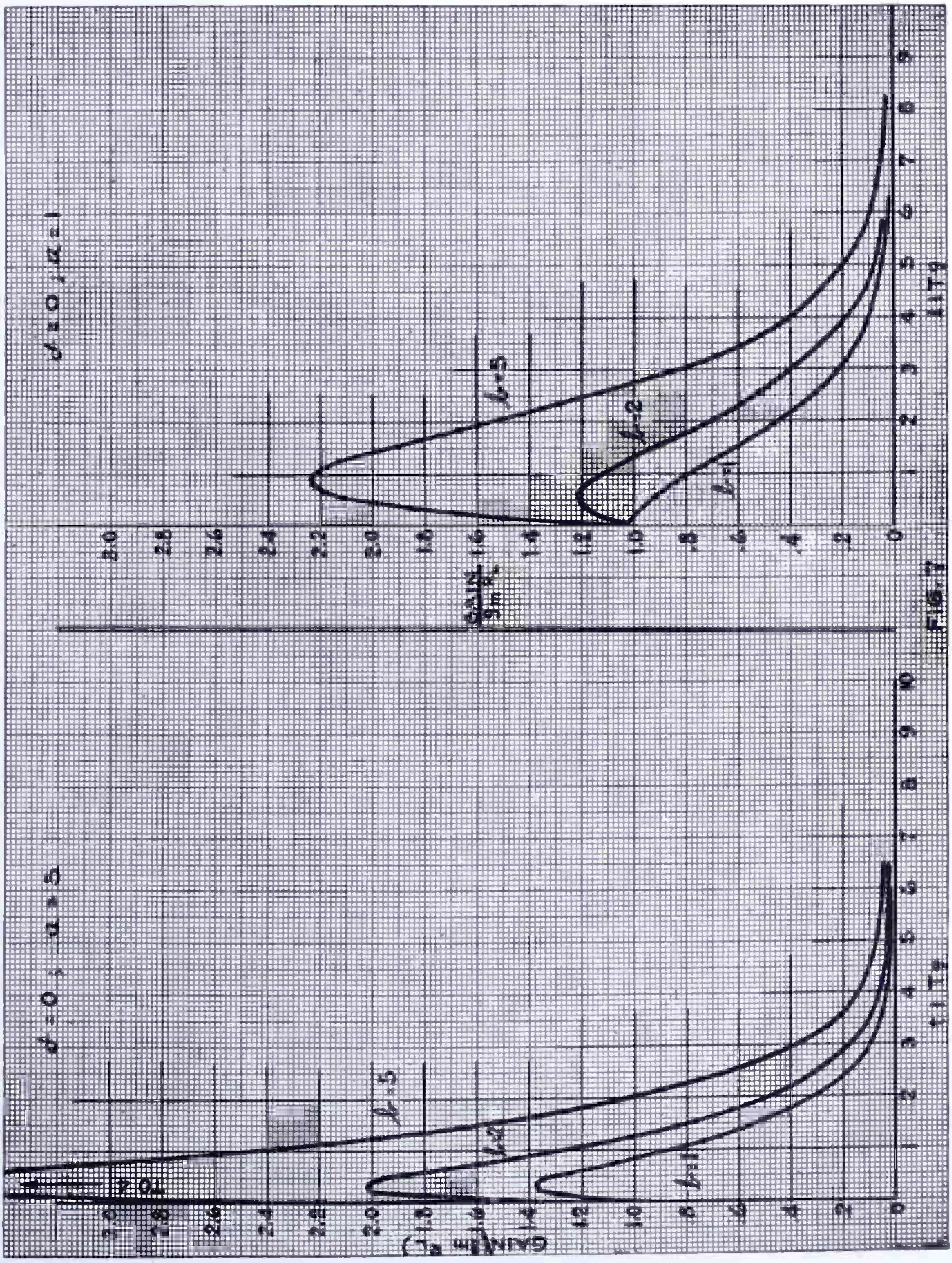


FIG. 4

determined. It is to be noted that for this case R_g should be large with respect to R_L.

If one takes the same conditions as above, but selects the curves for $\alpha = 0$, $a = 0.5$, $b = 2$ (Figure 3), the phase characteristic is again the determining factor and gives $\omega T_g = 1.8$; thus, $T_g = 1.8/62.4 = 0.029$. For this case $R_F = 2R_L$ and $T_F = 2T_g$. This means, for the same value



of R_L as in the above case, a smaller filter condenser but a value of R_F twice as large, a condition which may be desirable for filtering action (or undesirable if the value of R_L is high).

To illustrate the use of the transient curves, suppose it is desired that unit voltage stay flat within 10 per cent for 1/30 of a second. From the curve $\alpha = 0$, $a = 1$, $b = 1$ (Figure 7), it is seen that the response is down 10 per cent at $t/T_g = 0.55$, or $T_g = 1/(30)(0.55) = 0.061$. Since $a = b = 1$, then $R_F = R_L$ and $T_g = T_F = 0.061$ a value which determines C_g, C_F where R_g is much larger than R_L. For these same conditions, from curve $\alpha = 0$, $a = 0.5$, $b = 2$ (Figure 6), the response is down 10 per cent at $t/T_g = 0.76$ a value which makes $T_g = 1/(30)(0.76) = 0.044$. The values $b = 2$, $a = 0.5$ mean that $R_F = 2R_L$ and $T_F = 2T_g$. Thus, $C_F = 0.044/R_L$, a smaller value for the filter condenser than given by the previously chosen characteristic.

III. Multistage Amplifier

The steady-state characteristics of multistage amplifiers are easily derived from the single-stage characteristics given above. Thus, the amplitude characteristic of the multistage amplifier is merely the product of the amplitude characteristics of the individual stages and the phase characteristic is the sum of the phase characteristics of the individual stages.

The transient characteristics of multistage amplifiers were derived by a method described in a previous paper.[1]

The symbols have the same meaning as previously given. Thus, the unit of time is taken as the grid time constant $T_g = R_g C_g$ of one of the stages, a condition which makes t/T_g the independent variable. The dependent variable is taken as gain$/(g_m R_L)^n$ for an amplifier having n identical stages. The plate resistor R_L is chosen as part of the dependent variable since its value is dictated solely by high-frequency considerations. Incidentally, the curves presented show the effect of the coupling circuits only and disregard the 180-degree phase shift caused by the tube of any stage.

(9) *Any Number of Identical Uncompensated Stages*

The uncompensated ($R_F C_F$ filter omitted in circuit of Figure 1) resistance-coupled amplifier has been used so long that it would seem superfluous to consider it at this time. However, although most designers are very well acquainted with the transient response of the single stage, it is felt that relatively few are well acquainted with transient response of the multi-stage case. (The curves also serve as standards for comparison with the curves of the compensated stages.)

The expression for the response to unit function of an n stage uncompensated amplifier is

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[1] D. W. Epstein and H. L. Donley, "The Application of the Tensor Concept to the Complete Analysis of Lumped, Active, Linear Networks," RCA Review, Vol. IV, pp. 73-82; July, 1939.

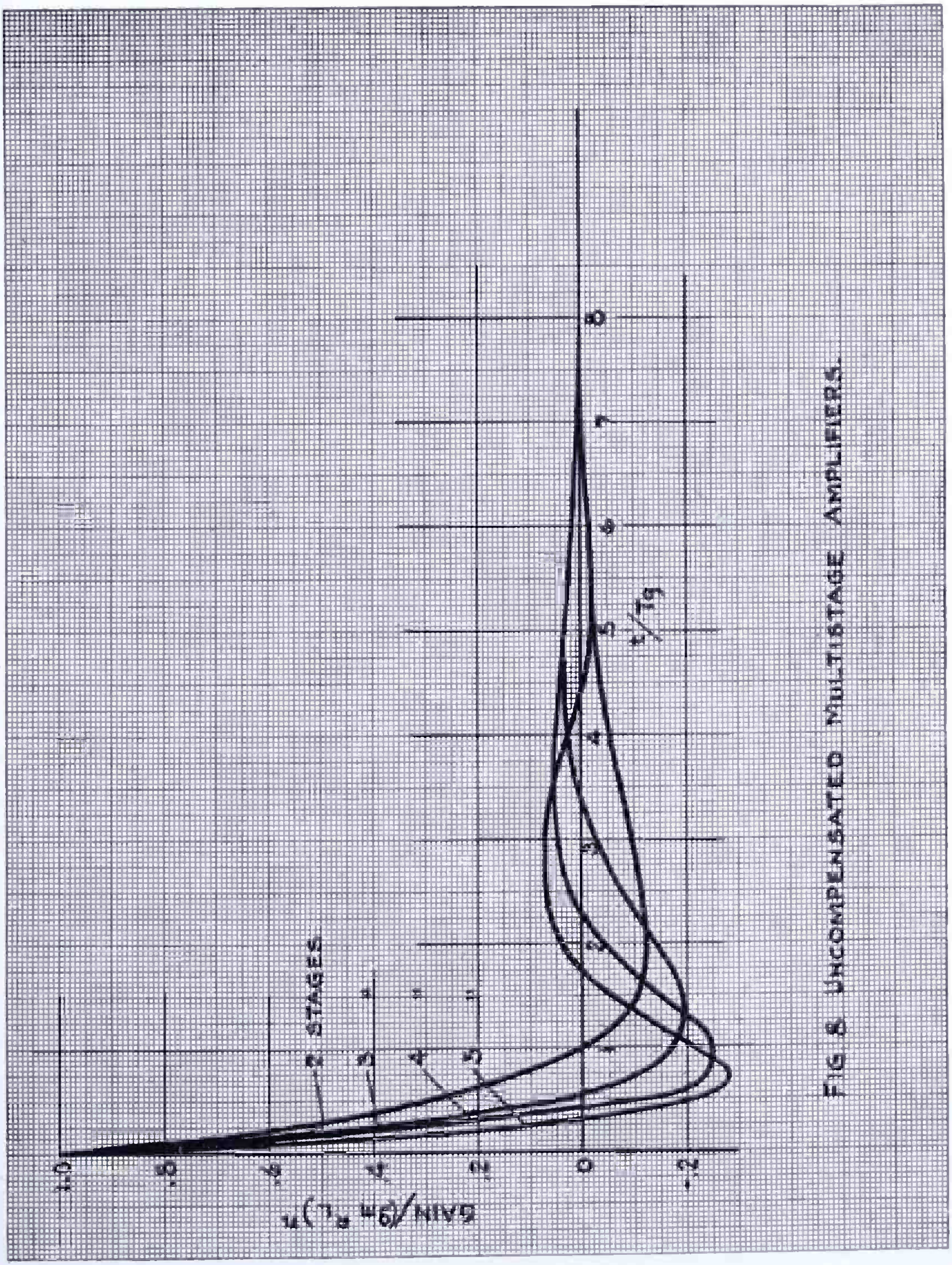

FIG 8. UNCOMPENSATED MULTISTAGE AMPLIFIERS.

$$\frac{\text{gain}}{(g_m R_L)^n} = e^{-t/T_g} \sum_{k=0}^{k=n-1} (-1)^k \frac{(n-1)^{C}k}{k!} \left(\frac{t}{T_g} \right)^k \qquad (8)$$

where $(n-1)^{C}k$ are the binomial coefficients.

Figure 8 shows the response to unit function of 2, 3, 4, and 5-stage uncompensated amplifiers. There are several noteworthy characteristics of multistage amplifiers that may be seen on Figure 8. These characteristics are true for both the compensated and uncompensated amplifiers. The first fact is that the addition of a stage adds half an oscillation to the response. Thus, in the case of two stages the response, starting positive, swings down negative and approaches zero from the negative side, while for three stages it again starts positive, swings down negative, swings up positive and approaches zero from the positive side. In the case of four stages the approach to zero gain at infinite time is again from the negative side, etc. However, because of the factor e^{-t/T_g} the oscillations after the fifth are practically damped out. Another noteworthy characteristic is the increase in amplitude of the first negative swing and its earlier occurrence as the number of stages is increased.

(10) *Response of Any Number of Identical Stages with $T_g = T_F$*

A general expression for any number of identical stages which is applicable for any compensation possible with the circuit of Figure 1 becames so involved that it is relatively useless. However, an expression for any number of identical stages with the particular compensation that the grid and filter time constants are equal, i.e., $R_gC_g = R_FC_F$ is relatively simple. The expression is

$$\frac{\text{gain}}{(g_mR_L)^n} = \frac{e^{-t/T_g}}{(2n-1)!} \sum_{k=0,\ r=0}^{k=n,\ r=2n-k-1} \frac{(2n-k-1)!}{(2n-k-r-1)!}\, {}_nC_k \, [-(1+b)]^k \, {}_{(2n-1)}C_r (-t/T_g)^{2n-r-1} \tag{9}$$

where $b = R_F/R_L$, $T_g = R_gC_g$, and ${}_{(2n-1)}C_r$ and ${}_nC_k$ are the binomial coefficients. The summation in Equation (9) is evaluated by first assigning to k the values 0 to n; there will then result $(n+1)$ simple summations with respect to r.

For a two-stage amplifier, Equation (9) reduces to

$$\frac{\text{gain}}{(g_mR_L)^2} = e^{-t/T_g}\left[1 - (1-2b)\left(\frac{t}{T_g}\right) + \left(\frac{b^2-2b}{2}\right)\left(\frac{t}{T_g}\right)^2 - \frac{b^2}{6}\left(\frac{t}{T_g}\right)^3\right] \tag{10}$$

and for a three-stage amplifier Equation (9) becomes

$$\frac{\text{gain}}{(g_mR_L)^3} = e^{-t/T_g}\left[1 - (2-3b)\,t/T_g + \frac{(1-6b+3b^2)}{2!}\left(\frac{t}{T_g}\right)^2 + \frac{(3b-6b^2+b^3)}{3!}\left(\frac{t}{T_g}\right)^3 + \frac{(3b^2-2b^3)}{4!}\left(\frac{t}{T_g}\right)^4 + \frac{b^3}{5!}\left(\frac{t}{T_g}\right)^5\right] \tag{11}$$

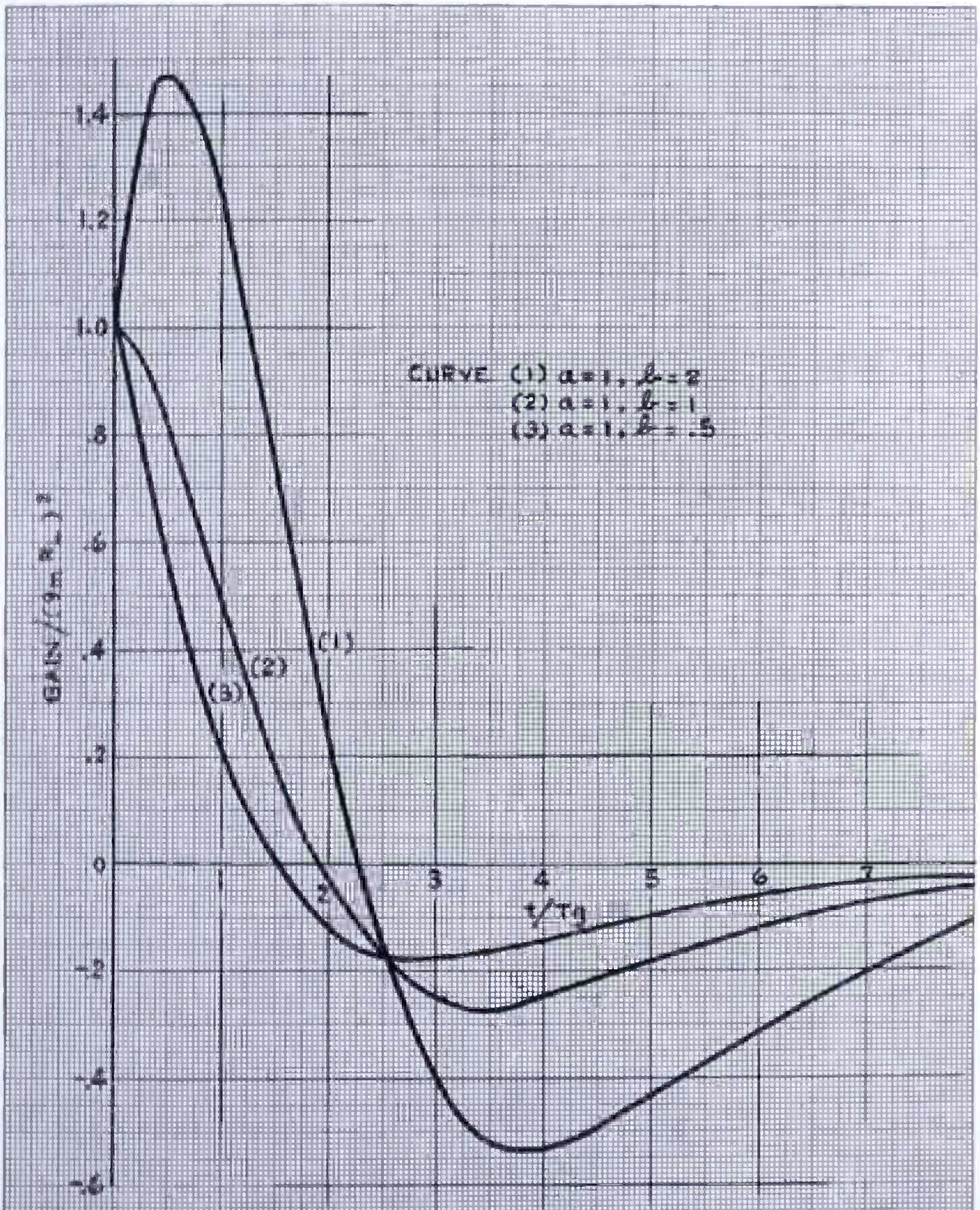

FIG. 9 TWO SIMILAR STAGES.

It follows from Equation (9) that the term containing the highest power of t/T_g is

$$(-1)^{3n-1}\frac{b^n}{(2n-1)\,!}\left(\frac{t}{T_g}\right)^{2n-1} e^{-t/T_g}$$

and the sign of the term changes with the addition of a stage (an

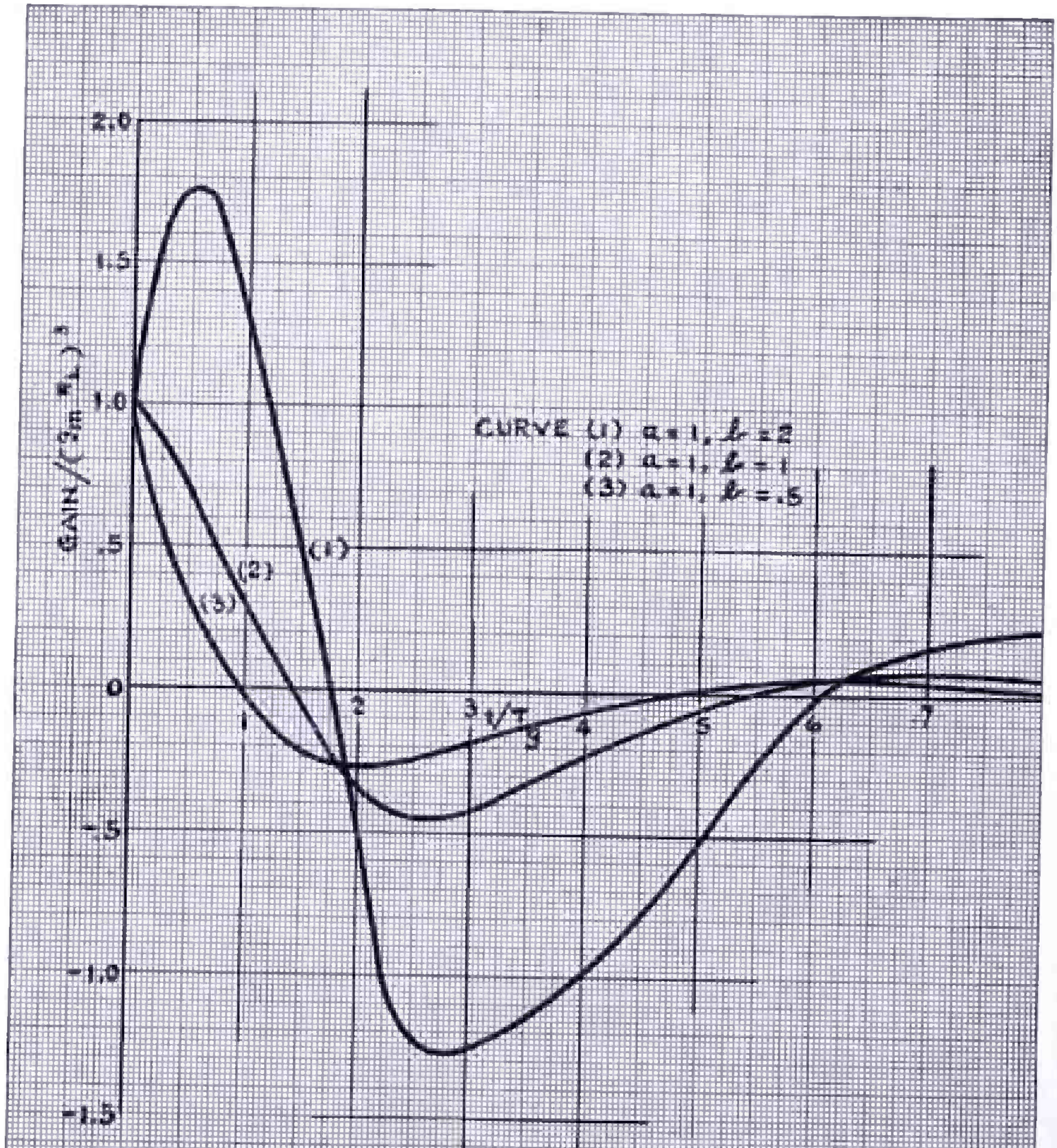

FIG. 10 THREE SIMILAR STAGES.

increase of n by unity). Hence, as in the uncompensated amplifier, the addition of a stage adds half an oscillation to the response.

Figure 9 shows the response curves of a two-stage amplifier wherein the grid time constant equals the filter time constant ($R_gC_g = R_FC_F$) and for three ratios of filter resistance to load resistance

$$\left(b = \frac{R_F}{R_L} = 0.5,\ 1,\ 2\right).$$

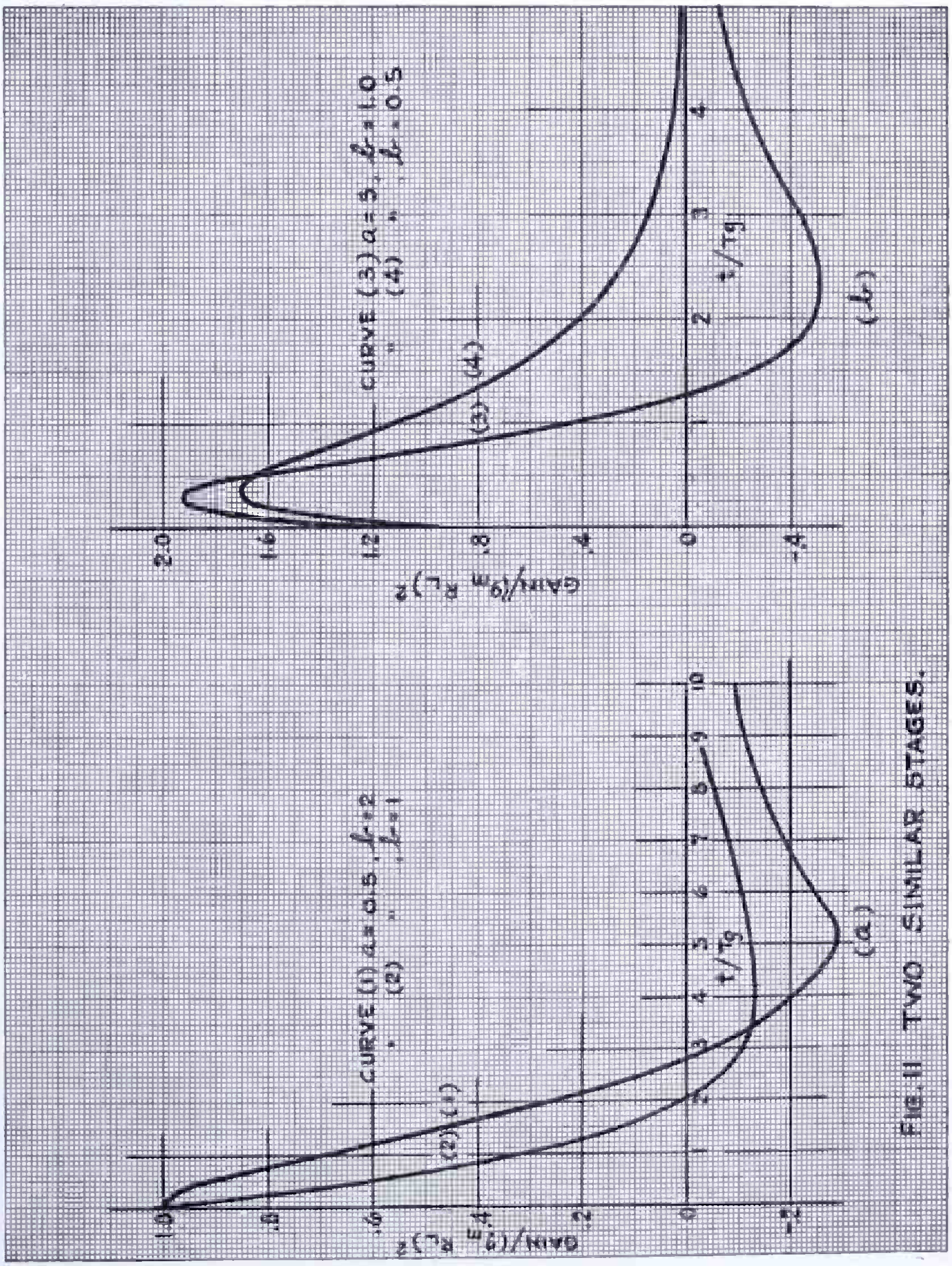

FIG. 11 TWO SIMILAR STAGES.

Figure 10 gives the corresponding response curves for a three-stage amplifier.

(11) *Response of Two and Three Identical Stages with T_g and T_k Unequal*

For a two-stage compensated amplifier where the grid time con-

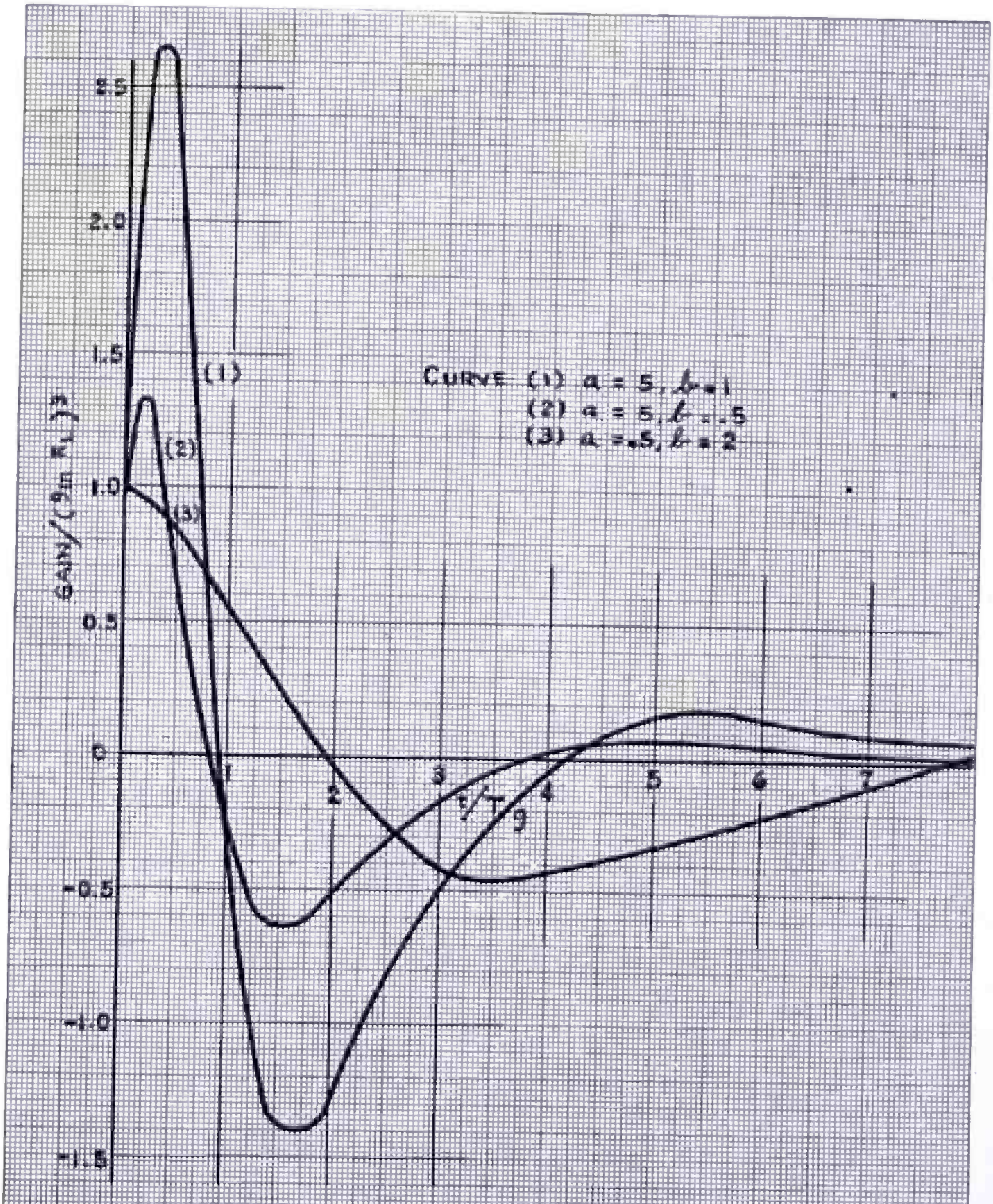

FIG. 12 THREE SIMILAR STAGES.

stant is a times the filter time constant, i.e., $T_g/T_F = a \neq 1$, the response to unit function is given by

$$\frac{\text{gain}}{(g_m R_L)^2} = \left[1 + \frac{a^2 b}{(1-a)^3}(2-b-2a-ab) - \frac{(1-a-ab)^2}{(1-a)^2}\frac{t}{T_g}\right] e^{-t/T_g} - \left[\frac{a^2 b\,(2-b-2a-ab)}{(1-a)^3} + \frac{a^3 b^2}{(1-a)^2}\frac{t}{T_g}\right] e^{-a t/T_g} \qquad (12)$$

Figure 11 shows the response curves of a two-stage amplifier for $a = 0.5$ and $a = 5$.

The expression for the response of a three-stage amplifier for the case $T_g \neq T_F$ is too involved to give here, but Figure 12 shows the response of such an amplifier for the values $a = 0.5$ and $a = 5$.

(12) *Grid Compensation*

The amplifier shown in Figure 1 is of the plate-compensated class. Occasionally, however, a grid-compensated amplifier is under consideration. In the grid-compensated amplifier, R_L and the $R_F C_F$ filter are in the grid circuit of the next stage with R_g as the load resistor of the preceding stage. So far as the coupling circuit alone is concerned, the impedance function is the same in both cases. Therefore, grid and plate compensation are equivalent. Hence, the results of this paper are directly applicable to the interstage coupling circuits of grid-compensated as well as plate-compensated circuits. Thus, it is tube behavior and practical considerations rather than coupling-circuit behavior that dictate one type of compensation instead of the other.

AN IMPROVED INTER-ELECTRODE CAPACITANCE METER

By

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Summary—A recent investigation of the possibilities for improvement in the tube-measuring equipment of this laboratory has indicated the desirability of certain modifications and revision in the equipment used for the determination of inter-electrode capacitances. The changes which were incorporated in the equipment were brought about primarily as the result of an attempt to obtain improvement in flexibility and operating convenience. However, factors concerning stability and accuracy were by no means neglected.

General

THE basic piece of apparatus used was a unit which at one time was designated as the RCA Victor Direct-Capacitance Meter. The original model of the unit was battery operated and contained an oscillator which supplied radio frequency, at about 500 kilocycles with voltage of a few hundred volts. This potential was impressed upon a calibrated standard concentric-cylinder capacitor in series with a thermocouple. For measurements the standard was set at maximum capacitance and the thermocouple indicator reading noted. The unknown inter-electrode capacitance was then shunted across the standard and the standard decreased until the thermocouple indicator returned to the initial reading. The inter-electrode capacitance could be read directly on an inverted scale on the standard capacitor.

This system had a number of undesirable features, many of which subsequently were corrected. A number of earlier improvements were made. Briefly, these improvements were:

1. Increased oscillator strength for greater sensitivity.

2. The inclusion of a variable R-C network in the feedback portion of the oscillator circuit. This made it possible to adjust the oscillator amplitude-vs.-frequency characteristic and, hence, to reduce considerably the inherent error caused by detuning or loading of the oscillator by shunt tube capacitances (those tube elements not involved in the measurement were grounded and, therefore, added shunt capacitance to the oscillator).

3. Replacement of the thermocouples by vacuum-tube voltmeters. This considerably increased the sensitivity.

4. Use of an improved type of socket and adaptor which accommodated the then "new" six and seven-prong tube types.

At the time these changes were made they afforded considerable improvement. However, the unit was still battery-operated and its increased sensitivity tended to make the unit somewhat unstable. Also, the trend toward the octal-base tube types, with their wide variety of base pin connections, necessitated either a great number of adaptors or else continual rewiring of the adaptor socket connections. In addition, the improvements in tube design led to decreased grid-plate capacitances and, consequently, increased difficulty in obtaining accurate measurement. It was with these facts in mind that the present investigation was undertaken.

CONVERSION FOR A-C OPERATION

Revision of the capacitance meter to permit a-c operation is highly to be desired. This is true because the current drain on the plate-voltage supply of the old model was rather large and as a result, even though heavy-duty "B" batteries were used, there occurred a very noticeable and undesirable slow drift of the "zero-capacitance" balance point of the vacuum-tube voltmeter. This of course necessitated re-checking and rebalancing after each capacitance measurement. Then too, because of the high current drain, the battery life was rather short. This necessitated frequent battery replacement and was particularly undesirable because the "run downs" seemed to have a faculty for occurring in the middle of a long series of measurements.

The use of a storage battery as the filament supply caused similar difficulties and disadvantages.

The stability requirements of the plate supply indicated the need for some form of voltage-regulated power supply. It was found that these requirements might be fulfilled partially by the use of one of the RCA TMV 118-B regulated power units which was available as standard laboratory equipment. Additional measures of stability and regulation were obtained by generous usage of gaseous regulators (of the VR-150 and VR-105 types) at various critical points in the circuit. The final result was an excellent order of stability. Line voltage variations (plate power unit input only—not including heater supply) of ± 15 per cent were found to cause errors less than the limit of readability of the capacitance standard scales.

A cursory consideration of the heater supply requirements for a-c operation might indicate that little difficulty should be experienced insofar as stability is concerned. However, preliminary tests revealed that heater-voltage variation was a possible source of considerable error. It was found that line-voltage variations caused proportional variations in capacitance readings:—i.e., a 5 per cent change in line voltage caused a 5 per cent error in the capacitance reading. Some reflection on the problem led to the fact that changes of line voltage changed the contact potentials of the various tubes and subsequently changed the radio-frequency output voltage and also the d-c bias of the vacuum-tube voltmeter. Some attempt was made to use

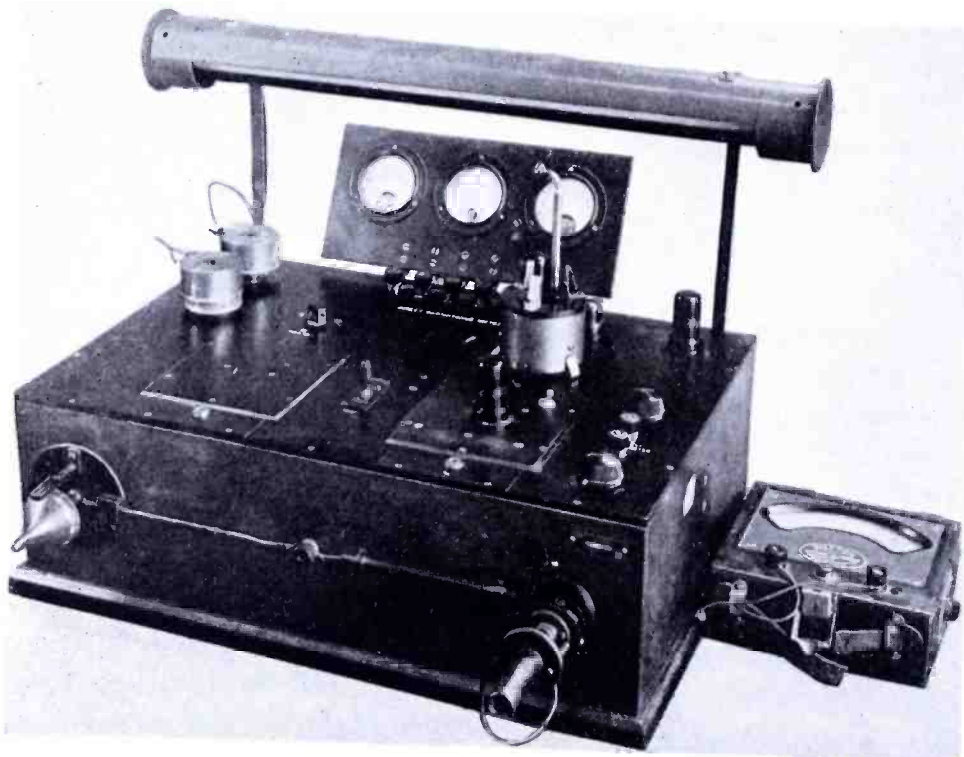

Fig. 1—Assembled view of the inter-electrode capacitance meter.

duplicate tubes in a circuit which caused the contact potentials of the two tubes mutually to "buck-out" each other. However, this met with little success because of variations in contact potential between various tubes (of the same type) and also because of variations in contact potential with age. A satisfactory solution was finally evolved employing the obvious method of regulating the heater voltage. The method used was suggested by Monroe H. Sweet in the August 1940, issue of "*Electronics*". It consists of utilizing the negative-resistance characteristic of a fluorescent lamp to compensate for line-voltage variations. The lamp is supplied with a series current-limiting reactance and operates with a tube drop of about 65 volts. This voltage decreases as the line voltage is increased and vice versa. Obviously, at some intermediate point on the series current-limiting impedance the net effect of line-voltage variations is zero. The regulated output is obtained in our application by using a shunt voltage divider across the 0.5-henry series reactor. It must be noted that fluorescent lamps of the type used (GE 20w 3500°C white) employ heated emitters for starting purposes. These heaters are automatically cut out of the circuit after a short time by a thermal relay actuated by the current through the limiting reactor. Hence, it is necessary to remove all external loads from the circuit for the starting of the fluorescent lamp and then subsequently to apply the load to be regulated. It is possible that, under conditions of abnormally low line voltage, some difficulty may be experienced with this regulator. The lamp may extinguish and will not start again until the load has been removed from the circuit and the line voltage raised above 105 volts. This difficulty can be eliminated by the permanent installation of a series line booster using a small 6.3-volt heater transformer properly poled. This is necessary only if the line-voltage fluctuation is excessive. Satisfactory regulation of the heater supply was obtained for nominal line voltages within the range of 100-130 volts.

It was found advantageous to mount the fluorescent lamp above the capacitance meter so that it might be used for illumination as well as regulation.

The Radio-Frequency Source

The source of 500-kilocycle potential used in the original model of the capacitance meter consisted of a self-excited oscillator, the low-capacitance output tank of which had a relatively high-tuned impedance. Consequently, the magnitude of the radio-frequency output was considerably affected by the application of shunt conductance. In addition, the oscillator frequency was changed considerably by the detuning effect of shunt capacitances.

These undesirable effects were caused by shunt conductances and capacitances introduced across the oscillator tank when the tube to be tested was inserted in the adaptor socket. Thus, when the tube was inserted, the radio-frequency source no longer had the same amplitude and frequency as when the "zero-capacitance" reading was taken. Hence, the zero point was shifted an unknown amount by the presence of the tube being tested. In the original model some improvement was effected by adjusting the oscillator amplitude-vs.-frequency characteristic to compensate for changes in shunt capacitance. However, the correction was only approximate and could not compensate for conductance changes and capacitance changes simultaneously. In addition, it required readjustment for each tube, particularly when the tube being measured had appreciable conductance (dielectric loss or leakage).

The undesirable features of the self-excited oscillator were greatly minimized in the improved model of the capacitance meter. This was done by using a highly stable oscillator to drive a buffer-amplifier stage. The amplifier stage output tank impedance was made as low as conveniently possible (1000 ohms or so) without having to provide excessive plate-current swings in the amplifier stage. The high-capacitance tank in the output circuit served to swamp the detuning effect of shunt

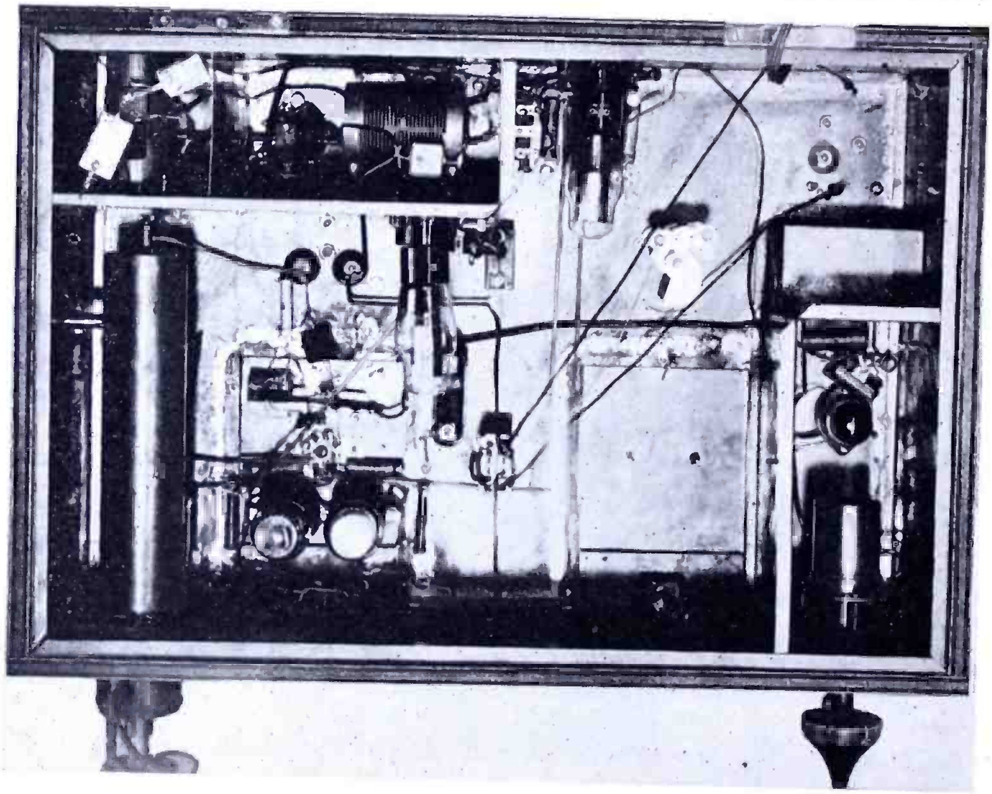

Fig. 2—Sub-chassis view of the inter-electrode capacitance meter.

capacitances and the low-tuned impedance provided good regulation for conductive loads. Additional stability of the radio-frequency potential was achieved by the use of an automatic-gain control on the amplifier stage. This consists of using a biased diode detector, driven from the radio-frequency potential, to supply d-c bias to the amplifier-tube control grid. Thus, any increase or decrease in the radio-frequency output potential, no matter what its cause, alters the bias of the amplifier tube in such a manner as to cause the output to return approximately to its original value. The nominal value of the output voltage is determined by the value of the d-c bias (delay voltage) on the diode detector. This system provides an additional improvement of about 10 to 1 in the regulation of the radio-frequency source. The resulting effective output impedance is of the order of 100 ohms.

Vacuum-Tube Voltmeters

The older model of the capacitance meter contained two vacuum-tube voltmeters, one for each of the two capacitance ranges. The one used on the low sensitivity range (0-14$\mu\mu$f) was a plate-circuit detector and the one on the high sensitivity side (0-0.4$\mu\mu$f) consisted of a diode detector followed by a d-c amplifier.

In the improved model, heater type tubes 6SJ7 and 6H6 are employed. The 6SJ7 operates as a conventional plate-circuit detector on the low-sensitivity range and as the d-c amplifier for the 6H6 detector output on the high-sensitivity range, the change being accomplished by a d-p-d-t switch.

Sources of Error

The sources of possible error in the improved capacitance meter are of two distinct types. First, there are errors caused by the limit of stability of the measuring equipment. Into this category fall any factors which might cause the indicator readings to be altered during the period between the initial and final readings necessary in the determination of a particular capacitance. Since the time involved in the measurement of a single capacitance is but a matter of seconds we need consider only those factors which might cause rapid changes. Thus, effects of temperature, humidity, and age upon the various circuit elements (including the standards) need not be considered because such changes are obviously of a lethargic character and need not be considered as contributing measurable error during short intervals. Hence, the remaining cause of error of the first kind is line-voltage variation. Tests indicate that the magnitudes of errors caused by a line-voltage variation of ± 5 per cent of nominal 115 volts are:

Low-sensitivity range—error $\pm 0.01\mu\mu$f.

High-sensitivity range—error $\pm 0.0015\mu\mu$f.

Note that these errors are of the same order of magnitude as the limit of readibility of the scales on the standard capacitances.

The second kind of error which needs to be considered is one which might be termed inherent. That is, errors introduced by, or necessarily accompanying, the particular method of measurement which is used. Since the various factors involved in the consideration of errors of the second kind differ somewhat for the high and low-sensitivity ranges of the instrument, it is advantageous to treat each range separately.

Errors may be caused in the low-sensitivity circuit by:

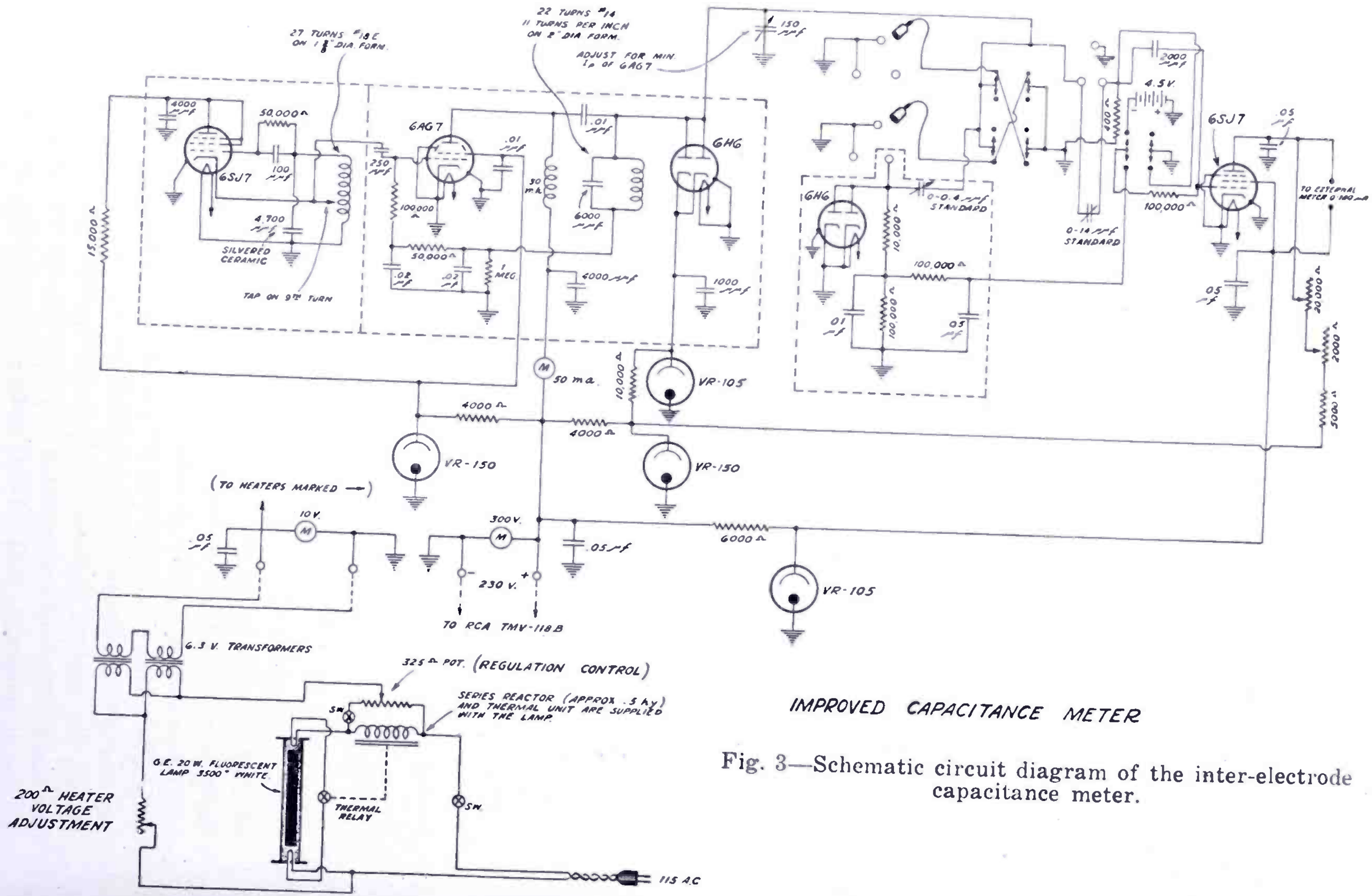

Fig. 3—Schematic circuit diagram of the inter-electrode capacitance meter.

1. Conductance or capacitance changes across the radio-frequency source.
2. Conductance changes across the standard capacitance.
3. Conductance or capacitance changes across the vacuum-tube voltmeter input.

In each case we are concerned with changes which occur when the tube to be tested is inserted in the adapter socket. These changes should not be confused with changes which might occur due to factors already discussed in the consideration of stability.

Errors caused by the introduction of shunt capacitance or conductance across the radio-frequency output circuit will be minimized by making the output impedance of the radio-frequency source small in comparison to the magnitude of the shunting impedance.

Errors caused by the introduction of conductance across the capacitance standard are a function of the power factor of the inter-electrode capacitance being measured, lower-power factors causing decreasing error.

Errors caused by the introduction of conductance or capacitance across the input of the vacuum-tube voltmeter will be minimized by making the measuring resistor (across the voltmeter input) small in comparison with the shunting impedance.

The magnitude of shunt impedance which might be encountered under the most adverse conditions might be of the order of 1 megohm for the resistive component and 16,000 ohms ($20\mu\mu$f or so) for the capacitive reactance. Calculations indicate that, for the circuit components used in the improved capacitance meter, shunt impedance of the order mentioned would cause inherent errors in the capacitance measurement (on the low-sensitivity range) of considerably less than $0.01\mu\mu$f.

Errors may be caused in the high-sensitivity circuit by:

1. Shunt loading of the radio-frequency source. This is similar to the situation considered for the low-sensitivity circuit. Here, however, the use of a similar tube as a dummy load during the zero adjustment reduces the effect by a factor which is a function of the difference between tubes of the same type. Even without this second tube the resulting error would be small.
2. Variations of impedance shunting the voltmeter circuit. However, since the capacitance appearing across the voltmeter is changed only by the amount of the capacitance being measured, (this happens when the grid is grounded on the check position) the impedance change is negligible compared to the input impedance of the voltmeter.

3. Poor power factor of the grid-plate capacitance being measured. This is the most difficult factor to evaluate. It is believed that the grid-plate conductance is sufficiently low in most tubes to obviate error from this source. However, even if this were not true, there would be no simple solution to the problem. Also, the presence of appreciable conductance would make the tube undesirable and this would be indicated adequately by an apparent increase in the grid-plate capacitance.

Adaptors

It has been noted that when the older type capacitance meter was used, appreciable error was sometimes caused by the adaptors. That is, tests with a number of adaptors gave varying results even though all of the adaptors were adequate insofar as shielding was concerned. The cause of the error was found to lie in the differences in conductance (leakage and dielectric losses). With adaptors having greater losses the compensation afforded by adjustment of the oscillator amplitude-vs.-frequency characteristic was less complete. However, in the improved model the effects of such conductances are negligible and results obtained with various adaptors are much more uniform (assuming all adaptors are adequately shielded). This necessitates less standardization of mechanical construction of the adaptors. With the advent of newer tube types, suitable adaptors may easily be designed. In such adaptors adequacy of shielding is the only critical factor. The use of a group of sub-adaptors for one basic octal adaptor has proved very convenient and is finding wide usage in the capacitance-measuring equipment of the tube industry.

TELEVISION RECEPTION WITH BUILT-IN ANTENNAS FOR HORIZONTALLY AND VERTICALLY POLARIZED WAVES

By

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Summary—Television antennas suitable for mounting within a console receiving cabinet are described. A small loaded dipole was found to be more sensitive than a loop of equal size.

Data are given for reception in buildings on receivers with built-in antennas. Reflections caused standing waves, which affected reception of both horizontally and vertically polarized waves. The presence of people near the receiver had the most effect on the signal strength received when vertically polarized waves were utilized. Good reception in steel-frame buildings was limited to the side of the building having an unobstructed path to the transmitter. Normal obstructions in the vicinity of the antenna, such as might be encountered in residential locations, were found to attenuate vertically polarized waves more than horizontally polarized waves.

A field survey of wave propagation through normal city obstructions is recorded. A close agreement with theoretical open-country propagation characteristics was obtained.

THE loop antenna enjoyed a few years of popularity in the early days of broadcasting, but was later discarded in favor of the better performing outdoor antenna. Recently, changed listening habits of the public, higher-power broadcast stations, technical improvements in receivers, and other factors have contributed to the revival of the built-in loop antenna for standard-broadcast reception.

It is natural to ask whether the future trend of the television receiving antenna will follow the history of the standard-broadcast antenna. It seems likely that the popularity of the built-in antenna for standard broadcast will stimulate a demand for a built-in antenna for television. Factors related to this question such as the propagation of ultra-high-frequency waves through buildings and their reception on small antennas have been recently investigated. The results obtained are reported in this paper.

Before taking up these results, it may be well to review the work of others which seems most pertinent to the subject. It has been shown by Trevor and Carter[1], Norton[2], and Brown[3] that for outdoor reception free from obstructions and at ultra-high frequencies such as 50 megacycles, the field strength near the ground is substantially stronger for

[1] Trevor and Carter, "Notes on Propagation of Waves Below Ten Meters in Length," *Proc. I.R.E.*, March 1933.

[2] K. A. Norton, "Statement on Ultra-High-Frequency Propagation," *Television Hearing Before FCC*, Jan. 15, 1940.

vertically polarized waves than for horizontally polarized waves. Data are presented in the present paper which show substantially the same relative response, as found by the above mentioned investigators, for waves received at an outdoor location free from nearby obstructions after having been propagated through low buildings such as are found in a city residential district. Brown[3] further shows that as the receiving antenna is raised approximately 30 feet above ground, the two types of polarization yield practically identical field intensities, when the transmitting antenna is at least one wavelength above ground. Also the usual radio-noise fields in the ultra-high-frequency range are stronger in the vertical than in the horizontal plane. Therefore, in spite of the preponderance of vertically polarized field near the surface of the earth, horizontally polarized waves yield a more favorable signal-to-noise ratio for television and aural broadcast services (between 30 and 100 megacycles) where the transmitting antenna is at least a few wavelengths above ground level.

Wickizer[4] found 4.3 db higher average field strength for horizontally than for vertically polarized waves during a survey along highways with the receiving antenna 10 feet above ground. This can be explained by assuming that the normal obstructions encountered along the highway attenuated vertically polarized waves more than horizontally polarized waves. Englund, Crawford, and Mumford[5] showed that trees along the roadside absorbed and reflected vertically polarized waves. Data are presented in this present paper which indicate that trees do not materially affect horizontally polarized waves at 69 megacycles.

Jones[6] showed field-strength contours within a dwelling with reception of vertically polarized waves. Data are presented in this present paper which indicate that wood frame houses interfere more with vertically polarized waves than with horizontally polarized waves.

Antenna Designs

A television receiving antenna, confined within a console cabinet, may be directional with means for orienting its reception characteristics or it may be nondirectional. A vertical loop may be employed as a bi-directional antenna for reception of vertically polarized waves or a horizontal dipole may be employed for bi-directional reception of

[3] G. H. Brown, "Vertical versus Horizontal Polarization," *Electronics*, Oct., 1940.

[4] G. S. Wickizer, "Mobile Field Strength Recordings of 49.5, 83.5, and 142 Mc from Empire State Bldg. Horizontal and Vertical Polarization," RCA Review, April 1940.

[5] Englund, Crawford, and Mumford, "Some Results of a Study of Ultra-Short Wave Transmission Phenomena," *Proc. I.R.E.*, March 1933.

[6] L. F. Jones, "A Study of the Propagation of Wavelengths Between Three and Eight Meters," *Proc. I.R.E.*, March 1933.

horizontally polarized waves. For nondirectional reception a vertical dipole or a capacitive element terminated through a coupling inductance to chassis ground may be employed for vertically polarized waves or a horizontal loop or folded dipole may be employed for nondirectional reception of horizontally polarized waves.

A directional built-in antenna with means for rotating it can be employed to discriminate against interference, including undesired

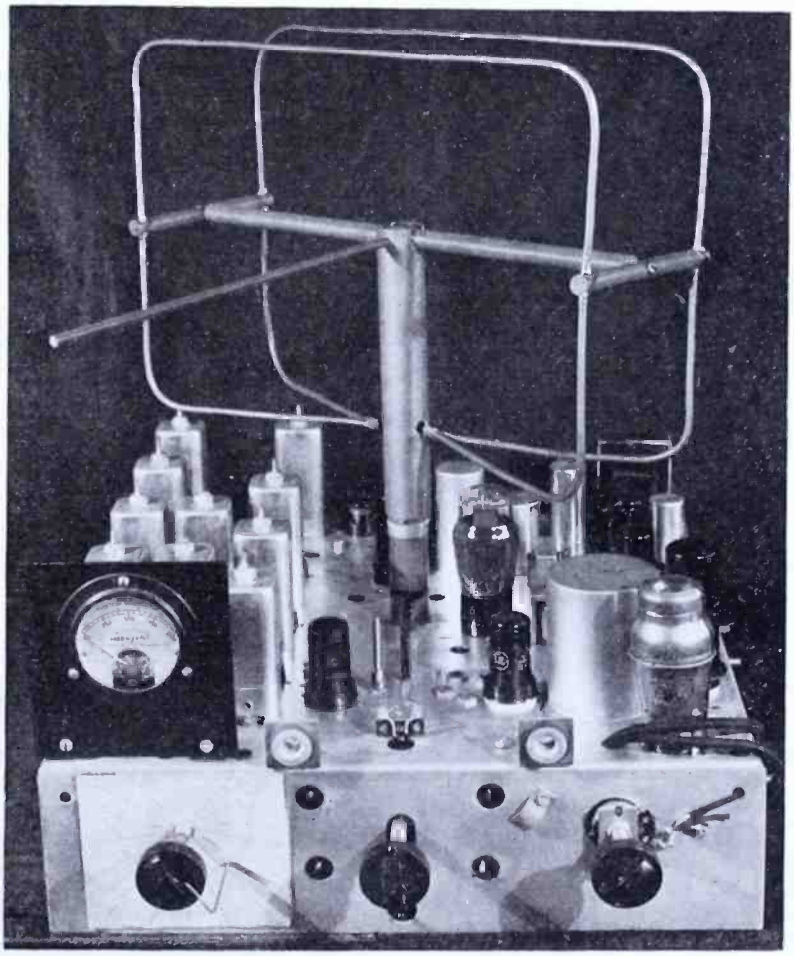

Fig. 1

reflections. The nondirectional type of built-in antenna is less expensive and usually will occupy less cabinet space.

Figures 1 and 2 are photographs of two experimental types of built-in antennas which were adapted to the RCA TRK-120 television-receiver chassis. Figure 1 shows a vertical loop-type antenna. The two turns are in parallel and are connected to an inductor through a wave-change switch. The antenna circuit functions as a full-wave resonant circuit and is coupled to a conventional, resonant grid circuit. The circuits are designed to give a band-pass characteristic of about 5 megacycles width. Figure 2 shows a horizontal dipole with end-capacitance load. It connects to an inductor which couples to a resonant grid circuit as in the case of the loop design. These antennas both have a figure-eight reception pattern in the horizontal plane. Both are rotatable about a vertical axis. The loop is 10 by 14½ inches. The dipole ends are 8½ inches square and are separated by 12 inches. The same cabinet space will accommodate either antenna. Provision is also made through a wave-change switch for operating the sets on conventional antennas through a transmission line.

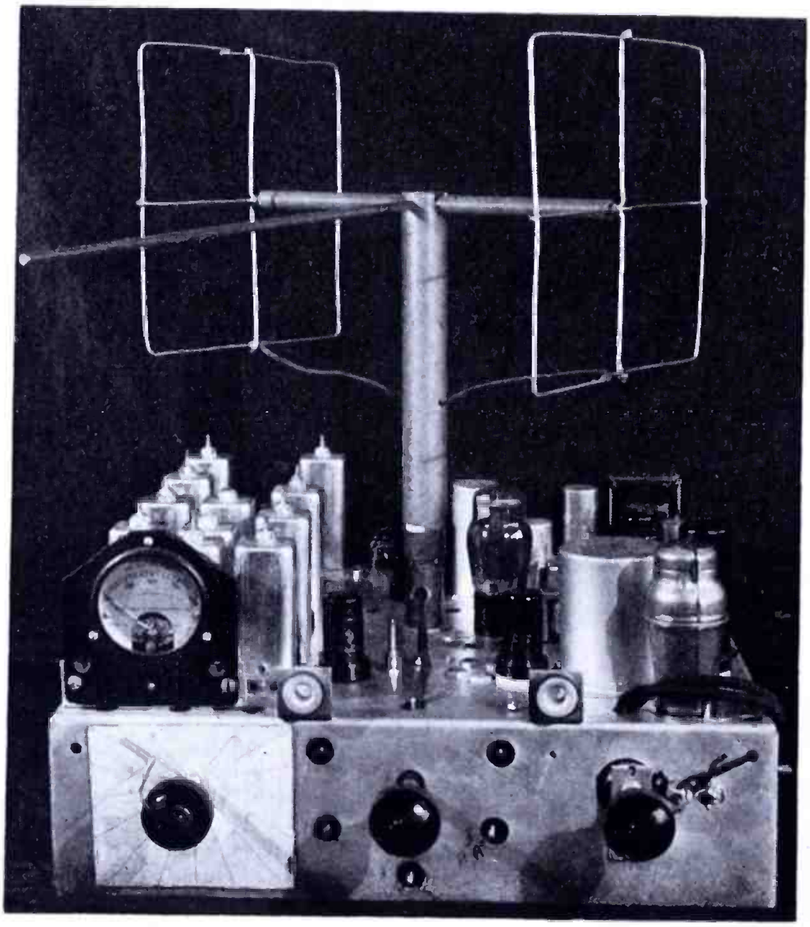

Fig. 2

The relative sensitivity of these antennas and of a half-wave dipole connected to the receiver through a short transmission line of negligible loss is given below. The measurements were made at 69 Mc in an open field with horizontal-wave polarization. The loop was in a horizontal position for this test.

Type Antenna	*Relative Sensitivity*
Half-Wave Dipole	6
Loaded Dipole	3
Loop	2

The greater sensitivity of the loaded dipole as compared with that of the loop works out as an advantage for directional reception of horizontally polarized waves (dipole in horizontal position) and as an advantage for nondirectional reception of vertically polarized waves (dipole in vertical position).

EFFECT OF WOOD-FRAME HOUSE ON RECEPTION

A survey was made comparing the reception on the two receivers of Figures 1 and 2 in a typical wood-frame dwelling. A small portable transmitter with loop antenna was set up in four different locations: 1T, 2T, 3T, and 4T adjacent to the dwelling. See Figure 3. The two television chassis, with loop and loaded-dipole antennas, were tested in three different locations within the dwelling on the first floor and in one location in the field adjacent to the house. These locations are shown as 1R, 2R, 3R, and 4R. Maximum and minimum antenna microvolts (obtained by rotating the antennas around a vertical axis) were recorded for both antennas and with both polarizations. It should be noted that in these tests the dipole was always in a horizontal position and the loop, in a vertical position. The data obtained are as follows:

FIELD TEST FROM PORTABLE TRANSMITTER ON 69 MC

Trans. Position	*Rec. Position*	*Vertical Polarization*				*Horizontal Polarization*			
		Dipole		*Loop*		*Dipole*		*Loop*	
		Max.	*Min.*	*Max.*	*Min.*	*Max.*	*Min.*	*Max.*	*Min.*
1T	1R	221	55	215	50	75	5	63	13
1T	2R	125	42	125	13	125	17	38	26
1T	3R	125	62	38	20	101	23	44	13
2T	1R	161	45	113	51	161	60	130	41
2T	2R	161	16	76	23	17	6	32	5
2T	3R	68	10	88	38	51	17	63	13
3T	1R	177	75	169	40	247	45	125	32
3T	2R	87	17	26	18	195	10	33	13
3T	3R	110	75	204	40	210	45	88	33
4T	4R			225					
1T	4R	62	62	377	44	161	29	95	38
*		189	57	155	45	163	33	93	28

* Average for transmitter positions 1T, 2T, 3T and receiver positions 1R, 2R, 3R, corrected for 100-foot separation.

The figures in the table indicate microvolts output from the receiving antennas. The transmitter loop was 2½ feet above ground. The receiver loop and loaded dipole were 6¼ feet above ground for all tests. The field strength of the vertically polarized wave at receiver position 4R from transmitter position 1T was 3.5 times the field strength of the horizontally polarized wave. This field-strength ratio in favor of vertical polarization is abnormally high. The ratio from a normal distant transmitter would be approximately as indicated in

Figure 6. The loaded dipole is 1.5 times more sensitive than the loop at a given field strength.

The average effect of the house on reception is obtained by a comparison of the readings obtained outdoors (with the transmitter in positions 1T and 4T and the receivers in position 4R) with the readings obtained with the receivers indoors (with the transmitter in positions 1T, 2T, and 3T and the receivers in positions 1R, 2R, and 3R). The last line of the chart contains the average for all the indoor readings, with corrections for the difference in transmission distances compared to the outdoor readings for positions 1T and 4R.

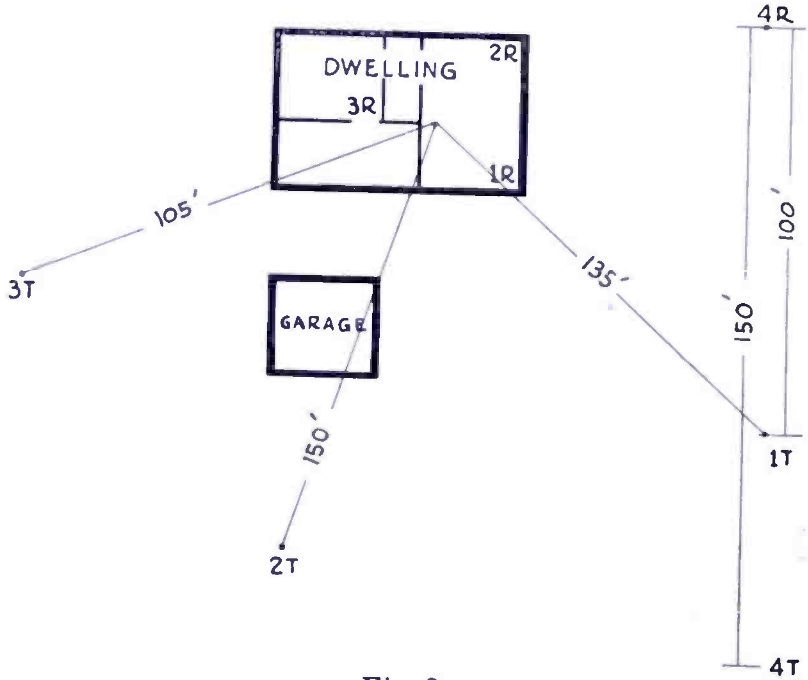

Fig. 3

The individual readings for the different transmitter and receiver positions varied widely, indicating the presence of standing waves within the house for both wave polarizations.

For horizontally polarized waves the average indoor readings were substantially the same as the outdoor readings.

For vertically polarized waves the loop maximum signal dropped from 377 microvolts outdoors to an average of 155 microvolts (40 per cent) indoors. This indicates that the polarization plane of the waves was distorted or that the waves were attenuated. The dipole maximum signal increased from 62 microvolts outdoors to an average of 189 microvolts indoors. This change indicates that the polarization plane of the waves was distorted so as to have a substantial component in the horizontal polarization plane.

The maximum voltage recorded outdoors for vertically polarized waves on the loop was 2.3 times the maximum voltage recorded for horizontally polarized waves on the loaded dipole. Indoors, the respective average maximum voltages were substantially equal. This suggests the possibility that rain pipes, electric wiring, and plumbing as they are situated in wooden frame houses may adversely affect vertically-polarized waves more than horizontally-polarized waves.

During the tests it was noted that the maximum signal on the vertical loop, for reception of horizontal waves, occurred when the loop was turned broadside to the arriving wave. Mr. A. H. Turner offered the theory that this response was due to the differences in field strength at the top and bottom of the loop, i.e., due to the vertical voltage gradient of the horizontally polarized wave. If correct, this theory would require that the response remain constant with height of loop above ground so long as the rate of change of field strength with height remains constant. This conclusion was verified by experiments which appear to confirm the voltage-gradient theory for vertical loop reception of horizontally polarized waves.

Body Effect on Reception

It was observed that persons moving about in the vicinity of the receiving antenna affected the reception, the greatest effect on the received signal strength occurring when a vertical dipole or vertical loop was being used. This result is to be expected since the body acts as a vertical dipole. The body effect was further investigated as follows:

The first tests were made in the open field with the portable transmitter located at point 4T and a half-wave receiving dipole located at point 4R of Figure 3. The receiving dipole was 6 feet, 3 inches high at its center. A vertical dipole was used for vertically polarized wave reception and a horizontal dipole rotated for normal maximum reception was used for horizontally polarized wave reception. A man 6 feet tall stood on a wooden support 22 inches above ground in positions at 10-inch intervals in front and in back of the receiving antenna. The recorded data are shown in Figure 4 for 69 megacycles and 45 megacycles. When the man's arms were raised parallel to his shoulders and parallel to the dipole, the effect on horizontally polarized wave reception was increased.

For each test the receiver gain was first adjusted to give the same arbitrarily chosen output of 100 microamperes without the presence of the man in the vicinity of the antenna. The new meter reading caused by the presence of the man was then recorded. The curves are, therefore, only an indication of the relative change in output due to the presence of the man.

The tests were also made with the man in positions along a line at right angles to the direction of wave propagation. The variations in signal recorded under this condition were never greater than those indicated for positions in line with the direction of wave propagation.

A second set of tests at 69 Mc were conducted with the receiving antenna located near the middle of the living room of the dwelling as illustrated in Figure 3. In these tests the man stood on the floor. The same horizontal dipole was used for horizontally polarized wave reception. Two vertical dipoles, spaced 40 inches apart and cross connected, were used for vertically polarized-wave reception. This type of

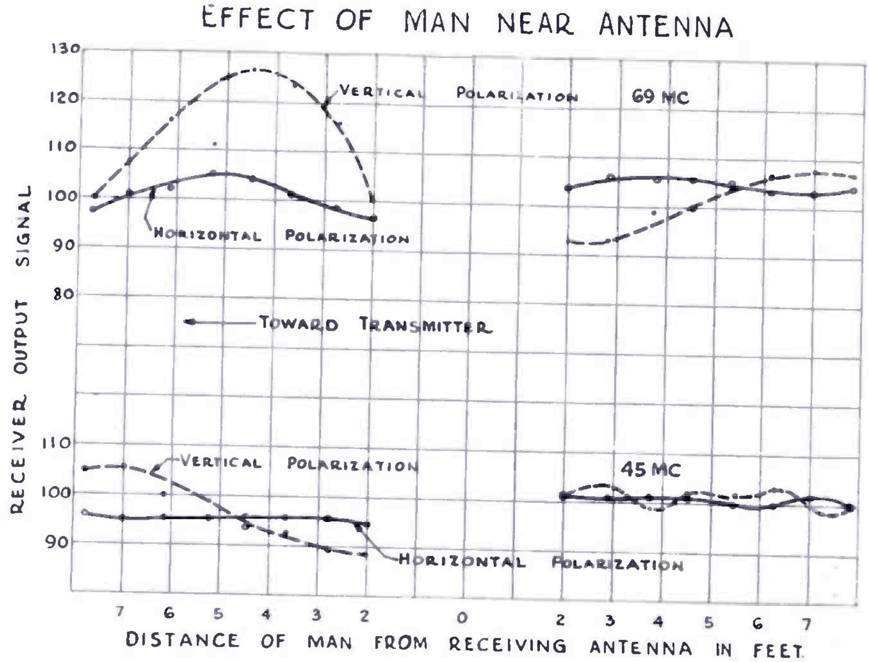

Fig. 4

antenna gives the same bidirectional reception for vertically polarized waves as a vertical loop.

When the antennas were oriented for maximum signal strength, the results were substantially the same indoors as outdoors. In one test, with the antennas rotated 45 degrees from the maximum-gain position, the response varied 2-to-1 for vertical polarization as the man walked across the room. For horizontal polarization the gain varied only 10 per cent. As the antennas were oriented towards the minimum-reception position the effect of the body became more pronounced for both polarizations.

These tests confirm the opinion that the movements of people in the vicinity of receivers operating on frequencies of the order of 70 megacycles with a built-in antenna are more likely to interfere with the reception from vertically polarized waves than with that from horizontally polarized waves. The greatest effect will be observed on the minimum response from bidirectional antennas oriented to reduce multiple images and other interferences.

Reception in Steel-Frame Buildings

A number of field tests were conducted in New York City on television reception from Station W2XBS, Empire State Building, operating on the former No. 1 channel (44 to 50 megacycles). The results obtained at three locations on the receiver with the loaded-dipole antenna were as follows:

At 26 East Ninety-Third Street in a tenth-floor apartment, an input of 95 microvolts was obtained in a room location which gave poor results. At another location removed 15 feet, in the same room, an input of 560 microvolts gave a fair-quality picture when the antenna was oriented to reduce multiple-image responses. This location was on the side of the apartment away from the transmitter. The distance was 3 miles from the transmitter. A better picture was obtained on an outdoor antenna located on the roof.

At 75 Varick Street on the sixteenth floor facing the transmitter, an input of 1550 microvolts was recorded. This signal gave an excellent picture. Moving the receiver back towards the middle of the building gave poor results. The distance was 2 miles from the transmitter.

At the RCA Building on the fifty-third floor facing the transmitter, an input of 3000 microvolts was recorded. This gave a good picture. Another location on the opposite side of the building gave an input of 150 microvolts and a very poor picture due to multiple images. The distance to transmitter was 0.7 mile.

This survey indicates that in office buildings and apartment houses of steel construction, dependable service using built-in antennas will probably be found in locations facing the transmitter and preferably within line of sight. A bidirectional antenna is desirable to reduce multiple images.

Effect of City Obstructions

The relative field strength of vertically and horizontally polarized waves passing mainly through residential areas was also investigated. For these tests a half-wave dipole receiving antenna was located remote from the receiver and buildings so as to minmize the effect of nearby obstructions.

The small test transmitter previously referred to was placed 5 feet above ground in a residential location at Haddonfield, New Jersey. The receiving dipole antenna was placed in three different locations in a field, at heights ranging from 4 to 12½ feet. At the transmitter site the ground was about 40 feet higher in elevation than the receiving locations, most of the ground rise occurring near the transmitter. The transmission distance was 0.6 mile. The receiving locations were about 150 feet from each other and about the same distance from the nearest trees and metal fences. There were eight rows of detached dwellings between transmitter and receiver. The nearest houses in line with the propagation path were 300 feet from the receiving locations.

The data obtained are recorded in Figure 5. The dots are for vertically polarized waves and the circles are for horizontally polarized waves. The solid-line curves *A* and *B* were plotted from the results

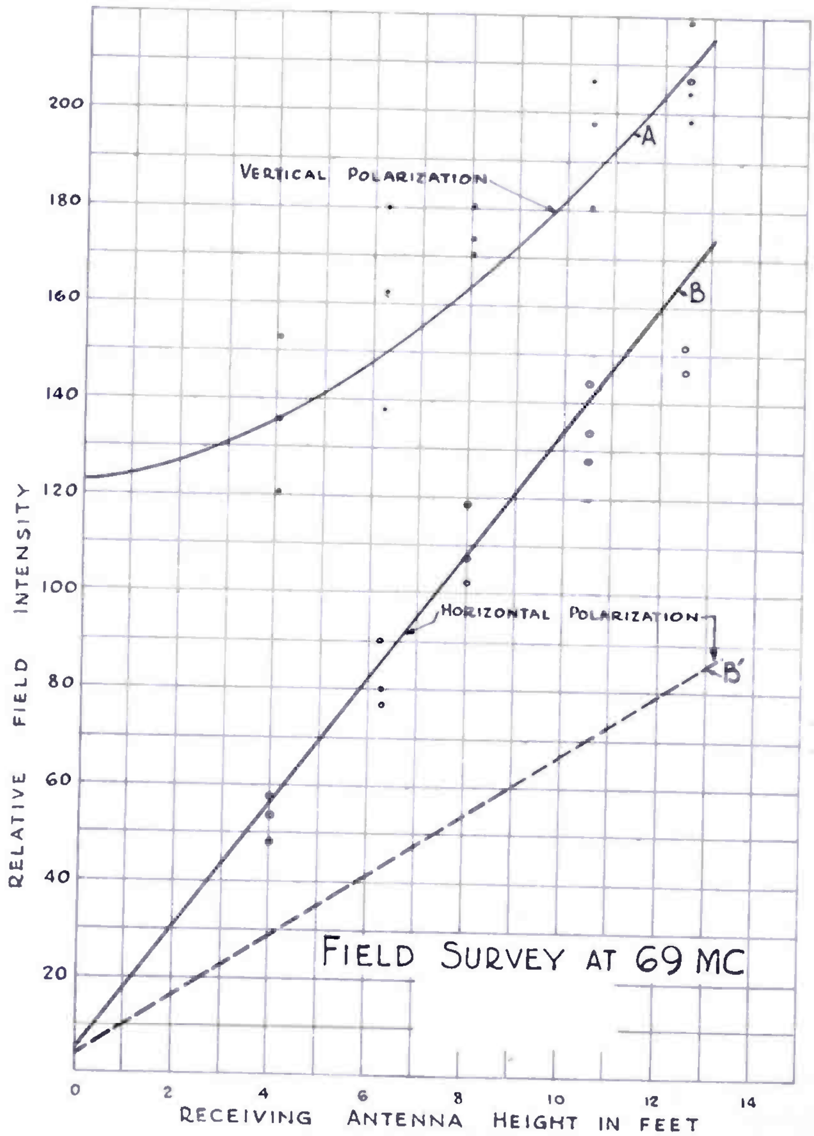

Fig. 5

of theoretical calculations[3], in which a ground dielectric constant of 15 and a transmitter height of 43 feet were assumed. With a transmitter antenna height of 5 feet, the response to horizontally polarized waves relative to vertically polarized waves would be approximately in the ratio of Curve *B′* to Curve *A*.

Further tests were conducted with the portable transmitter located 10 feet above the roof of Building No. 5, RCA Manufacturing Company, Camden, New Jersey. The loop antenna was about 110 feet above ground. Figure 6 gives the field strengths recorded at the Camden Airport, a distance of 2.5 miles. As in Figure 5, the solid curves represent the theoretical calculations. Most of the intervening buildings along the transmission path were of brick and metal-frame construction. The terrain was practically level throughout the transmission path.

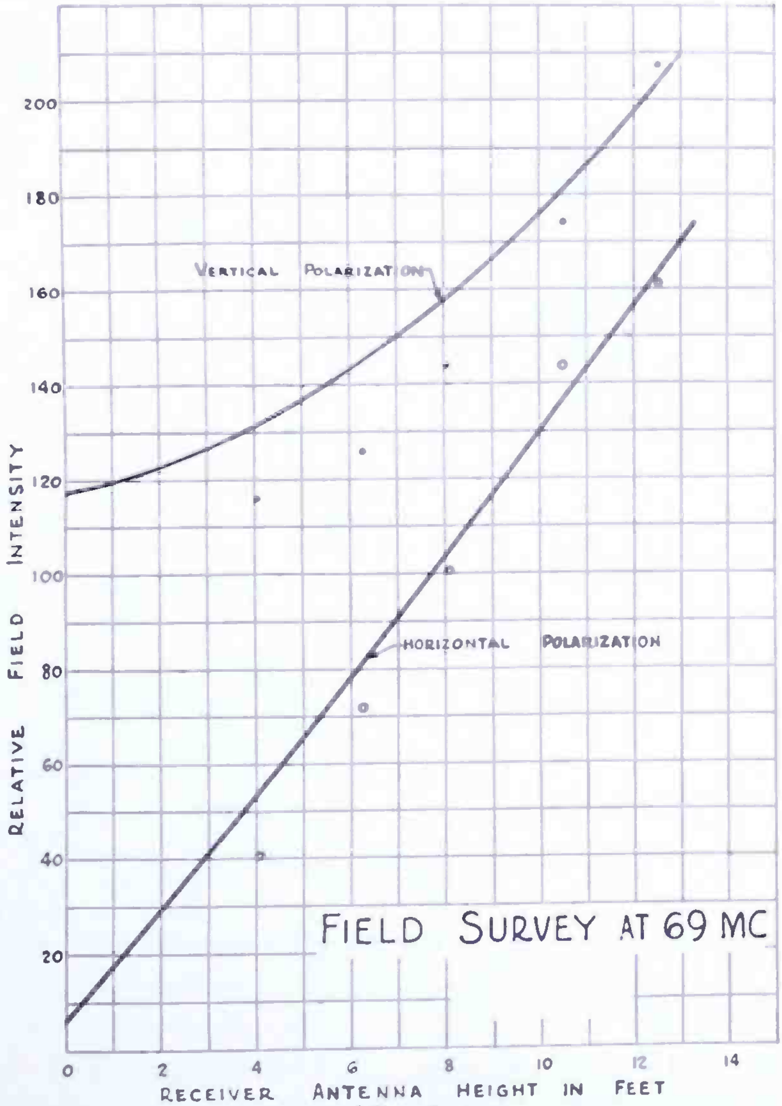

Fig. 6

A test run in back of the airport gave the same field strength for horizontally polarized waves as recorded in Figure 6. The field strength for vertically polarized waves was about the same as for horizontally polarized waves. Around the receiving location the only obstruction which might have caused this drop in vertically polarized signal was a long 6-foot high metal fence 1000 feet away from the receiver in the direction of the transmitter. A reflected wave from some distant object may have caused this result.

With the transmitter in the same location, another group of observations were made with the receiver located in Knight Park, Collingswood, New Jersey. On vertically polarized reception the field strength was normal in one location which was 200 feet remote from any obstacle, see Curve A in Figure 7. The field strength (Curve A') was considerably reduced for the second location surrounded by trees. These observations were made in November. There was close agreement in the recorded data for horizontally polarized waves at the two locations. See recorded data B and B' in Figure 7. The terrain was

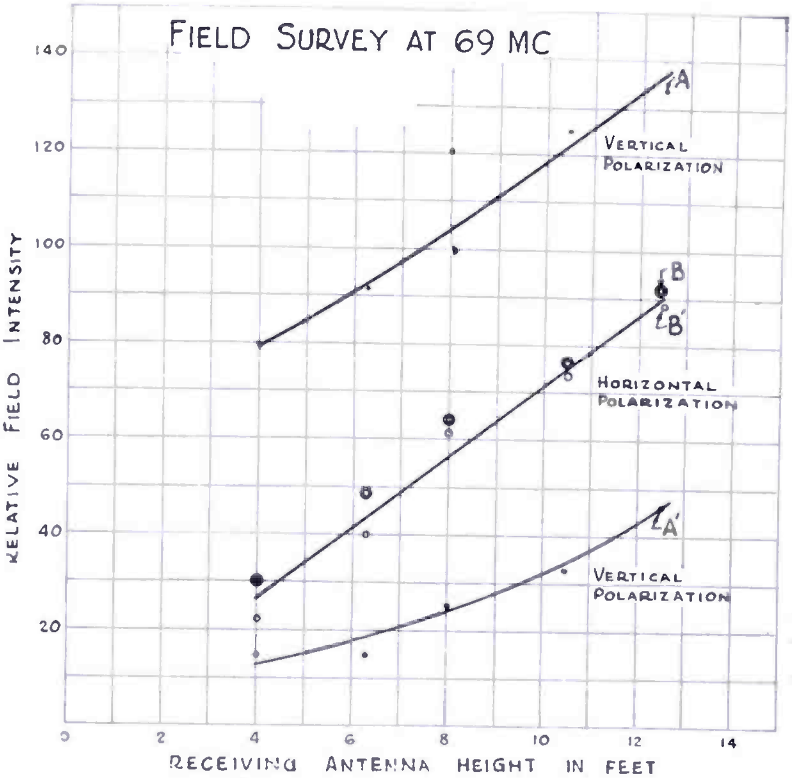

Fig. 7

fairly regular over the 3½-mile transmission path. There were numerous dwellings and miscellaneous buildings between transmitting and receiving locations.

The close agreement between experimental data and theoretical calculations as recorded in Figures 5, 6, and Curves B and B' in Figure 7 indicate that low buildings and other city obstructions in the transmission path do not materially affect the relative field strengths of horizontally and vertically polarized waves. The observations which did not agree with the theoretical calculations can usually be accounted for by objects in the vicinity of the receiving location which absorbed and reflected vertically polarized waves more than they did horizontally polarized waves.

The author expresses appreciation for the assistance of Dr. G. H. Brown and Messrs. E. O. Johnson, V. D. Landon, and A. H. Turner in connection with this investigation.

LOW-CAPACITANCE A-C POWER SUPPLIES

By

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Summary—*With the curtailment of strategic materials, particularly aluminum, the design of power filters with a minimum of capacitance is of increasing importance.*

If aluminum for electrolytics is to be available in restricted quantity, the use of low-capacitance sections, say ⅓ the size of previous liberal design practice, is indicated. If, however, aluminum is to be restricted totally, then paper capacitors are the logical substitute. This paper describes a few filter systems which employ sufficiently low-capacitance filter sections to permit the use of paper capacitors in lieu of aluminum, or of very small electrolytics if aluminum is available.

The systems described herein take into account the importance of copper and steel, and hence consider comparable systems with and without filter chokes. The systems do not require dynamic speaker fields larger than those commonly associated with small receivers.

The number of "filter circuits" conceivable is unlimited, and the systems discussed herein are merely those of the many tried in this development which permit the use of paper capacitors of moderate size and number.

Doubtless there are other systems which will produce comparable or perhaps even better results. The systems below are hence offered for comparison as well as for their own merit. Nevertheless it is believed that they require something like a minimum of capacitance where criticality is a factor.

ACCEPTABLE HUM INTENSITIES

MODULATION hum may be measured in decibels below 100 per cent modulation for full undistorted signal output. Reduction in hum to provide a 40-db discrepancy may be considered acceptable for some low-priced designs, with 50 db considered excellent and 60 db superlative. Zero signal hum levels may be measured directly in intensity. With a medium sized dynamic speaker of average sensitivity the consumer used to be satisfied with as much as 100 microwatts of hum. However, within the last few years the economy of high

* Now with Stromberg-Carlson Telephone Manufacturing Company, Rochester, N. Y.

capacitance electrolytics has enabled the ready reduction of hum to 5 microwatts or so. This reduction is definitely too conservative and it is doubtful that the majority of consumers will discriminate between no hum and say, 20 microwatts, other commercial factors being satisfactory. While electrolytics are still available the 5 microwatt level may easily be achieved, even with reduction of capacitance below the values now being used in practice. However, if the curtailment of aluminum forces the use of paper condensers or electrolytics of comparable capacitance values then consideration should be given to higher hum output levels. In the event of a critical shortage some universal sacrifice in hum level should be made to enable the production of the largest number of sets from the available materials.

Power Factor of Capacitors

The power factor of electrolytics is usually higher than that of paper capacitors, but in any usual application the resistance component of either may be neglected. Hence, in the systems described electrolytics may be used in place of paper wherever capacitance drift inherent with electrolytics is not a disturbing factor.

Hum Reduction in A-C Receivers

In the past, with aluminum available in any desired quantity, the price of electrolytics increased very little with increase in capacitance above a certain base price. This led to the then economical filter design wherein two large electrolytics were used in conjunction with a speaker field or filter resistor. Economy in microfarads of capacitance, however, is indicated by the use of several sections of lower capacitance. For example, three 3-μf sections of capacitance may produce a lower hum level in the speaker than two 12-μf sections, with a marked reduction in aluminum. Very probably the future technique of filter design will be directed toward the reduction of materials and away from the reduction of filter sections. Labor costs may be increased by this trend, yet indications are that labor will be more available than material.

One of the most simple and economical expedients for the reduction of hum is to employ cathode degeneration in a single-tube power output stage. This produces an improvement in zero signal hum of some 6 db, reducing hum derived from plate, screen, and driver tube, and minimizing the effect of inaccuracy in speaker bucking-coil balance. Its use also conserves the capacitor usually used as a cathode by pass. The loss in audio gain may be tolerated in most designs.

Since the power-tube screen circuit is more susceptible to hum than the plate circuit a separate screen filter usually proves more economical of material than the use of a common voltage point for screen and plate.

A system which follows this plan is shown in Figure 1. A tapped field to minimize hum at point B is indicated. The hum voltage at B is 3.5 r-m-s volts and at A is 1.6 volts. This produced 17 microwatts of hum in the voice coil of substantially 120-cycle tone. The speaker used was of the light six-inch type having a 700-ohm 2-henry field

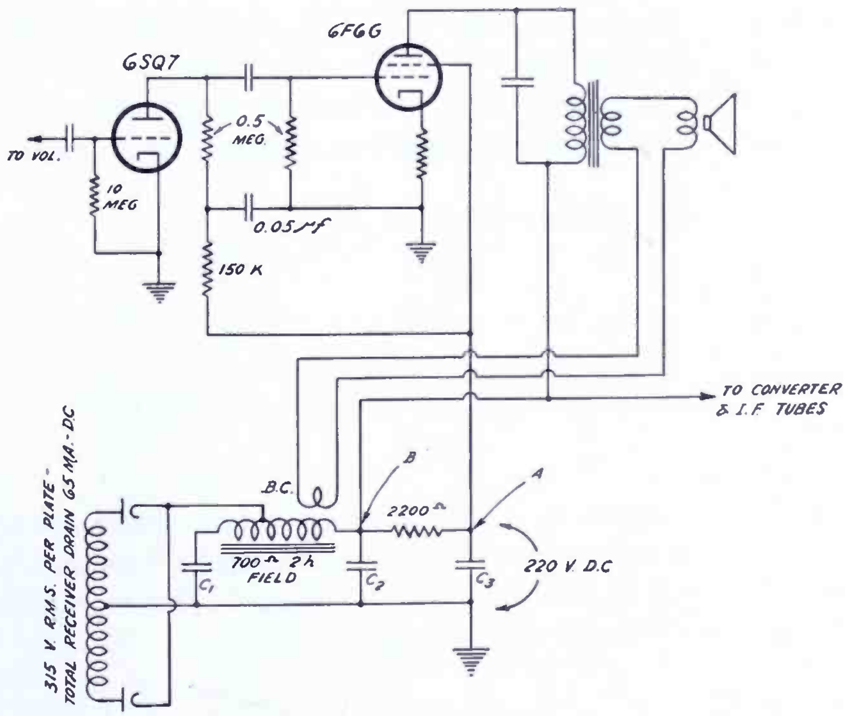

Fig. 1

utilizing 0.2 pound of copper in the winding. The capacitors used were:

$$C_1 = 1\ \mu f$$
$$C_2 = 2\ \mu f$$
$$C_3 = 1\ \mu f$$

Increasing C_3 to 2 μf reduced the zero signal hum to 5 microwatts. The capacitors used were paper. If electrolytics were used the sections could be of comparable values with C_1 increased to say 3 μf and the tap omitted from the field. This would permit wider capacitance drift. This type of balance is not very critical, however, permitting C_1 to vary from 0.5 to 2 μf without important change in hum level.

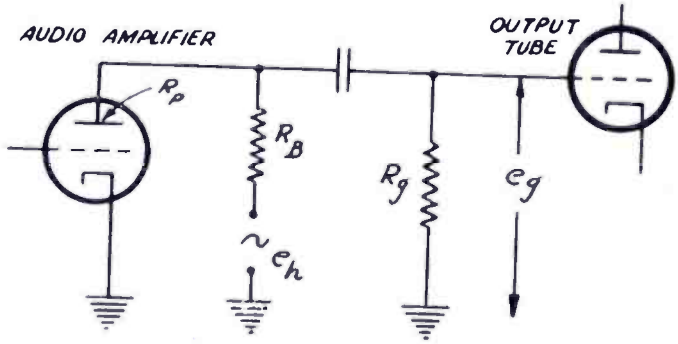

Fig. 2

The balance between voice coil and bucking coil was found satisfactory, limiting the induced hum power from field to voice coil to a negligible level. The necessity for exact balance increases somewhat with the magnitude of ripple volts across the field and imposes this

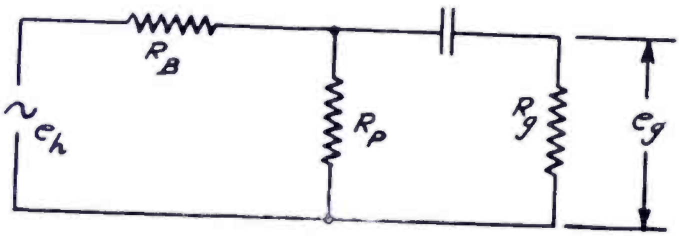

Fig. 3

precaution in manufacture. Filter systems using large electrolytic input or choke input will permit wider variation in bucking-coil balance as the hum intensity in the field is much less. In the case shown in Figure 1 the ripple voltage was 80 r-m-s volts.

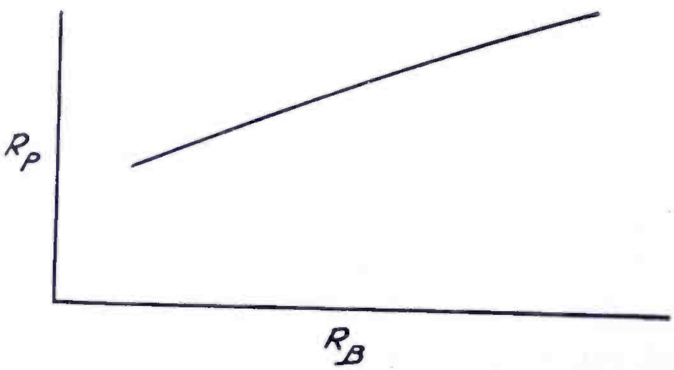

Fig. 4

Power-supply ripple may appear on the grid of the output tube through the plate circuit of the driver as shown by Figure 2. The portion of the ripple which is impressed on the grid is determined by the voltage divider formed by R_B, R_p, and R_g of Figure 3. R_p increases somewhat as the value of R_B is increased as shown in Figure 4. The rate of increase of R_p is not commensurate with that of R_B, however, so that the greatest reduction of hum is obtained by making R_B as large as possible. The limiting value of R_B will then be determined by the size of R_g which may be increased up to the limit imposed by gas current conditions in the power-tube grid circuit. From this standpoint self bias operation of the power tube is to be preferred to fixed bias since a much higher value of R_g is then permissible. The hum may be still further reduced, if necessary, by a resistance capacitance filter in series with R_B. The filter may be high resistance, low capacitance, if R_B is also high, with a resulting economy. A section comprising a 150,000-ohm resistor and 0.05-μf capacitor is indicated in Figure 1. This prevented any contribution to hum from the driver tube.

The use of a filter choke will permit the deletion of a filter section, as shown in Figure 5. Only if the choke is tuned may the inductance

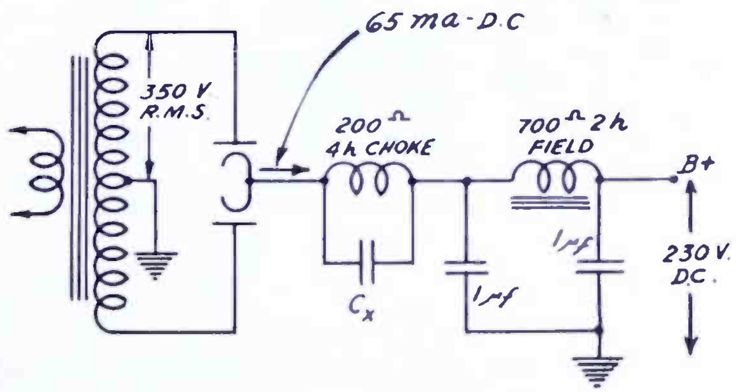

Fig. 5

be small. The type used was 4-henry, 200-ohm, using 0.085 pound of copper and 0.42 pound of steel.

The speaker of Figure 1 was used without the tap as the use of the tap in this case introduced too many harmonics.

The choke was of little value until it was tuned. The tuning is not critical, and most acceptable hum output, tone considered, was obtained when the tuning capacitor C_x was made small, say 80 per cent of its resonating value. The resulting harmonic content of the hum was then greatly reduced. The use of the choke filter requires in addition to the choke and tuning capacitor an increase in secondary voltage on the power transformer with resulting increase in copper. The ultimate desirability of choke input may be determined by considering the availability and costs of copper and steel vs. the materials for paper or electrolytic capacitors.

Acceptable modulation hum requires a low-ripple voltage on the screens of the carrier and i-f frequency tubes, in the order of 0.3 volts. In the "straight a-c" type of set an appreciable drop in d-c voltage from $B+$ to screen is required. The dropping resistor serves as one leg of a filter which may be terminated by a capacitance from these screens to ground. A capacitor in the order of 0.5 μf is adequate. The a-c/d-c type circuits do not lend themselves readily to filtering with low capacitance values, since high storage capacity of the first capacitor is required to maintain a good d-c output.

This may be illustrated by the following measurements which were obtained using an a-c/d-c receiver having a current drain of 45 milliamperes. Using an a-c line voltage of 120 volts the following relation

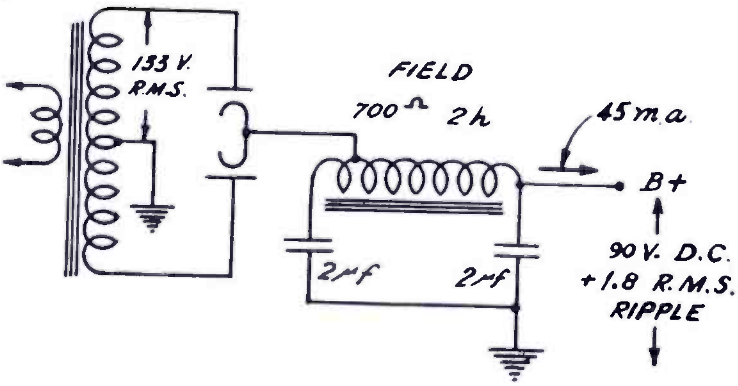

Fig. 6

was established between the filter input capacitance and the rectified voltage developed:

Capacitance	*D-C Voltage*
20 μf	116 Volts
10 "	107 "
8 "	103 "
6 "	98 "

Less than 12-μf sections will cause objectionable hum. It would seem therefore that a-c/d-c operation is dependent upon electrolytics for its utility, with something like two 20-μf sections working in conjunction with a speaker field as the probably desirable minimum. Tapped field circuits and other balancing systems may reduce this estimate considerably although balancing systems are only effective when the balance is not critical and when the hum level resulting from unbalance is not intolerable.

If the a-c/d-c size of chassis is still desirable in the event electrolytics are not available the voltage-doubler system may have merit, as these systems may be built with less total capacitance than the a-c/d-c type for the same d-c voltage output. The following d-c voltages were measured at the filter input of a voltage-doubler system operating from a 120-volt line with a current drain of 55 milliamperes. The filter input was composed in each case of two condensers of the capacitance indicated, connected in series.

Capacitance	*D-C Voltage*
8 μf	224 Volts
4 "	163 "
2 "	136 "

Also the voltage-doubler system has as its fundamental frequency 120 cycles instead of the more difficultly filtered 60.

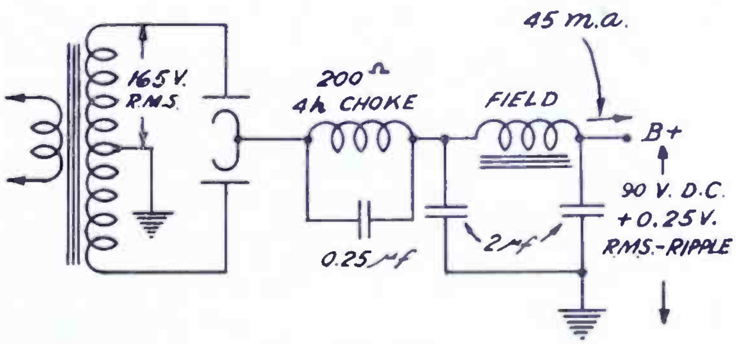

Fig. 7

The 120-cycle pulse may also be produced by a low-voltage transformer and full-wave rectification. Unfortunately the screens of the converter r-f and i-f tubes are not easily filtered by RC networks unless an appreciable d-c voltage differential is produced. The circuit and constants of Figure 6 produced low zero-signal hum, but had considerable modulation hum. The choke input method illustrated in Figure 7 is capable of further reduction in zero-signal hum with considerable reduction in modulation hum. Specific converter and i-f circuit design intended to reduce modulation hum may be carried out to provide tolerable hum levels with these low voltage systems. Economy of copper and steel will result with the use of an auto transformer instead of the primary coupled type providing the two a-c plate voltages are balanced in phase.

Conclusions

The utility of multi-sectioned filters in minimizing total capacitance necessary for acceptable hum levels has been demonstrated. This procedure should prove economical in materials at the possible expense of labor and manufacturing costs.

An a-c receiver with pentode output tube may be filtered with (say) 1, 2, and 1 μf of paper capacitors without the use of a filter choke or large speaker field. If electrolytics of small capacitance are developed to meet the material shortage now becoming acute, then comparable capacitance values are likely to prove permissible.

Paper capacitors or extremely low-capacitance electrolytics do not appear feasible for a-c/d-c operation. Small a-c receivers of this size may be developed using a-c/d-c connection of heaters, but a low-voltage transformer to permit full-wave rectification and satisfactory d-c voltage output. This type of receiver has small economy over the described higher-voltage type and should find utility only in the event electrolytics for a-c/d-c use are completely curtailed. In the event of partial curtailment, voltage doubling circuits give promise of replacing a-c/d-c circuits.

A DISCUSSION OF SEVERAL FACTORS CONTRIBUTING TO GOOD RECORDING

BY

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Summary—*It is the desire, in the transcription field, that the reproduced quality be a facsimile of the original program. The recording unit, the disc, and the reproducing unit play important parts in achieving the desired results. A discussion of a few of the operating characteristics of these items and their effect on record quality is presented.*

INTRODUCTION

MANY variables are encountered in recording and reproducing transcriptions. Certain of these variables can be controlled by the setting of standards. Others can be controlled by a realization of the variables and consequent employment of a technique which reduces their magnitude.

At the present time, there is under consideration by both the National Association of Broadcasters and the Radio Manufacturers Association the setting of recording standards which in turn establishes reproducing standards. This should do much to eliminate various malpractices which have been in existence in the transcription field. There will remain, of course, the necessity of using good engineering practices to get the most satisfactory results. It is the purpose of this paper to describe the operating characteristics of certain recording and reproducing components, and to give a few suggestions pertaining to the employment of good engineering practice in their use.

THE CUTTER HEAD

There is no particular problem with present-day equipment in obtaining the desired electrical and distortion-free characteristics in the amplifier chain from the microphone up to the input terminals of the cutter head. The cutter head, on the other hand, represents an item which is subject to great variation dependent upon its manufacture and manner of use.

The first step necessary in placing a cutter in operation is to have it engrave the desired frequency characteristic on the disc. This characteristic should not be an arbitrary one, but should follow some set of standards. The analysis of practically any standard frequency characteristic which has ever been proposed will show that it may be broken down to certain basic sections. The one to be discussed has, as a foundation, a constant amplitude section extending from the lowest frequency of 50 cps to 500 cps and a constant velocity section from 500 cps to 10,000 cps. The frequency 500 cps is therefore called the "cross-over frequency" indicating the transition from "constant amplitude" to "constant velocity". With this characteristic as a basis, any desired pre-emphasis curve may be added.

It may be well at this point to mention that the characteristic curves which are to follow have been plotted on a velocity basis. In the region from 500 cps to 10,000 cps we will encounter a curve which follows, let us say, the zero axis for the ideal condition since this is the con-

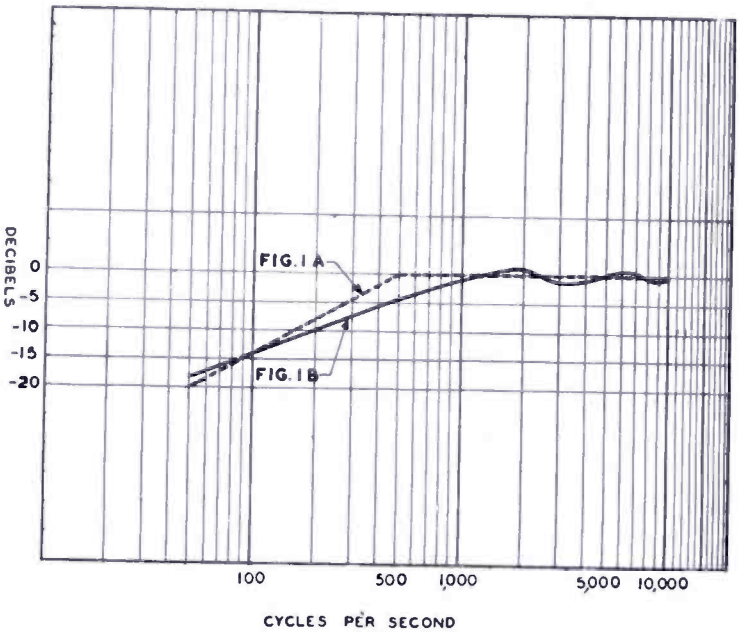

Fig. 1

stant velocity section. Below 500 cps is encountered the constant amplitude section; however, since the characteristic is to be expressed on a velocity basis, the equivalent curve will be one which steadily diminishes in the region starting at 500 cps and progresses down to 50 cps. Furthermore, the characteristic must fall at the rate of 6 db per octave correctly to convert the expression from an amplitude basis to a velocity basis.

The existing characteristic of the cutter head is first determined and a comparison to the ideal characteristic is made. The amount of correction to be applied will be apparent. Such a comparison is shown in Figure 1-a and Figure 1-b. Figure 1-a is the ideal characteristic shown with a sharp corner at 500 cps for the sake of clarity. In actual practice, all such transition points are permitted to "round off" to the extent of approximately 1.5 db to avoid the undesirable use of complicated multi-section compensators. Figure 1-b shows the characteristic of a particular present-day lateral recording head of the magnetic variety designed for transcription service. It is seen that the cross-over frequency is not well defined, but is located at approximately 1000 cps. Furthermore, a departure from constant amplitude is present below 500 cps in that the slope is approximately 5 db per octave, instead of 6 db. It is necessary, therefore, to resort to compensation. In the case under discussion, the 500 cps region is so "peaked"

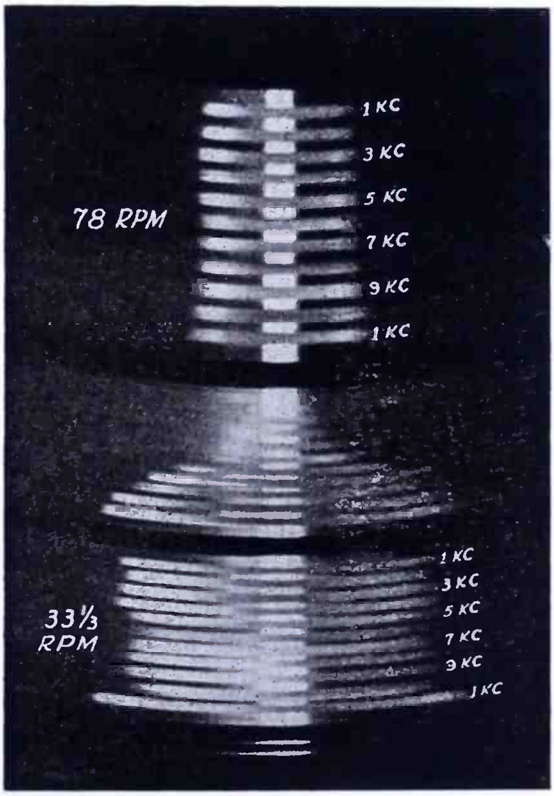

Fig. 2

by the use of corrective electrical networks that the cutter characteristic is altered to be reasonably close to the ideal characteristic.

This electrical correction can be made anywhere in the channel equipment, providing it is always associated with a particular cutter. Under normal circumstances, all cutter heads of a given manufacture require similar compensators for the basic correction of the crossover point. However, minor irregularities in the form of high-frequency peaks are sometimes encountered which are not the same for all heads. Such irregularities can be corrected in the compensator. It is for this reason that it is advisable to avoid the use of a compensator with any cutter head other than that for which its circuit elements were adjusted.

Method of Measurement

The characteristic of a recording head is measured by engraving various single-frequency tones throughout the spectrum on a disc. The pattern, when observed visually under proper light conditions is generally referred to as a "Christmas Tree" pattern. Since the frequencies in the region from 1000 cps to 10,000 cps are to be of constant velocity, the observed tone bands in this section should give rise to a light-diffraction pattern of equal band spreads. The departure from this condition is an indication of the variation of the recording-head characteristic from normal. The amount of change in level of the recording amplifier that is necessary to establish the flat condition is a measure of the original deviation.

Frequencies below 1000 cps are more conveniently measured by reproducing them through a pickup head which has been calibrated previously by means of a known tone record. (Several such records are available on the market—RCA T-2485-2, etc.)

Figure 2 is a photographic reproduction of a recorded tone disc. It will be noted that the flat-top section is the high-frequency portion of the spectrum. It is more satisfactory to use 78 rpm for recording the tone patterns due to the resulting sharper picture of the higher frequencies. The photograph here presented shows the use of both 78 rpm and 33⅓ rpm.

The relationship between the diffraction pattern and the engraved characteristic has been established mathematically by others and has been accepted by the art for many years. It is sufficient here to say that the band spread can be considered equivalent to voltage. Therefore, should a band spread be encountered for a particular frequency which has twice the linear dimension of the patterns generated by other frequencies, it is to be considered as being 6 db greater than the reference frequencies.

The term "band spread" as here used refers to the total width of the diffraction pattern created when modulation is applied, measured at right angles to a radial axis of the disc. It should not be confused with the thickness or duration of the band, which latter is purely a function of the extent of time the modulation is applied to the cutter head.

Application of Pre-emphasis

After the basic recording characteristic is determined, it is then relatively easy to apply the particular pre-emphasis curve required by the standards.

Figure 3 shows a proposed lateral-recording characteristic. It follows basically the construction outlined in the foregoing discussion. There is one difference however; that is, a compromise has been made to accommodate simplified compensator design, especially for the play-back circuit. It is noticed that no attempt has been made to preserve the sharp corner at the crossover frequency of 500 cps. The tolerance of ±2 db permits the use of several frequency characteristics that are in use today. These represent standards for different organizations which account for a very large percentage of lateral recordings. The tolerance of ±2 db appears, at first glance, to be excessively liberal,

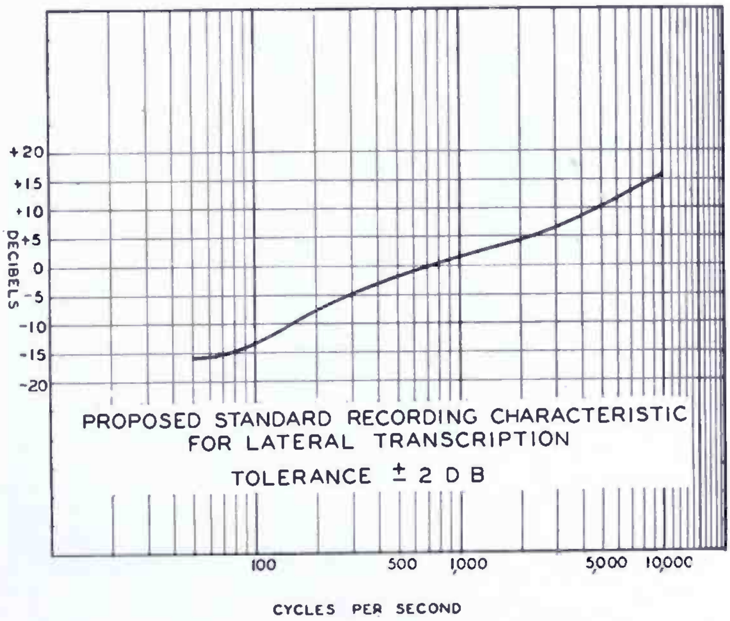

Fig. 3

but it must be realized that this is the final recorded characteristic and, consequently, must absorb the various irregularities in the entire recording channel. The particular pre-emphasis as shown in this case is a 100-microsecond curve for the treble section. The curve is essentially constant amplitude below 500 cps and in addition there is a slight amount of pre-emphasis below 100 cps.

The pre-emphasis curve just mentioned is normally obtained from an electrical circuit consisting of L and R in series, said components having a time constant of 100 microseconds. The formula is $L/R = 0.0001$, where L is expressed in henries and R is expressed in ohms.

Figure 4 shows the proposed standard recording characteristic for vertical recording. It differs from the lateral primarily in having a crossover frequency at 300 cps and a different rate of increase at the high frequencies. Likewise, this characteristic represents a present-day standard for those organizations now making vertical recordings.

THE RECORDING STYLUS

Present-day recording styli are sapphire jewel points in practically all cases. They are ground into a wedge shape in such a manner that a shaving of lacquer (in the case of "instantaneous" recording) is removed from the disc. It is essential that the resulting groove be quiet upon reproduction. Sharpness of the point is therefore necessary. It is found from experience that if a burnishing edge is ground on a sapphire, a quiet groove results. This burnishing edge, however, if carried to extreme, will cause a loss of high frequencies due to the fact

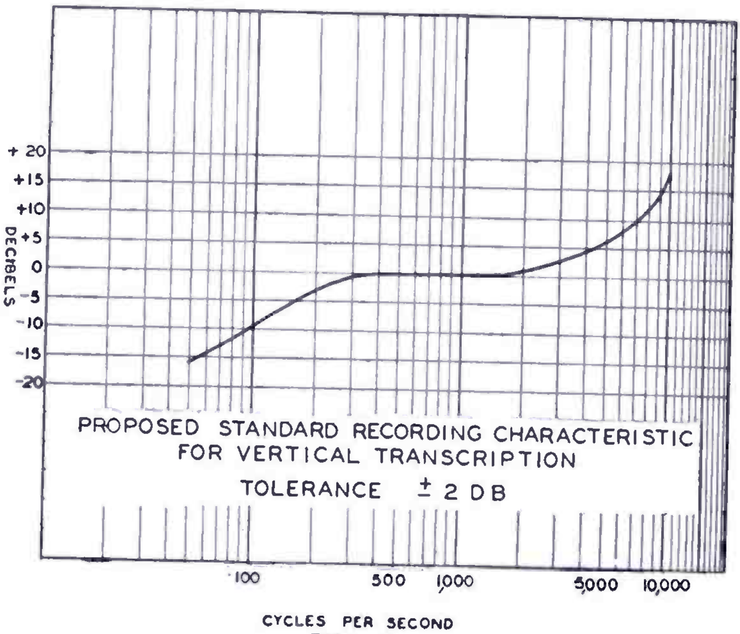

Fig. 4

that a "bull-dozing" action results in the displacement or flow of the lacquer rather than its removal.

As will be seen later in the discussion of reproducers, the groove size is of utmost importance. A good fit must be obtained between the side walls of the groove and the reproducer point, in the case of laterally recorded discs, to avoid a chattering effect and consequent distortion. The tendency today is to use a stylus with a 70° included angle for the face. The radius of the bottom is approximately 0.002 inch. Figure 5 shows the essential dimensions of a cutting stylus which is in use for lateral-transcription work. These dimensions may be changed slightly upon further investigation by the N.A.B. Standards Committee.

In the case of vertical recording, it is preferable to use different dimensions since upon reproduction it is desired that the playback stylus track firmly on the bottom of the groove, utilizing the side walls only as a guide in following the pitch of the grooves. If separate vertical and lateral reproducers are to be used, both vertical and lateral systems could independently have their own standards. However, with the present tendency of using a combination reproducer with a fixed-dimensioned stylus, it is seen that the two systems will have to employ coordinated standards for the recording groove sizes. (This means that the vertical groove should be larger than the lateral to permit bottom tracking in the case of vertical and to permit tight sidewall coupling in the case of lateral. This problem is also under consideration by the N.A.B. Standards Committees.)

The groove depth is important in that if too shallow, the reproducer

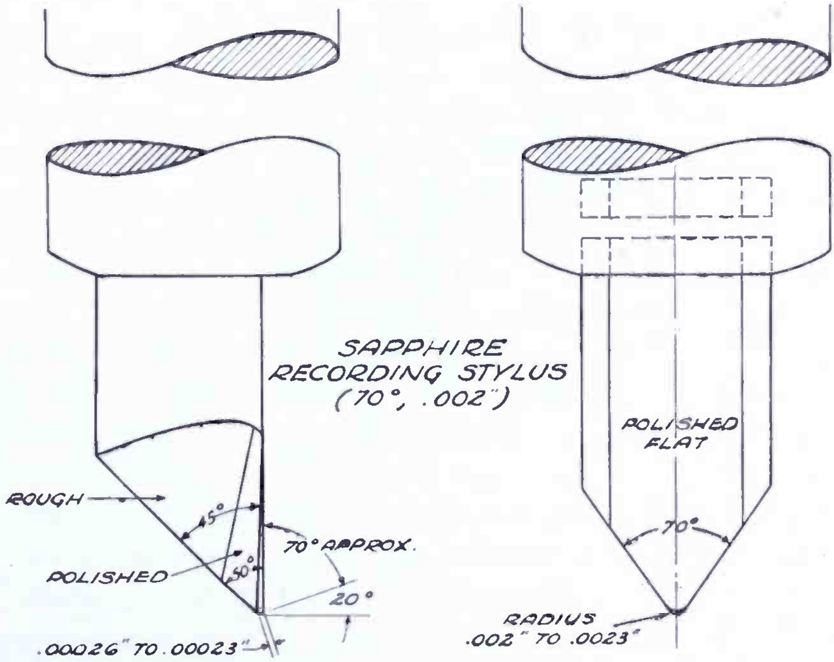

Fig. 5

will not be tightly coupled to the disc and either distortion will result, or in extreme cases the reproducer stylus will actually "skip out" of the groove and slide across the face of the disc. On the other hand, if the groove depth is too great, the groove sidewalls will tend to be deformed or actually disappear on peak modulation with the result that either echoes from the adjacent grooves will be heard, or in extreme cases the reproducing stylus will break through into one of the adjacent grooves. The proper groove depth is obtained when the ratio of the groove width to the "land" width is 60-40 (at a pitch of 136 lines per inch).

The Recording Disc

The disc used for recording plays a very important part in the eventual result. Unfortunately beyond selecting discs for optimum hardness (that is, discs not so soft as to permit the loss of high frequencies, nor so hard that high scratch levels ensue), and employing careful handling there is very little the consumer can do to vary the results as far as the finished recording is concerned. The manufacturer holds a great responsibility for such items which pertain to the disc dimensions, and to the lacquer coating. Many requirements could be mentioned which go into the fabricating of a good instantaneous transcription disc, but it should suffice to say that lacquer-disc manufacturing has made great strides in the past few years and, consequently, the market now offers satisfactory products.

The Reproducer

An otherwise good recording can be ruined easily by a faulty reproducer. Present-day reproducers, of the transcription variety, are a great improvement over those of even a few years ago. Nevertheless, they still lack several desirable features. The stylus and its associated vibratory system unfortunately must have stiffness and mass. However, these elements now have been reduced to small values. At high frequencies, conditions are such that it takes considerable force to swing the stylus. The coupling between the groove and the stylus, and also the hardness of the disc is insufficient to make the stylus perform a faithful excursion of the groove contours. It is probable that the groove walls compress, permitting the stylus tip to "short cut" around the peaks of modulation, particularly at the inner diameters of lacquer discs. In the case of pressings, which are a harder medium, the effect is not so pronounced and, consequently, the reproduction of more high frequencies is apparent. However, with the harder pressing, appreciable driving forces are still involved and after a certain number of playings the high-frequency peaks are worn off, with resultant loss of frequency range and an increase in distortion.

This loss of high frequencies is not a constant throughout the disc. The outer circumference of a disc is traveling at a greater relative linear velocity than is the innermost recorded groove. This means that for a given frequency and amplitude, the physical wavelength of the engraved pattern is longer and, consequently, better defined than that of the innermost engraving. The recording and reproducing styli have finite dimensions, so that because of the finite size and the use of the burnished edge on the recording stylus mentioned previously, a deterioration of the wave shape takes place toward the central portion of the disc. The loss of high frequencies thus incurred is generally referred to as "translation loss". Strangely enough, there is an opposite effect which occurs under some conditions; that is, the high-frequency response tends to rise with increase in frequency on reproduction over that which was recorded. This effect is encountered at the higher groove velocities and is especially pronounced at the outer diameters of a

78 rpm recording. The reason for this is that the vibratory system of the reproducer and the material in which it is working set up a resonant condition. In the case of relatively soft lacquer, the resonant frequency may well appear within the working range of the system, while with the harder pressings, it may appear beyond the pass band of the system, producing the same effects, but to a lesser degree within the working frequency range.

Figure 6-a shows translation curves for a typical good reproducer and a lacquer disc. The loss of high frequencies toward the center of

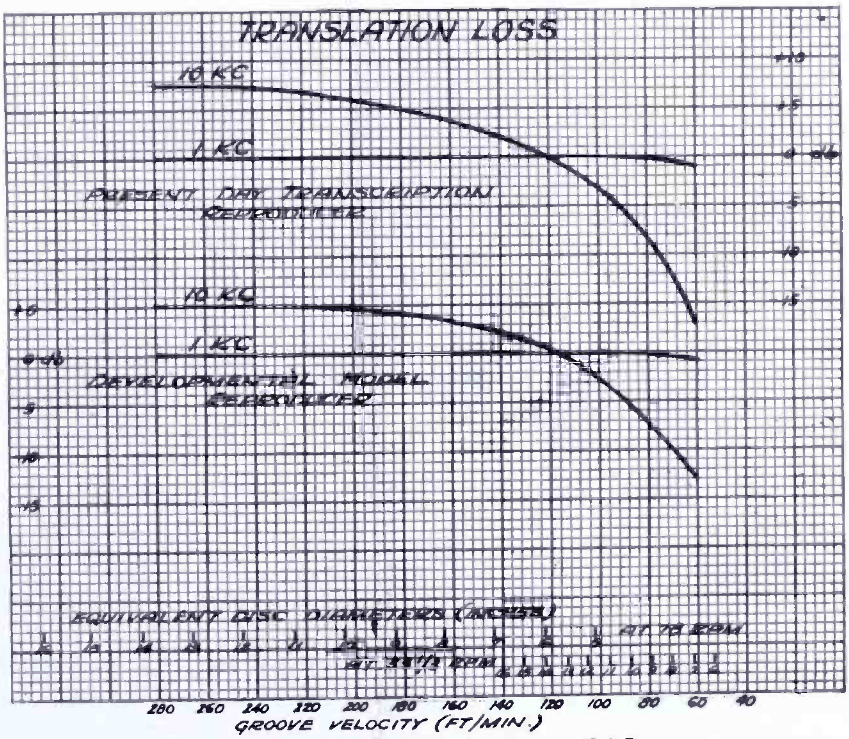

Fig. 6 [top (a), bottom (b)]

the disc is very apparent. The rise of the high frequencies due to resonant conditions at the higher groove velocities may also be seen.

Superior performance has been obtained in specially built reproducers. Such units have been classified as laboratory models. In general, they are extremely light in weight and are sufficiently delicate to cause their use in the commercial transcription field to be somewhat hazardous. With the incorporation of a little more ruggedness in the construction of these laboratory-type reproducers, and with the proper education of the user, it is reasonable to believe that additional advances will take place in the reproducer field in the near future.

Figure 6-b shows the translation losses encountered in a fairly rugged laboratory model reproducer. It is seen to be an improvement over the previous curve.

Figure 7 shows a family of characteristics obtained at various disc diameters. It conveys essentially the same information given in Figure 6-b, but in a more useful form.

The improvement in reproducers lies in the hands of the manufacturers and also is contingent upon the demands imposed by the field. The user can contribute his part at the moment by insisting upon using the best the market has to offer. In any event, if high fidelity is demanded, there is no excuse in transcription work for the use of the heavy reproducer with its massive steel stylus, which was in vogue only a few years ago.

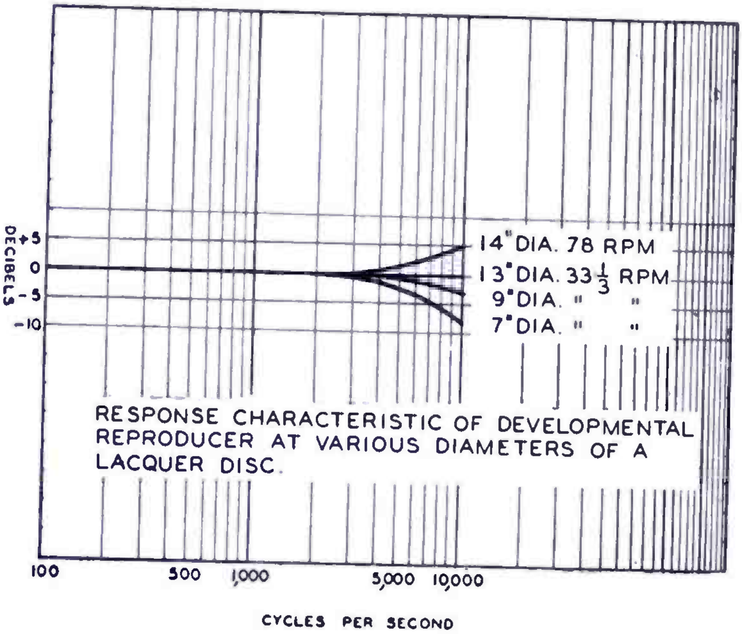

Fig. 7

Conclusion

The mention of other than a very few specific dimensions has been purposely avoided in this paper. This is to avoid possible confusion, since it is to be expected that the results of the standards committees will be published in the near future.

The use of standardized recording and reproducing techniques by certain organizations has provided excellent operating experience to help in the establishment of what is hoped will be the use of the same standards by all. The use of the same standards and the employment of good engineering practice will permit a coordination between the recording and reproduction of the records with resultant improved performance.

RECEIVER INPUT CONNECTIONS FOR U-H-F MEASUREMENTS

BY

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Summary—Three methods of obtaining push-pull output voltage from a signal generator with single-sided output are discussed in relation to u-h-f receiver measurements. The three circuits are compared from the standpoint of output voltage accuracy, impedance presented to the receiver input circuit, and operating convenience. It is pointed out that for accurate voltage measurements the proper dummy antenna resistance must be used, and that the receiver input circuit must be connected to the receiver chassis.

The most convenient input connection for making u-h-f receiver measurements is a direct connection between the signal-generator output and the receiver input. This connection requires no special equipment, and is adequately accurate for most receiver measurements. Certain precautions in making the ground return path correct in length are necessary and are discussed fully in the text.

THE technique of making overall receiver measurements on television and frequency-modulation receivers is complicated by the fact that these receivers are frequently designed with balanced or push-pull antenna input systems, while standard signal generators are equipped with single-sided output. Furthermore, receivers designed with balanced input systems are intended to be used with a balanced transmission-line input from the antenna. The antenna and transmission-line system will generally look to the antenna circuit like a pure resistance load equal to the characteristic impedance of the transmission line, so that any measurements made with a signal generator should present the same loading to the input circuit. In the case of television receivers, if the loading presented to the antenna circuit is different than that out of which the antenna circuit is designed to work, reflection may exist.

The problem of obtaining a balanced output from a standard signal generator with single-sided output, and of having this output present the correct loading to the input circuit, will be discussed in this paper. Three methods of interconnection will be presented, any one of which will give satisfactory results, but with various degrees of operating convenience.

Transformer Coupling

A transformer, the circuit of which is illustrated in Figure 1, will transform single-sided r-f voltage from a signal generator to a balanced r-f voltage.

The transformer coils are wound on ⅝-inch tubing with the two-turn primary winding located between the two secondary windings which are three turns each. All of the coils are wound with No. 36 enameled wire close spaced so as to provide the maximum coupling. The coupling is 69 per cent, a value which requires that the leakage reactance be tuned out, otherwise the device will not present a pure resistance input load to the receiver under test. The leakage reactance is tuned out by means of the ganged tuning condensers C_1 and C_2 which have a range of 8 to 140 $\mu\mu$f per section. The capacitor range provides a frequency coverage of 20 to 63 Mc. Because this range is not suffi-

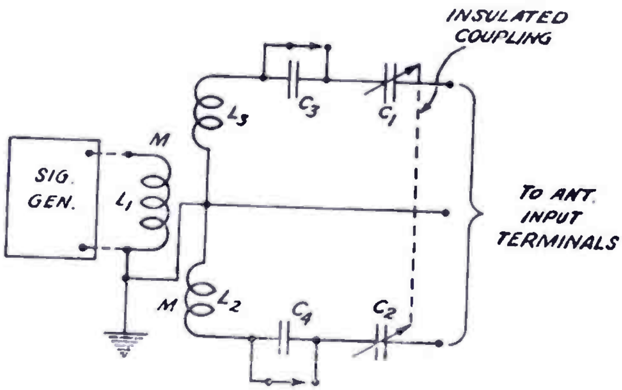

Fig. 1

cient to cover all of the television bands, it was extended by adding the series condensers C_3 and C_4 which in combination with C_1 and C_2 provide an additional tuning range of from 64 to 90 Mc. It would be possible to lower the self-inductance of the secondary coils and raise the frequency range to some extent with C_3 and C_4 shorted. However, this procedure results in a lower coefficient of coupling and, hence, a higher percentage of leakage reactance, and, therefore, is not as beneficial as it might first appear. The reduction of the coefficient of coupling is due in part to the fact that an appreciable amount of the leakage reactance is in the leads, hence, can not be changed by coil changes.

The tuning out of the leakage reactance is best accomplished by terminating the primary with a resistance equal to the output resistance of the signal generator that is to be used, and adjusting the tuning condenser to the setting that makes the output impedance look like a pure resistance. An impedance bridge or impedance-measuring device may be used to indicate the nature of the output impedance and the establishment of the tuning points for the calibration of the tuning condensers. It would be possible to determine the correct tuning point of C_1 and C_2 if a receiver with balanced input that presents a pure resistance to the antenna were available. However, most receiver input circuits do not look like a pure resistance, but have a reactance component as well. If a reactance component is present in the input circuit of the receiver, an erroneous calibration of C_1 and C_3 will result, as in this case C_1 and C_3 will tune out the total reactance in the circuit rather than that residing only in the balanced input device.

The voltage gain from a single-sided input to a balanced output measured in a high-impedance secondary load is tabulated below for the two operating ranges.

Range	*Frequency*	*Gain*
Low	30 Mc	2.1
"	35	2.1
"	40	2.1
"	45	2.1
"	50	2.0
"	55	1.8
"	60	2.0
High	65	1.7
"	70	1.3
"	75	1.5
"	80	1.5
"	85	1.7

The impedance transformation or step-up is four to one when the input is terminated in a resistor of the order of 15 ohms.

In the use of this device some precautions are necessary if reliable results are to obtain: The lead lengths to and from the device must be short. A separate calibration of tuning, voltage gain, and impedance transformation ratio for each different unit should be made, as small mechanical changes in such a coil arrangement lead to seriously large electrical changes. In making measurements it is necessary to set the condensers C_1 and C_2 for each new frequency and to use the corresponding gain factor.

Another method of constructing such a transformer is to use a trifilar winding. In this case the three wires comprising the separate circuits are twisted together. While somewhat higher coupling may be secured by this winding method, the same precautions should be observed as with the transformer described above.

TRANSMISSION-LINE COUPLING

A balanced transmission line may be so connected with respect to ground that the short-circuiting effect of the ground return is not present due to the standing-wave phenomenon existing on the ground return. Such an arrangement is shown in Figure 2. In effect two transmission lines are used, one is indicated by L_1, the twisted pair, (not necessarily a twisted pair in practice), and the second is made up of the ground return "G" and the two wires of "L_1" acting together as a single conductor. This second transmission line is indicated in Figure 2 as "L_2" and is seen to be an open wire line.

The physical length and electrical length of an open wire transmission line are equal for all practical purposes and the characteristic impedance of the line may be made relatively high by merely increasing the spacing between the two wires. Impedance in excess of 1000 ohms are easily obtained in practice.

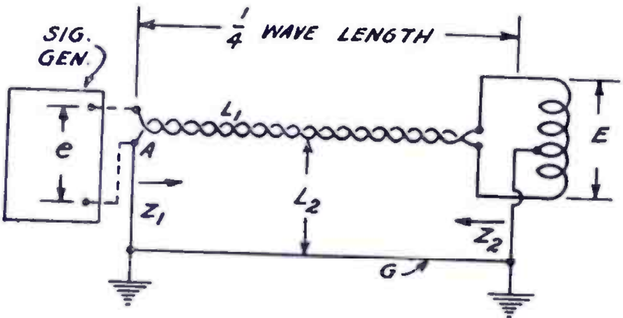

Fig. 2

The input impedance of a ¼ wave length transmission line is

$$Z_{in} = \frac{Z_o^2}{Z_T}$$

Where Z_o = the characteristic impedance of the line and,
Z_T = far end terminating impedance.

The physical length (and electrical length) of the open wire line L_2 of Figure 2 is made ¼ wave length at the mean operating frequency and the characteristic impedance is made high (say 1000 ohms) by spacing the two conductors.

With the above factors in mind, the magnitudes of the impedance looking into either end of the line L_2 may be determined with sufficient accuracy to evaluate the shunting effect of the ground-return circuit.

First consider the impedance Z_2 between the ground return lead "G", and the side of the transmission line L_1 that connects to the ground side of the signal generator at A. The terminating resistance Z_T in this case is a short-circuit; therefore, Z_2 looks like an infinite impedance (or open-circuit) and no short-circuiting action takes place at the receiving end.

In determining the magnitude of Z_2 for the side of the transmission line L_1 connected to the high side of the signal generator, it is necessary to know the apparent output impedance of the signal generator. The apparent output impedance of the signal generator will usually be such as to correctly terminate the transmission line L_1. Most transmission lines currently used for connection between the antenna and receiver have approximately 100 ohms characteristic impedance, so that it is reasonable to assume the apparent signal-generator output impedance to be 100 ohms. From this assumption the value of Z_2 may be determined for the side of the line L_1 connected to the high side of the signal generator, bearing in mind that the characteristic impedance of line L_2 may be of the order of 1000 ohms or higher.

$$Z_2 = \frac{Z_o^2}{Z_T} = \frac{1000^2}{100} = 10{,}000 \text{ ohms}$$

This value is high compared to the impedance across half of the antenna input circuit, so may be disregarded so far as its shorting effect is concerned.

The value of Z_1 may be determined in a similar fashion to that above. However, the impedance between either side of this antenna input circuit and its center tap can never be greater than one-half the characteristic impedance of the transmission line L_1, provided L_1 is properly terminated at the signal-generator end. Assume again the same values of characteristic impedances for lines L_1 and L_2, namely 100 and 1000 ohms; then, Z_1 for either side of the line L_1 will never be less than

$$Z_1 = \frac{Z_o^2}{Z_T} = \frac{1000^2}{\frac{100}{2}} = 20{,}000 \text{ ohms.}$$

This value is also high compared to the output impedance of the signal generator and, hence, has no short-circuiting action on it.

The frequency range over which this system will operate satisfactorily is approximately 1.5 to one.

From the above discussion it is evident that the ground return connection "*G*" acts electrically as if it were not present and that a single-sided voltage is effectively transformed into a push-pull voltage by the circuit of Figure 2.

The transmission through the line L_1 from signal generator to receiver may be considered to be loss free, due to the short length of line used, when the line is properly terminated. If the line is not correctly terminated, the transfer loss is still negligible if the mismatch is of the order of two or three to one. For a transfer loss of 10 per cent the mismatch may be 2.5 to one. Such an error in receiver sensitivity measurements is not excessive at ultra-high frequencies.

The impedance that the line L_1 presents to the receiver antenna circuit will be the characteristic impedance of the transmission line when the line is correctly terminated at the signal generator end. For a line not so terminated but with negligible loss the impedance at the receiving end is

$$Z_R = \frac{Z_G \cos\theta + j\, Z_o \sin\theta}{\cos\theta + j\,\dfrac{Z_G}{Z_o}\sin\theta}$$

where Z_G = Signal generator output impedance,
Z_o = Characteristic impedance of line L_1 and
θ = The electrical length of the line in radians.

This method of obtaining push-pull voltage from a signal generator with single-sided output is convenient provided the transmission L_1

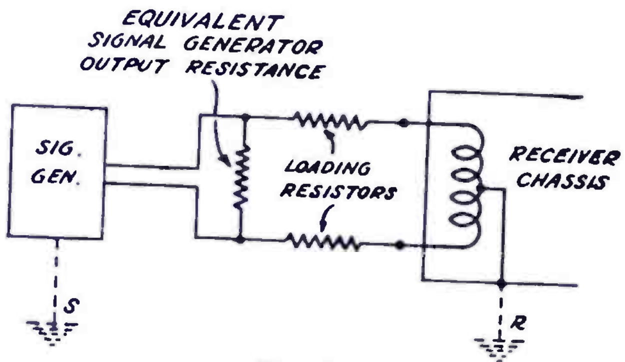

Fig. 3A.

has a characteristic impedance equal to the impedance out of which the antenna circuit is designed to work, and that the apparent signal-generator output impedance is made equal to the characteristic impedance of the line.

Direct Connection Between Signal Generator and Receiver

The circuit for direct connection between signal generator and receiver is shown in Figure 3A with an equivalent circuit in Figure 3B. In the circuit of Figure 3A two ground points are shown; one, the output of the signal generator at "*S*" which is connected to the chassis of the signal generator; and the other, the center tap of the antenna input circuit connected to the receiver chassis at "*R*". The ground path through the chassis of the two units back through the power line is shown as an impedance *Z* in the equivalent circuit of Figure 3B. At frequencies in the u-h-f range, *Z* has generally been found to be so high in any practical set up as to be entirely negligible in its effect on shunting one-half of the input circuit. At frequencies at which the return circuit is close to series resonance (an even number of quarter-wave lengths), this impedance may drop to an undesirably low value. Changing the physical length of the return circuit will correct this and may be used as a test for low impedance in this circuit.

This type of operation is illustrated by a series of sensitivity measurements on a typical receiver at 43 Mc. In this series of measurements the only changes that were made were changes in the connections between the signal generator and the receiver. The signal generator used had an output resistance of 15 ohms, while the antenna input circuit was designed to operate out of a 100-ohm balanced transmission line. It was, therefore, necessary to add an 85-ohm dummy antenna between the signal generator and receiver input terminals.

Twelve different methods of connecting the signal generator to the receiver are illustrated in Figure 4. The ground points shown on the circuits of Figure 4 represent connection from the signal source to

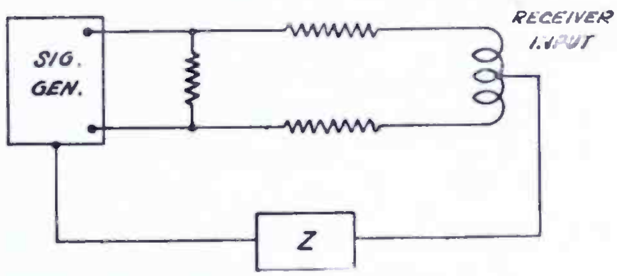

Fig. 3B.

the chassis of the signal generator, and from the primary winding to the receiver chassis, respectively. The two ground points on each of the Figures 4A to 4J inclusive are connected together as shown by the impedance *Z* of Figure 3B. It must be kept in mind that these two ground points are not a common or low-impedance ground connection, but rather the ground points of the two units.

The output for each measurement, illustrated by Figure 4, was maintained at the same level. The antenna input necessary to produce this standard output is tabulated on Figure 4 along with the different connections. It is to be noted that the input circuit is unbalanced in some of the measurements. This was done to show that the point of grounding the antenna primary winding is not critical, so far as this introduced voltage is concerned.

The circuits of Figures 4K and 4L have the primary ground removed and are not reliable. The input necessary with the circuit of 4L shows the largest departure from the average of any of the circuits considered.

The average input required to produce standard output for the connections shown by Figures 4A to 4J inclusive is 9.53 microvolts.

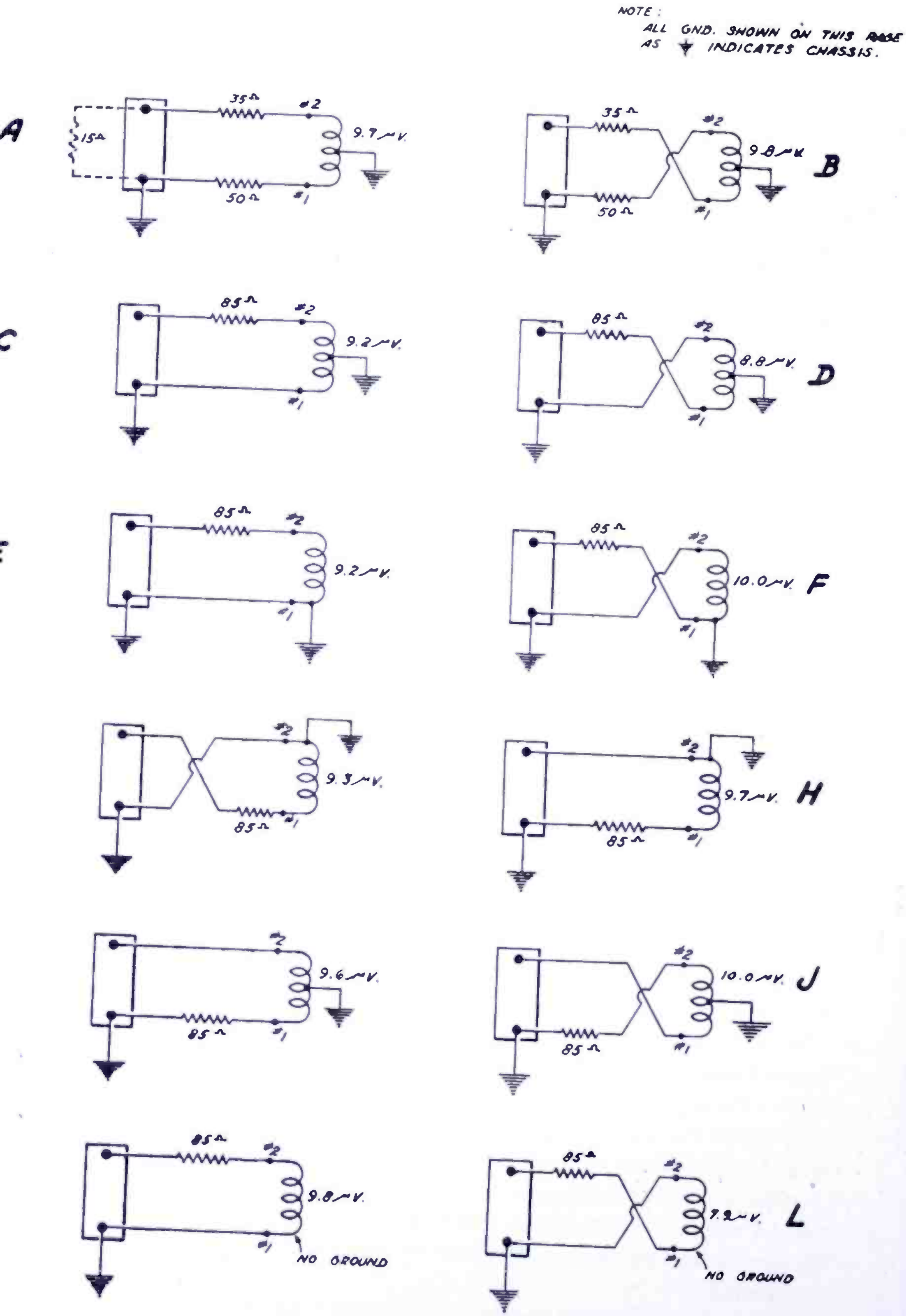
NOTE:
ALL GND. SHOWN ON THIS BASE AS
INDICATES CHASSIS.
A
35Ω
#2
15Ω
9.7 mV.
50Ω
#1
35Ω
#2
9.8 mV.
B
50Ω
#1
C
85Ω
#2
9.2 mV.
#1
85Ω
#2
8.8 mV.
D
#1
85Ω
#2
9.2 mV.
#1
85Ω
#2
10.0 mV.
F
#1
#2
9.3 mV.
85Ω
#1
#2
9.7 mV.
H
85Ω
#1
#2
9.6 mV.
85Ω
#1
#2
10.0 mV.
J
85Ω
#1
85Ω
#2
9.8 mV.
#1
NO GROUND
85Ω
#2
7.2 mV.
L
#1
NO GROUND

Fig. 4.

The departure from the average of Figure 4D is the largest of any of the cases with a ground connection on the primary winding. However, the departure is only eight per cent, an error which is believed to be very small for receiver sensitivity measurements at these frequencies.

For these sensitivity measurements, the dummy antenna resistance was varied, both above and below the correct value of 100 ohms. The sensitivity followed the variations of the dummy antenna very closely when the impedance of the input circuit was taken into consideration.

The series of sensitivity measurements discussed above leads to two conclusions regarding the use of a direct connection between the output of a single-sided signal generator and the input of a balanced antenna circuit; first, the primary of the antenna input circuit must be connected to the ground point of the input circuit, and second, the correct value of dummy antenna resistance must be used. In using this direct connection between the signal generator and receiver, it is well to make two simple tests to be sure that measurements are valid. First, the polarity of the signal-generator output should be reversed, and second, the power-line connection for either the signal generator or the receiver should be moved to a different outlet. Normally no change in receiver sensitivity should be observed on making either of these two changes.

Other methods of obtaining balanced output from a single-sided generator have suggested themselves. However, in view of the simplicity offered by the last, of the three methods discussed, they do not appear to be attractive.

OUR CONTRIBUTORS

ALLEN A. BARCO, a native of St. Louis, Missouri, received his degree of B.S. in Electrical Engineering from Washington University in 1937. Following his graduation he joined the engineering staff of the Radio Corporation of America License Laboratory, where he continues to be engaged. Mr. Barco is an associate member of Sigma Xi.

WENDELL L. CARLSON was graduated from the Bliss Electric School in 1918. Since 1918 he has been engaged in radio receiver development, first at the Washington Navy Yard from 1918 to 1923; next with the General Electric Company at Schenectady from 1923 to 1930; and then in his present connection, the RCA Manufacturing Company, at Camden, N. J., which he joined in 1930.

HUGH L. DONLEY received the B.S. degree from Hobart College in 1930; the M.S. degree from Brown University in 1932, and the Ph.D. degree from the same University in 1935. From 1930 to 1933 he served as Assistant in Physics, Brown University, and was honored with a University Fellowship in Physics, Brown University, 1933-34. Since May, 1935, he has been in the General Research Division of the RCA Manufacturing Company at Camden, N. J. Dr. Ronley is a member of Phi Beta Kappa, of Sigma Xi, of the American Physical Society, and an associate member of the Institute of Radio Engineers.

DAVID W. EPSTEIN received a B.S. degree in engineering physics from Lehigh University in 1930, an M.S. in 1934, and a D.Sc. in electrical engineering in 1937 from the University of Pennsylvania. Since joining RCA in 1930 he has been in the Research Department of the RCA Victor Division, RCA Manufacturing Company. Dr. Epstein is a member of the American Physical Society and an associate member of the Institute of Radio Engineers.

CHARLES W. FINNIGAN completed his studies at the Massachusetts Institute of Technology in 1934, where he received the degrees of BSc., and E.E. During 1935-1936 the Philco Radio and Television Co. engaged his services, and throughout 1937-1942 he was associated with the RCA License Laboratory as Laboratory Engineer. At the present time he is connected with Stromberg-Carlson Telephone Manufacturing Co. in the position of Radio Engineer.

DR. ALFRED N. GOLDSMITH received the degree of Ph.D. at Columbia University, 1911, and Sc.D. (Honorary) at Lawrence College, 1935. He was Professor of Electrical Engineering at the College of the City of New York, 1918-1923, and became Associated Professor of Electrical Engineering at that Institution, with life tenure, in 1923. He was Consulting Engineer, General Electric Company, 1915-17; Director of Research, Marconi Wireless Telegraph Company of America, 1917-19; Director of Research Department, Radio Corporation of America, 1919-22; Chief Broadcast Engineer, Radio Corporation of America, 1922-23; Vice President, RCA Photophone, 1928-29; Vice President and General Engineer, Radio Corporation of America, 1927-33; and subsequently has been Consulting Engineer. He received the National Pioneer Award in 1940, the Institute of Radio Engineers Medal of Honor in 1941, and the Townsend Harris Medal in 1942.

ROLAND A. LYNN, a native of Hagerstown, Maryland, graduated from the University of Maryland, class of 1927, with a BS in Electrical Engineering. He joined the General Electric Company at Schenectady and engaged in various radio developmental projects. He followed through on the problem of broadcast synchronization when he joined the Engineering Department of the National Broadcasting Company in 1931, and since that time has been active in various problems of a technical nature which are assigned to the NBC Development Group. Mr. Lynn has given special attention to the problems associated with the recording and reproducing of broadcast transcriptions.

GARRARD MOUNTJOY, following his graduation with a B.S. degree from Washington University in 1929, joined the Sparks-Withington Company as a development engineer. For that company he spent some time in Europe designing radio sets for local conditions. He later became Chief Engineer of the Sparks-Withington Radio Development Department which position he held until 1935. Prior to entering college he spent a year with the Westinghouse Company. Since 1935, Mr. Mountjoy has been on the staff of the RCA License Laboratory, and in 1940 received a "Modern Pioneer" award from the National Association of Manufacturers. He is a member of I.R.E. and Sigma Xi.

JOHN A. RANKIN received his degree of B.S. in Electrical Engineering from Michigan State College in 1934. From 1934 to date he has been an engineer in the RCA License Laboratory. He is a member of Tau Beta Pi. In 1935 he became an associate member of the Institute of Radio Engineers.

TECHNICAL ARTICLES BY RCA ENGINEERS

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BARCO, A. A.—see SEELEY, KIMBALL, and BARCO.

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HALLER, CECIL E.—The Design and Development of Three New Ultra-High-Frequency Transmitting Tubes—*Proceedings of the I. R. E.*, January.

HEROLD, E. W.—The Operation of Frequency Converters and Mixers for Superheterodyne Reception—*Proceedings of the I. R. E.*, February.

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KIMBALL, C. N.—see SEELEY, KIMBALL, and BARCO.

KNOX, JAMES B.—see LAPORT and KNOX.

LAPORT, EDMUND A. and JAMES B. KNOX—Radiating System for 75-Megacycle Cone-of-Silence Marker—*Proceedings of the I. R. E.*, January.

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VOLKMANN, JOHN E.—Polycylindrical Diffusers in Room Acoustic Design—*The Journal of the Acoustical Society of America*, January.

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* Formerly with RCA Manufacturing Co., Inc.