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EDITOR L. E. Q. WALKER A.R.C.S.

Marconi's Wireless Telegraph Company Limited, Baddow Research Laboratories
West Hanningfield Road, Great Baddow, Essex, England

The Monitoring of Receiver Performance under Operational Conditions

I s generally agreed that it is convenient to be able to check, on operational ipment, whether the receiver performance is satisfactory, to which end e form of apparatus like that for noise factor measurement is frequently l. The performance check is then commonly referred to as a noise factor surement though in fact the conditions necessary for the true noise factor e established are not fulfilled. As a result quite misleading figures are uently quoted and no true indication of performance may really be obtained. hniques by which measurements can be made to yield reliable information discussed below.

T re is no doubt that the best indication of system performance is ained by observing the signal-to-noise ratio of a permanent echo, since components of the system then contribute to the result. Convenient manent echoes do not always exist, or the system does not permit of ir close examination, and thus it becomes necessary to measure the formance of individual components such as the radiated power of the nsmitter, or the signal-to-noise ratio of the receiver. Since it is not venient to have remotely sited measuring or signal generating equipnt, the performance of which must be constant and beyond reproach, the aerial itself automatically becomes excluded from the performanc check; one measures the power into the aerial, or injects a signal betwee aerial and receiver. In radar systems, owing to the damaging effect o high peak powers, both the receiver and the signal source to be used mus be protected and the duplexer used for this purpose between aerial an receiver likewise becomes excluded from the performance check. One i left with no choice therefore but to inject a signal at a point in the system close to the receiver input terminal; it is essential that this injected signa remains at constant level under all conditions and at all times. The ga discharge noise source most closely fulfils this condition of constancy and it can be fitted in either a waveguide or a co-axial mount. One form of th latter is described in *Marconi Review* No. 129, p. 43.

Before considering the techniques for carrying out a performance check some reference must be made to the frequency of such checks. There i wide divergence of opinion on this point amongst users of equipmen operating on a twenty-four hour day basis; some with stand-by equipmen suggest that once a week is sufficient, others demand “continuou monitoring” even when stand-by equipment is fitted

Continuous monitoring implies a degree of reliability higher than tha of the system equipment, requires continuous observation if it is to b effective, and usually results in slight but barely perceptible degradatio of the display (or in some systems obvious degradation in limited areas by virtue of the increase in noise level. It is also implied that the nois reference signal be permanently coupled into the system in such a wa as to minimize any insertion loss in the signal channel. Although th indication obtained provides a fair measure of performance, it is in n sense a noise factor measurement since there are small but not necessaril negligible contributions to the smoothed receiver output from any hig level permanent echoes or targets in the beam of the aerial which wi consequently vary with azimuth and, further, the aerial itself does no provide the reference termination to the receiver at constant resistanc and constant temperature that is an essential for a noise factor measurement, on account of its variable VSWR and the fact that the space it look at has a lower effective temperature than earth ambient. Muting of th receiver for a small proportion of the repetition period during an immediately following the transmission period, however, is sufficientl effective to reduce the unwanted energy at the receiver output to acceptabl proportions.

Where, on the other hand, checks are carried out daily or weekly, fo instance during a maintenance period, the noise reference source may b independent of the system. The receiver is then disconnected from th system and connected to the reference source for the measuremen Carried out under these conditions the check does not differ from

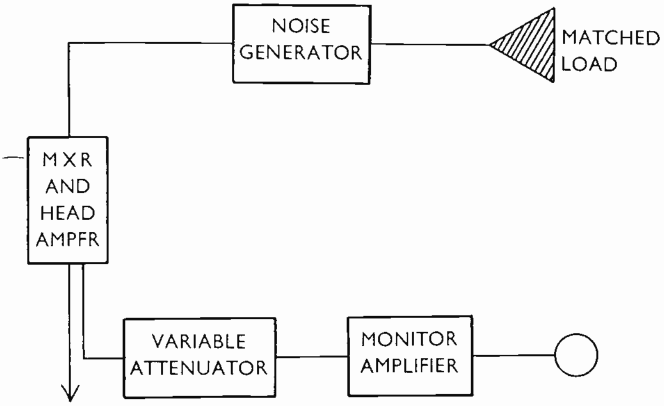

Fig. 1.

asurement of noise factor in the laboratory; no complicated equipment
required, as it is unnecessary either to pulse the source or to mute the
eiver.

t may be that the customer requirements are best met by a compro-
se between these two extremes. One method that has given satisfactory
vice is brought into operation only when required, and makes use of a
se reference source of low insertion loss, permanently coupled into the
tem, which is switched on and off alternately by a motor-operated
tch for five-second periods (to give sufficient time to read the meter).
the noise tube is switched on, the gain of the monitor amplifier is
nultaneously reduced by an amount such that the meter reading (which
es not have to be set initially to a given value) decreases, should per-
mance be below some pre-determined amount, corresponding to say a
dB degradation of the designed noise factor. Blanking of transmitter
lse and local permanent echoes is provided and a pilot lamp near the
ter indicates when the noise tube is on. This system has the advantage
at noise is injected into the signal channel only during the actual check
ich can occupy less than thirty seconds. If desired, gain reduction
ring operation may be included in the signal channel to minimize the
nge in noise level when the source is switched on. Noise does not then
urate the tube, but signal levels of course decrease for the duration of
e check.

The Marconi Company's S.232 and S.264 series 50 cm-band multi-
rpose surveillance radar equipments are fitted with performance check-
arrangements of this type; both control and indication may be
ected remotely over cable or radio link.

The various methods are shown in block schematic form in the figures.
e standard method for noise factor measurement is shown in Fig. 1

in which the noise source is backed by a matched load. When the noise generator (assumed to be a gas discharge tube) is switched on, the attenuator is adjusted until the meter reading is reduced to that obtained with the generator off. Noise factor is then readily calculated from the attenuatio inserted and the known noise constant of the tube used. With some forms of noise source it is not always possible to obtain a sufficiently close match to the waveguide or cable used with the tube both on and off, in which case it is customary to match the tube in the on condition and to make th comparison against a resistive load connected directly to the receiver input terminal.

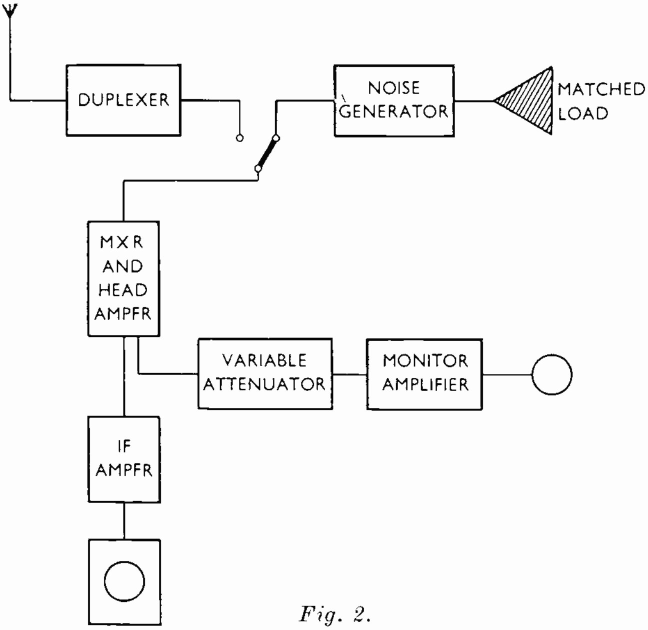

Fig. 2.

The daily check (Fig. 2) differs little from a noise factor measuremen and can in fact be carried out in the same way, the aerial being disconnected. Clearly this can only be done during a shut-down period.

The semi-automatic check (Fig. 3) can be carried out during an operational period provided the noise source is permanently fitted into th system. The transmitter need not be shut down for the check since gating pulse may be used to eliminate energy due to it and to loca permanent echoes affecting the output reading. In place of a manuall operated variable attenuator it is more convenient to change, by mean of a relay, the gain of the monitor amplifier simultaneously with th switching on of the noise source (as indicated by a pilot lamp) by a pre-se

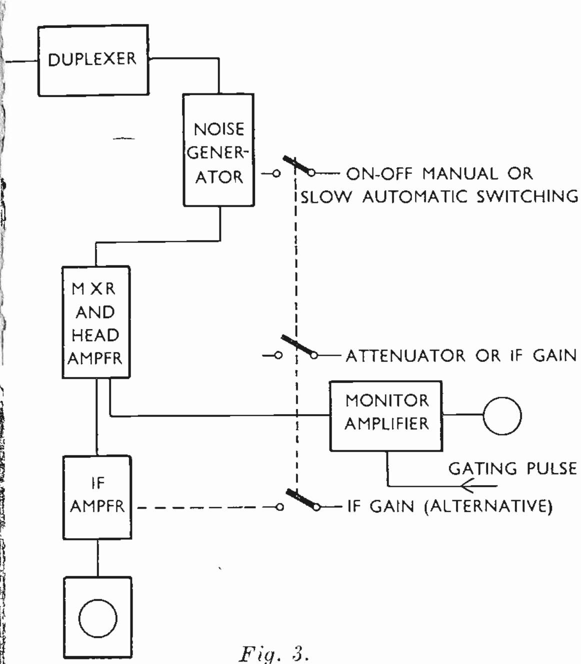
DUPLEXER
NOISE GENERATOR
ON-OFF MANUAL OR SLOW AUTOMATIC SWITCHING
MXR AND HEAD AMPFR
ATTENUATOR OR IF GAIN
MONITOR AMPLIFIER
GATING PULSE
IF AMPFR
IF GAIN (ALTERNATIVE)

Fig. 3.

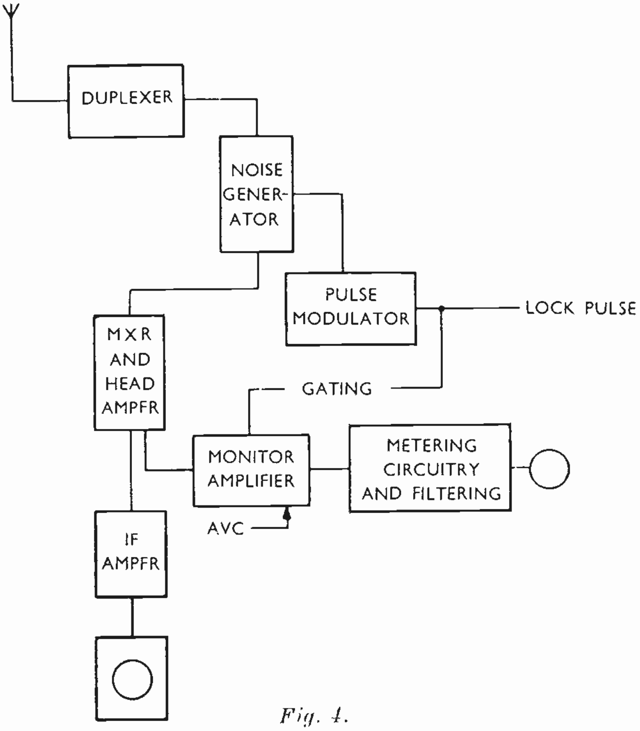
DUPLEXER
NOISE GENERATOR
PULSE MODULATOR
LOCK PULSE
MXR AND HEAD AMPFR
GATING
MONITOR AMPLIFIER
METERING CIRCUITRY AND FILTERING
AVC
IF AMPFR

Fig. 4.

amount such that, should the meter indication decrease, receiver performance has degraded below a pre-determined acceptable level. With this arrangement there is no need to set the meter indication to some particular value prior to the operation of the noise tube as is preferably the case when a variable attenuator is used.

With continuous monitoring (Fig. 4) there is the added complication of pulse modulating the noise source, abstracting by filtering the modulation and providing efficient AVC in order to minimize the number of manual adjustments.

O. E. KEALLE

BOOK REVIEW

A FIRST COURSE IN WIRELESS *by "Decibel"* — THIRD EDITION

Sir Isaac Pitman and Sons Ltd. Price 12s. 6d.

This is a well-known text for the non-technically minded. Starting from very first principles of electricity, the author gives an explanation of inductance, capacitance and resistance, AC circuits, modulation and other fundamentals to the radio art. This part of the book has been well written, and by the time the tyro has studied the first ten chapters covering these aspects, and a later particularly lucid chapter on sidebands and selectivity, he will have gained a useful elementary insight into the theory underlying the transmission of wireless signals.

In the later chapters, radio receiver circuits are described, ranging from "Simple Receiver Circuits" to "Mains Receivers." Judged from the standpoint of current design of receivers, these chapters are of little value. For example, the single valve receiver circuits use grid detectors and headphones or a diode rectifier and headphones. The audio frequency amplifiers have a vintage appearance, particularly Fig. 44 which shows an amplifier using battery valves and having choke-capacitance ($2\mu F$) coupling to the loudspeaker "to prevent the anode current passing through the loudspeaker." The relevant text informs the reader that such an arrangement "is often used"—a statement that was correct in 1930 but hardly since.

We are told that iron cored chokes are usually employed instead of resistors for smoothing the rectified mains supply "to avoid excessive drop in HT voltage." On the contrary, designers of broadcast receivers commonly employ resistance-capacitance smoothing either with or without hum bucking in the primary of the output transformer.

For the new edition, a chapter on crystal diodes and transistors has been added. These subjects have been effectively dealt with and the newcomer will find this a valuable introduction to the subject. Transistor receiver circuits are however not considered. Frequency modulation is referred to briefly, but descriptions of FM receivers or circuits are lacking.

This is typical of the inadequacy of the revision that the author has carried out; the omission is, however, surprising because mains receivers without an FM band are rapidly becoming as scarce as an Eskimo in Pall Mall.

MODIFIED SYNTHESIS PROCEDURE
OR TWO-TERMINAL PAIR NETWORKS

By S. S. FORTE, B.Sc, Ph.D, A.M.I.E.E, M.I.R.E.

a recent paper(11), the author formulated a theorem stating the necessary l sufficient conditions for a set of prescribed driving point and transfer ctions to be realized as a simple symmetrical lattice structure with series pedances or shunt admittances at either end.

These conditions are rather restrictive and, in the present article, modified ditions are given whereby the synthesis procedure can be extended, in a ticular case, to sets of functions which do not necessarily comply with the ginal theorem.

mbols and definitions

z_{22}, z_{12} = Driving-point and transfer open-circuit impedances of two-terminal pair

= Driving-point impedance

r_{22}, r_{12}, R = Real parts of z_{11}, z_{22}, z_{12}, and Z, respectively, on the boundary

$f(j\omega)$ = Real part of (λ) on the boundary

p_{22}, p_{12}, p_z = Residues of any poles of z_{11}, z_{22}, z_{12}, and Z, respectively, on the boundary

= Angular frequency

= The complex frequency variable $v + j\omega$

= A constant multiplier

= The optimum value of k

BOUNDARY

e complex frequency variable is defined as $v + j\omega$. Network behaviour terms of zeros and poles can be depicted on an Argand diagram with v the real axis, and $j\omega$ as the imaginary axis. This forms the complex quency plane and the imaginary axis is known as the boundary.

-FUNCTION

positive real function, i.e, one whose real part is $\geqslant 0$ for all real frequen- s (i.e, everywhere on the boundary), which has no poles to the right of boundary and in which poles occurring on the boundary are simple th positive residues. A necessary and sufficient condition for the realiza- ity of a driving point impedance (or admittance) function is that it be sitive and real.

Introduction

The first contribution to the science of Network Synthesis was made by R. M. Foster(1) who, in his Reactance Theorem, gave the necessary and sufficient conditions for a function to be the impedance or admittance function of a purely reactive two-terminal network as:

(i) All poles and zeros of the function must lie on the imaginary axis in the λ plane.

(ii) The poles and zeros must mutually separate each other.

Cauer has extended Foster's result for the purely reactive case to all networks containing two kinds of elements only, and has shown that the necessary and sufficient conditions for a function to be the impedance or admittance function of a *RC*, *RL* or *LC* two-terminal network are:

(i) All poles and zeros of the function must lie on the negative real axis in the λ plane.

(ii) The poles and zeros must mutually separate each other.

The first general method for the exact realization of any prescribed or admittance function having a finite number of poles and zeros into a general two-terminal network containing all three kinds of circuit elements was given by O. Brune(2) who proved that the necessary and sufficient conditions for a function $f(\lambda)$ to be the impedance or admittance function of a passive two-terminal network is that the function must be Positive Real (p.r.). In general, Brune's synthesis procedure, while resulting in the minimum number of elements, involves the use of mutual coupling which is a rather undesirable feature.

The existence proof together with a synthesis procedure without mutual coupling was first given by R. Bott and R. J. Duffin(3). Their process is based on a transformation due to Richards which creates a remainder whose rank is equal to or less than the rank of the original function and possesses either a pole or a zero which can be extracted, thus allowing the synthesis to continue.

F. M. Reza(4) has solved the same problem by a direct continuation of the Brune process, leading to the same structure as that of Bott and Duffin.

Thus in the field of the realization of driving point impedances as two-terminal networks the results of Foster and Cauer offer a complete solution to the problem restricted to networks with two kinds of elements only, while for networks containing all three kinds of elements, the Brune process necessitates the use of perfectly coupled coils but leads to a network containing the minimum number of elements while the Reza and the Bott and Duffin processes eliminate mutual coupling but introduce the need for surplus elements.

The first general synthesis for two-terminal pair networks was given by C. M. Gewertz(5) who proves that the necessary and sufficient conditions

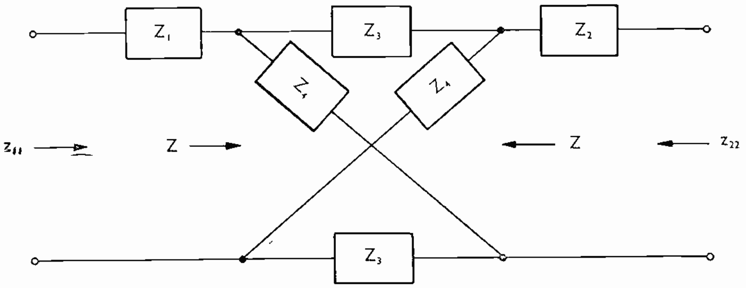

Fig. 1.

a set of functions f_{11}, f_{22}, f_{12}, to be a family of impedances or admittances racterizing a two-terminal pair network are:

(i) The prescribed functions must be real for λ real.

(ii) No poles must lie to the right of the imaginary axis in the λ plane.

(iii) At poles on the boundary, f_{11} and f_{22} must each have positive, real, finite residues.

(iv) The determinant of the residues at a common pole on the boundary must be real and positive.

(v) $\mathcal{R}\, f_{11}\,(j\omega) \geqslant 0$ and $\mathcal{R}\, f_{22}\,(j\omega) \geqslant 0$ for all real values of ω.

(vi) $\mathcal{R}\, f_{11} \,.\, \mathcal{R}\, f_{22} - (\mathcal{R}\, f_{12})^2 \geqslant 0$ for all real values of ω.

wertz's realization consists of a set of simple networks interconnected ideal transformers. These are not physically realizable, and suffer m the added disadvantage of introducing infinite quantities into an erwise finite system.

A considerable body of research has been and is being conducted to try exclude the ideal transformer from the synthesis of two-terminal pair works. Several solutions have been offered for the special cases of works containing only two kinds of elements (Darlington(6), Fialkow l Gerst(7), Talbot(8), Guillemin(9) *et al.*) or for the special cases of thesis from a prescribed transfer function or insertion function rather n the impedance or admittance matrix (Darlington, Weinberg(10) *et al.*).

In his first article the author has shown that in order to obtain a lizable symmetrical structure from a prescribed set of impedance ctions z_{11}, z_{22}, z_{12}, an arbitrary function Z, the driving point impedance the symmetrical lattice, would have to be chosen so that (with reference Fig. 1):

$$\begin{aligned} Z_1 &= z_{11} - Z \quad \text{is p.r.} \\ Z_2 &= z_{22} - Z \quad \text{is p.r.} \\ Z_3 &= Z - z_{12} \quad \text{is p.r.} \\ Z_4 &= Z + z_{12} \quad \text{is p.r.} \end{aligned}$$

suitable synthesis procedure was then derived leading finally to the mulation of a theorem:

THEOREM I

The necessary and sufficient conditions for a set of driving-point and transfer impedance or admittance functions f_{11}, f_{22}, and f_{12} to be realizable as a two-terminal pair network without ideal transformers, consisting of a symmetrical lattice network with series reactances or shunt susceptances at either end of the structure are

$$f_{11} \pm f_{12} \text{ must be p.r.}$$
$$f_{22} \pm f_{12} \text{ must be p.r.}$$

These conditions are rather restrictive, and a slight relaxation is therefore introduced for a special case.

The Modified Synthesis Procedure

For the special case of a network open-circuited at one pair of terminals, it is possible to relax the conditions of theorem I by the introduction of a constant multiplying factor k for the transfer function, as will be discussed later.

The p.r. requirements of theorem I are then modified to

$$\begin{aligned} &f_{11} \pm kf_{12} \text{ must be p.r.} \\ &f_{22} \pm kf_{12} \text{ must be p.r.} \end{aligned} \tag{1}$$

A set of prescribed functions not satisfying the above relations with $k = 1$ (the general case as set out in theorem I), could be made to satisfy the realizability requirements by a suitable choice of k, smaller than unity. This necessitates that for all real frequencies

$$\begin{aligned} r_{11} \pm kr_{12} \geqslant 0 \\ r_{22} \pm kr_{12} \geqslant 0 \end{aligned} \tag{2}$$

and at any boundary pole the residues satisfy

$$\begin{aligned} p_{11} \pm kp_{12} \geqslant 0 \\ p_{22} \pm kp_{12} \geqslant 0 \end{aligned} \tag{3}$$

Conditions (3) need only be considered for poles on the boundary which are common to z_{11} and z_{12} and/or to z_{22} and z_{12}, for any pole in z_{11} or z_{22} not contained in z_{12} will have been extracted as a series reactive network at the appropriate end of the structure prior to the application of the synthesis procedure.

The value of k, if existing, just satisfying relations (2) and (3) above can be determined for any prescribed set of functions, yielding the optimum value K.

The arbitrary function Z, the driving-point impedance of the symmetrical lattice, must be so chosen that

$$\begin{aligned} Z_1 &= z_{11} - Z \quad \text{is p.r.} \\ Z_2 &= z_{22} - Z \quad \text{is p.r.} \\ Z_3 &= Z - Kz_{12} \text{ is p.r.} \\ Z_4 &= Z + Kz_{12} \text{ is p.r.} \end{aligned} \tag{4}$$

The real part R of the arbitrary function Z must be so chosen that e real parts of the driving-point impedances of the component branches the network be positive for all real frequencies. It is evident that a value R can be found to lead to a realizable solution, if for all real quencies

$$\begin{aligned} R &\geqslant K \mid r_{12} \mid \\ R &\leqslant r_{11} \\ R &\leqslant r_{22} \end{aligned} \qquad (5)$$

can be determined as a rational function in ω^2 by means of any itable method of approximation from the curve lying between the nits given by (5).

Z' is determined quite readily as a p.r. function in λ from the real part by the use of Gewertz's method for example. This function will ntain no boundary poles and, therefore, poles will have to be added for ery boundary pole in z_{11} common to z_{12} and in z_{22} common to z_{12}, which tisfy the residue conditions

$$\begin{aligned} p_{11} - p_z &\geqslant 0 \\ p_{22} - p_z &\geqslant 0 \\ p_z \pm K p_{12} &\geqslant 0 \end{aligned} \qquad (6)$$

king $p_z = K \mid p_{12} \mid$ at every boundary pole, ensures that the above nditions are satisfied with the residues in the poles of one of the functions or Z_4 vanishing each time, thus resulting in a reduction of elements. ius, if a suitable value of k ($= K$) can be found to satisfy the conditions

$$\begin{aligned} f_{11} \pm k f_{12} &\text{ is p.r.} \\ f_{22} \pm k f_{12} &\text{ is p.r.} \end{aligned}$$

e conditions (2), (3), (5), (6) and therefore (4) will automatically be tisfied, and a realization will be possible.

This realization is strictly not a synthesis of the prescribed matrix , z_{22}, z_{12}, but of a modified matrix z_{11}, z_{22}, Kz_{12}. In certain cases $K = 1$ ill satisfy the necessary and sufficient conditions, so that a rigorous nthesis is obtained, but in general K will be < 1.

If the realization is restricted to networks with one pair of terminals pen-circuited, the introduction of a factor K for the transfer function presents a constant loss and does not otherwise affect the prescribed aracteristics of the network as specified by the original matrix. This stricted use is often met in the case of inter-valve networks, where the put impedance of a valve can be considered to be an open-circuit, so at limited though it may seem, this solution would represent a useful alization for that application.

A second theorem is therefore formulated:

IEOREM II

or the particular case of two-terminal pair networks working into an pen-circuit at one pair of terminals, the sufficient conditions for a prescribed set of driving-point and transfer functions f_{11}, f_{22} and f_{12} to be realizable as a structure without ideal transformers, consisting of a symmetrical lattice network with series reactances or shunt susceptances at either end of the structure, accepting a constant loss through the network, are:

$$f_{11} \pm kf_{12} \text{ must be p.r.}$$
$$f_{22} \pm kf_{12} \text{ must be p.r.}$$

(where k is a constant multiplier

Conclusion

An extension has been indicated to the general theorem given previously, for the particular case of two-terminal pair networks working with one pair of terminals open-circuited, which, even if rather restricted in application, may prove to be of some use.

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A METHOD OF PRODUCTION OF HIGH ACCURACY DIGITAL DISCS

By J. J. WEAVER, B.Sc, and E. G. D. YOUNGS, B.Sc

The increasing importance of automatic control systems has given rise to the mergence of two main types of control system, the analogue and the digital. Both types of system require information representing the desired state and the actual state of the process to be controlled. From these can be derived the error r difference signal which, through some power amplifier, tends to make the actual state approach that desired.

It is evident that the accuracy of these systems depends almost entirely on the accuracy of the device from which the actual state information is derived.

One of the most important and widely used systems is that for the angular position control of a shaft. It is the purpose of this article to describe a method or the production of a highly accurate device for the measurement of angular position and to provide this information in a suitable form for either inclusion n a control system or as a straightforward measuring device in a data transmission system.

Limitations of the Analogue System

The analogue type of system uses a continuous flow of information from the angle sensing device. This method has been used extensively where the accuracy requirement has not been very stringent. This is because of the inherent inaccuracies of the devices used, such as potentiometers and magslips, etc., and also it is extremely difficult to keep the linearity of the system to much better than 0·1%.

A number of ingenious methods have been evolved in which analogue devices are geared and interconnected to improve the resolution of the system but at the cost of considerable complexity. Again, the controlling information must be in analogue form and, if a system is to be completely automatic, this information must be stored in some convenient form and made available when necessary.

The methods of storing information, such as magnetic tape, punched cards or tape, do not in general lend themselves readily to the storage of analogue information. It is necessary to provide some additional device o convert the information into a form acceptable to the analogue system.

One advantage of the information being in analogue form is that, after power amplification, it can be applied directly to the prime mover which s in general designed to give a response dependent on the magnitude of the input signal.

Another advantage is that the mathematical analysis of continuous systems has been adequately covered especially in the linear case, to which a great majority of analogue systems can be approximated, so the design of suitable systems is fairly straightforward.

Advantages of Digital Systems

In a digital system the measurement of the actual angular position is carried out in such a way as to give digital information directly. A number of advantages then accrue.

The accuracy of the system can be defined by the least significant digit of the measuring disc. Since, in a digital system using, say, a binary code, the devices are of the "on-off" type, the problems of information non-linearity do not arise. The accuracy is limited only by the "fineness" of the least significant digit that it is practical to produce.

It is often necessary to generate a complex controlling function, this can be done by programming a general purpose digital computer to produce the required information in punched card or tape form. In this form it can be conveniently stored until required and requires no further conversion before being used to operate the controlling system.

The error or correcting signal is derived from the desired or actual state information. The operations carried out on these must not affect their accuracy or linearity. In a digital system, even with final conversion to analogue form, the accuracy of information transfer need not be degenerated. The analogue system, however, will introduce significant errors especially when the long-term stability of the system is considered.

The mathematical analysis of digital system is considerably more complex than that of a continuous analogue system, owing to its inherent non-linearity. However, there are a number of analytical methods by the use of which a suitable system may be designed.

DATA TRANSMISSION

Apart from the use of digital discs in control systems there is a considerable field of use in data transmission systems particularly in those cases where unusual functions of angular position are required. Here, as will be shown below, the ease of production and high accuracy attainable of digital discs show distinct advantages over the equivalent analogue device where it exists.

THE DIGITAL DISC

The digital disc of the optical type, with which we shall be mainly concerned in this article, consists of a flat circular glass disc on which the pattern, from which the angular information will be derived, is printed in some way.

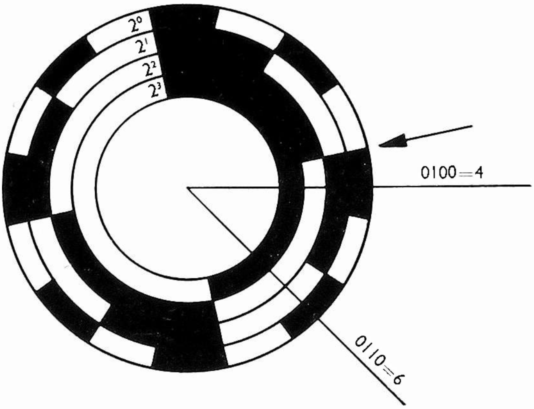

Fig. 1. Simple four digit disc

Fig. 1 shows a simple four digit disc, the 360° is divided into sixteen equal rts each of which is uniquely defined by a binary number which can be tained by scanning radially across the disc. The progression from least most significant digit is from the centre outwards, thus, if the shaded rtions represent "0" and the clear portions "1", binary numbers as own by the two examples on the diagram may be obtained.

It can be seen that at the start of the fifth segment, shown by arrow, ree rings change from one state to the other simultaneously, if the radial an were not exactly radial gross errors would occur. The cyclic permuting de was devised to reduce the effect of this type error by ensuring that ly one digit changes at a time (Fig. 2). Other codes and patterns have en devised(1) to avoid scanning errors but a detailed discussion is outside e scope of this article.

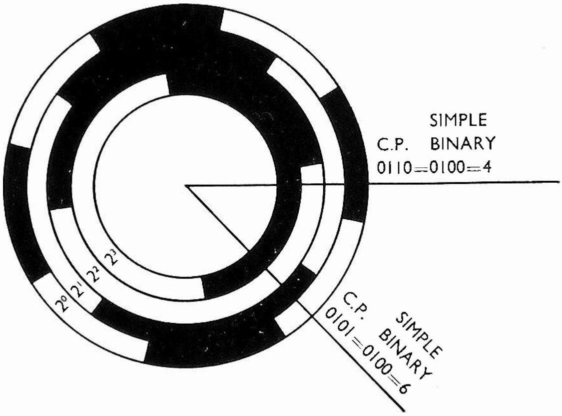

Fig. 2. Cyclic permuting code

The Digital Disc

Digital discs can be loosely divided into two main groups, those with high information rates of say, 1,000 bits/sec. and upwards, and those with low rates. This arbitrary limit is set about the point where photo electric cells become necessary in the "read out" systems due to the response rate required. Below this limit devices such as the Schwarz cells may be used in optical systems or at very low rates a mechanical brush and contact disc is sufficient although due to frinctional wear its life is limited.

The accuracy of the disc as an angle measuring device depends almost entirely on the number of bits that can be produced on it and the accuracy of the transition between opaque and clear segments in the optical type or the indeterminacy of the point of contact between conducting and non-conducting segments in the mechanical type. The highspeed disc would be of the optical type with a configuration of opaque and clear segments forming the binary code representation of the relevant angle. This pattern could be scanned radially by a beam of light and the resulting light modulation picked up on a photo electric cell, giving a pulse sequence serially in time. Alternatively a photo electric cell for each digit ring and a continuous illumination would give a parallel output.

The speed limitation is set by the response of the photo electric cell and the rate of the scanning beam, i.e. the time taken for one scan must be less than the time taken for the disc to rotate through an angle represented by the least significant digit.

THE OPTICAL TYPE DISC

The low speed disc could be of the mechanical type where a configuration of conducting and non-conducting segments represent the binary code and the read out is accomplished by making contact through the brush system. Of the two, the optical system is capable of a much higher degree of accuracy and is less susceptible to mechanical wear.

The system described below is capable of producing either type of disc, although only the optical type will be discussed since a high degree of accuracy is required.

The Optical Type Disc

It is apparent that at certain points on the disc with a straight binary code pattern, a number of opaque sections have their edges along the same radial line. Thus, if the scanning beam is not exactly radial gross errors will result. To avoid this the binary number may be expressed in some cyclic permuting code, in which adjacent patterns only change by the least significant digit.

There are a number of instances where angular information is not quired continuously and in such cases the pattern may be of the straight nary form. The use of a cyclic permuting code means that some conver-n is necessary before the information can be used. This, however, is not difficult task and detracts little from the major advantages of the digital c.

neral Description of the Disc Producing System

e problem can be divided conveniently into three stages, firstly the neration of the incremental information of the function required on the sc. Secondly the storing of this information in two forms, one permanent order to be available at a later date, and the other to operate the system the third stage in which the disc has the required pattern impressed on

In order to be able to produce as wide a range of functions as possible it s decided to use the DEUCE computer to produce the incremental formation in punched card form which could be stored indefinitely, if quired. Furthermore, by suitable programming, any cyclic permuting

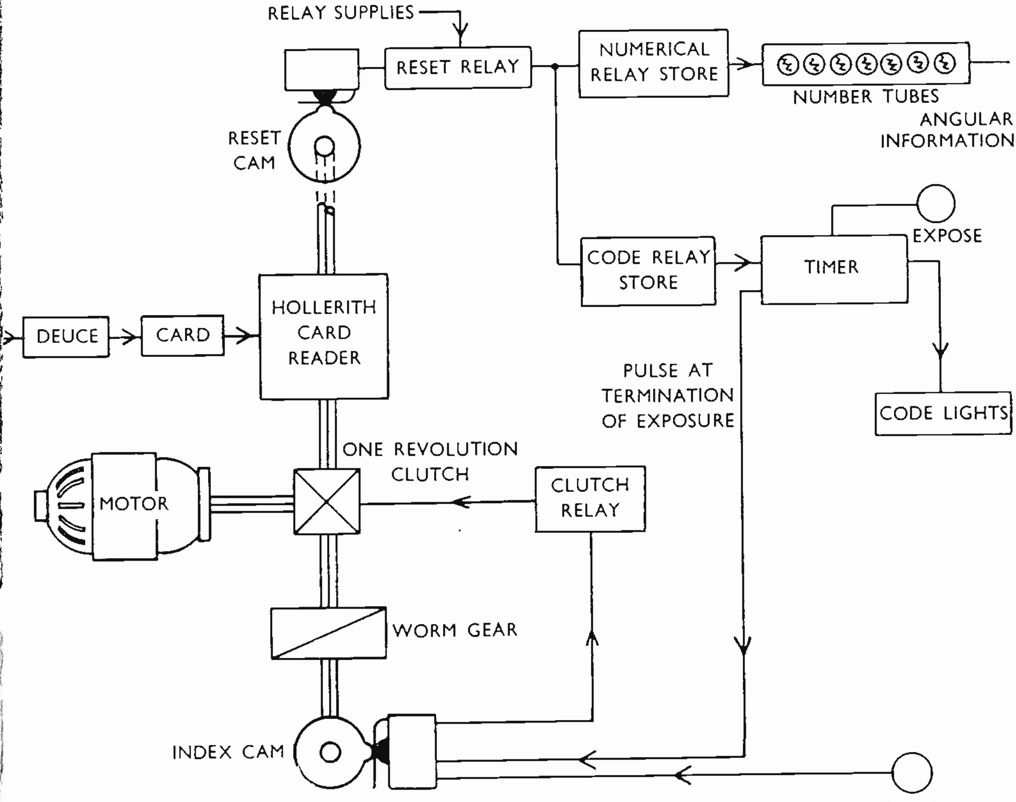

Fig. 3. Information flow

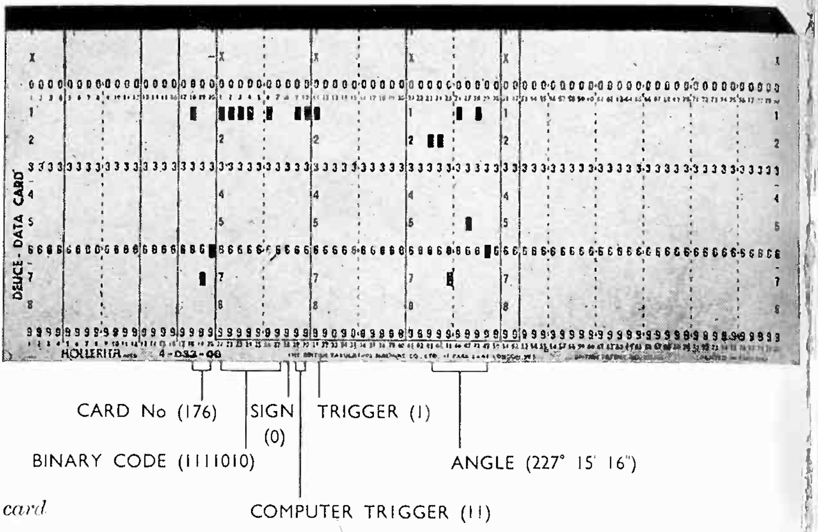

Fig. 4. Hollerith card

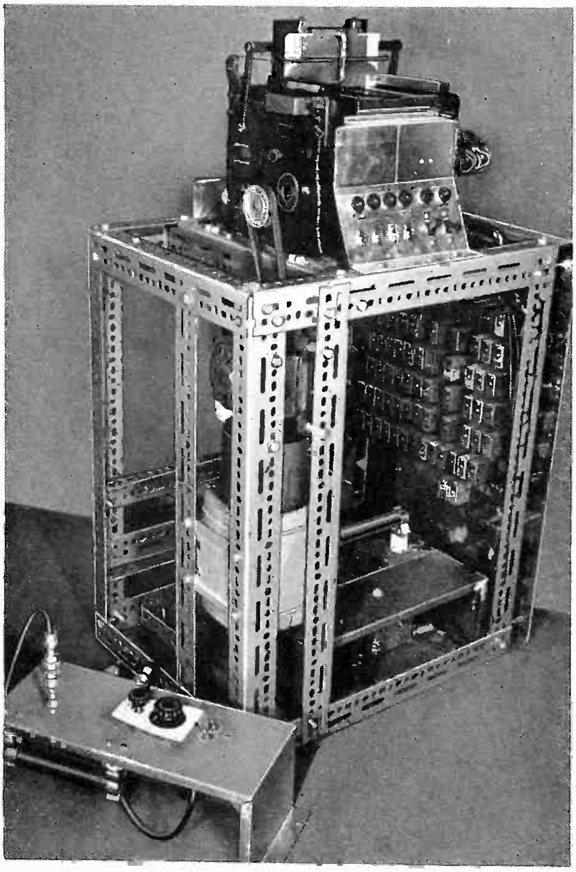

Fig. 5. Hollerith card reader

ode can be produced and any other relevant information could be punched n the cards. When required the information could be taken from the cards sing a card reader mechanism and used to set up a temporary store in the orm of a relay matrix.

It was decided that a photographic method using glass discs coated with high resolution emulsion was necessary to obtain the highest accuracy f a pattern. The disc was placed on a dividing table and a reduced image f a bank of light sources, of the required relative dimensions, projected n it to form a radial pattern.

The relay store selected the correct pattern of code lights and a row of umerical indicator tubes provided the angular information relevant to he code light pattern.

equence of Operation

he operations involved are shown schematically in Fig. 3.

The stock of punched cards giving the code light pattern and the ppropriate angular information were passed through a Hollerith card eading machine which extracted the information and set up the appropriate arts of the relay store as each card was indexed.

The dividing table was set up manually to the angular position shown n the row of numerical indicator tubes derived from the first card. The ush button was then operated bringing into action the timed circuit which witched the code lights on for a predetermined time. At the end of the xposure the next card was indexed and the process repeated until the isc was completed. The disc was then processed and became the master rom which as many contact prints as required could be made.

The operation was left as simple as possible to avoid human errors, only wo operations being required, the setting of the dividing table and the ressing of a button.

It was intended to make the operation fully automatic by servo conrolling the dividing table, the error signal being derived from a disc on ne table shaft and the information on the card. This would be very ecessary when making discs of a large number of digits where the probaility of human error is rather high.

The system is very flexible, a wide range of functions being possible ith little modification to the equipment.

etails of System

DEUCE COMPUTER PUNCHED CARDS

photograph of a typical card for a sine function disc is shown in Fig. 4.

HOLLERITH CARD READER AND RELAY STORE

his machine (see Fig. 5) accepts the cards produced by the DEUCE computer and extracts the information by means of a bank of brushes which make contact, through the punched holes, with a roller and energize the relays in the relay store in a particular column. The relevant row is selected by one of ten cams representing 0 to 9.

When a relay is energized it holds until the whole of the card has been scanned; as the next card is indexed into the machine a contact breaks and the store is cleared ready for the next set of numbers.

That part of the card information relating to the code light pattern is confined to the first row, since the information is in binary form, and the columns twenty-one to thirty inclusive in the example described below. Provision is made for storage capacity up to fourteen digits. From the circuit diagram (Fig. 6) it can be seen that, when the 1's row is being scanned by the brush and roller system, a circuit is made through a punched hole, the code relays switch, the reset relay, the 1's cam relay and a code light relay. Thus, a code light is primed and when required the timer switches the light on for the required time. Two sets of hold contacts on the code light relay ensure that the information is held until the next card is indexed. As the card moves out of the roller the reset relay is energized thus clearing the bank of relays for the new information and as

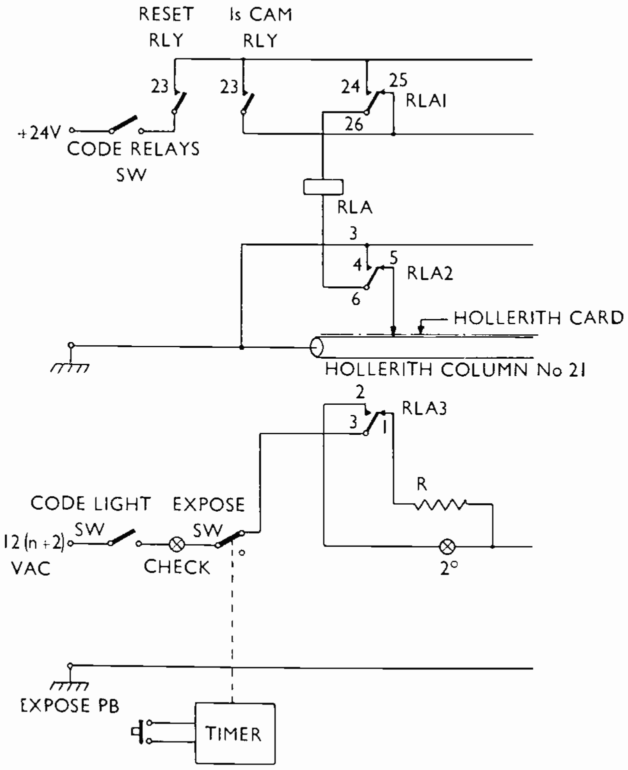

Fig. 6. Code light circuits

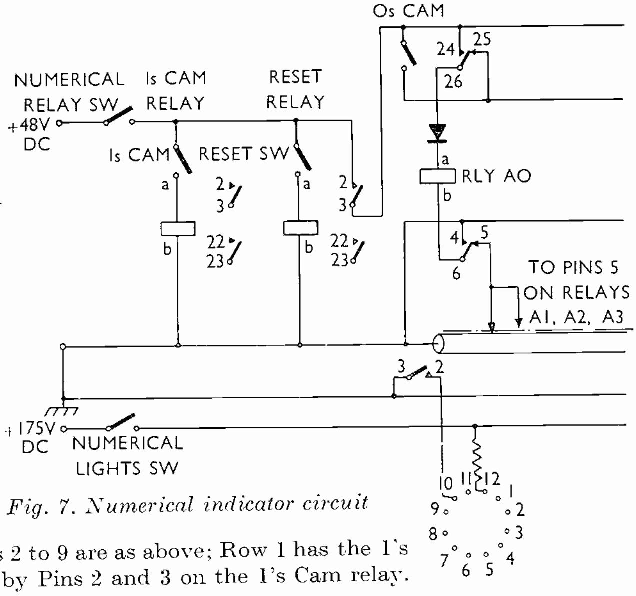

Fig. 7. Numerical indicator circuit

OTE: Rows 2 to 9 are as above; Row 1 has the 1's am replaced by Pins 2 and 3 on the 1's Cam relay.

he new card enters the reset relay closes priming the bank of relays. The ode lights are all connected in series and a check bulb is included in the ircuit to avoid errors due to bulb failure. In the automatic system this heck bulb would be replaced by a relay which would prevent further perations.

The angular information from the card in degrees, minutes and seconds s set up on the seven numerical indicator tubes in the following manner. onsider the information representing 0 in the hundreds of degrees ndicator tube. This would be represented by a punched hole in the 0's ow on a card and in column forty-three. As the card enters the roller the eset relay is energized priming all the numerical relays and when the 0's ow passes the brush and roller system a circuit is made through the 0's am and the punched hole energizing relay A0 (Fig. 7). A contact on elay A0 to the 0 pin on the "hundreds" numerical indicator is closed ausing a 0 to show.

A diode is included in series with the relay coil to prevent reverse urrents from other rows causing spurious operations.

The 1's row is used for both numerical indicator relays and code lights elays which have different supply voltages so the 1's relay operates two ets of contacts one in each supply. This was necessary only because nsufficient relays of one type are available.

PTICAL EQUIPMENT

The basis of the optical equipment was an Optical Measuring Tools Ltd dividing table, mounted on a heavy iron base. The row of numerical indicator tubes was attached to one side of this base, at a convenient height for a seated operator. A sturdy tripod, bolted to the base, supported the row of code lights approximately 3 feet above the table. A camera lens was mounted on a steel bridge which scanned a part of the dividing table. The complete arrangement is shown in Fig. 8. We will now consider each of the components in more detail.

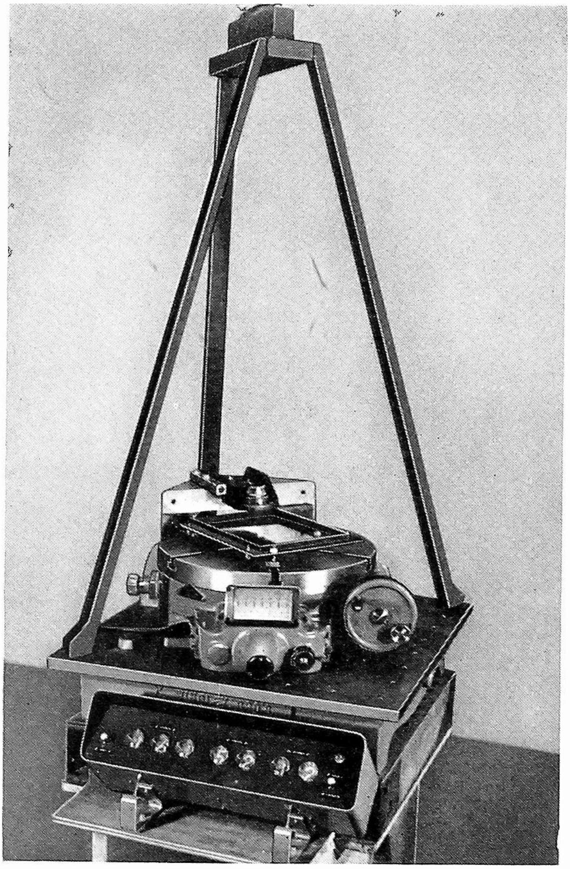

Fig. 8. Optical equipment

The table is in essence a heavy steel surface plate which can be rotated about a centre through any desired angle. The angular setting is indicated on a dial in degrees, minutes and seconds and is controlled manually. On the top of the table were mounted hole, slot and plane fixings which enabled a 10 inches by 8 inches photographic plate holder to be located kinematically. (Fig. 9). The plate holder was held in place by gravity and could be easily removed for loading. The plate itself was located in the plate holder by its upper surface, i.e. the emulsion side, so that any

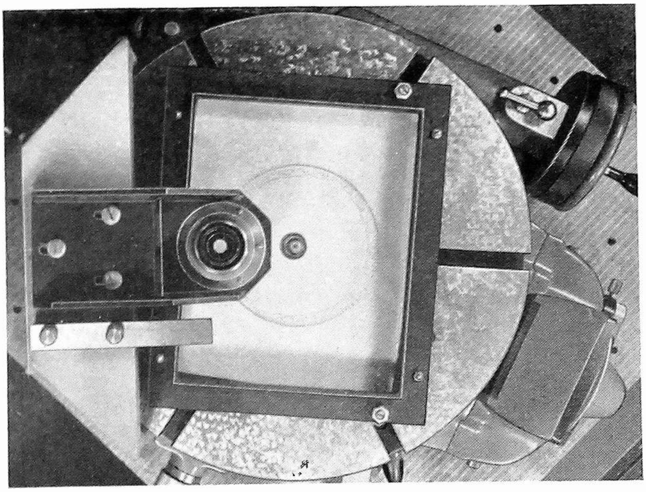

Fig. 9. Digital disc on table

fference of glass thickness between one plate and another was of no conse- ience. A large matt black metal plate attached to the lens bridge vered the whole of the photographic plate except for the part occupied r the optical image of the code lights. This masking plate has been moved in Figs. 8 and 9 so as to show the plate holder, etc.

The row of code lights is shown in Fig. 10. Each square or rectangle was uminated by a separate lamp enclosed in its own box. The boxes were att white on the inside and were closed at the lower end with pieces of hite opal glass. Separate glasses for each box were necessary to prevent

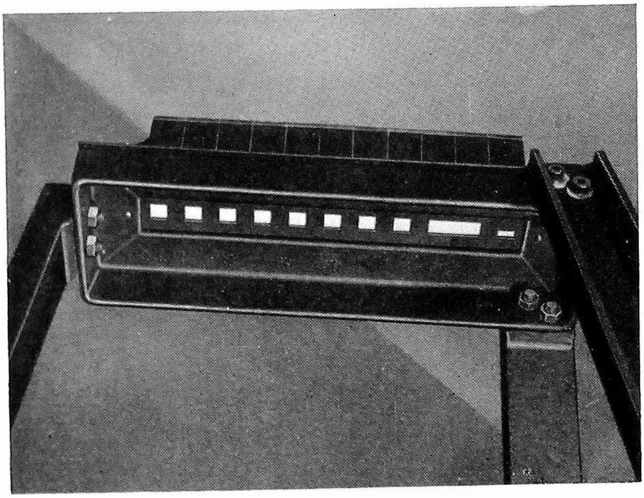

Fig. 10. Code lights

spreading of light from one square to the next. The glasses were recessed into their respective boxes so that no light escaped from the edges.

The camera lens used was a TTH Ental 50 mm f/3·5. This fitted into a simple brass focusing mount provided with an engraved scale.

SETTING-UP AND PRELIMINARY TESTS

The first essential was to adjust the plate holder until the emulsion surface was exactly perpendicular to the axis of rotation of the dividing table. Any error in this respect would result in a change of focus, as the point of the emulsion immediately below the lens would rise and fall as the plate was rotated. It was proposed to use the TTH Ental at about f/5. On a simple geometrical theory the diameter of the circle of confusion from a point object is one-fifth of the discrepancy in focus position at this f/No. Some early considerations had shown that the order of circle of confusion diameter which could be tolerated was 1/270th mm. (This was based on an accuracy of 10 seconds arc at 3 inches radius.) Thus the permitted focus tolerance was 5/270 mm or approximately 0·0007 inches.

A dial gauge was selected as the most convenient instrument for measuring these errors in plate position. It was clamped to the lens bridge with its point in contact with the plate at a radius exceeding 3 inches. The supporting screws of the plate holder were adjusted until the dial gauge reading remained constant to within ± 0·0001 inch when the dividing table was rotated through a complete 360°.

The lens bracket was adjusted until a specific square in the code light array (that corresponding to 2° in the binary code) was on the axis of the lens. This condition held when the row of images formed by multiple reflections within the lens was collinear.

The final adjustment was to set to a predetermined value the distance between the image of the code light array and the centre of rotation, i.e. the radius of the required digital disc. The following procedure was adopted. A sheet of paper was clamped in the plate holder and a circle drawn on it by rotating the OMT table while a fixed pencil (clamped to the lens bridge) was held in contact with the paper. The centre of this circle was determined by geometrical construction and about this centre a new circle of the required radius was drawn with a pair of compasses. A radius was also drawn. The OMT table was then moved (translated as well as rotated) until the image of the row of code lights fell along this radial line and at the required distance from the centre. For the first disc a radius of 2¾ inches was chosen for the extreme outer edge of the image.

The photographic emulsion used for all this work was the Kodak Maximum Resolution (MR) emulsion. This type of plate has an almost grainless emulsion of the Lippmann type and the emulsion layer is very thin. Although handled and processed in the same manner as an ordinary hotographic plate, it possesses remarkably high resolving power which, or practical purposes, is limited mainly by the optical apparatus used. Vith suitable equipment a resolving power of 1,000 lines/mm. is obtainable J.Sci.Inst.18, April 1941). It is recommended for very high resolution hotography, for the production of graticules and for X-ray micrography. he plate is sensitive to ultra-violet, blue and green and cuts off at pproximately 580 mμ. The speed is about one-twentieth of the working peed to tungsten light of a chloride lantern plate. Owing to the extremely ne-grain emulsion, the plate is necessarily slow, but when used for making hotographic graticules, the speed compares very favourably with other naterials which have considerably coarser grain. Kodak recommend the se of a Wratton No. 8 yellow filter when work of the highest definition s required. This filter was used throughout the work described in this rticle. It transmits red, orange, yellow and green and cuts off at approximately 460 mμ. Thus the actual band of wavelengths used extended from 60 mμ to 580 mμ. The developer used was that recommended by the nanufacturers—Kodak formula D.178.

The first photographic tests were naturally aimed at determining a uitable exposure. After several trial quarter plates, a value of 9 seconds vas decided upon and used for the first few discs. Recommended development times were used throughout the work (four minutes at 68°F).

For focus tests a fine wire (40 SWG) was stretched across the code ghts and a series of nine second exposures made at slightly different focus ettings. A fine focus run was then made on a 10 inches by 8 inches plate t four points at 90° intervals. This served as a critical check on the djustment of the plate holder made with the aid of a dial gauge.

The first digital disc to be attempted required a total of 256 exposures. hese were to occur on the plate at equal intervals of the sine of the angle f rotation, i.e, the angular settings of the dividing table were $\sin - 1\,\frac{N}{64}$ here N = 1, 2, 3, etc. up to 64. It was found possible to make one exposure very twenty-five seconds—nine seconds of actual exposure and sixteen econds occupied in reading the numerical indicator tubes and setting the ividing table. This was the maximum rate of working and could not be naintained continuously throughout 256 exposures. Approximately two ours were needed to expose a complete disc. Fig. 11 shows a completed disc.

EASUREMENT OF DISCS

he fact that photographic emulsions swell when wetted and shrink on rying suggests that the angular accuracy of a disc may suffer during rocessing. Thus some method of measuring the finished masters is very esirable. The obvious method is to replace the finished disc in the plate older, place it on the dividing table and view the photographic images

Fig. 11. Completed disc

with a fixed microscope. However, readings obtained in this way would only represent the true angular positions of the images if the centre of the digital pattern coincided with the axis of the dividing table. This, of course, is true during the exposing part of the process but it is not necessarily true after the plate has been removed for processing and replaced.

Instead of attempting to centre the disc very accurately ($\pm$ 0·0003 inch) a decision was made to centre it roughly and to eliminate errors in measurement due to de-centring by a mathematical method.

In Fig. 12 O represents the centre of rotation of the dividing table during measurement. Suppose a microscope is fixed at a radius R from the centre

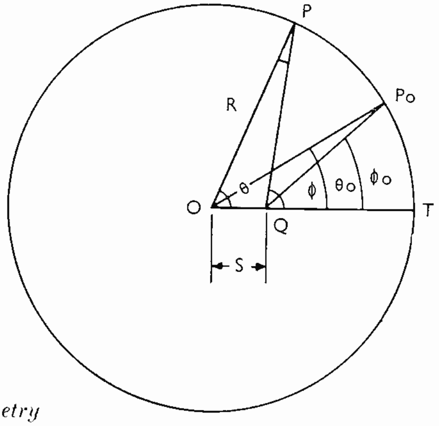

Fig. 12. Off-centre geometry

. Let P be any point on the disc, P_0 a reference point on the disc (in practice the position of the first exposure).

T is a distance R from 0 on the line joining 0 to the true centre Q of the digital pattern. It will be appreciated that although P, P_0 and T are not all at the same radius with respect to the pattern, they are all points which can be brought under the microscope by rotation of the dividing table since they are all equidistant from 0. Other distances and angles are indicated in the figure.

$$\text{In } \Delta\,\text{POQ} \quad \frac{S}{\sin(\phi - \theta)} = \frac{R}{\sin\phi}$$

$$\text{In } \Delta\,\text{P}_0\text{OQ} \quad \frac{S}{\sin(\phi_0 - \theta_0)} = \frac{R}{\sin\phi_0}$$

By rough centring, S can be made small with respect to R

Therefore $$\phi - \theta = (S/R)\sin\phi$$

Approx.

$$\phi_0 - \theta_0 = (S/R)\sin\phi_0$$

Subtracting and rearranging:

$$(\phi - \phi_0) - (\theta - \theta_0) = (S/R)\sin\phi - (S/R)\sin\phi_0 \quad (1)$$

The quantities $\phi - \phi_0$ and $\theta - \theta_0$ can be determined without knowing the position of the line of centres. Let $(\phi - \phi_0) - (\theta - \theta_0) = \varepsilon$. Then ε is the error arising from de-centring. Let $\phi - \phi_0 = I$ (this is the angle actually set on the scale when a disc is being made).

Therefore $\phi = I + \phi_0$

and $\varepsilon = (S/R)\sin(I + \phi_0) - (S/R)\sin\phi_0$

Thus if we plot I against ε we should obtain a sine wave of amplitude S/R, phase ϕ_0 and shifted vertically by a distance $-(S/R)\sin\phi_0$. Any departure from this sine wave will represent errors which are not caused by de-centring.

In practice measurements were made at a small number of points round the disc. Fig. 13 is a photograph of the set-up used for this. The small lamp and sheet of white paper which can be seen underneath the disc were for the purpose of providing illumination for the viewing microscope. The latter was equipped with a 16 mm. Apochromatic objective and a X10 Ramsden eyepiece giving an overall magnification of about × 100. The repeatability of setting was tested by making 120 readings on the same point. A standard deviation of 2·5 seconds arc was obtained.

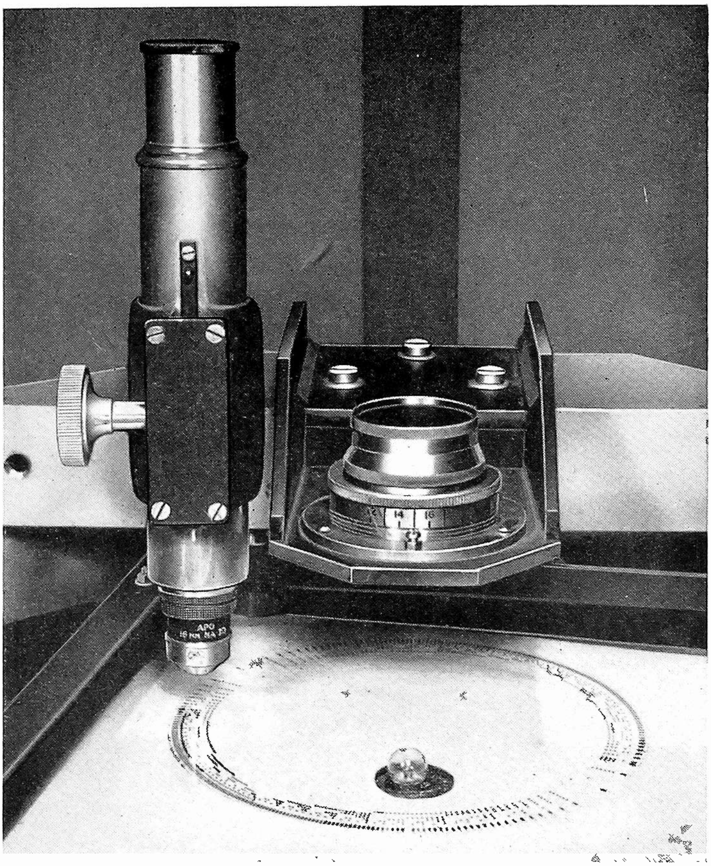

Fig. 13. Microscope arrangement

We have shown that for a decentred (but otherwise perfect) disc the true errors should lie on a curve of the form:

$$\bar{\varepsilon} = A \sin (I + \phi_0) + K$$

Here $\bar{\varepsilon}$ represents the ideal value.
Let ε represent the measured value.

$$\text{Then } \bar{\varepsilon} - \varepsilon = A \sin (I + \phi_0) + (K - \varepsilon)$$

Therefore

$$\sum_1^N (\bar{\varepsilon} - \varepsilon)^2 = \sum_1^N \left[A^2 \sin^2 (I + \phi_0) + 2A (K - \varepsilon) \sin (I + \phi_0) + (K - \varepsilon)^2 \right]$$

where N is the number of readings.

This is the sum of the squares of the deviations of the actual readings from the ideal. By differentiating with respect to A, ϕ_0 and K in turn and quating the derivatives to zero, we obtain three equations which can be lved for A, ϕ_0 and K. The values obtained are those that make

$$\sum_{1}^{N} (\bar{\varepsilon} - \varepsilon)^2 \text{ a minimum.}$$

A further simplication can be effected by choosing the values of I at hich measurements are taken so that certain constants vanish.

It can be shown by the above process that the sine wave of best fit is iven by:

$$A = \beta \frac{c_2}{\sin \phi_0}, \qquad K = \frac{d_1}{N}, \qquad \tan \phi_0 = \alpha \frac{c_2}{c_1}$$

here

$$\alpha = \frac{N - a_1}{N + a_1}, \qquad \beta = \frac{2}{N + a_1}, \qquad a_1 = \sum_{1}^{N} \cos 2I$$

$$c_1 = \sum_{1}^{N} \varepsilon \sin I, \qquad c_2 = \sum_{1}^{N} \varepsilon \cos I, \qquad d_1 = \sum_{1}^{N} \varepsilon$$

Most of the constants in these equations can be calculated once and for l (for this type of disc) since they are not functions of the errors. For ach disc which is measured we only have to calculate c_1, c_2, and d_1. The ethod of least squares has the advantage of giving a unique set of values o the constants A_1 K_1 ϕ_0. Moreover, the constants determined by this ethod give the most probable equation for $\bar{\varepsilon}$ in the sense that $\bar{\varepsilon}$ values omputed from it are the most probable values of the observations, it eing assumed that the residuals follow the Gaussian law of error. In short e principle of least squares asserts that the best representative curve is at for which the sum of the squares of the residuals is a minimum.

In an actual case the greatest errors were + 10 seconds and — 6 seconds, e RMS value of all the errors being less than 5 seconds. It will be recalled at a standard deviation of 2·5 seconds of arc was obtained for 120 settings f the dividing table on one point viewed through a microscope. Thus it ppears that the accuracy of disc production is close to the limit of ccuracy of the dividing table, although there is still room for a little mprovement.

ONTACT PRINTING

The master discs, made as described, were then contact printed on to imilar plates. From micrographs it has been shown that there is no perceptible loss of sharpness arising from the printing process. The master was held in contact with an unexposed plate by means of the plate holder used for making the master. With about 3 foot-candles of illumination (tungsten light) an exposure of two minutes was quite satisfactory. Measurements were made on the print by the technique described in the previous section and an RMS error of 5·0 seconds is obtained. This cannot be considered a significant increase over the errors of the master.

RESOLUTION TESTS

Some experiments were made to determine the limiting resolution of the optical system used in conjunction with the MR emulsion.

A high contrast Sayce chart was placed over one of the code lights and photographed by the system in the usual way. Some extra fine focus and exposure runs were made in order to achieve the very best possible result. The image which appeared on the plate was studied with a microscope and showed that the limit of the system was approximately 330 lines per mm.

This limit is not of course due to the emulsion (it has already been stated that 1,000 lines/mm. is possible on an MR plate). The factors determining the limit in this case are lens aberrations and diffraction by the lens aperture. In this connection it is instructive to calculate the magnitude of the diffraction effects since the phenomenon lends normally to an absolute theoretical limit.

The classical theory of diffraction shows that the brightness distribution in the neighbourhood of the image of a point source formed by an aberrationless lens limited by a circular step is given by:

$$I = \text{const. } x \, \frac{J^2{}_1(z)}{x^2}$$

where J_1 is a Bessel function of order 1.

$$z = \frac{\pi D \, . \sin \theta}{\lambda} \quad \text{where } D = \text{diameter of circular aperture}$$

θ = angular distance of point considered from geometrical centre of image.

λ = wavelength of light used.

It has been stated by Lord Rayleigh (see Scientific Papers Vol. 1, pp. 415-423) that two points may be considered to be just resolved when the central maximum of one image falls on the first minimum of the other. The first zero of $J_1(z)$ occurs at $z = 3{\cdot}83$ giving:

$$\sin \theta = \frac{3{\cdot}83\lambda}{\pi D} = \frac{1{\cdot}22\lambda}{D}$$

In the case here considered:

$D = 9{\cdot}94$ mm. The range of wavelengths used extended from 0·46μ to 58μ. Taking $\lambda = 0{\cdot}52\mu$ we obtain 3·24μ as the distance in the focal ane between the images of two points which are just resolved according the Rayleigh criterion.

We would expect therefore an upper resolution limit of

$$\frac{10^3}{3{\cdot}24} = 309 \text{ lines per mm.}$$

It has been shown that 330 lines/mm. has been achieved. There are veral explanations of this apparent contradiction of the theory.

(i) The relative effect of each wavelength within 0·46-0·58μ band is not known. It may well be that a shorter wavelength than 0·52μ (the mean) is dominant in the formation of the photographic image. The theoretical limit for the shortest wavelength used is 350 lines/mm.

(ii) The above theory refers to points. The case of parallel lines is considerably more difficult to treat. Rayleigh says " The character of the image of a luminous line cannot be immediately deduced from that of a luminous point. It has, however, been investigated by M. Andre, who finds that the first minimum of illumination occurs at a somewhat lower obliquity (smaller θ) than in the case of a point. A double line is therefore probably more easily resolvable than a double point."

(iii) The Rayleigh criterion itself is partly a convenience. It can be shown very easily that for two images separated by a distance Δ, the ratio of the peak intensity to the minimum midway between them is:

$$Y(\Delta) = \frac{\Delta^2 + 4\,J_1^2(\Delta)}{32\,J_1^2(1/2\ \Delta)} \tag{5}$$

The value of $Y(\Delta)$ for $\Delta = 3{\cdot}83$ (the Rayleigh limit) is 1·36. The minimum between the two peaks does not completely disappear ($Y(\Delta) = 1$) until $\Delta = 3{\cdot}14$.

Using the extreme criterion $Y(\Delta) = 1$ we obtain a limiting resolution of 2·66μ corresponding to 376 lines/mm. (for $\lambda = 0{\cdot}52\mu$).

(iv) The Rayleigh criterion concerning the minimum resolvable distance is intended to be applied to visual phenomena. In this work we are concerned with photographic resolution and the contrast increasing properties of the MR emulsion must be taken into account.

The gamma of the MR emulsion when processed in the normal way is 5.

This exceedingly high value means that with a suitably chosen exposure, small brightness differences appear as large density differences on the developed plate. Thus the (photographic) value of Y (Δ) is greatly increased, and consequently the two points whose resolution we are considering can be moved closer together before they become indistinguishable. A mathematical treatment of this effect shows that a limit of 359 lines/mm. is more realistic in the photographic case.

References

1 R. H. Barker: A Transducer for Digital Data Transmission Systems. *Proc.I.E.E.*, 1956 103, Pt. B, p. 42.

BOOK REVIEW

HIGH QUALITY SOUND REPRODUCTION

by J. Moir. Chapman and Hall. Price 70s.

As befits a book in the Publishers' series of Advanced Engineering Textbooks the subject matter is dealt with as an engineering problem without any concessions to "hi-fi cult." The author, a sound film equipment engineer, has extended his interest to high quality reproduction in the home and a most informative and readable book results. The characteristics of music, speech and noise are discussed in relation to those of the ear; realistic performance specifications are suggested based upon a critical appreciation of various listening tests, and the author's observations: his comment, written before the current boom in stereo reproduction, that the use of monaural systems is the chief reason for a preference for reduced loudness and a very important factor leading to a preference for restricting frequency range, will be readily appreciated by those now accustomed to the newer instruments.

The components of the reproducer system are then treated in turn, more stress being laid upon performance characteristics than details of design which are the province of the specialist. This balance is most clear in the chapter on loudspeakers where considerable space has been devoted to mountings and enclosures, and very little to the component itself; in the case of microphones and pick-ups (not mentioned in the index) the component is dealt with in great detail however. A chapter is devoted to the often neglected acoustic problem of the listening room and indicates what can be done in the home to improve overall performance without too much disturbance to domestic requirements; these considerations apply with even greater force to a stereo installation. Reproduction from records and tape is covered in separate chapters, another related to sound reproduction in the cinema is of more direct interest to the professional.

About one-third of the work is devoted to the electronic requirements, very full design information being given for voltage and power amplifiers, rectifiers and feedback requirements, as well as tone control, dividing and mixing methods.

The last chapter is devoted to stereophonic sound reproduction. This technique brings into play other characteristics of the ear with the result that loudness and frequency response both depart from values acceptable for monaural listening.

The printing, layout, diagrams and illustrations are excellent; appendices, suggestions for further reading and references follow the chapters to which they refer. For a book o this size and content the index is hardly adequate.

HIGH Q WAVEMETER DESIGN

By. E. F. GOODENOUGH, B.Sc. (Eng)

n the development and operation of microwave systems it is sometimes esirable to have available means for measuring not only the principal equency of a transmitter, but also deviations therefrom, arising, for example, om lack of frequency stabilization or from purposeful frequency modulation. uch a device should be convenient and simple to use, and the simplest is ndoubtedly a cavity resonator. The design of an instrument that will fulfil e requirements is, however, fraught with difficulties, especially at ultra-high equencies. The purpose of this article is to explain the design of a wavemeter aving a frequency discrimination better than 1/35,000 Mc/s at Q-band.*

esonator Design

is clearly desirable that the operating Q of the cavity should be of the rder of the inverse of the discrimination required; hence the unloaded Q the cavity should be about twice that, viz. 70,000. As is well known, e H_{01} mode in a cylindrical cavity has the lowest losses and is also the ost convenient because there are no longitudinal currents in the walls d hence no contact difficulties arising from the adjustable piston. here is, of course, the well-known difficulty in this type of cavity, that avoiding spurious responses of the meter due to resonances at other odes, but first one must decide on the shape and size of the cavity to ve the required Q value.

The formula for the Q of a cavity given in the literature is not particurly helpful in the form in which it is presented, but it may be made uch clearer by rearrangement (Appendix 1) from which the curves of ig. 1 have been constructed. These are in terms of the parameter $Q\delta/\lambda =$ nstant for length against diameter of the cavity, where δ, the equivalent pth of current penetration into the metal surface at wavelength λ (cm), r copper is $3{\cdot}8\sqrt{\lambda} \times 10^{-5}$. Thus, the minimum value of the parameter δ/λ to give a Q of 70,000 at $\lambda = 0{\cdot}86$ cm is about 3.

As well as giving information about Q values and dimensions, Fig. 1 so shows the possibility of higher circular modes that must be rigorously voided. Thus, for $Q\delta/\lambda = 3$ the diameter D is between $2{\cdot}5\lambda$ and 3λ and e H_{02} mode is possible in addition to the H_{01}. The excitation of the anted mode alone is discussed below.

Before the final dimensions of the resonator can be chosen, there is a rther factor to be taken into consideration, viz. the dial discrimination. his should be of the same order as the minimum frequency discrimination

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British Patent No. 711,378 (1951)

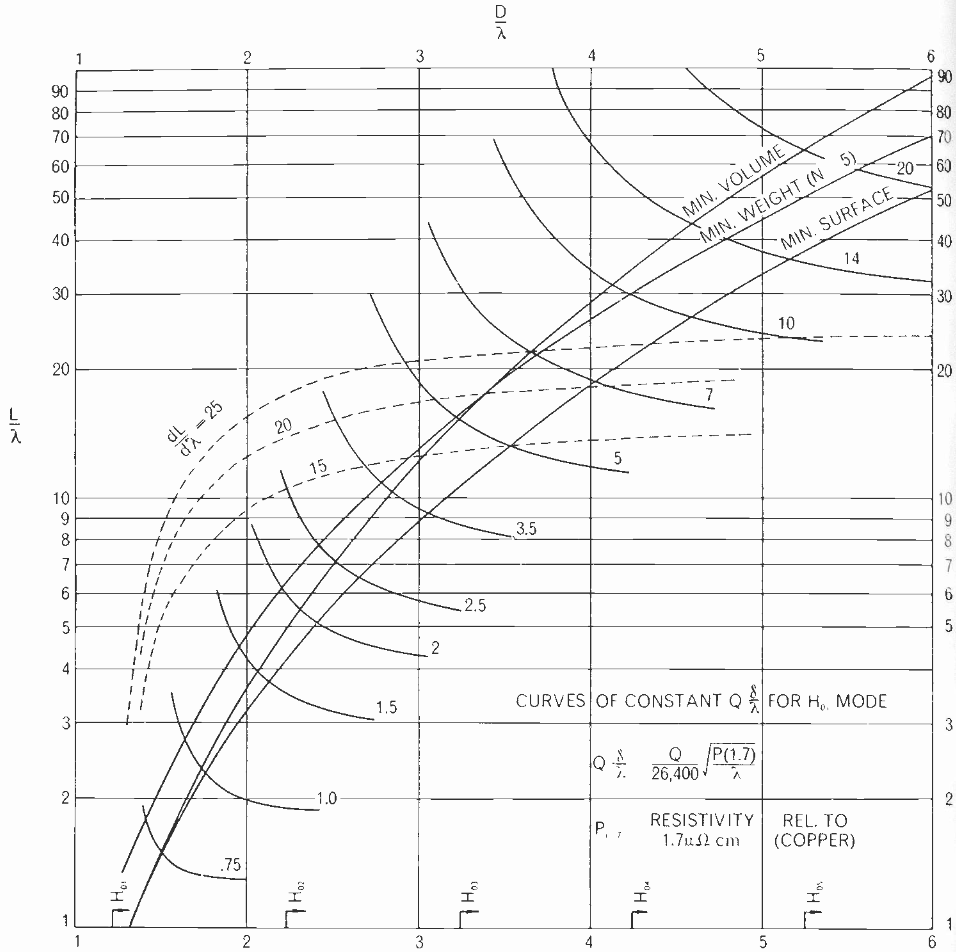

Fig. 1. Curves of Constant $Q\frac{\delta}{2}$ *for* H_1 *Mode*

required, but is a matter of practical compromise, limited by the mechanics of the tuning mechanism. The simplest tuner is a piston moved on a thread with a micrometer dial, which can give about 4-5,000 divisions per inch of movement. The conditions for this order of dial discrimination are easily calculated (Appendix 2) and are plotted on Fig. 1.

The curves of Fig. 1 show that if the Q is limited to $Q\delta/\lambda = 3$ the required dial discrimination can be obtained with a comparatively long narrow resonator. They also show that, if the diameter be increased from say 2·30λ to 3·20λ and the length remains at 18λ, the Q of the cavity is nearly doubled.

The relative diameter can be increased further, if desired, without loss of dial discrimination, but is open to two serious objections:

(1) The H_{03} mode becomes possible and, as will be shown later, this is more difficult to avoid than the H_{02}.

) The electrical discrimination becomes so high relative to the dial scrimination that tuning is difficult.

Thus, a practical limit is in the region of $D = 3\lambda$, $L = 18\lambda$, $Q\delta/\lambda = 5$, e exact dimensions being finally chosen to give an optimum dial libration, say 1 Mc/s per division at the middle of the frequency range. nce the dial discrimination, Mc/s per division, is roughly proportional to equency, it is not constant over the tuning range.

As a further check on the suitability of dimensions, curves of minimum lume and of minimum surface area are shown in Fig. 1. Also shown is a rve of dimensions for minimum relative weight for a resonator whose ds have a mean thickness five times, for example, the wall thickness (see ppendix 1). They are a guide to the economical use of space or weight. the example quoted above, there should be ample Q to allow the use of uminium instead of copper, thus saving weight. The Q value obtained, duced in the ratio of the square roots of resistivity of copper to that of uminium, would be about 22% lower, and still achieve a Q of 90,000 at 8 mm wavelength.

xcitation of the Cavity

agnetic coupling is usually the more convenient method of exciting a vity, particularly at very high frequencies, since it is effected by simple les. The magnitude of coupling may be varied, in general by the size of e holes. Their position is, however, of profound importance as is their umber and relative phase.

Holes have maximum coupling to a particular mode in the cavity if ey are located in a position of maximum wall current characteristic of at mode, and zero coupling if the mode wall current is zero. Thus a hole a cavity wall will provide coupling to every mode that causes sufficient rrent to flow at that point. It is, sometimes, possible to achieve eferential excitation of a mode by the use of more than one hole, so ranged and phased that they all contribute to the required mode but ncel one another out for other modes. If it is possible to use a large umber of holes that all contribute to the wanted mode, it may be ranged that the other modes to which they could couple are too complex r the resonator to support them and thus unwanted resonances are oided.

It is difficult to provide for more than two holes at most for exciting a vity directly from a waveguide, but the number of unwanted modes is nsiderably reduced in a cavity that is only just large enough to carry e wanted mode, especially if it is only half a wavelength long so that the equency spacing between the wanted and unwanted modes is so large at the unwanted modes can be kept outside the frequency range it is quired to cover.

Thus, in exciting a clean H_{01} mode in a cavity that can support an H_0 circular mode as well as numerous others, the following features must b incorporated.

(1) Excite a pure H_{01} mode in a primary cavity that can be easily couple to a waveguide by a single aperture. The loaded Q of this cavity can b relatively low.

(2) Couple the H_{01} mode in this cavity to the H_{01} mode in a high (secondary cavity without exciting the H_{02} mode by locating the couplin in a region of maximum H_{01} current and zero H_{02} current.

(3) Use sufficient equally spaced coupling holes to ensure that th longitudinal mode they excite is more complex than the highest the cavit will support.

The two cavities are essentially coaxial and are separated by a meta diaphragm in which the coupling holes are drilled. The optimum locatio of these holes is determined by reference to the formula for the current i the diaphragm. Thus the circular current is given in terms of Besse functions, viz. for H_{lmn} modes,

$$H_r = \frac{k_3}{k} J_l'(k_1 r) \cos l\theta$$

and for the radial current by

$$H_\theta = -l \frac{k_3}{k} \frac{J_l(k_1 r)}{k_1 r} \sin l\theta$$

For E_{lmn} modes

$$H_r = -l \frac{J_l(k_1 r)}{k_1 r} \sin l\theta$$

$$H_\theta = -J'_l(k_1 r) \cos l\theta$$

where

$$k_1 = 2\,x_{lm}/D = 2\pi/\lambda_c$$
$$k_3 = n\pi/L = 2\pi n/\lambda_g$$
$$k = k_1^2 + k_3^2$$
$$x_{lm} = \text{roots of } J_l(x) \text{ and } J'_l(x)$$

Thus for the circular current of the H_{om} mode,

$$H_r = \frac{n\pi/L}{((2x_{om}/D)^2 + (n\pi/L)^2)^{1/2}} J'_o\left(\frac{2r}{D} x_{om}\right)$$

and for the radial current, $H_\theta = 0$

Ignoring the first term of H_r, the amplitude varies with r according t $J'_o\,(2r\,x_{om}/D)$, where $x_{01} = 3{\cdot}83$, $x_{02} = 7{\cdot}016$, $H_{03} = 10{\cdot}174$, etc. Tl general shapes of these quantities are plotted in Fig. 2, which shows tha where a cylindrical cavity is large enough to carry an H_{02} mode as well a

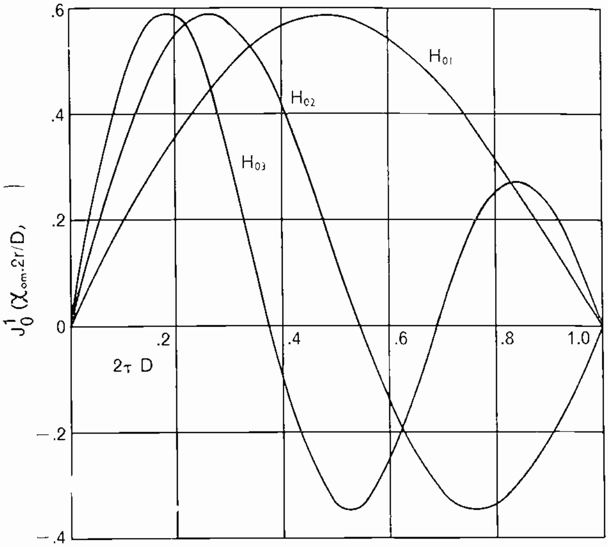

Fig. 2. Current Distribution in Ends of Resonator for H_{OM} Modes

$_1$, i.e, $D > 7{\cdot}016\lambda/\pi$, the current due to the H_{02} mode is zero at $= 0{\cdot}547D$ ($= 3{\cdot}83D/7{\cdot}016$), and the H_{01} mode current is large. is then is the radius at which a pure H_{01} mode in one cavity may be upled into another larger cavity without producing an H_{02} mode.

A larger cavity, where $D > 10{\cdot}174\lambda$, would also carry an H_{03} mode with ros at $2r = 0{\cdot}376D$ and $2r = 0{\cdot}69D$. But these radii also correspond to ge values of the currents due to the H_{02} mode, albeit these are in opposite rections. Excitation of the H_{02} mode can theoretically be avoided by aking the two couplings equal. In practice this can be done experi- entally. The condition, however, is not only critical but also involves e use of a driving cavity having a larger diameter, with consequent loss band width for the pure H_{01} mode. Hence, unless a much higher Q is quired, a larger diameter than that which just fails to support an H_{03} ode, say $D/\lambda = 3{\cdot}2$, is not justified.

Since the driving cavity provides a reasonably pure circular driving rrent, coupling radial current is unlikely. There is, however, the possi- ity of coupling to H_{l1} modes having circular components of current, here l = the number of coupling holes. For example, if $D/\lambda = 3{\cdot}2$ and ere are eight coupling holes, the H_{81} mode could be excited since the nimum diameter for that mode is $D = 3{\cdot}07\lambda$ since, $x_{81} = 9{\cdot}65$. A upling comprising nine or more holes is therefore required.

e Primary Resonator

s stated above, this primary resonator should be dimensioned so that ly the H_{011} mode resonates over the frequency band required. It is

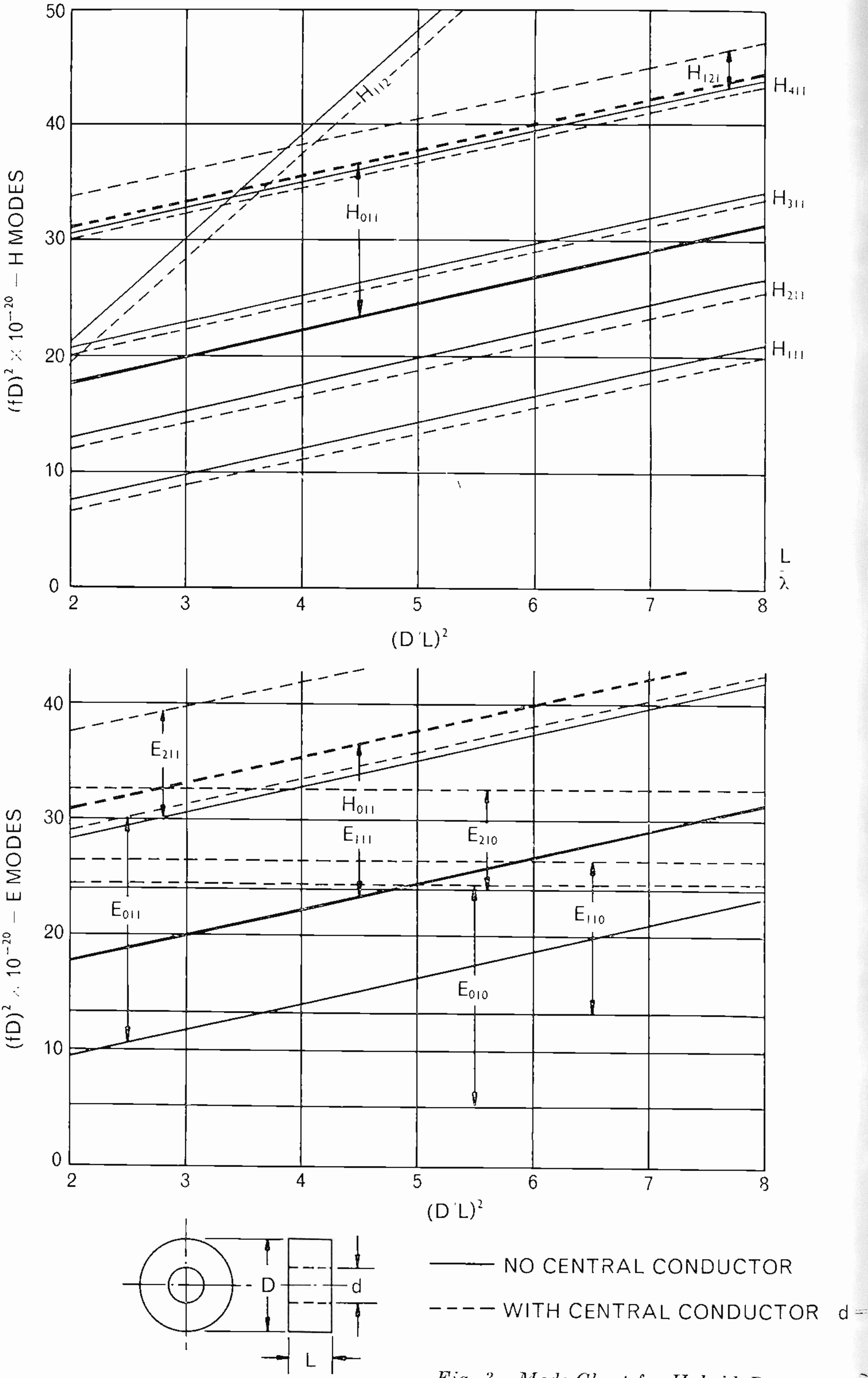

Fig. 3. Mode Chart for Hybrid Resonator

ecessary, however, to make its diameter large enough to embrace the upling holes to the secondary resonator. Thus, if the latter has a ameter given by $D/\lambda = 3$ say, and the coupling holes lie on a diameter 55D, the diameter of the primary radiator is $> 1{\cdot}65\ D/\lambda$.

Ease of tuning is most desirable in this resonator as it provides the itial meter response on which the secondary high Q cavity response is perimposed. The requirements are therefore a low Q and a large dial ovement. The low Q can be provided by tight coupling to the input and tput waveguides (in the case of a transmission type wavemeter). The al movement for an H_{011} mode is small in the case of a plain cylindrical vity. It may be increased however by using a hybrid type of resonator, which a comparatively thin concentric cylindrical post is the tuning ement. The propagation constant of the resonator is changed by the esence of the post to a degree depending on the diameter of the post.

Thus it is possible to choose a size of post such that, when fully in, the sonator tunes to one end of the band (viz. the high frequency end), and lly out, to the other end of the band. This gives the greatest possible ning discrimination of the primary cavity.

The presence of the post modifies the factor k_l and the modified values x_{lm} for various ratios of post diameter to cylinder diameter have been rked out by Kinzer and quoted in Montgomery(1). Charts for the propriate modes are shown in Fig. 3 which shows the range limits for e post fully in and fully out. H modes and E modes are shown separately r clarity. The H modes, with the exception of the H_{01} mode, are not anged appreciably by the post, but the E modes are seen to be very nsitive to it.

Since the coupling to the circular H_{01} mode is required to be high, the aveguide connection is made near midway between the ends of the linder with the broad face of the guide parallel to the axis. In this sition, coupling to the longitudinal modes would be expected to be nall. Nevertheless, a spurious mode is liable to arise in practice which is splaced from the H_{01} mode setting by a constant dial distance but which uples only weakly to the high Q resonator. This is probably the E_{11} ode which has the same propagation constant as the H_{01} mode for the post lly in or fully out. The hybrid resonances, with the post partly in, differ ightly however. This difference is affected by the shape of the end of the ost, e.g. square or tapered. It may also be increased by a small cylindrical pression in the centre of the diaphragm separating the two resonators d the spurious resonance suppressed to negligible proportions by the sertion of a piece of 200 ohm resistance card in the depression. This has effect on the H_{01} mode. The low Q resonator is most conveniently librated against a standard wavemeter anyway, as calculation of the sonance condition of the hybrid resonator, with post partly in, is not practicable. Spurious resonances of short range, or, at " spot " frequencie due to other H modes such as H_{311}, H_{411} and H_{112}, are avoided by choice o D and of D/L (see Fig. 3).

Coupling between Resonators

If the low Q cavity is used as a transmission resonator, resonance of the high Q cavity is shown as a reduction in the output, the extent of tha reduction being dependent on the amount of coupling between th resonators. With small coupling, the " dip " is small and sharp and may be difficult to find. With too much coupling the " dip " is large and therefore easy to find, but it may be so broad that the planned discrimination is lost. There is thus an optimum practical compromise, which turns out to be when the dip is about half the output power.

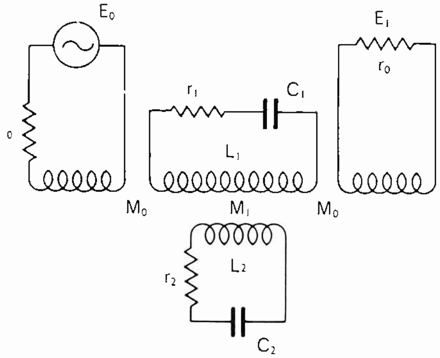

Fig. 4. Coupled Circuits

Consider the circuit shown in Fig. 4, in which two circuits $L_1C_1r_1$ an $L_2C_2r_2$ are coupled by mutual inductance M_1. Input and output circuits o impedance r_o are coupled by mutual inductances M_o to L_1. An input voltag E_o is applied in series with r_o of the input circuit and an output voltage E appears across the output resistance.

It may be shown that

$$E_1 = E_o \Big/ \left[2 + \frac{r_1}{k^2{}_o r_o} (1 + jq_1) + \frac{k_1^{\,2}}{k^2{}_o} \frac{r_2}{r_o} \frac{1}{1 + jq_2} \right]$$

where $k_o = \omega M_o/r_o$ and $k_1 = \omega M_1/r_2$

$$q_1 = \frac{\omega L_1}{r_1} (1 - \frac{\omega^2{}_o}{\omega^2}) \qquad q_2 = \frac{\omega L_2}{r_2} (1 - \frac{\omega^2{}_o}{\omega^2})$$

$$\fallingdotseq Q_1 \frac{2(f - f_o)}{f} \qquad \fallingdotseq Q_2 \frac{2(f - f_o)}{f}$$

$$\omega^2{}_o = \frac{1}{L_1C_1} = \frac{1}{L_2C_2}$$

If $Q_2 \gg Q_1$ and $r_1 \gg 2\, k_o^2\, r_o$ as will be the case in the wavemeter being onsidered, the formula may be simplified to

$$E_1 = \frac{E_o/2}{1 + \dfrac{A}{1 + jq}}$$

here the effective coupling factor between the tuned circuits

$$A = k^2{}_1\, r_2/2\, k^2{}_o\, r_o \text{ and } q \equiv q_2.$$

In practice, however, a crystal detector is usually used as an output oad, giving a reading proportional to power, i.e.

$$P_1 \propto E_1{}^2 \propto \left(\frac{E_o}{2}\right)^2 \frac{1 + q^2}{(1 + A)^2 + q^2}$$

When the high Q circuit is a long way off tune, q is very large and $_1 \propto (E_o/2)^2 = 1$ say; in tune, $q = 0$ and $P_1 = 1/(1 + A)^2 = P_o$. Thus r other values of q, by substituting for $(1 + A)^2$ we have

$$P_1 = \frac{1 + q^2}{1/P_o + q^2}$$

A family of curves for various values of P_o is shown in Fig. 5 for P_1 gainst q. The criterion of sensitivity is the magnitude of the power change r a given frequency change from resonance, say to $q = 1$. The curves ow that, with this criterion in mind, the value of A should be such that $_o$ is between about 0·25 and 0·6 with an optimum at about 0·4. If the

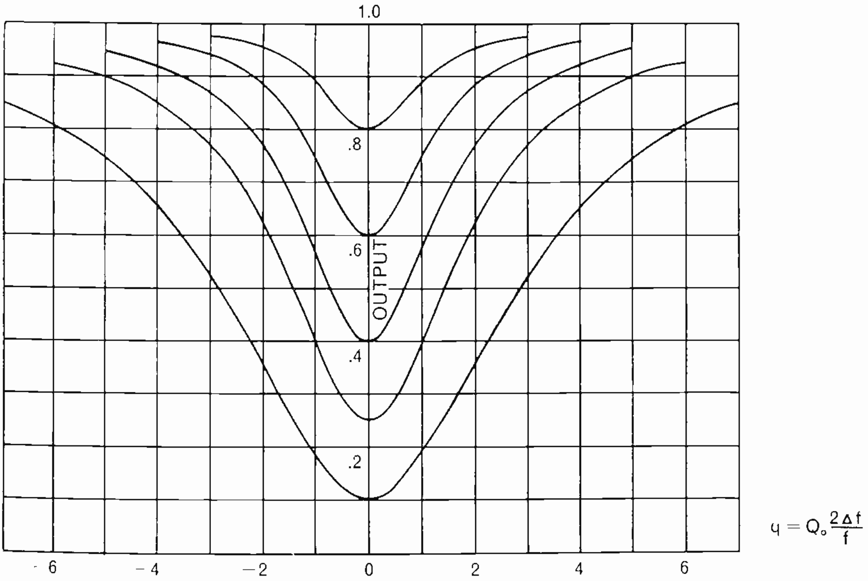

Fig. 5. Output Power Variation for Various Degrees of Inter-Cavity Coupling

apparent Q is given by the frequency bandwidth at which the “ dip ” is halved we have from consideration of the dip amplitude $(1 - P_0)$ the following relationships:

$$1 - P_1 = \frac{1 - P_0}{1 + P_0 q^2} = \frac{1 - P_0}{2} = \frac{1 - P_0}{1 + \left[Q_{\text{app}}.\, \frac{2(f - f_0)}{f}\right]}$$

Hence
$$q^2 = \left[Q_2{}^2 \frac{(f - f_0)}{f}\right]^2 = 1/P_0$$

and
$$\left[Q_{\text{app}} \frac{2\,(f - f_0)}{f}\right]^2 = 1$$

giving
$$Q_{\text{app}} = Q_2 \sqrt{P_0}$$

Thus the apparent Q is higher as P_0 is increased. It is of little practica value, however, to obtain a larger apparent Q than that given by $P_0 = 0·$ since the power change is reduced in magnitude.

The unloaded Q of the resonator can be determined by measurin the bandwidth f_b at which $P_1 = \dfrac{2P_0}{1 + P_0}$ or $\dfrac{5P_0}{1 + 4P_0}$ when $Q_2 = f_0/f_b$, or $2f_0/f_b$ respectively. This follows from the equation fo P_1 above if q^2 is set at 1 or 2.

It is important to note that the magnitude and phase of the couplin between the two cavities is directly affected by the impedance matchin conditions at the input and output of the low Q transmission cavity since r_0 appears in the expression for the coupling factor A. Thus to avoi under or over coupling, the oscillator should be padded with an attenuat and the detector or output circuit reasonably well matched. This als avoids errors in the frequency calibration of the wavemeter, due to reactive load, although the low Q portion is more likely to be affected tha the high because it is so tightly coupled to the external circuits.

With no padding, the source oscillator is likely to be affected by tunin the wavemeter and this likelihood increases with the amount of couplin between the resonators. It may be shown that, if the resistance of the lo Q resonator itself be neglected, the input impedance is given, at resonanc by:

$$Z = 1/(1 + 2A)$$

The power reflected is

$$P_r = \left(\frac{1 - Z}{1 + Z}\right)^2 = \frac{A^2}{(1 + A)^2}$$

t $P_o = 1/(1 + A)^2$

erefore $P_r = P_o\,(1/\sqrt{P_o} - 1)^2 = (1 - \sqrt{P_o})^2$

$= 0{\cdot}25 \text{ at } P_o = 0{\cdot}25$

d

$= 0{\cdot}04 \text{ at } P_o = 0{\cdot}64$

us from the point of view of mismatching the input of the wavemeter,
s better to under-couple the high Q resonator.

actical Realization

e principles described above have been applied in the Marconi Instru-
nt Wavemeter, Model T, shown in Fig. 6, the mechanical design of
ich is due to Mr. G. T. M. Carman of Marconi Instruments. This
trument covers a frequency range of almost 33,000 to 36,000 KMc/s.
e high Q resonator has an unloaded Q of over 70,000 although the
trument is made of aluminium to keep down its weight. The effective
f the primary resonator is a mere 200. To achieve this low value, the
ut and output waveguides are connected to the resonator coupling
es by polystyrene-filled waveguide sections.

bliography

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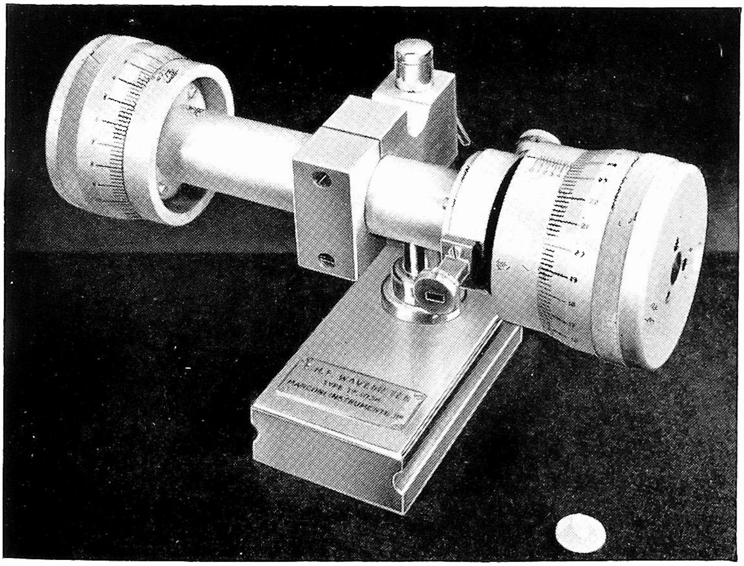

Fig. 6.

APPENDIX 1

The general formulae for the Q of a cylindrical resonator of length L ar diameter D is given for the $\mathrm{H}_{l\mathrm{m}}$ modes as

$$2Q\frac{\delta}{\lambda} = \frac{1-\left(\frac{l}{x_{1,\mathrm{m}}}\right)^2}{\pi} \cdot \frac{\left[x_{1,\mathrm{m}}^{2} + \left(\frac{n\pi}{2}\right)^2\left(\frac{D}{L}\right)^3\right]^{3/2}}{x_{1,\mathrm{m}}^{2} + \left(\frac{n\pi}{2}\right)^2\left(\frac{D}{L}\right)^3 + \left(1-\frac{D}{L}\right)\left(\frac{nl\pi}{2x_{1,\mathrm{m}}}\cdot\frac{D}{L}\right)^2}$$

where δ = skin depth

$x_{1,\mathrm{m}}$ = the m^th^ root of $J'_{l}(x) = 0$

In the case to be considered $l = 0$, and

$$2Q\frac{\delta}{\lambda} = \frac{\pi\left[x^2 + \left(\frac{\pi n}{2}\right)^2\left(\frac{D}{L}\right)^2\right]^{3/2}}{\pi\left[x^2 + \left(\frac{\pi n}{2}\cdot\frac{D}{L}\right)^3\right]} \text{ where } x = x_{01} = 3{\cdot}83.$$

To put this in a more convenient form, divide top and bottom of t RHS by x^3 and multiply both sides by $\left(\frac{x}{\pi}\frac{\lambda}{D}\right)^3$, giving

$$2Q\frac{\delta}{\lambda}\cdot\left(\frac{x}{\pi}\right)^2\cdot\left(\frac{\lambda}{D}\right)^3 = \frac{\left[\left(\frac{x}{\pi}\cdot\frac{\lambda}{D}\right)^2 + \left(\frac{n}{2}\cdot\frac{\lambda}{L}\right)^2\right]^{3/2}}{1+\left(\frac{n}{2}\cdot\frac{\lambda}{L}\right)^2\cdot\left(\frac{\pi}{x}\cdot\frac{D}{\lambda}\right)^2\cdot\frac{D}{L}}$$

From the conditions for resonance

$$\left(\frac{x}{\pi}\cdot\frac{\lambda}{D}\right)^2 + \left(\frac{n}{2}\cdot\frac{\lambda}{L}\right)^2 = 1$$

Putting $$2Q\frac{\delta}{\lambda}\left(\frac{x}{\pi}\right)^2\cdot\left(\frac{\lambda}{D}\right)^3 = \frac{1}{X}$$

and $$\left(\frac{x}{\pi}\right)^2\cdot\left(\frac{\lambda}{D}\right)^2 = \frac{1}{Y}$$

and eliminating $\left(\frac{n}{2}\cdot\frac{\lambda}{L}\right)^2$ by means of (3) reduces (2) to

$$X = 1 + (Y-1)\,D/L$$

Rearranged, this becomes

$$L = D\,\frac{Y-1}{X-1}$$

In Fig. 1, L/λ is plotted against D/λ for different constant values λ. Although shown continuous, the curves are of course the loci of the rresponding values of D, L and λ which satisfy the resonance formula (3). The volume of the resonator is proportional to D^2L, i.e.

$$V \propto D^2 \frac{Y-1}{X-1} \qquad (7)$$

is is a minimum, at $Q\delta/\lambda$ = constant, when

$$\frac{Y-1}{X-1} = \frac{2}{3} Y \qquad (8)$$

ving the relationship between length and diameter for minimum volume

$$L_V = \frac{2}{3} D\, Y \qquad (9)$$

Of more practical value is the condition for the minimum amount of tal in the resonator and therefore the minimum weight. This is roughly ven by

$$W \propto \frac{N}{2} D^2 + D\,L \propto D^2\left(\frac{N}{2} + \frac{Y-1}{X-1}\right) \qquad (10)$$

where N = ratio of mean thickness of ends (piston etc) to wall thickness. is is a minimum (for $Q\delta/\lambda$ = constant) when

$$\frac{3\,(Y-1)}{(X-1)^2} - \frac{Y+1}{X-1} - N = 0$$

ving the relationship between length and diameter for minimum weight

$$L_W = (D/6)\left[Y + 1 + \left((Y+1)^2 + 12\,N\,(Y-1)\right)^{1/2}\right] \qquad (11)$$

This has been plotted on Fig. 1 for $N = 1$, corresponding to minimum rface area, and, as an example, for $N = 5$. These curves may be used as guide to the choice of optimum dimensions, but the minima are not very itical with respect to change of dimensions along a curve of constant δ/λ.

The quantity $Q\delta/\lambda$ is given a more practical significance if evaluated terms of a particular material, e.g. copper.

$$\text{Skin depth } \frac{\delta}{\lambda} = \left(\frac{\rho}{120\pi^2\lambda}\right)^{1/2} = \frac{1}{26{,}400}\left(\frac{\rho}{1{\cdot}7\lambda}\right)^{1/2}$$

here ρ = resistivity of the surface metal in microhms cm.

$$\text{Hence } Q\delta/\lambda = \frac{Q}{26{,}400}\left(\frac{\rho}{1{\cdot}7\lambda}\right)^{1/2} \qquad (12)$$

APPENDIX 2

The dial discrimination can be expressed in terms of $dL/d\lambda$ or $c.dL/d$ From equation (3) in Appendix 1,

$$\frac{1}{\lambda^2} = \left(\frac{n}{2L}\right)^2 + \left(\frac{x}{\pi D}\right)^2 \text{ at resonance.}$$

Differentiating,

$$-\frac{2d\lambda}{\lambda^3} = -\frac{2dL}{L^3}\left(\frac{n}{2}\right)^2$$

i.e

$$\frac{dL}{d\lambda} = \left(\frac{2L}{n\lambda}\right)^2 \cdot \frac{L}{\lambda}.$$

$$= \frac{L/\lambda}{1 - \left(\dfrac{x}{\pi}\dfrac{\lambda}{D}\right)^2} \text{ from (3).}$$

Curves of $dL/d\lambda = 15$, 20 and 25 are shown on Fig. 1. These correspo to dial discriminations of approximately 5,000, 4,000 and 3,000 Mc/s/i respectively.

BOOK REVIEWS

RADIO AND ELECTRONICS edited *by J. H. Reyner* (2 volumes)

Pitman. Price £5 5s. the set

Of the difficulties which beset the editor of a scientific treatise, the maintenance of a continuous style and a consistent technical standard must surely be among the greatest, and it is to this editor's credit that with few exceptions his contributors have achieved a conformity of presentation which makes these volumes successful as a reference work, whether for general or specialized information.

It is difficult adequately to appraise the value of all aspects of the subject so widely covered, which include not only the "electronic" subjects of radio and television circuitry, the basic subjects of propagation and transmission techniques, radar and sound recordings, but the "heavier" ones of motors, generators and power distribution. The whole runs to over 1,000 pages, and it is hoped that in this short review the sampling process has not resulted in too biased a view of the whole work.

Vol. I on first acquaintance was dis pointing as it was here that there seemed be some lack of direction, a variability standard as though the design expressed the foreword "to provide for the stude the craftsman and even the young pro sional engineer . . ." was proving too w an aim. The realization that here, howev was something for everyone dispelled t feeling, but whatever the standard ought to expect a consistency in symboli and mathematical contractions. Loge been familiar for a long time but at le mention should have been made in chapter on engineering mathematics of modern style ln. elsewhere logh is used; t is so unusual that it has to be defined in text! One wonders whether this chapter mathematics is not out of place as it d not really go far enough. It would be proved with some real radio engineer examples.

mong the many informative and authorive chapters certain omissions are arent, e.g, little is said about transformer l and special cone materials, Foster and ley are absent yet their names occur ntaneously to FM enthusiasts. while F FM broadcasting is not treated in the actical" Vol. II. More space could have n allowed for gramophone reproduction other aspects of HI-FI. One would also e liked to have seen a practical chapter transistor receivers which are now out of laboratory stage and currently popular. ur reviewer looked in vain for informa on metal detectors which might have eared under Industrial Applications.

ne frequently has the impression that tributors have stopped short. possibly to space considerations. so that the vital e of information is missing. In the chap dealing with Television. the impression is gained that they were written before the ITA had commenced transmissions and some hurried references to Band III inserted later. Where is the turret tuner or the BREEMA recommendations for intermediate frequencies?

One last point: under Voltage Doubler in Vol. I. one is referred to the conventional full-wave circuit, it is left to the sound engineer in Vol. II to show both this and the useful half-wave circuit in which one side of the A.C. is common with one side of the D.C.

Printer's errors seem few and the odd slips include the omission of a subscript from L in reference to Fig. 7.43. Vol. II. page 246. and the omission of Δ in line 3 of the algebra on page 247.

Despite the omissions noted there is much authoritative information packed between these two sets of covers which will amply repay the reader's diligent attention.

E SERVICES TEXTBOOK OF RADIO. VOL. 5

U. D. Glazier and H. R. L. Lamont. H.M. Stationery Office. Price 25s.

volume is one of seven. promulgated by three Fighting Services. that are gned under the authorship of specialists, present a unified comprehensive and oritative survey of the theory and techie of radio. The volume under review is erned—in the words of the authors— the means by which electromagnetic gy is conveyed from place to place.

he writers have attempted, with conrable success, to meet the needs of the nner, the technician and the more adced reader. The omission by the novice hose sections of the book deliberately cated as more advanced will provide in general with a lucid and logically lved exposition of the behaviour and ipulation of electromagnetic energy.

part from the section on propagation, book preserves an admirably unified tment of its subject. A series of Appens after each chapter will be found able to mathematically inclined lents, design engineers and research ntists, and in fact to all those needing to uire or refurbish their fundamental trical knowledge.

he first quarter of the book (perhaps an essive fraction in view of the book's wide pe) is devoted. with a wealth of physical and engineering background. to the properties and applications of parallel-wire and coaxial transmission lines. Useful related techniques are included such as the construction of terminations. stub matching. quarter-wave transformer techniques and broad banding. A concise chapter on some fundamental properties of electromagnetic waves forms a necessary bridge between the concepts of voltage and current and those of electric and magnetic fields. This paves the way for chapters on guided waves and waveguide components and techniques. These subjects are handled with the same care and insight as are evident in the treatment of transmission lines. The coloured illustrations of waveguide field configurations by Mr. E. M. Wells. and numerous other perspective drawings. worthily support the text in this section.

After preparatory chapters on radiation aerial elements and arrays there is a comprehensive survey of the main types of aerial covering virtually the whole radio frequency spectrum. A useful section on dielectric and metal-plate lenses is included.

It is when we read the chapter on wave propagation that we find a lack of cohesion. Although the principles of ionospheric propagation are satisfactorily summarized.

the discussion on the influence of the ground and the troposphere is likely to confuse and mislead the novice on a number of counts. Although they have assembled a series of formally correct statements, the authors have become enmeshed, through an apparent lack of insight, in a clutter of unco-ordinated factors that obscure the foundations of the subject. Even in the limited space allotted to this specialized field, more could have been done to delineate its main outlines by the use of carefully chosen limiting cases. The authors could well, for example, have brought some welcome relief to the student by mentioning that, at sufficiently high frequencies, the field strength at practical aerial heights no longer depends on the wave polarization and ground constants but only on the path geometry.

In discussing height-gain functions, the authors give theoretical height-gain curves for a flat earth. Had they instead shown charts based on a *curved* earth, they would have avoided an irksome limitation on the valid range of their curves while presenting information of wider application whose range of validity would be restricted only by the simple requirement of avoiding too small a terminal separation.

Regarding the author's treatment of tropospheric influences, the important mechanism of trapping in ducts could with advantage have been clarified, so as to include perhaps the approximate but readily understood exposition (analogues to elementary waveguide theory) involving interference between downcoming refracted waves and upgoing ground-reflected waves. Finally, the single page devoted to scatter propagation could well have been enlarged several fold, in view of the growing importance and understanding of this subject.

To sum up, this moderately priced volume has, with reservations mainly confined to the propagation section, successfully covered a very large field in a way wel suited to the needs of the practising engineer and the radio research scientist.

TRANSMISSION CIRCUITS *by E. M. Williams and J. B. Woolford*

The Macmillan Co., New York and London. Price 30s.

The text of this book has been used by the authors at Carnegie Institute of Technology as a shortened course for senior electronic engineering students in circuits with distributed parameters for transmission of power and information; power, voice and radio frequency line circuits are dealt with in that order after a discussion of fundamentals, and two chapters on transients and lumped-constant transmission lines respectively complete the work. The object has been to provide a foundation upon which the studen may build, and the general plan whereb the spectrum is covered from the low to th high end assists in this.

The problems at the end of each chapte are on the whole good. The two appendice one on the hyperbolic functions and th other on electro magnetic field theory an waveguides, are hardly adequate. The boo although excellent in conception is rathe uneven and some mis-statements occur.