IV COMMUNICATIONS AND RELATED PROJECTS

A MODULATION STUDIES SPECTRUM UTILIZATION EFFICIENCY OF POWER UTILIZATION SIGNAL-TO-NOISE RATIOS

Description of work In the June 30th Report a description was given of a study being made to determine the relative advantages of the various systems of modulation which might be employed for communication The study includes evaluation of efficiency of spectrum utilization, power utilization, signal-to-noise ratios, distortion, and so on Since the last report considerable information has been obtained

1 Modulation Studies

Staff W G Tuller
T P Cheatham, Jr
F R Kretzmer

Status Signal-noise analyses have been made on many systems of modulation, including all those discussed in the June 30 progress report This work has been done by a method which, it is believed, brings out the physical nature of the noise reduction process The results agree in general form with those arrived at by the investigator (Z Jelonek of England) whose analysis seems most accurate, but differ in a multiplying numerical constant by at most $\sqrt{2}$ Work is now going on to resolve this trouble, as it has been learned that experimental work done on pulse phase modulation checks the Jelonek formula No record of other experimental checks has been found

The analyses mentioned above have also been converted to a form making them suitable for use in analysis of television sound systems

A beginning has been made on an analysis of transmission of intelligence through noise This analysis is being put on a very broad base, and done along the lines indicated in "The Application of the Hartley Law to Time Modulation" a paper presented before the IRE-URSI meeting in Washington last spring It is believed that such an analysis can be made to show the advantages, if such exist, of such complicated systems as pulse code modulation without requiring a laborious and highly specialized analysis of the detailed modulation processes Novel viewpoints of the general transmission problem are being arrived at which should justify the new approach

A pulse amplitude modulation decoder and receiver gate and dunk pulse generator have been built The gate and dunk pulse generator have been tested, while the decoder is completely wired and tested up to the "box-car" generator The decoder is of the type that converts amplitude modulated pulses into amplitude modulated "box-cars", or long pulses separated by a very short interval The modulation frequency is then filtered from the box-car train

2 Signal-to-Noise Ratios

Staff W G Tuller
T P Cheatham Jr

Status 1 The design construction and experimental testing of an adjustable bandwidth discriminator utilizing a cathode follower (constant voltage source) as the driving stage preceding the discriminator has been completed Results are described in Technical Report No 6

2 Analysis and experimental testing of various conventional limiters used in f-m receivers have been started The analysis and study are being extended to the i-f stages, discriminator and de-emphasizer circuits since it is found there is a contributing effect from these It is planned eventually to extend the study and analysis of limiters in f-m receivers to "noise-limiters" for all systems of high-frequency communications, including the variou pulse type systems

3 A unique method of obtaining experimentally the transient effects of the various types of interference on the main carrier signal has been devised The equipment used consists mainly of an A/R scope and a MK-3 test pulser with the pulser modified for double triggering and for the frequency under consideration By using the strobe trigger of the A/R scope, it is possible to obtain both a d-c pulse and a pulsed carrier, each being separately variable in duration and amplitude Since the pulsed carrier is coherent, it is possible to move the d-c pulse through the carrier in time phase and hence study the transient effect At present the method is being used to study impulse-noise response in an f-m receiver, but it is obviously flexible in its application since the d-c pulse can be used to trigger other noise or interfering sources and the pulsed carrier can be frequency or amplitude modulated

3 Pulse Modulation Studies

Staff W G Tuller
E R Kretzmer

Status As previously reported, (Final Report June 30 1946), harmonic analyses have been carried through whereby it is possible to predict the distortion inherently produced in pulse-width and pulse-position modulation systems A report summarizing this work has been written and is being submitted for publication in the Proceedings of the Institute of Radio Engineers

A spectrum analysis has been made of a step-function-approximated intelligence wave Such a wave occurs in pulse-amplitude modulation and may also be useful in certain other analyses This type of problem arises whenever an intelligence wave is sampled at discrete intervals, and it is therefore a fundamental problem in connection with pulse modulation The work done on the simplest type of step-approximation has been summarized in a report It is intended to carry out analyses of more involved types, the results of which may be applicable to special types of pulse modulation, such as pulse-code modulation

The operation of the components of the 10 kc pulse generator mentioned in the Final Report of June 30 1946, has been examined in detail and some modifications have been made The circuit has beer tested and found to operate satisfactorily

An experimental analysis, component by component, of a ten-channel pulse-position modulation receiver has been begun This receiver, intended for use with the above-mentioned generator, has one channel built up completely but begins with video rather than r-f stages A "top-and-bottom" limiter using two high back voltage crystals such as type 1-N34, has been devised for use in the video stages and has been incorporated in the receiver This circuit neatly slices the pulses at two predetermined voltage levels without causing any appreciable increase in the rise and drop time of the pulses which is a fraction of a microsecond The analysis of the receiver is to be continued

IV B STABILIZED OSCILLATOR PROBLEMS

Staff Professor T S Gray
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Description of project Since stable frequency sources are vitally necessary for both communications systems and more sophisticated research in the microwave region, efforts to improve existing systems of stabilization are continuing

Status. The analysis of the components comprising the feed-back loop of a microwave i-f, stabilized oscillator has been continued An approximation has been made to the system response and the characteristics and limitations of most of the components are known Experimental checks are still to be made on some of the calculations

A two-stage, 30 megacycle, i-f amplifier of calculated and experimentally verified performance has been constructed for use in the study of system phase response

In line with the development of an i-f amplifier to be used for modulated carrier systems such as this frequency stabilized oscillator a four-stage, 30 megacycle i-f amplifier is being constructed This amplifier consists of identical, center-tuned, low Q stages Further investigation is contemplated of an optimum i-f amplifier design to give the required phase shift versus frequency response Stagger-tuned and double-tuned amplifiers will be considered to determine what improvement over the center-tuned circuit is possible

A first model of a full-wave 30 megacycle, phase detector has been constructed which should increase the frequency response and ripple frequency by factors of two over the half-wave detector used at present The proposed tests of this unit will determine if the improved performance outweighs the additional complexity It is also hoped that the complexity of this type of phase detector can be reduced

A tentative goal has been set for a stabilized 3 cm system that is stabilized for frequency deviations at a rate up to 2 megacycles A short-time, center-frequency stability of one part in 10^8 is desired

Modulation investigations can then be made of this system Design will be based on a 400 kilocycle peak deviation which is the maximum compatible with the discriminator bandwidth These investigations are expected to indicate the most feasible manner of introducing modulation

IV C MULTIPATH TRANSMISSIONS

Staff Professor L B Arguimbau
J Granlund

Description of work. As stated in the report of June 30 1946, pages 64-65, a project is under way to study the relative desirability of various types of modulation under fading conditions caused by multipath transmission

Status Since the last report the main equipment has been made to function satisfactorily and preliminary measurements have been made Unfortunately trouble has been experienced with the conventional signal generators used with the equipment The amplitude-modulated signals supplied by the various commercial generators available are also frequency-modulated by at least 10 kilocycles Similarly the only frequency-modulation generator available in the laboratory cannot be used with a pre-emphasized deviation of more than 10 - 15 kilocycles Steps are being taken to remedy these difficulties

Enough has been done to indicate that the method is a satisfactory one for studying the effects of fading, but it is too early to draw any practical conclusions from the work as the low deviation ratios and low amplitude-modulation percentages obtainable from our equipment are not representative So far tests have been restricted to the transmission of speech and music but consideration is being given to an extension of the study to include television

IV D CIRCUIT PROBLEMS

1 Synchronous Operation of Magnetrons

Staff R M Fano

Status. The problem of operating a number of magnetrons in synchronism has come up recently in connection with the design of the microwave linear accelerator discussed on pages 24-33 of this report The synchronous operation of magnetrons, however, may have a much wider field of application because it offers an alternative solution to the problem of designing more powerful magnetrons

It is well known that a magnetron can be represented to a first approximation by means of a parallel tuned circuit shunted by a negative conductance When the tube is oscillating, the total admittance, including the load admittance, measured at the terminals of the negative conductance must be zero This condition determines the power output as well as the frequency of oscillation, since the negative conductance depends on the output r-f voltage

When a system contains more than one magnetron the same type of representation can be used, but in this case one has to deal with a non-linear problem In fact, the values of the negative conductances must be such that the total admittance between any two nodes is zero and moreover, the corresponding r-f output voltages must be consistent with one another This last constraint complicates considerably any analysis but on the other hand prevents the system from oscillating in most of the undesired modes One must remember, however, that the system may oscillate simultaneously at two or more different frequencies although this situation is not likely to occur when the magnetrons are closely coupled to one another

Another consideration of importance is the stability of the operation of a system with respect to changes of the load impedances, of the lengths of the connecting lines, etc If a system is designed to operate at a given frequency with all the magnetrons delivering their rated power a small change of the system results, in general, in a change of frequency and a redistribution of the load between the magnetrons If the change is too large, the magnetrons may not be able to readjust themselves to the new conditions for instance one magnetron may not be able to supply the required overload What happens in this case, it is hard to say, probably the system would spark over at some point

The above discussion indicates that the connecting lines should be made as little frequency-sensitive as possible This amounts to saying that the presence of standing waves should be avoided and that the line lengths should be made short and an integral number (even or odd, depending on the case) of quarter waves long These principles have been applied to the system shown schematically in Figure 1 The numbers indicate normalized conductances The internal loads and the magnetrons are

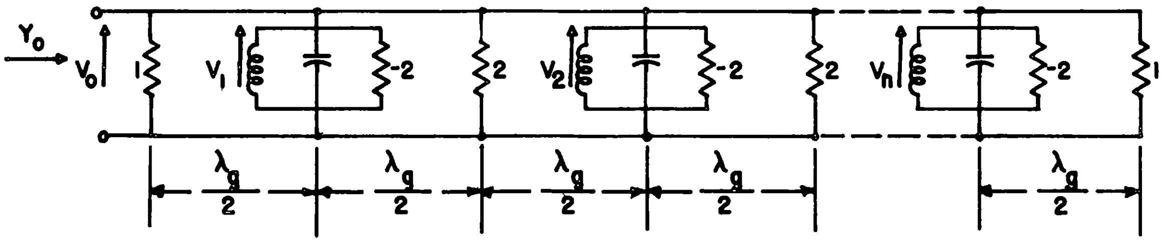

Figure 1

connected to the main guide by means of matched T junctions that is of junctions which present a match in the leg of the T when the two arms are properly terminated Figure 2 shows the equivalent circuit for one of these T junctions The system of Figure 1 is a modification of a scheme developed by Everhart in connection with the

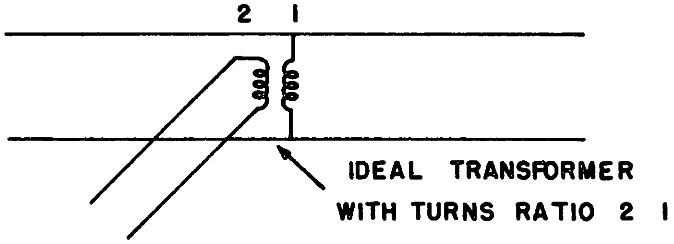

Figure 2

design of a microwave accelerator The analysis of this system was carried out as follows The last magnetron was represented together with the terminating conductance, by an admittance $Y_n(\omega, V_n)$, where ω is the frequency and V_n is the r-f voltage across the tuned circuit The admittance Y_n and the voltage V_n were then transferred along the structure to obtain the admittance $Y_{n-1}(\omega, V_{n-1})$ measured at the terminals of the next magnetron of which V_{n-1} is the output voltage Proceeding in the same manner along the structure one obtains finally the admittance $Y_0(\omega\ V_0)$ The zeros of this admittance represent possible modes of oscillation of the system

The analysis was carried out assuming that the negative conductance of the magnetrons (all identical) was inversely proportional to the output r-f voltage In order to use the actual characteristics of the magnetrons, one must follow a graphical procedure similar to the analytic procedure described above This analysis shows that the effect of the connecting lines is relatively small, so that only one mode of oscillation is possible in a 2% band centered at the normal frequency of operation of the magnetrons A three magnetron structure of this type was operated satisfactorily by the "Microwave Accelerator" group

2 <u>Microwave Filters</u>

Staff R M Fano

<u>Status</u> <u>Four-cavity, x-band filter</u> Further tests and theoretical computations have been performed on a band-pass filter built a year ago at the Radiation Laboratory in collaboration with Dr A W Lawson This filter consists of four-rectangular cavities coupled by quarter-wave sections of guide The measured values of the insertion loss of this filter checked very well (roughly within experimental error) with the curve computed from the physical dimensions and the measured values of the unloaded Q of the cavities These results have been incorporated in a report written

in collaboration with Dr Lawson *

<u>Band-pass filter using a three-mode cavity</u> A cavity resonator which behaved like a two cavity filter was developed at the Radiation Laboratory in collaboration with Dr A W Lawson The same principle has now been extended to the design of a cavity which behaves like a three-cavity band-pass filter The cavity is of the circular cylindrical type and is so dimensioned that the $TM_{0,1,0}$ mode and the two degenerate $TE_{1\,1,1}$ modes have the same resonance frequency (see Figure 1)

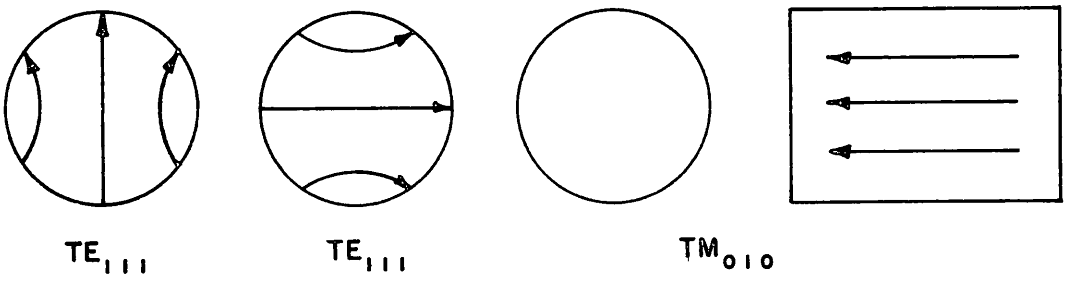

Figure 1

The input and output guides are coupled only to the two $TE_{1\,1\,1}$ modes as shown in Figure 2 Thus no power can be transmitted through the cavity if the direct coupling between the input and output irises is neglected However if the two $TE_{1\,1,1}$ modes

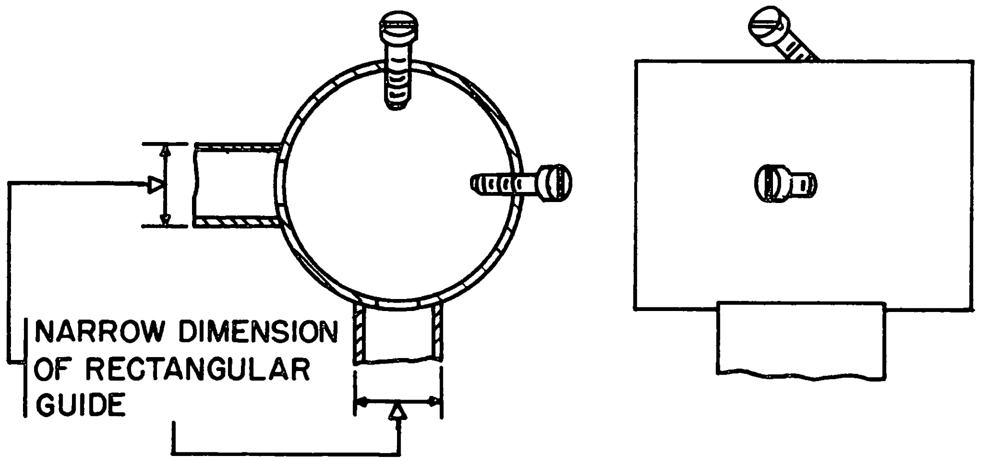

Figure 2

are coupled inside the cavity to the $TM_{0\,1,0}$ mode by means for instance of the two screws shown in Figure 2 the cavity becomes equivalent to the circuit of Figure 3 in

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* Fano R M, <u>Microwave Filters Using Quarter Wave Coupling</u>, NDRC Division 14, Research Laboratory of Electronics, Massachusetts Institute of Technology Technical Report No 3, June 28 1946

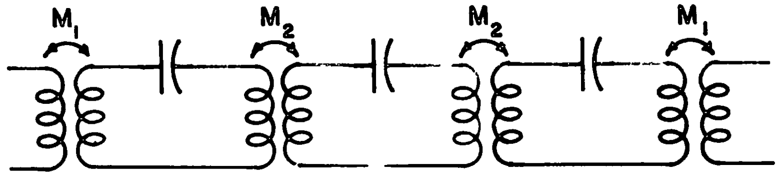

Figure 3

which the three loops are tuned to the same frequency This equivalent circuit is recognized as a triple-tuned filter The two screws take the place of the two mutual inductances M_2 This three-mode cavity has not yet been tested because of the present lack of a suitable sweep-frequency oscillator which was found to be an almost indispensable tool for the line-up of the two-mode cavity

3 Microwave Swept Frequency Oscillator

Staff Professor J B Wiesner
R M Fano
H M Bollinger

Description of work To facilitate research on microwave components it is desirable to have a wide band sweep frequency oscillator with sufficient accuracy to permit measurement and adjustments of components without resorting to point by point measurements It is the purpose of this project to develop such a device

Status Tests have been made on a cavity-tuned 10 cm oscillator (723B), showing that with constant reflector-voltage, a rotatable plunger in the cavity varies the output frequency a maximum of 0 7 cm Power output over this range when operating into a well-padded broad-band thermistor detector varies about 5 db At constant cavity resonance a change of 20 volts in reflector voltage is sufficient to swing output power from minimum to maximum in one mode, power and frequency vary about 5 db and 0 1 cm respectively over this range The shape of the output mode curve has a marked dependence on plunger position in the cavity

Design of a broad-band directional-coupler has been considered, from data in RL Report 724, a branched-coax type has been decided on, and construction of such a unit is now in progress in the shop Over a 10% band of output frequencies the coupling coefficient of this device should vary less than 0 5 db

Preliminary tests on an alternate scheme to maintain constant output power have been made This method involves the use of a magic T in the output waveguide, variation in power being obtained by impedance changes in the side arms of the T, with a matched load in one side arm of the coaxial T and a thermistor fed from the amplified and rectified output of a directional-coupler preceding the T in the other side arm this system provides a small improvement in power stability Because of the poor frequency characteristics of the coupler and crystal detectors used in the test and the unknown frequency response of the coaxial-type magic T, results of the test are inconclusive but the scheme appears to hold some promise of success

IV E A STUDY OF TRANSIENT PHENOMENA IN GUIDED WAVES

Staff M V Cerrillo

In the mathematical study of the transient phenomena in wave guides a theorem was found which permits the evaluation of some inverse Laplace transforms This theorem, of general character seems to be very suitable for the solution of certain problems of wave propagation in dispersive media It was applied to the evaluation of some involved inverse transforms encountered in connection with wave guide studies

Let $f(t\ k)$ be a single valued function of the independent variables t and k and such that by hypothesis it has the properties

1
$$f(t\ k) = \begin{cases} 0 & \text{for} \quad 0 \leq t < k \\ \neq 0 & \text{for} \quad t > k \end{cases}$$

2 $f(t,k)_{t \to k}$ can be different from zero

and the same for partial derivatives up to n order

3 The inverse transformation

$$f(t\ k) = \frac{1}{2\pi i} \int_{c-i\infty}^{c+i\infty} F(s\ k) e^{st} ds$$ exists and it is known

then

$$\left\{ \frac{\partial^n}{\partial t} + n \frac{\partial^n}{\partial t^{n-1} \partial k} + \frac{n(n-1)}{2!} \frac{\partial^n}{\partial t^{n-2} \partial k^2} + \quad + \frac{\partial^n}{\partial k^n} \right\} f(t\ k) = \varphi(t,k) =$$

$$= \frac{1}{2\pi i} \int_{c-i\infty}^{c+i\infty} \left\{ s^n F(s\ k) + n s^{n-1} F'_{(k)}(s,k) + \frac{n(n-1)}{2!} s^{n-2} F''_{(k)}(s\ k) \right.$$

$$\left. + \quad + F_{(k)}^{(n)}(s,k) \right\} e^{st} ds$$

This new transform between brackets inside the integral has an important property. Suppose that the original transform $F(s\ k)$ goes as $\frac{1}{s^\gamma}$ when $s \to \infty$, the new one goes as $\frac{1}{s^{\gamma-n}}$ when $s \to \infty$

In some problems on propagation in dispersive media $F(s\ k)$ has the form

$$F(s\ k) = \frac{e^{-kF_1(s)}}{F_2(s)}$$

In this case the above result has the simple form

$$\varphi(t\ k) = \frac{1}{2\pi i} \int_{c-i\infty}^{c+i\infty} \left[s-F_1(s)\right]^n \frac{e^{st-kF_1(s)}}{F_2(s)}\, ds$$