IV COMMUNICATIONS AND RELATED PROJECTS

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

1 General Analysis of the Transmission of Information

Staff: W G Tuller

This investigation is now essentially completed except for report writing Results are

a If a continuous function of time with a limited bandwidth is to be exactly duplicated by a filtered discontinuous function of time, (as described in RLE Technical Report No 12), the function requiring the fewest discontinuities will be the one with its discontinuities occurring at regular time intervals

b The discontinuous function of time containing the maximum amount of information is that discontinuous function in which the amplitude of the function at any one discontinuity is independent of the amplitude at every other discontinuity, and has a probability independent of amplitude

c A system is physically realizable that can transmit information over a circuit of given limited bandwidth at a rate higher than that held possible by previously published theories

d The system given by (c) has been analyzed in detail and the practical engineering limitations have been discussed It has been shown that there is no theoretical limitation on the rate of transmission of information other than the quantization of energy, if noise is absent from the system

e An expression has been derived giving the limitation imposed by thermal noise on the rate of transmission of information over a circuit of restricted bandwidth, and this limit has been evaluated

f An expression has been derived relating the maximum possible rate of transmission of information, circuit bandwidth, signal-to-noise ratio, and time of transmission

g No electrical transmission system employing a time invariant relationship between modulating and transmitted signal can achieve signal-to-noise ratio higher than carrier-to-noise ratio multiplied by KB/f_c, where B is the bandwidth of the modulated carrier f_c is the bandwidth of the modulating signal, and K is a constant of order of magnitude one This is true whether or not the modulation process is linear providing the demodulation process operates on the modulated wave to produce an exact replica of the modulating wave

h Coding information so as to destroy the time invariant character of the modulation process can at best make signal-to-noise ratio equal to carrier-to-noise ratio raised to the power KB/f_c, where K, B, and f_c are as defined in (g)

i An expression has been derived relating the maximum possible rate of transmission of information, circuit bandwidth, carrier-to-noise ratio, and time of transmission

j Systems capable of realizing the maximum possible rate of transmission of information have been described

k The agreement between practice and theory has been demonstrated for those theoretical results given above which are susceptible to practical verification

4 A discussion has been given of the application of the theory to "non-communication" fields: radar, telemetering, servomechanisms, computing mechanisms, The inefficiency of some presently accepted practices and the efficiency of others have been demonstrated

2 Pulse Modulation Studies

Staff W G Tuller
E R Kretzmer

The pulse-position modulation system, described in some detail in the Progress Report of April 15, 1947, has been subjected to some further tests These tests have been concerned with frequency response and distortion of the over-all system The two demodulation schemes used in the receiver have been found to exhibit basic differences with regard to these characteristics From measurements made so far, the trigger demodulation scheme (whereby pulse-position modulation is converted to pulse-duration modulation) appears somewhat superior to the coincidence demodulation scheme This is true especially for very low audio-modulation frequencies

The current phase of the work on this system is being brought to a close for the time being A laboratory memorandum, dealing mostly with pulse-position modulation equipment, has been prepared It contains photographs, circuit diagrams, and explanations, with the object of facilitating future work on the system

3 Properties of Random Noise

Staff G E Duvall

During the last quarterly period effort has been directed toward the construction and assembly of apparatus for measuring shot noise under conditions of large transit time This apparatus consists of a low-noise preamplifier tuning from 5 to 40 Mc in three bands, the r-f and i-f sections of an SX-28 Hallicrafter receiver, and a detector which measures the direct current through a crystal The noise source is a specially constructed diode with large spacing between cathode and anode This is connected in parallel with a WE 708A connected as a diode to act as a standard noise source

4 The Action of Limiters and Discriminators in FM Receivers in the Presence of Noise

Staff W G Tuller
T P Cheatham, Jr

Based on the analyses and results contained in two reports,[1,2] work has been started on an FM receiver designed for compactness, simplicity and good impulse-noise response A receiver has been constructed and is presently being tested

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[1] T P Cheatham, Jr "Transient Analysis of Impulse Noise in FM Receivers" RLE Technical Report No 28, being prepared for publication

[2] T P Cheatham, Jr "A Logarithmic Limiter for Use in FM Receivers in the Presence of Impulse Noise" RLE Technical Report No 36, April 24, 1947

B STABILIZED OSCILLATOR PROBLEMS

Staff: Dr C G Aurell
W C Galloway
F P Zaffarano

1 Equal-Arm Microwave Frequency-Discriminator

The investigation of the equal-arm microwave frequency-discriminator mentioned in the last progress report has been essentially concluded A complete status report in the form of a thesis is now available [1] The results of this work have been to develop a 9000-Mc discriminator which will operate over a frequency range in excess of 1100 Mc with no adjustments A sensitivity increase over the Pound circuit of nearly two is obtained for a given input power.

Depending on the modulating crystal efficiency, a power input increase of from 6 to 13 db is theoretically permissible before the detector-crystal current will rise to the same value as is used in Pound's discriminator This makes possible a total improvement factor of 4 to 10 in stabilizing action, if the noise generated by the modulating crystal is not an overshadowing factor (a factor which has not yet been evaluated)

While the analysis has been reported for the assumption that the detector crystal of the discriminator acts as a linear detector, the squ re-law case has lately been investigated and would indicate greater output than can be justified experimentally

A paper entitled "Recent Developments in Microwave Frequency-Stabilization" was presented by W G Tuller at the last meeting of the New England Section of the Institute of Radio Engineers On request, a similarly titled article is being prepared for publication in the Proceedings of the IRE.

2. Distortion Due to Frequency Modulation of a Frequency-Stabilized Klystron

Work has been initiated to determine the distortion resulting when a frequency-stabilized klystron is frequency modulated The first investigation will be to determine the manner in which the shape of the microwave-discriminator curve limits the modulation Preliminary calculations have been made to determine the distortion to be expected in the FM output when the modulation is applied at the reflector electrode of the klystron in a Pound i-f stabilizing system To facilitate the measurements, all of the circuits in the stabilizer and measuring instruments are being made with a much wider bandwidth than the reference cavity to be used Thus, any distortion in the FM output of the klystron should be caused principally by the reference cavity

A receiver has been constructed for detecting the FM output of the klystron The receiver utilizes a stabilized microwave oscillator to act as a local oscillator and produce a 40-Mc signal at the output of a crystal mixer This signal is passed through a low-gain amplifier and is detected by a discriminator Both the amplifier and discriminator have a bandwidth of 10 Mc which is large compared to the 2-Mc cavity bandwidth

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[1] F P Zaffarano, "An Improved Microwave Frequency-Discriminator", M S Thesis, E E Dept , MIT, June, 1947

3 Square-Wave Modulation of the Pound Frequency Stabilizer

This project is one of several attempts to use the Pound circuit for producing a stabilized frequency which is a predetermined function of time The present investigation deals with the generation of a voltage with a frequency which is periodically shifted between two values, or is shifted between on and off This is achieved by letting the repeller voltage (e_1) of the klystron oscillator be obtained by the sum of the output voltage (e_3) from the stabilizer and an impressed square-wave voltage (e_4) as shown in the diagram, Fig 1

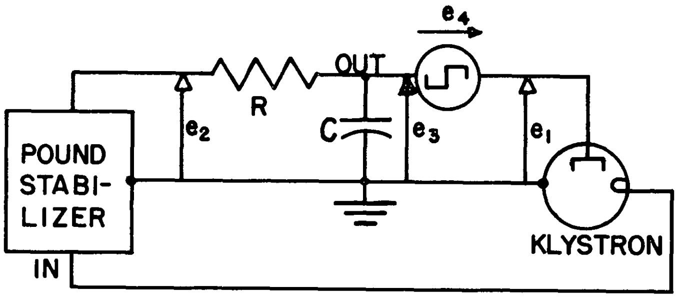

Figure 1

The RC-circuit at the output of the stabilizer has a much smaller bandwidth than the rest of the circuit and mainly governs the transient behavior It can therefore, to a first approximation, be assumed that the response $e_2 = D(e_1)$ is instantaneous The differential equation for the repeller voltage is

$$T\frac{de_1}{dt} = e_4 + T\frac{de_4}{dt} - \left[e_1 + D(e_1)\right]$$

where T = RC Thus if $e_1 - D(e_1)$ is plotted as a function of e_1 as in Fig 2, it is seen that the derivative (with reversed sign) is proportional to the ordinates in the shaded region, Fig 2

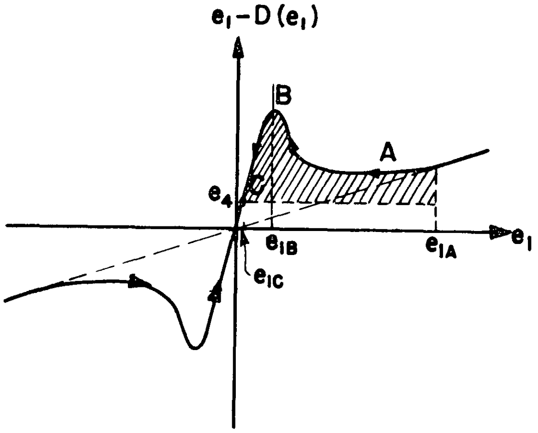

Figure 2

The stable value of e_1 corresponds to $de_1/dt = 0$ Figure 3 shows e_1 as a function of time As the voltage e_3 across C cannot change instantaneously, e_1 is carried way off the stabilized value when e_4 jumps from one level to another This gives the new initial value e_{1A} The time t_1 can be appreciably shortened by reducing e_4 The final voltage e_{1C} is reached from a point B by an essentially exponential curve with the time constant T/(1+G), where G is the loop gain For small deviations of e_1 the output frequency from the klystron is approximately proportional to the repeller voltage e_1 In case it is wanted to produce a signal which is periodically interrupted, one of the half cycles of the voltage e_4 should be chosen so as to stop the oscillation

A final report on this work is now being prepared

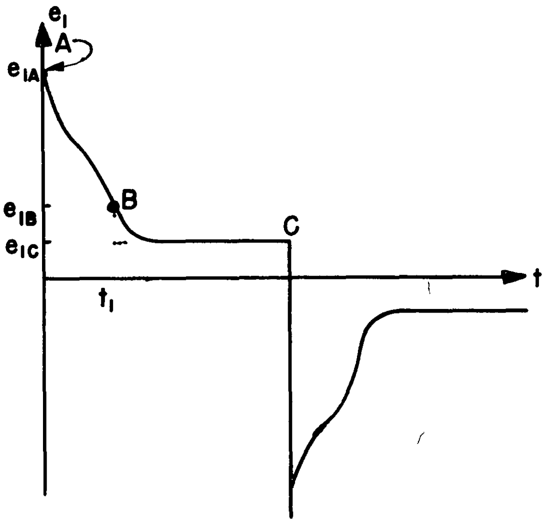

Figure 3.

C MULTIPATH TRANSMISSION

Staff Professor L B Arguimbau
J Granlund

Since the last progress report a new experimental receiver has been tested These tests show that a theory tentatively proposed concerning a method of decreasing the effects of multipath conditions on long paths is essentially correct The method gives promise of providing undistorted transatlantic communication by frequency modulation For this reason it is desirable to give a brief summary of the whole development A more complete report is in preparation

The essential problem of multipath FM communication is indicated in Fig 1 The solid curve indicates the variation of the instantaneous frequency of a signal arriving by one path The dotted curve shows the frequency of the same signal arriving by a second, delayed path It is assumed that in this particular instance the signal represented by the solid curve has a somewhat larger amplitude than the other This problem consists of making a receiver which will give a direct voltage output that is instantaneously proportional to the solid curve

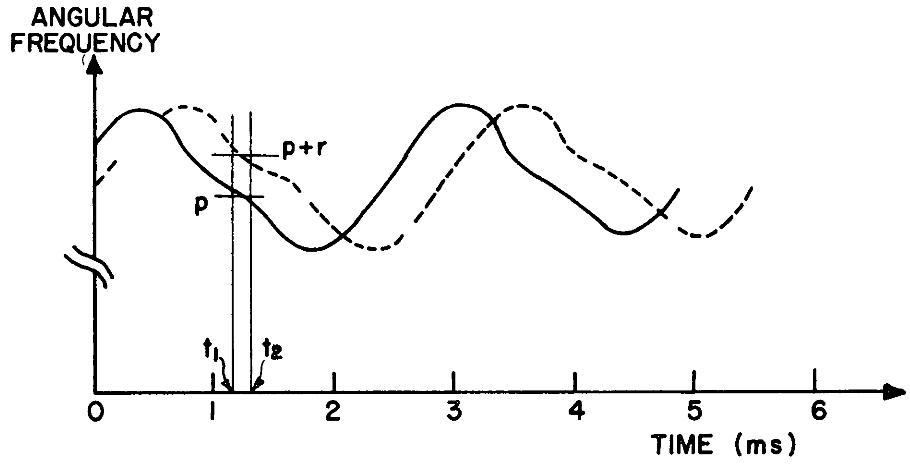

Figure 1

Since the frequency varies relatively slowly, it is convenient to consider it as momentarily constant in order to study the influence of one constant-frequency carrier on the response to a second one Thus in Fig 1 the angular frequency of the desired signal path (solid curve) can be considered to have the constant value, p, between t_1 and t_2 while the interfering signal has a frequency, p + r The desired signal is assumed to have unit amplitude and the undesired signal, an amplitude, a The nearer a approaches one, the more trouble will result Hence we may consider the case where a is only slightly less than one In accordance with common practice,[1,2] the two signals are represented by the vector diagram of Fig 2

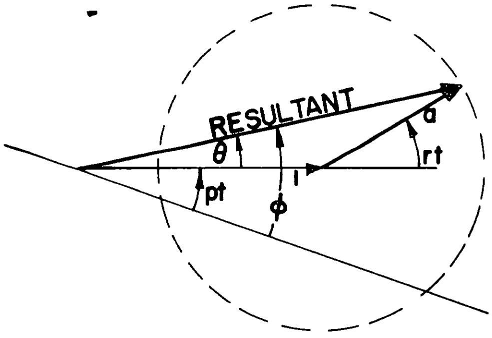

Figure 2

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[1] M S Corrington, Frequency-Modulation Distortion Caused by Common and Adjacent-Channel Interference, R C A Review, 7, 522, December, 1946

[2] F L H M Stumpers, "Interference Problems in Frequency Modulation," Philips Res Rep 2, 136, April, 1947

The "instantaneous frequency" of the resultant is usually taken to be $d\phi/dt$, a quantity that determines the frequency of zero crossings of the resultant signal but is not necessarily related to the spectrum. When the amplitudes are nearly equal, $a \cong 1$, and except when the two vectors are almost out of phase ($rt = \pi$), $\theta \cong rt/2$ and the frequency of the resultant is $p + \frac{r}{2}$. Thus except for short time intervals, the frequency of the resultant is almost exactly the average of the two radio frequencies. On the other hand, the angle θ never numerically exceeds $\pi/2$. This means that the <u>time average</u> of the instantaneous frequency is exactly the frequency of the larger signal and is not at all influenced by the smaller. Thus the resultant frequency is almost always $p + \frac{r}{2}$ but has an average value of exactly p. This fact arises, because when rt is nearly π in Fig. 2, the instantaneous frequency decreases sharply to a value $p - \frac{ar}{1-a}$ for a very short time. This situation is indicated in Fig. 3 which shows the time variation of the instantaneous frequency.

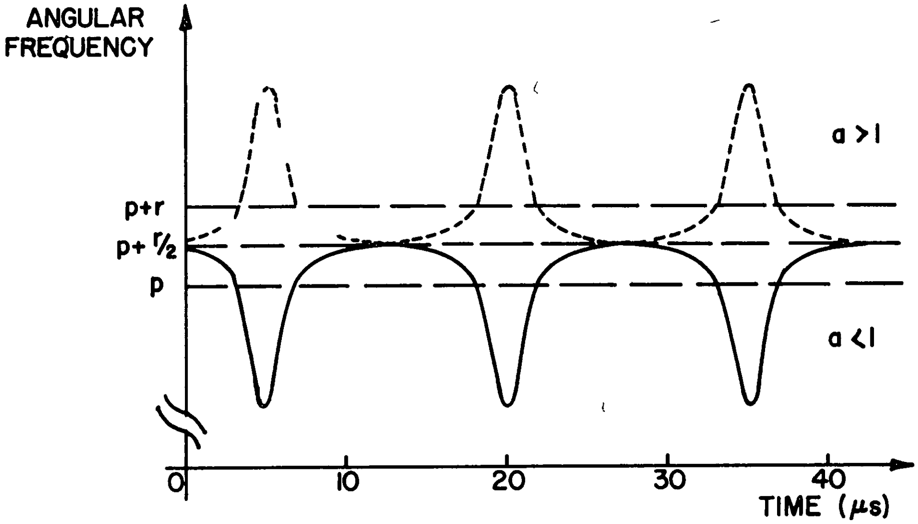

Figure 3

The resultant is nearly always at $p + \frac{r}{2}$, but $\frac{r}{2\pi}$ times per second the frequency dips in a sharp spike in such a manner as to give an average frequency of p. If the relative amplitude <u>a</u> is slightly larger than one the dotted curve shows that the frequency is usually near $p + \frac{r}{2}$ but occasionally has a positive peak or spike to give an average of $p + r$, the frequency of the larger signal.

The "instantaneous frequency" as defined by $\frac{d\phi}{dt}$ in Fig. 2 is a quantity determining the frequency at which the resultant instantaneous signal vanishes, but it does not imply that the spectrum includes terms over the full frequency range covered by the variation of $\frac{d\phi}{dt}$. In fact in the example of Fig. 2 there are only two frequencies present, p and $p + r$. A network designed to pass these two frequencies alone will pass the disturbance regardless of our ideas about the sharp instantaneous frequency excursion below p.

After the two signals p and p + r have been impressed on a limiter, however, the situation is fundamentally changed. Ideally the limiter produces a square wave whose repetition rate follows the repetition rate of the zero of the impressed function. Thus the limiter output is ideally a square wave whose zero crossings are given by the diagrams of Figs. 2 and 3. This wave has a fundamental component in the vicinity of p and it has sidebands extending over the full range covered by the frequency excursion in Fig. 3. In order to reproduce this signal, the amplifiers and discriminator following the limiter must be able to cover at least the full range from $p + \frac{r}{2}$ to $p - \frac{ar}{1-a}$. If they do this, the average voltage output from the discriminator corresponds to p. If the full frequency range is not passed, the average voltage output will be influenced by the presence of the signal of frequency p + r and may tend toward the value which corresponds to $p + \frac{r}{2}$.

The receiver mentioned at the beginning of this report is provided with an amplifier and discriminator of about 4-Mc bandwidth. Thus the receiver is able to follow the frequency spectrum generated by the limiter, when the products generated by the limiter fall within this band, a condition which is fulfilled for all values of a, not very close to one.

Preliminary results on this receiver have shown that it operates in approximate conformity with the theory outlined above. Signals have been modulated by ± 75 kc with speech and music. These have been subjected to multipath conditions and have been received without noticeable distortion as long as the transmission efficiency of the two paths differed by one decibel or more. Even when the two paths had equal transmission, the received signals were superior to those obtained on the average transatlantic program.

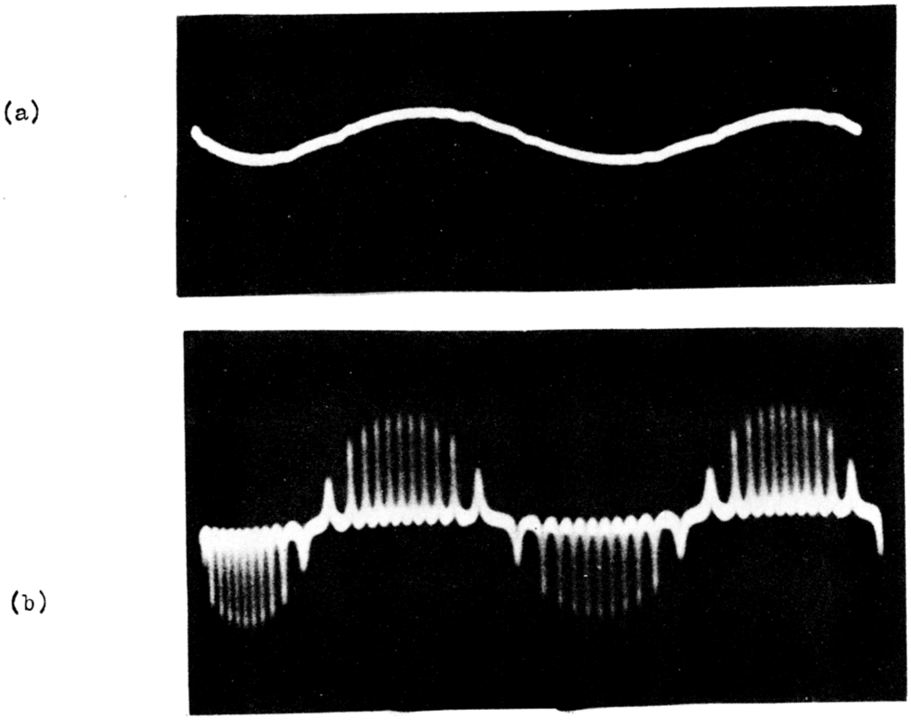

Figure 4.

Figures 4(a) and (b) show typical multipath interference patterns with sinusoidal modulation Figure 4(b) was taken under the same conditions as Fig 4(a) except that an appropriate audio filter was used The action of the filter in averaging the connected "frequency spikes" to restore the original modulation is apparent It may be observed from Fig 4(a) that, since the base line of the spikes corresponds to a constant frequency, the average frequency of the desired and undesired signals is constant This condition, which occurs when the relative time delay between the two paths causes a 180-degree phase shift of the modulation, is the most troublesome one obtainable with multipath transmission

It should be pointed out that the laboratory tests have been carried out under severe but idealized multipath conditions The receiver referred to above is still in the experimental stage and must be further developed to assure dependable operation This work is in process It is the writers' belief that the laboratory tests should be supplemented at the earliest possible date by field tests

D RESPONSE OF NETWORKS TO FREQUENCY TRANSIENTS

Staff Professor E A Guillemin
D M Powers

The purpose of this research is to determine the response of electrical networks to frequency transients To this end, several experiments have been made as described in the 1 st progress report Furthermore, the theoretical study has gone ahead to develop a theory or procedure for handling the problem and in particular to check the results of the experiments already mentioned Work along the lines of the superposition integral was carried far enough to reveal some insight into the problem and to indicate that the method was a difficult one Recently, more attention has b en directed to the methods of contour integration, by which means it is expected that the problem will be resolved