

#### IV. COMMUNICATIONS AND RELATED PROJECTS

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Program. The general problem of the transmission of information, or in other words the problem of communication, has attracted the attention and aroused the interest of several additional members of this Laboratory since the Progress Report of July 15, 1947 was written. It seems appropriate, therefore, to state at this time the long range aims of the research which is being carried out under the general heading of "transmission of information".

\* It is convenient, for the purpose of discussion, to divide this research program into two parts. The first part deals with the nature of the limitations on the rate of transmission of information in a communication system. It should lead eventually to the definition in operational terms of an optimum communication system. The second part of the research program consists of the study of present-day communication systems, such as amplitude modulation, frequency modulation, television, etc. It should lead to the determination of their inherent advantages and limitations and to the actual design and construction of better equipment. Both parts of the research program should eventually converge into the construction of a communication system with characteristics approaching optimum.

As stated above, one part of the program is concerned with the theoretical limitations on the rate of transmission of information. Some work along these lines has been reported by Tuller in the July Progress Report. This work is being carried forward. An important question that is being investigated is that of the meaning of information and of the measurement of the quantity of information supplied by an arbitrary signal in the presence of noise. Because of the random nature of both the signal and the noise, it is clear that one can talk about information only on a statistical basis. It is also clear that information must be defined in such a way as to lead to the precise notion of what is vaguely called the "quality of reception".

A statistical definition of information has been proposed by Wiener, Shannon, and others. A critical study will be made of this definition in

regard to its conformity with the subjective notion. One must also consider whether information defined in this manner can be detected by an ideal receiver with realistically defined properties.

After a physically sound definition of information has been made, the next step will be to determine the theoretical limit on the rate of transmission of information. One will also be in a position to analyze the present-day communication systems on a more precise statistical basis. In addition, it is reasonable to expect that the same techniques employed in the solution of the electrical communication problems will aid in the study of the operation of human communication systems. In particular, this work should lead to a better understanding of the nature of speech and its bandwidth requirement and throw additional light on the operation of the ear. As has been implied above, the measurement of the information content of a signal involves the knowledge of the statistical character of the noise associated with the signal as well as of the signal itself. Although considerable work has already been done on the noise problem, many questions are still far from being settled.

The Wiener theory of optimum prediction and optimum filtering is an outstanding classical work in the statistical study of message and noise, which has a direct bearing on the statistical theory of information. As no appreciable amount of experimental work on the Wiener theory is available, some of this work will be undertaken as part of the program. The extension of the theory to other problems is contemplated.

In connection with the second part of the program, the investigation of specific communications systems, studies of amplitude-modulation, frequency-modulation and pulse-modulation systems, and the application of these systems to specific practical problems have been undertaken.

One of the vital problems of communication is that of establishing better transatlantic communication facilities. Work in progress at the laboratory promises to improve such transmission by the use of frequency modulation at the expense of increased bandwidth.

While various apparatus problems remain in connection with this frequency-modulation transmission of speech and music, they do not seem to be fundamental. We hope to be able to make field tests over long distances to determine whether or not results with idealized laboratory models represent the real problem. Considerable theoretical work must still be done to put frequency-modulation network theory on a firm basis.

Our knowledge of pulse modulation reception is not, as yet, on a solid basis and until more experimenting is done we are not in a position to formulate the interference problem with full assurance. We plan to push experimental techniques forward in this field in order to get a better understanding of the possibilities of the various pulse systems.

Application of frequency modulation to television is in a similar state. We should like to do much more with this problem in order to understand the possibilities of applying the various types of modulation and preemphasis to the transmission of transient waveforms."

#### A. Pulse Modulation Studies

Staff: E. R. Kretzmer

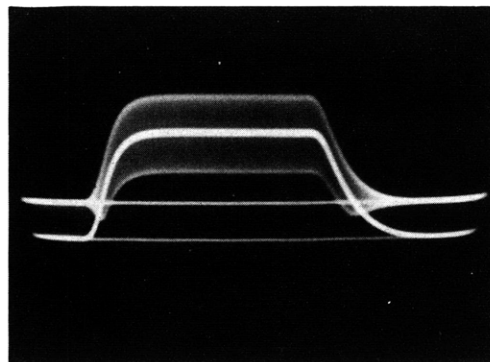
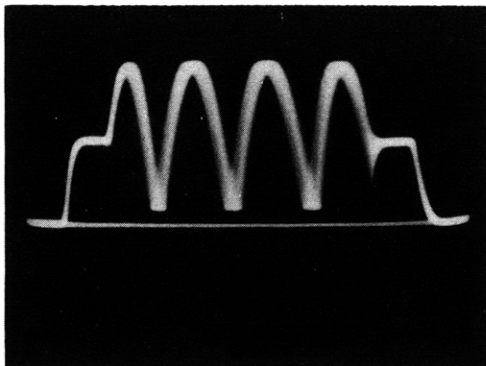
Work is continuing on the study of the interference problem in pulse modulation, which was first outlined in the Progress Report of October 15, 1947.

In the initial experimental investigations of common-channel interference between two pulse-duration modulated transmissions, considerable difficulty was caused by direct interaction between the two pulsed oscillators. This trouble was cured by modifying the oscillators so as to minimize their susceptibility to being time-modulated by external r-f signals.

Experimental observations of the results of common-channel interference agree with theoretical considerations carried out so far for the case where the desired signal is more than twice as large as the interfering signal. The interference appears mostly in the form of noise with a certain degree of randomness. The effective value of the noise on each pulse edge, as a function of several variables, has been computed. This noise has some similarity in origin to quantizing noise such as is found in pulse code modulation.

When the interfering signal is more than half as large as the desired signal, it causes much more severe and complex interference which includes the modulation of the interfering signal and a strong beat between the two pulse repetition frequencies.

Photographs of the detected receiver output ahead of the limiter have been taken under various conditions of interference. Two typical pictures are shown below. Figure 1 shows interference between pulses of equal magnitudes, durations roughly 20 and 30  $\mu$ sec, respectively, radio frequencies differing by about 180 kc, and pulse-repetition frequencies synchronized and phased in such a way that the pulses coincide. The oscilla-



tion is the 180-kc beat between the two r-f carriers. In Figure 2, the magnitude of the desired pulse is three times that of the interfering pulse, its duration is roughly 4  $\mu$ sec, and the pulse repetition rates are unequal, the oscilloscope sweep being synchronized to that of the larger pulse. The photograph is in effect a superposition of a large number of separate successive situations. In some of these, the interfering pulse does not coincide with the desired pulse which is then reproduced perfectly (heavy white line). In other instances, the pulses do coincide, the r-f phase difference being different each time, so that the resultant pulse amplitude takes on many different values (blurred portion of photograph). The amount of jitter in the pulse edges shows how much noise is to be expected in the receiver output.

Work is now in progress on the pulse-position modulation detector mentioned at the bottom of page 45 in the October 15, 1947 Progress Report.

#### B. STABILIZED OSCILLATOR PROBLEMS

Staff: W. C. Galloway

The determination of the distortion in the frequency-modulated output of a stabilized microwave oscillator is being carried out. Measurements have been made of the distortion resulting when the Pound type and equal-arm type discriminators are used. These measurements will be compared to the theoretical values of distortion.

#### C. MULTIPATH TRANSMISSION

Staff: Professor L. B. Arguimbau  
J. Granlund  
W. L. Hatton  
L. Dolansky

Speech and Music. Since the last progress report a paper has been presented at the National Electronic Conference in Chicago. In preparation for this, the numerical conditions governing multipath transmission were expressed in somewhat simpler form. Among other things it was shown that the improvement obtained in suppressing multipath interference by the use of frequency modulation is proportional to the ratio of the frequency deviation and the preemphasis double-power frequency.

As was mentioned in the last report the experimental receiver previously used has been far from ideal. It has been decided to construct a new receiver which will more nearly approach the "ideal receiver". The new receiver is being constructed of three sections of 10-cm waveguide which may be joined into one unit by conventional waveguide couplers. The advantage of using a long and narrow chassis (such as a piece of waveguide)

has been proved by the excellent characteristics of the radar amplifiers developed during the war. Splitting the receiver into functional sections allows a quick interchange of like sections for comparison purposes, or, if one section is found to be unsatisfactory, a new one may be added without rebuilding the entire receiver.

At present the limiter section mentioned in the previous progress report has been completed and partially tested. Also, a front end to drive the limiter has been built, and is in the process of being tested. The design of the discriminator section is not yet complete.

Television. Since the last progress report the project has been expanded to include an investigation of the relative desirability of amplitude and frequency modulation for television transmission.

In order to facilitate this work, AXT and AXR low-definition television transmitter and receiver units have been set up. It is planned to use these units as part of amplitude- and frequency-modulation multipath systems.

A preliminary study is being made on the possibility of using pre-emphasis with television. As mentioned above, this advantage of frequency modulation is proportional to the ratio of the frequency deviation to the preemphasis frequency. Thus it would be desirable to provide such pre-emphasis without prohibitively overloading the transmitter by steep wavefronts.

#### D. PROPERTIES OF RANDOM NOISE.

##### 1. Statistical Properties.

Staff: Professor Y. W. Lee  
Professor J. B. Wiesner  
T. P. Cheatham, Jr.

The presence of random noise places a basic and finite limitation on the transmission of information. A mathematical treatment of random noise has been given by S. O. Rice<sup>1</sup>. An experimental study of random noise has been started, the method of approach being to photograph the instantaneous noise fluctuations of a resistor after the noise fluctuation has passed through variously shaped filters. The following statistical information is being tabulated from film strips: (a) instantaneous amplitude distribution, (b) envelope distribution, (c) maxima and minima distribution, and (d) zero crossing distribution.

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1. S. O. Rice, "Mathematical Analysis of Random Noise", B.S.T.J. vol. 23, p. 282 - 332 (1944); vol. 24, p. 46 - 156, (1945).

#### IV. D. 2. Effect of Transit Time on Shot Noise

Staff: G. E. Duvall

In the last progress report it was mentioned that the minimum measurable noise from a diode had been found to be greater than originally expected. This has made it necessary to design a new diode which will deliver at least the minimum detectable noise current under conditions where the transit angle is large and the observation frequency is less than 60 Mc/sec. This new diode is under construction and will probably be completed within two weeks.

#### E. SYNTHESIS OF OPTIMUM LINEAR SYSTEMS

##### 1. Optimum Filtering

Staff: Professor Y. W. Lee

There is available in current literature experimental data on the relative merits of various filter attenuation characteristics for the transmission of speech in the presence of noise, but no theoretical computations have been made for comparison. It has been experimentally demonstrated that a sloping characteristic is superior to a steep one for high quality transmission, but the best characteristic is not known. On a statistical mean-square error basis, there is an optimum filter characteristic which may be computed by following Wiener's theory. An attempt is being made to obtain an optimum filter characteristic for comparison with published results.

##### 2. Optimum Prediction

Staff: Professor Y. W. Lee  
R. Cohen

Experimental work is being planned for checking some significant results of Wiener's prediction theory. As a preliminary step, the autocorrelation curve of a random function is computed. Graphical records of random motion suitable for a prediction test do not seem to be available in convenient forms. A suitable random motion will be chosen for test after preliminary trial calculations have been completed.

#### IV. F. RESPONSE OF NETWORKS TO FREQUENCY TRANSIENTS

Staff: Professor E. A. Guillemin  
D. M. Powers

Further study of the method of contour integration has been made as a necessary part of the work of determining the response of networks to frequency transients. The method is first used to discover the direct transforms of certain functions in which the frequency is a function of time. These transforms are then multiplied by network functions and the inverse transformations are taken to obtain the time response. Particular functions on which work is progressing are the linear frequency function and the FM function.