Code 2020

[redacted]

NRL REPORT 3832

DECLASSIFIED

COPY NO. 76

SIMULATION OF COMPLEX PULSE MODULATIONS

DECLASSIFIED by NRL Contract Declassification Team
Date: 1 Feb 2017
Reviewer's name(s): A. THOMPSON, P. HANNA
Declassification authority: NAVY DECLASS GUIDE/NAVY DECLASS MANUAL, 11 DEC 2012
06 SERIES

DISTRIBUTION STATEMENT A APPLIES
Further distribution authorized by
UNLIMITED only.

NAVAL RESEARCH LABORATORY

WASHINGTON, D.C.

[redacted]

[redacted]

[redacted]

DECLASSIFIED

[redacted]

DECLASSIFIED

NRL REPORT 3832

[redacted]

SIMULATION OF COMPLEX PULSE MODULATIONS

J. D. Young

July 27, 1951

Approved by:

H. O. Lorenzen, Head, Countermeasures Branch
L. A. Gebhard, Superintendent, Radio Division II

NAVAL RESEARCH LABORATORY
CAPTAIN F. R. FURTH, USN, DIRECTOR
WASHINGTON, D.C.

[redacted]

DECLASSIFIED

DISTRIBUTION

	Copy No.
OpNav	
Attn: Op-201X	1-2
Attn: Op-202X	3-4
Attn: Op-341D	5
Attn: Op-42	6-7
Attn: Op-421D	8-10
ONR	
Attn: Code 470	11-12
BuShips	
Attn: Code 838	13-22
BuOrd	
Attn: Code Re9	23-24
BuAer	
Attn: Code EL-91	25-26
Attn: Code TD-4	27-28
CO & Dir., USNEL	29-30
CDR, USNOTS	
Attn: Reports Unit	31-32
CDR, NADC	33-34
CDR, NATC	
Attn: Electronics Test	35
CDR, USNOL	36
ComOpDevFor	37
Supt., USNPGS	38
CO, Fleet Training Center, Norfolk	39
CO, C.I.C., Team Training Center, Boston	40
CO, Fleet Training Center, Newport for OinC RCM	41
CO, USN School of Electronics, Great Lakes, Ill.	
Attn: Lt. J. J. Bartko	42-43
OCSigO	
Attn: Ch. Eng. & Tech. Div., SIGTM-S	44
Attn: SIGGE-01	45

Armed Forces Security Agency	
Attn: Code 03A3	46
Hdqs., USAF, Directorate of Res. and Dev., AFDRD-EL-2	47-48
Dir., Evans Signal Laboratory	
Attn: Countermeasures	49
CG, SCEL	
Attn: SCEL Liaison Office	50-52
Ch. of Staff, USAF	
Attn: AFOAE	53-54
Attn: AFMEN-2	55
Wright-Patterson AFB	
Attn: BAU-CADO	56
Attn: CADO-E1	57-58
Attn: Ch., Electronics Subdiv., MCREEO-2	59
Attn: Aircraft Rad. Lab., Advanced Dev. Branch, MCREER	60
CO, Watson Laboratories, AMC, Griffiss AFB, Rome, N. Y.	
Attn: ENR	61
CINCNELM	
Attn: RCM Officer	62
CG, Hdqs., SAC, Offutt AFB	
Attn: Electronics Section	63-64
Hdqs., 311th Air Div., Barksdale AFB	
Shreveport, La.	
Attn: Deputy Chief of Staff Operations	65-66
CG, APG, Eglin AFB, Fla.	
Attn: Elect. Br., Operational Testing Div.	67
RDB	
Attn: Information Requirements Branch	68-69
Attn: Navy Secretary	70
Naval Res. Sec., Science Div., Library of Congress	
Attn: Mr. J. H. Heald	71-72

[redacted]

[redacted]

[redacted]

CONTENTS

[redacted]

ABSTRACT

Analysis of complex pulse modulations is essential to effective countermeasures. This report describes the various types of pulse modulation, discusses the development of a laboratory device for simulation of these signals, and illustrates the appearance of the modulated pulses on the most versatile signal analyzer (AN/SLA type) available at the present time. Results of this investigation verify the need for development of new techniques for analysis of signals of this type.

PROBLEM STATUS

This is an interim report; work on this problem is continuing.

AUTHORIZATION

NRL Problem R06-09R
NE 071-235

Manuscript submitted for publication: April 27, 1951

SIMULATION OF COMPLEX PULSE MODULATIONS

INTRODUCTION

In recent years many advances have been made in communication theory, and as a result, more and more complex signals have been brought into use for communication and control purposes. In many of these systems, variations and combinations of complex modulating schemes have been used to maintain secrecy. Often it is more economical to depart from conventional technique, wherein a separate channel is used for each source of information, and instead to multiplex several information sources on a common radio-frequency channel.

Analysis of these complex pulse modulations is essential to effective countermeasures. This report shows that electronic countermeasures equipment in use at the present time will not provide complete analysis of these signals, but will indicate only the general type of pulse modulation.

In order to detect the fact that an enemy is using a pulse-modulated signal, it must first be assumed that the signal has been intercepted by some type of wideband search receiver. Assuming that such a receiver is available and that a pulse signal suspected of carrying intelligence is received, it then becomes necessary to obtain certain fundamental information about the electrical characteristics of the signal. This fundamental information should include the average pulse rate, the pulse length, and the type of complex pulse modulation.

This report is concerned only with the third part of this information, the type of modulation, which will either identify or assist in the identification of modulated pulse systems.

The early part of the report discusses the various types of modulation that might be used in a pulse system. An explanation of the essential features of each modulation type is given, together with an illustrating photograph.

To further the progress of modulation studies involving signal analyzers, the need of a convenient and versatile method for producing many of the different types and combinations of pulse signal modulation has become a prerequisite. The second part of the report furnishes information on a complex-pulse modulation simulator originated for such studies. Several different types of modulated pulse systems which might be encountered in a typical countermeasures intercept problem have been simulated by use of the equipment, and the results illustrated with photographs.

Finally, several modulated pulse signals have been simulated and photographed as they appear on a Navy pulse analyzer of the AN/SLA type.

MODULATION SYSTEMS

In identifying an intercepted signal, it is first necessary to determine whether it is amplitude-, phase-, or frequency-modulated cw. An amplitude-modulated signal is easily identified by monitoring the output from the amplitude-modulation detector of the intercept receiver. The same can be done for phase- or frequency-modulated cw by means of their respective detectors. In receivers not provided with these detectors, the modulation of p-m or f-m signals can be detected by detuning the receiver slightly and using the sloping sides of the i-f amplifier frequency-response curve to convert the signal to amplitude modulation. When these signals are received, modulation patterns can be seen on the cathode-ray tube indicators used for the visual display.

Pulse signals can be easily observed on a cathode-ray tube having a time display. If means are given to adjust the time base, or if several time bases of different durations are used simultaneously, distinct patterns, characteristic of the particular type of system used, will indicate the presence of complex modulations.

Characteristics of several of the pulse systems are enumerated in the following pages. Definitions and nomenclature for the various types of modulation to be considered have been made in agreement with published information.[1,2]

Photographs illustrating the individual identification characteristics have also been included. These waveform photographs were taken with a Dumont 271-A camera on a Tektronix oscilloscope having a P-11 screen. Except where otherwise noted, the sweep calibration has been adjusted to 10 μsec/cm. The centimeter grid marks, five either side of the vertical center line, appear in the background of the pictures.

Pulse Amplitude Modulation

One of the more familiar modulated pulse systems is pulse amplitude modulation. To make the flight testing of pilotless aircraft economically practical, telemetering of test flight information is often sent back in a time division system which is pulse amplitude modulated.[3] In this system of modulation the amplitude is increased or decreased about a mean pulse level in accordance with the degree of modulation applied. The recurrence frequency, as well as the pulse width, are fixed and do not vary with modulation.

This type of modulation is usually easy to recognize when the signal is displayed on a time base which is short in comparison to the fundamental pulse repetition rate, since only one or two pulses will be seen on the oscilloscope sweep. An example of such a signal is shown in Figure 1. In this photograph, pulse amplitude modulation has been applied to the second pulse of a group of three. The modulating voltage is a sine wave of about 400 cycles. The degree of modulation is about 100 percent. It will be noticed that when the time base is short and properly synchronized to the pulse repetition rate, the pulse appears as a rectangular block, the height of which depends on the degree of modulation.

---

[1] Atwood, J. B., and Hansell, G. E., "Preliminary Report on Identification of Pulse Communication Systems," RCA Laboratories, Riverhead, New York. Project R R-325, Report 895-22 (Restricted), January 15, 1944

[2] Deloraine, E. M., "Pulse Modulation," IRE, Proc. 37: 702-705, June 1949

[3] Chisholm, J. P., Buckley, E. F., and Farnell, G. W., "A Multichannel PAM-FM Radio Telemetering System," IRE, Proc. 39: 36-43, January 1951

[redacted]

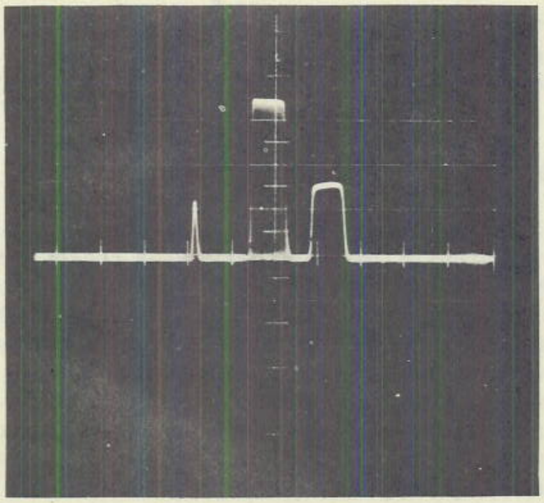

Figure 1 - Pulse amplitude modulation applied to the second pulse of a group

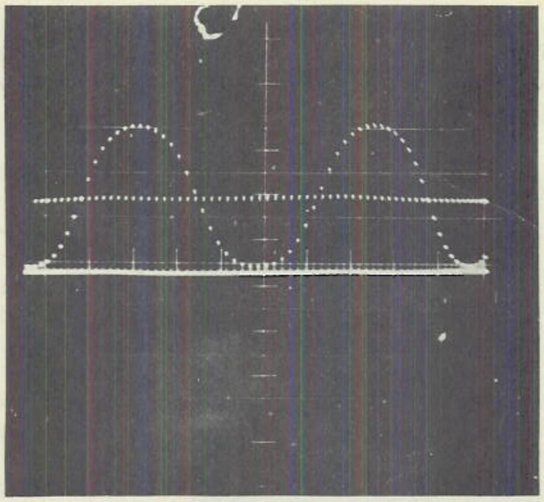

Figure 2 - Pulse amplitude modulation applied to one pulse of a pair of pulses

Pulse amplitude modulation is also easily distinguished on a time base which is a submultiple of the fundamental pulse rate and long in comparison to the pulse recurrence rate. Then an envelope of the modulating frequency is obtained. If a single sine-wave modulating tone is used, the pattern will appear as in Figure 2. This photograph shows two pulses displayed on a long time base with only one pulse being amplitude modulated. The sweep calibration is 480 μsec/cm. The modulating voltage is again a sine wave of 400 cycles and the degree of modulation is 100 percent.

Figure 3 illustrates pulse amplitude modulation applied to the second pulse of a pair. For comparison, the unmodulated condition of the same signal has been added to the photograph on the lower sweep trace. The modulating voltage used is a 3000-cycle sine wave and the sweep calibration is 14 μ sec/cm.

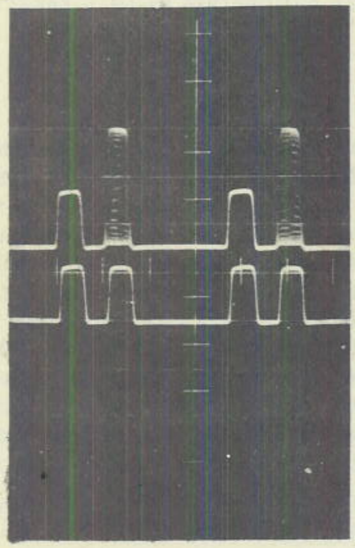

Figure 3 - Pulse amplitude modulation applied to second pulse of upper trace. Lower trace displays the unmodulated pulses.

[redacted]

In pulse amplitude modulation systems, as well as in all the other systems to be described, the pulse width and repetition frequency can be obtained in the unmodulated condition from a calibrated, triggered sweep, such as used in the AN/SLA type pulse analyzer.

Pulse Phase Modulation

Next to be considered is pulse phase modulation, also referred to as position or time modulation. In recent years considerable research has been done on the use of position or time modulated signals in the broadcast field. Since there is a definite indication that broadcast facilities in the near future will far exceed the available channels, engineering has been undertaken on experimental uhf multiplex broadcasting systems which use pulse position modulation. Such a system has been put in use by Federal Telecommunications Laboratories of Nutley, N. J.[4] In pulse phase modulation the phase of the pulse is advanced or retarded from the position it normally occupies in an unmodulated state. This pulse system can be examined on an oscilloscope, preferably one which has a variable time base or several time bases operating simultaneously. If a fast, triggered sweep is used, the pulse position excursion under modulating conditions can be easily seen. It should be noted that the pulse amplitude and width are not changing during modulation. If the modulation is a single tone and the sweep frequency is a subharmonic of the pulse rate, a deviation in position caused by the modulation is obtained as shown in Figure 4. In this photograph pulse position modulation has been applied to the second pulse of the upper trace. The lower sweep displays the same signal unmodulated. The modulating voltage is a 3000-cycle sine wave, and the sweep calibration is 14 μsec/cm. Figure 5 illustrates this modulation on a short time-base wherein the pulses are advanced in phase on one-half of the modulation cycle and retarded on the other half of the cycle, the amount of phase shift being proportional to the amplitude of the modulating signal. The modulation, as shown in this photograph, is applied only to the second pulse of a three pulse group. The sweep calibration is 10 μ sec/cm; the modulating frequency is a 1200-cycle sine wave.

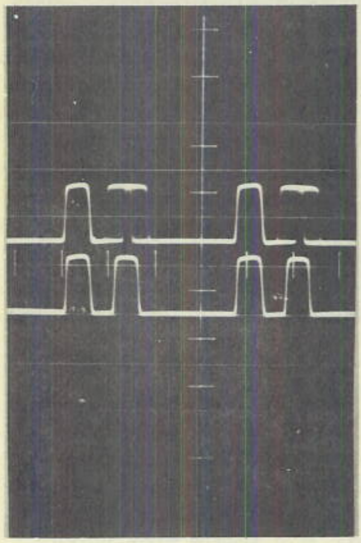

Figure 4 - Pulse position modulation applied to the second pulse of top trace

Pulse Repetition-Frequency Modulation

In pulse repetition-frequency (prf) modulation, the instantaneous repetition frequency of the pulse rate is increased or decreased according to the modulation applied. The average pulse rate remains at the unmodulated value when cyclic modulating signals, such as sine waves, are applied. The amount of frequency deviation depends on the amplitude of the modulating signal. Figures 6 and 7 are examples of prf modulation displayed on different time bases. In Figure 6 the sweep calibration is 80 μ sec/cm and in Figure 7 the calibration is 38 μ sec/cm. Once again the pulse width and amplitude remain fixed and only the instantaneous repetition rate of the pulses is changed. The modulating voltage in Figure 6 is a 2500-cycle sine wave and in Figure 7, a 3000-cycle sine wave. Figure 8 shows a prf modulated signal synchronized with a fast, triggered sweep. It should be noted in this case the modulation is applied to all three pulses, as is evidenced by their displacement. The modulation signal in Figure 8 is a 1200-cycle sine wave, and the sweep calibration is 10 μ sec/cm.

---

[4] Kandoian, A. G., and Levine, A. M., "Experimental Ultra-High-Frequency Multiplex Broadcasting System," IRE, Proc. 37: 694-701, June 1949

Pulse phase modulation without a reference pulse and prf modulation cannot be distinguished by means of the oscilloscope, as is clearly shown by comparing the two photographs of Figures 7 and 9. In Figure 9 the sweep calibration is 38 μsec/cm and the modulating frequency is a 3000-cycle sine wave.

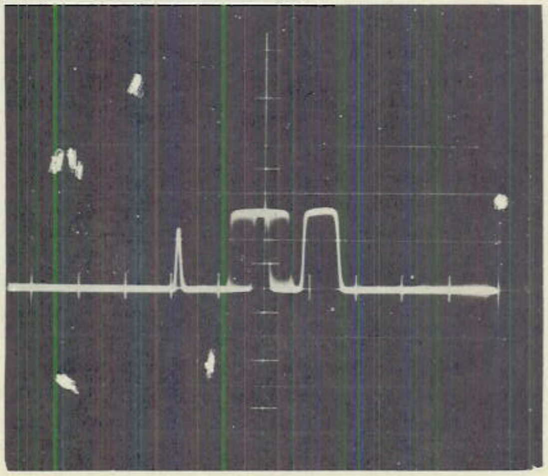
Figure 5 - Pulse position modulation applied to the second pulse of a three-pulse group

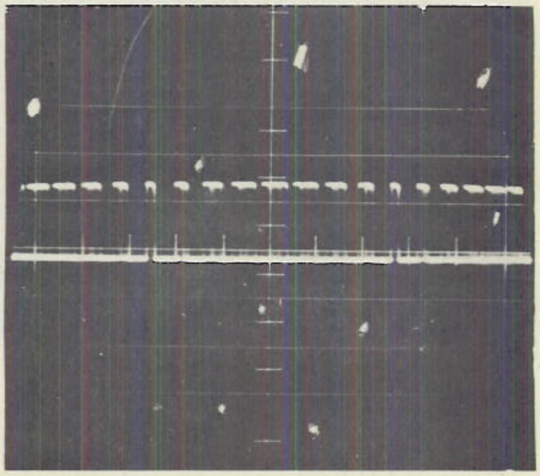
Figure 6 - Pulse repetition-frequency modulation

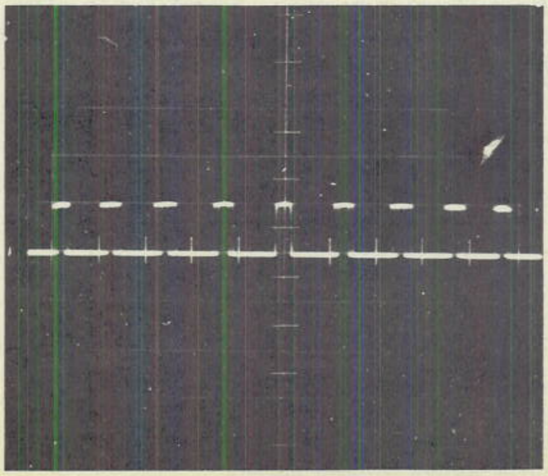
Figure 7 - Pulse repetition-frequency modulation

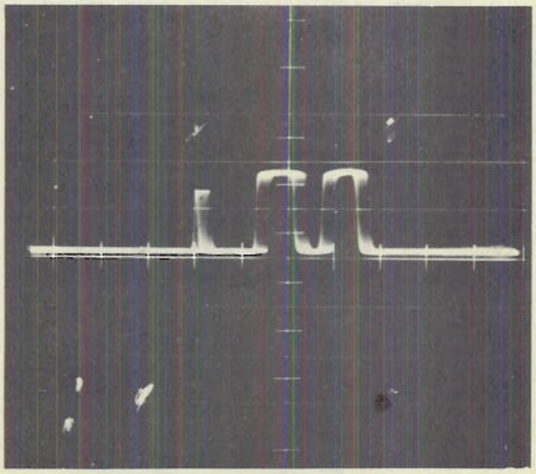
Figure 8 - Pulse repetition-frequency modulation applied to three pulses

Pulse Width Modulation

Pulse width modulation, wherein the width of the pulse is changed with the applied modulation, is another type of complex pulse system. The amount the width is changed

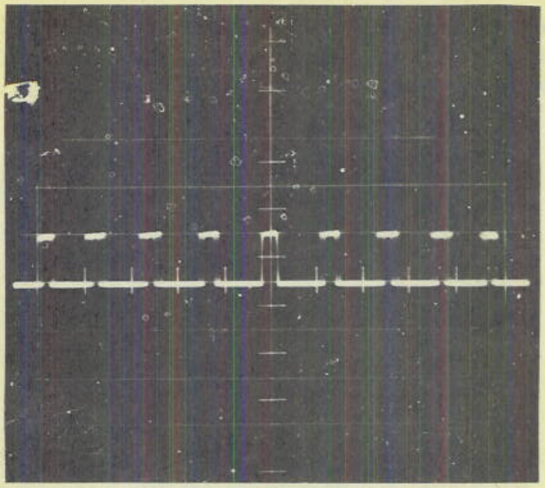

Figure 9 - Pulse phase modulation shown without a reference pulse

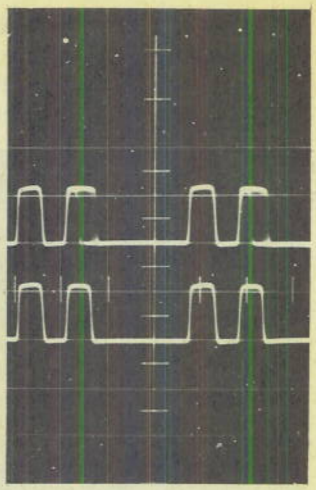

Figure 10 - Pulse width modulation applied to the second pulse of the top trace

depends on the amplitude of the modulating wave. An example of this is shown in Figure 10, where the back edge of the pulse is modulated at a sine-wave frequency of 3000 cycles. The lower trace in this photograph displays the unmodulated signal condition. The sweep calibration is 14 μsec/cm.

Figure 11 illustrates a pair of pulses, the first of which has been modulated in width and the second in amplitude. Noise has been added to the pulse signals. The unmodulated signal has been placed on the bottom trace of the photograph to shows the comparison between modulated and unmodulated conditions. The sweep calibration is 14 μsec/cm.

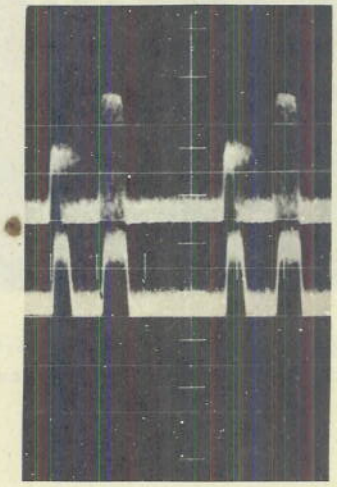

Figure 11 - Pulse width modulation applied to first pulse of upper trace and pulse amplitude modulation applied to second pulse of upper trace, with noise added to both pulses

[redacted]

Differential Double-Pulse Modulation

In differential double-pulse modulation, groups of two pulses are transmitted and the interval spacing between the two pulses is varied with applied modulation. The amount of deviation is dependent upon the amplitude of the modulating signal. In this system the pulses move in opposition during one-half of the modulation cycle and toward each other during the remaining half cycle. The modulated signal illustrating the group of two pulses appears as in Figure 12.

Figure 12 shows the modulated pulse groups as they appear when an external synchronizing signal (sync) is available from the modulation source. In this case both the prf of the pulse and the oscilloscope sweep have been locked in phase by use of a sync from the modulating source. The various degrees of separation can be clearly seen. This picture would not be obtained in the field, since the modulation sync is not available. Figure 13 indicates the character of the scope pattern to be expected in the field where the sync is derived from the modulated pulse groups themselves; Figure 14 shows the pulse group in the unmodulated condition.

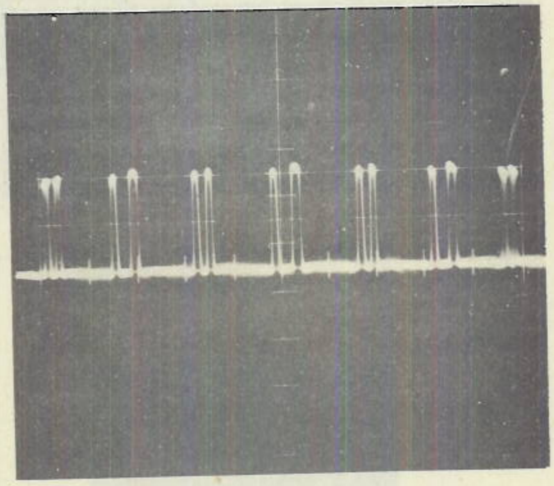

Figure 12 - Differential double-pulse modulation with external synchronization

Short-Pulse Number Modulation

The short-pulse number modulation system is composed of a group of several pulses transmitted with a fixed group-repetition rate. In the unmodulated state, the number of pulses in a group remains fixed; with the application of a modulating signal the number in a group is increased and decreased, the extent depending on the amplitude of the modulation. The number of pulses is decreased during one-half of the modulating cycle and increased during the remaining half. Figure 15 is an example of a modulated pulse group. The spacing between pulses, as well as between groups, can be read from the triggered calibrated sweep when the signal is unmodulated. The sweep calibration is 110 μ sec/cm. When the sweep rate is synchronized to a submultiple of the group rate, the individual pulses stand out clearly because the interval between pulses, as well as the pulse width, remains fixed. Figure 16 illustrates the same signal shown in Figure 15, but in the unmodulated condition. Under modulated conditions, the visual presentation on the oscilloscope continues to illustrate groups of individual pulses. In Figure 15 the pulses have been stopped by the camera action to show the change in the number of pulses in the group with single tone modulation of 2100 cycles applied.

Multichannel Pulse Systems

Many variations of multichannel systems are used in the communications field today. One particular system employing time division multiplexing, which has been tested in the field by the Western Union Telegraph Company, has been discussed in detail in a recent engineering publication.[5]

---

[5] Boothroyd, W. P., and Creamer, E. M., Jr., "A Time-Division Multiplexing System," Elec. Eng. 68: 583-588, July 1949

[redacted]

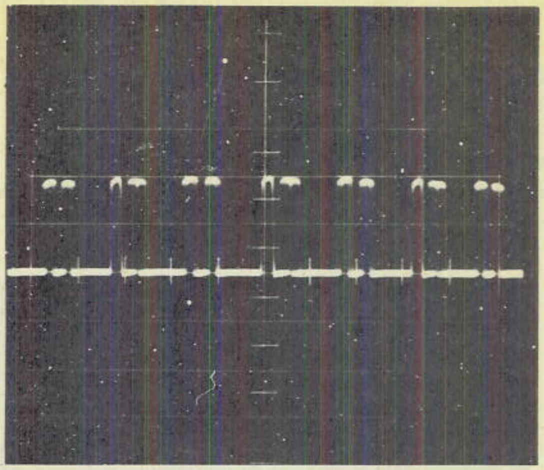

Figure 13 - Differential double-pulse modulation with signal synchronization

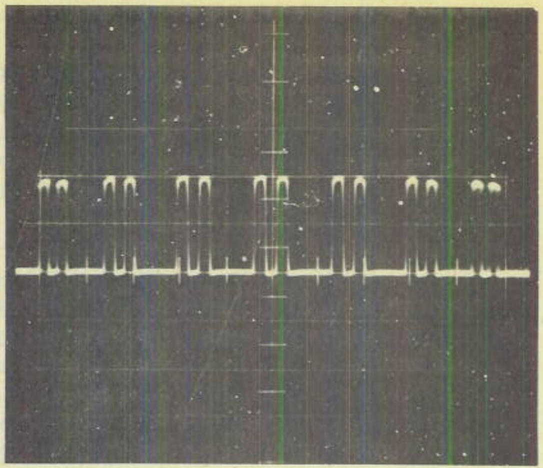

Figure 14 - The same signal as used in Figure 13, without modulation applied

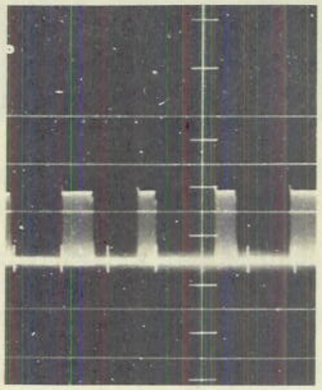

Figure 15 - Modulated pulse groups

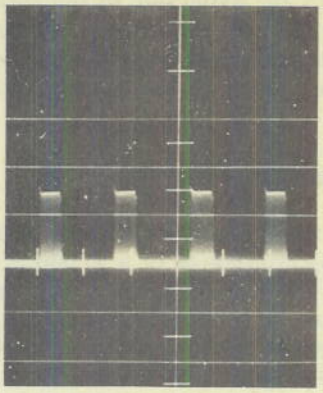

Figure 16 - Unmodulated pulse groups

A multichannel system is often recognized by a characteristic sync followed by a number of pulses which represent the intelligence channels. The number of channels may vary from two to as many as twelve. The channel pulses themselves are usually phase-modulated, although other types of modulation can be used, and these pulses are usually preceded by a characteristic sync which differs from the type of pulses used for the channels. The sync is acknowledged by the receiver circuits and is used to synchronize the channel-separating equipment with the transmitting equipment. The sync may be represented in many forms, such as two pulses close together, or a long and a short pulse, etc., but will always be distinct from the channel pulses. The channel separation is always wide enough so that under conditions of 100 percent modulation the channels will not approach each other too closely and cause "cross talk." Normally, then, a guard band between channels is allowed. Actually the channel spacings may not be alike; in fact, some channels may be missing or not used, depending on the system.

A two-channel system is represented in Figures 17 and 18. These photographs show variations in the type of modulation being applied to the channels. Any change in pulse width or spacing from the sync is significant and establishes each system as different from the next. The photograph shown in Figure 17 exhibits a sync followed by the first channel, which is pulse amplitude modulated. The second channel is represented by the last pulse, which in this case is modulated in width. The modulating frequency is a sine wave of about 300 cycles; the sweep calibration is 10 μ sec/cm. Figure 18 displays a simulated multichannel system in which the sync is followed by the first channel pulse, which in this case is unmodulated. The second channel, represented by the last pulse, is phase-modulated. Noise also has been added to the signals of Figure 18. The modulating frequency is a 400-cycle sine wave; the sweep calibration is 10 μ sec/cm. These figures illustrate a few of the many possible variations of a two-channel system that would distinguish them as different transmitted signals.

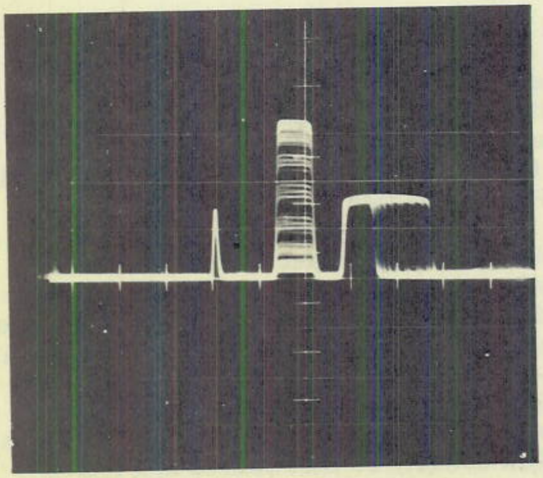

Figure 17 - Multichannel system consisting of a sync, an amplitude-modulated pulse, and a width-modulated pulse

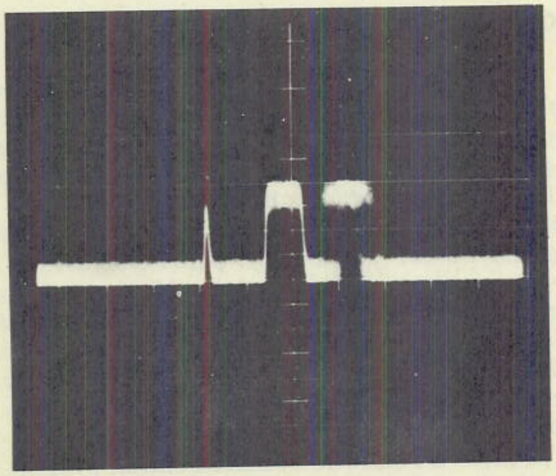

Figure 18 - Multichannel system with noise added to a sync, an unmodulated pulse, and a position-modulated pulse

A multichannel system will be recognized readily on a long time-base when the sweep is synchronized to a submultiple of the group rate, a group being identified as the sync and all channel pulses up to the next sync. Since a sync is usually transmitted, this signal serves as an aid in adjusting the oscilloscope to the proper rate to give a correct visual display of the channels transmitted. When more than one channel is being modulated in a multichannel system, the modulation of each channel is superimposed on the others and will appear in the output of a receiver which does not have the proper channel-separation circuits.

When an intercepted signal of this type is displayed on a variable triggered time base, the group rate, the type of pulse, the number of channels, the spacing between channels, and the type of sync can be obtained with reasonable accuracy.

Pulse Code Modulation

Pulse code modulation (pcm) involves the application of two basic concepts, the time-division principle and the amplitude-quantization principle. Although other arrangements are possible, one of the common methods used is to sample the input on a time-division basis.

Multiplex transmission of speech channels by sending short pulses selected sequentially from the respective speech channels is now well known in the telephone art and is called time-division multiplex. After the signal is sampled, each of the samples so obtained is represented by a quantized amplitude or integer number. Each of these integer numbers is represented as a binary number of n digits. Thus pcm represents each quantized amplitude of a time-division sampling process by a group of ON-OFF pulses, where these pulses represent the quantized amplitude in a binary system. A pulse code system starts with a pulse amplitude modulation system and adds the proper equipment at the terminals to enable the transmission of groups of ON-OFF pulses or binary digits. Each group represents the instantaneous amplitude of the primary modulating signal. A typical example of an experimental pcm system used by Bell is described in the Bell System Technical Journal.[6]

No photographs of a simulated pcm system are included in this report.

COMPLEX-PULSE SIMULATOR UNIT

The initial step in the investigation of methods by which complex-pulse systems might be analyzed was the development of a laboratory signal generator capable of simulating modulated pulses. This unit is driven from an internal blocking oscillator pulse generator, the output of which is split into two similar pulse-forming channels. The over-all functional diagram is provided in block form in Figure 19. Pulse repetition-frequency modulation has been made available and is applied, when desired, to the original pulse formed in the blocking oscillator. Each of the pulse channels is provided with separate modulating tubes to produce pulse position, pulse width, and pulse amplitude modulation. An inverter tube in the first channel provides an out-of-phase input for differential pulse phase modulation when used in conjunction with phase modulation in channel two. The pulse outputs of the two channels are mixed, along with the original sync, in a parallel-plate mixing circuit. Provision has been made for outputs consisting of channel one or channels one and two, with or without a sync. Another vacuum tube is used to provide grid-mixing of the composite pulse signals with noise to present a realistic communication system as might actually be encountered in a typical countermeasures intercept. The output of the mixer stages is inverted and used to drive a split-load output tube, which provides both positive and negative pulses. The various circuits provide many combinations of position, width, amplitude, and prf modulation on the pulses of both channels.

Blocking Oscillator

The modulated pulse generator circuit is shown in schematic form in Figure 20. The initial pulse is generated in V1, which is a 6AK6 miniature pentode used in a blocking oscillator circuit. Figure 21 shows the initial pulse (test point 1)* with a peak amplitude of 320 volts. In this circuit the oscillator actually cuts itself off after the completion of a cycle owing to the accumulation of negative charge on the 200 $\mu\mu$f condenser in the grid circuit. The discharge of this electron accumulation through the grid return path allows the tube to conduct again. The rate of this intermittent oscillation is determined by the time constant and bias potential in the grid circuit. In V1 the frequency has been made variable from about 2.5 kc to 17 kc by means of the potentiometer shown in the grid return. If desired, this frequency range could be lowered or raised easily, but the range chosen was considered adequate for the signal analyzer problems now under study.

---

[6] Goodall, W. M., "Telephony by Pulse Code Modulation," Bell Sys. Tech. J. 26: 395-409, July 1947

* Test points are indicated in the diagram by a numbered double circle connected to the point by a line.

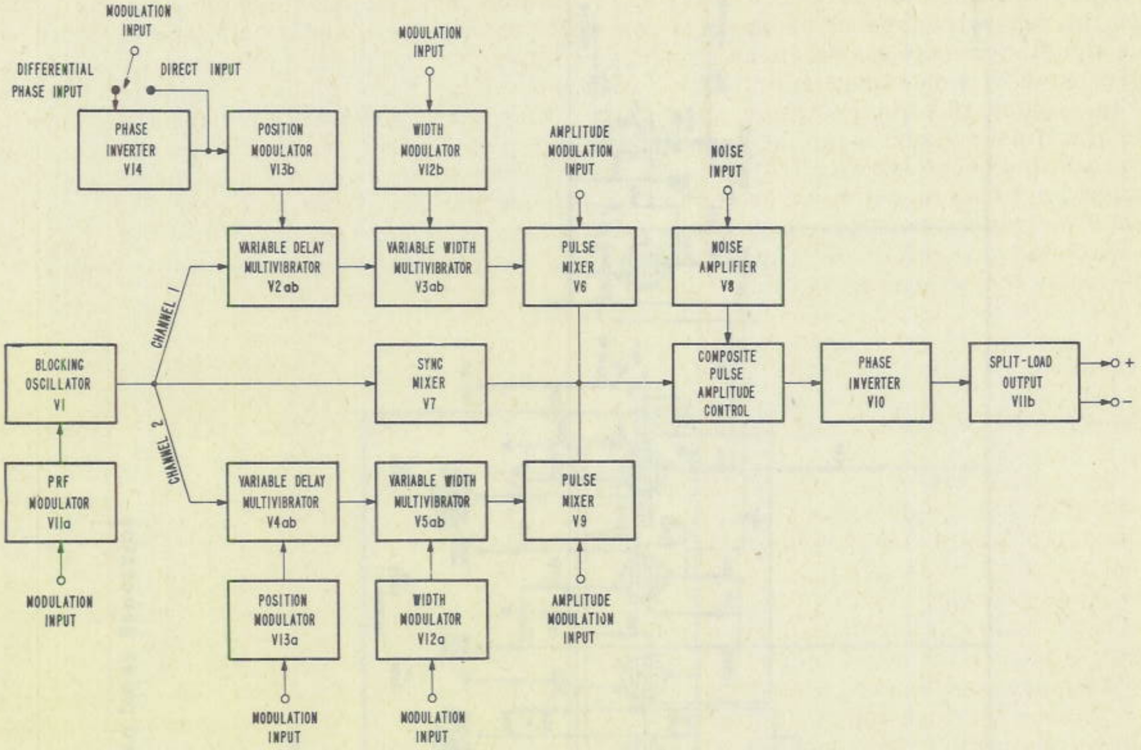

Figure 19 - Block diagram of modulated pulse generator

Pulse Repetition-Frequency Modulation

Pulse repetition-frequency modulation is obtained by use of V11a. The modulator consists of one-half of a 12AU7 tube operated as a cathode follower with 1-K load resistor. The audio input signal is applied to the grid and the varying cathode bias which is developed across the resistor is applied to the grid return of the blocking oscillator, thereby changing the instantaneous frequency of the blocking oscillator.

Channel 1

Delay Multivibrator - The pulse output of the blocking oscillator (test point 1) is differentiated sharply and used to trigger a delay multivibrator V2, a 12AU7 double section triode. Figure 22 illustrates the waveform as it appears at the plate of multivibrator V2 (test point 2). The peak amplitude is about 40 volts and the pulse width is 20 μ sec.

The multivibrator formed by V2a and V2b is a one-shot cathode-coupled type, the feedback from V2b to V2a occurring through the common cathode resistor of 1200 ohms. The grid of V2b is returned to a positive bias and the grid of V2a is returned to ground. Normally, without the application of an outside pulse, V2b is conducting because of the positive grid return. The application of a negative pulse causes V2b to be cut off and simultaneously V2a conducts as normal in this type multivibrator. After V2b grid circuit recovers, V2b again conducts. A photograph taken at V2b grid, showing a negative pulse width of 20 μ sec and a peak amplitude of 31 volts is shown in Figure 23.

DECLASSIFIED

SECRET

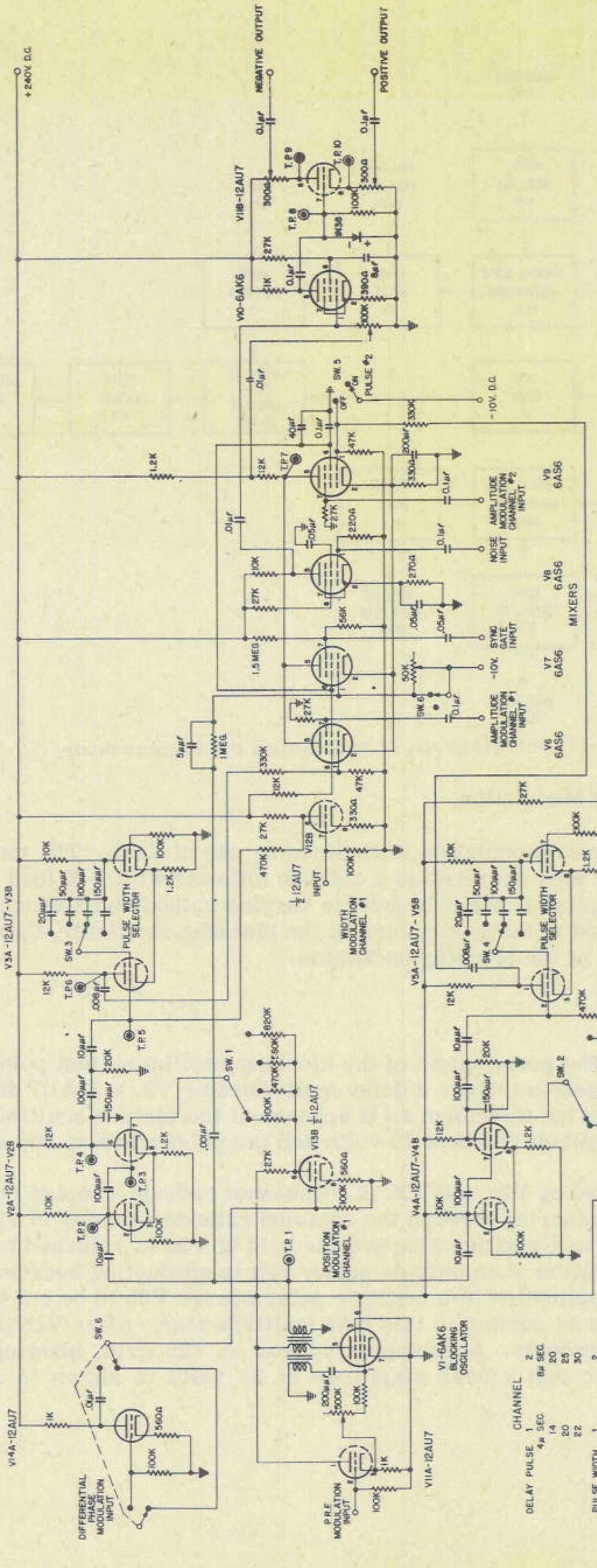

Figure 20 - Modulated pulse generator

SECRET

DECLASSIFIED

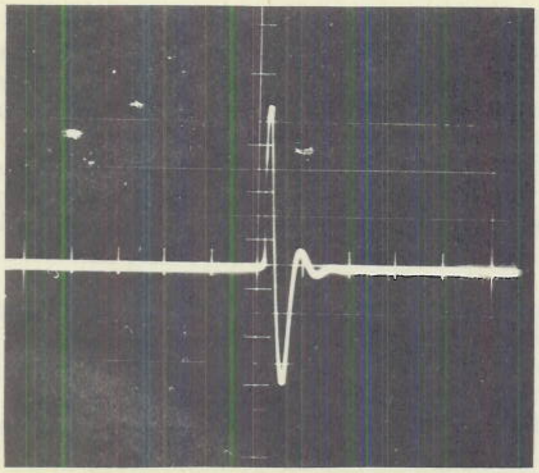

Figure 21 - The original trigger pulse derived from the blocking oscillator, taken at test point 1

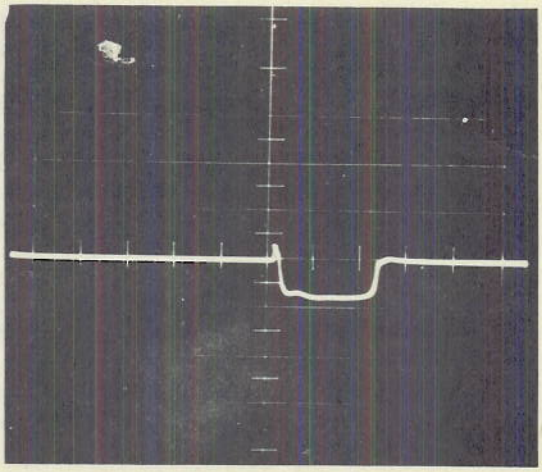

Figure 22 - Negative waveform at plate of delay multivibrator, test point 2

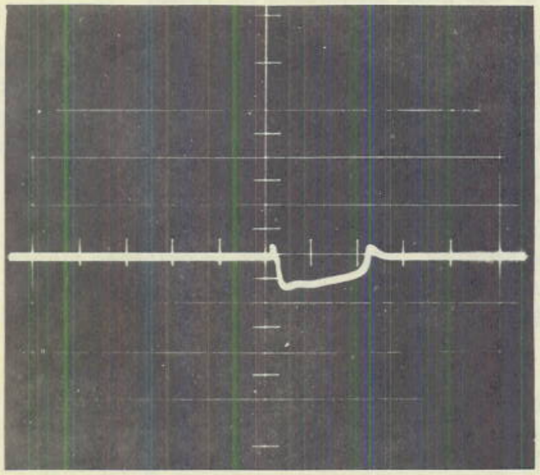

Figure 23 - Delay multivibrator grid signal, at test point 3

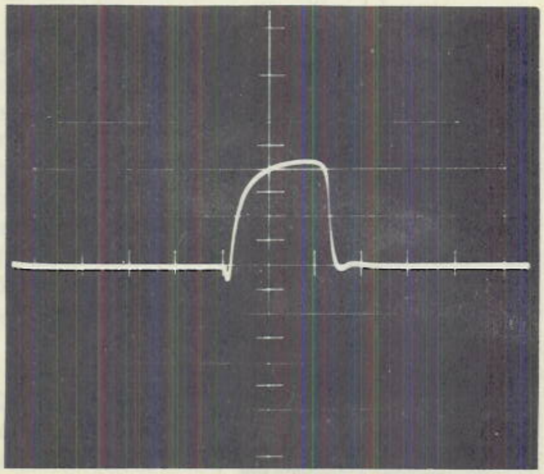

Figure 24 - Delay multivibrator output pulse, at test point 4

The pulse width of this multivibrator can be changed by altering the discharge time of V2b grid circuit. As seen in Figure 20, four variable pulse widths of 4, 14, 20, and 22 microseconds are obtained by changing the resistance of the grid time-constant with Switch 1. The pulse output is taken from the plate load of V2b and coupled into the following circuit. This positive pulse is shown in Figure 24 (test point 4). As will be noticed, the pulse rise time has been intentionally integrated to prevent the sync from appearing in the final output. The peak amplitude at this test point is 120 volts and the pulse width shown in the photograph is 20 μ sec.

Pulse Position Modulator - At this point it is in order to consider V13b, one-half of a 12AU7, which supplies modulation for pulse position. As will be noted in Figure 20, the grid-return resistor of V2b is connected to the 27-K plate load of V13b. This modulator tube is biased to operate on a linear portion of its plate characteristic curve. An applied voltage at its grid will be amplified and reproduced in the plate load as normal in a linear amplifier. The plate of this tube will rise and fall according to the input at its grid. This change in plate voltage is applied to V2b through the grid resistor selected by Switch 1, and the back edge of the output pulse from multivibrator V2 is then varied in time position in accordance with the applied modulation. The front edge of the pulse remains fixed in time position since it coincides with the sync input. The modulated back edge of the multivibrator is used to trigger another multivibrator, V3, thereby giving position modulation to the pulse output of V3.

Phase Inverter - A phase inverter, V14a, has been added in series with the input circuit of the pulse position modulator tube for Channel 1. The inverter consists of one-half of a 12AU7 operating in a linear manner and without appreciable gain. When inserted in the circuit by means of Switch 6, its purpose is to invert the phase of the modulation signal. When the switch is in the OFF position, the modulating wave is transferred directly to the input of V13b.

Pulse Width Multivibrator - To obtain a time delay with respect to the original trigger pulse, the positive output of V2 is differentiated, and the negative pip which results from the back edge of this pulse is used to drive another multivibrator, V3. Figure 25 shows the combination of the differentiated pulse and the negative grid pulse of V3. The pulse width in the photograph is about 16 microseconds, the peak amplitude 22 volts.

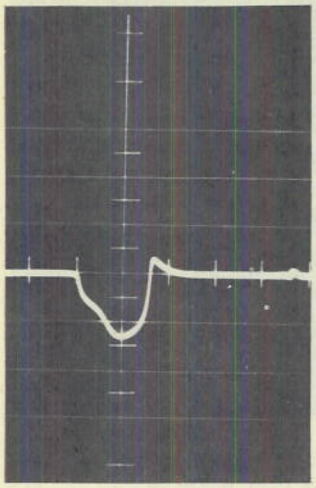

Figure 25 - Negative input at grid of pulse width multivibrator, test point 5

This multivibrator furnishes the pulse which is eventually coupled to the output circuit. If the start of this circuit, with respect to the initial pulse of the blocking oscillator, is delayed by changing the pulse width of V2, the pulse will be displaced by an amount equal to the pulse width of V2. If V2 is continuously modulated by applying a signal to V13b, again the start of the pulse formed in V3 will be displaced in time at the modulating rate applied. Thus a pulse is obtained whose start can be delayed in fixed steps and which is capable of continuous modulation.

Multivibrator V3 is similar in operation to the one formed by V2, since it is of the same type. The width of the pulse generated by V3 is determined by the discharge time-constant in the grid circuit. Switch 3 changes the grid condenser to permit selection of four different time-constants. The pulse widths available in Channel 1 are 3, 4, 10, and 15 μsec. It will be noted that the grid resistor for this stage is returned to the plate of V12b, which is used to supply a voltage for pulse width modulation.

The pulse formed in multivibrator V3 is applied to the grid input of mixer tube V6. This positive output pulse is shown in Figure 26. The pulse width in this particular case is about 15 μ sec and the peak amplitude as measured at test point 6 is 110 volts.

Pulse Width Modulator - V12b is one-half of a 12AU7 tube, and is operated linearly in a manner similar to that of V13b. A modulating voltage is applied to its grid and the changing voltage appearing across the 27-K plate load is direct-coupled into the grid circuit of multivibrator V3. As the grid bias of this stage is varied, the pulse width is changed,

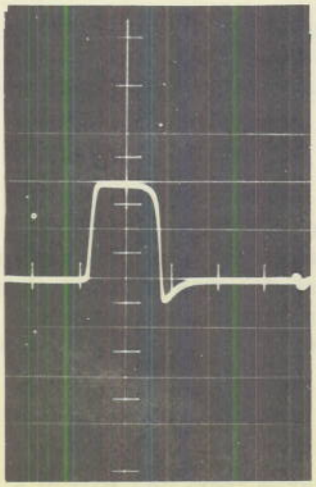

Figure 26 - Positive output at plate of pulse width multivibrator, test point 6

and the result is a pulse width variation which is in phase with the modulating signal applied to V12b. The amount of modulation is regulated by varying the grid input of V12b.

Channel 2

It will be noted that Channel 2, which is composed of V4 and V5, is a similar circuit and serves the same purpose as tubes V2 and V3 in Channel 1. This adjacent channel performs in the same electrical manner, providing a pulse output capable of being modulated in the same way as the one generated in Channel 1. Thus, two variable-width pulses can be generated, both of which can be pulse-width-modulated and displaced in time from the initial pulse. The only significant difference between the pulse outputs of Channels 2 and 1 is that the circuit time constants in the multivibrators of 2 have been adjusted to give somewhat longer delays and pulse widths. Reference to Figure 20 will indicate that V13a and V12a furnish position and width modulation in Channel 2, as do V13b and V12b in Channel 1. The delay from the initial trigger to the beginning of the second-channel pulse can be selected by Switch 2. Delays of 8, 20, 25, or 30 μ sec are available. The pulse width selected by Switch 4 can be either 8, 10, 14, or 20 μ sec.

Mixer Circuits

The outputs of both channels are fed into separate 6AS6 mixer tubes having a common load. Channel 1 is fed to V6 and Channel 2 to V9. Amplitude modulation of these signals is provided by applying a modulating voltage to the suppressor grid, which, in the 6AS6 tube, is an element having characteristics similar to the control grid. A signal applied to this third grid will vary the plate current, and therefore provide a convenient way to obtain amplitude modulation, simply by applying a modulating voltage directly to this grid. Channel 2 pulse mixer has been provided with an OFF-ON switch (Switch 5), so that it may be removed entirely from the mixer's output if desired.

V7 is also a 6AS6 tube working into the common plate-load of 12 K. V7 is used to provide means by which the initial sync may be added to the output pulses. As shown at the input of V7, a potentiometer of 50 K is provided for gradual increase of the sync amplitude level; also, Switch 6 in the same circuit will turn the sync on or off in the mixer's output. The output of the sync can also be cut off in the mixer by applying a negative potential of about 15 volts peak to the suppressor grid. Amplitude modulation of the sync can be obtained by applying a modulating voltage to the suppressor grid of V7.

Still another 6AS6, V8, is used to add noise to the composite signal obtained from the three, common plate-mixers. In this application, the 6AS6 third grid is returned directly to cathode and the tube is used as a normal pentode amplifier. The control grid is used to inject the noise voltage; and the output, as taken from the 10-K plate load, is grid-mixed with the composite pulse signals in the next tube, V10, a 6AK6 inverter. The amplitude of the noise in the mixer output is controlled externally at the noise source, thereby varying the input at the grid of the noise tube, V8. It is also possible to vary the pulse signal-to-noise-level ratio by increasing or decreasing the composite signal output from the mixer, as it is coupled to the inverter grid input by means of the 100-K grid potentiometer.

Figure 27 is a photograph of the composite mixer signal output. The original sync has been added and indicates a delay of about 20 μ sec from the sync to the pulse. The pulse width is about 15 μ sec, and the peak amplitude is 55 volts as measured at the mixer's output at test point 7.

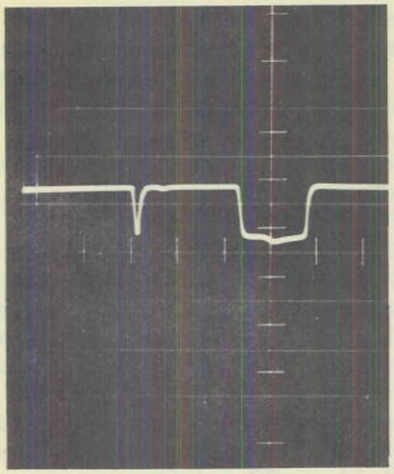

Figure 27 - Composite mixer signal output at test point 7, with original sync added

Inverter Stage

It was desired to have a positive-driven split-load amplifier in the final pulse output stage; as a result, an inverter tube, V10 (a 6AK6 pentode), was added to change the polarity of the negative composite signal from the mixer. The gain of the inverter is slightly greater than unity.

Split-Load Output

The final pulse output is taken from one-half of a 12AU7 tube, V11b, which has equal plate and cathode loads. This circuit is operated with a positive pulse on its grid and provides both positive and negative pulses of about 2 volts peak amplitude across 330-ohm loads. In the grid circuit, a 1N38 crystal diode is used as a d-c restorer for base-line stabilization under modulating conditions.

Figure 28 is a double-exposure photograph of the waveforms at the grid input and the plate output of the split-load amplifier. The upper trace was taken at the grid, test point 8, and the lower trace shows the output obtained at the plate, test point 9. The peak input voltage is about 7 volts; the output is 3.2 volts. The pulse width is about 15 μ sec.

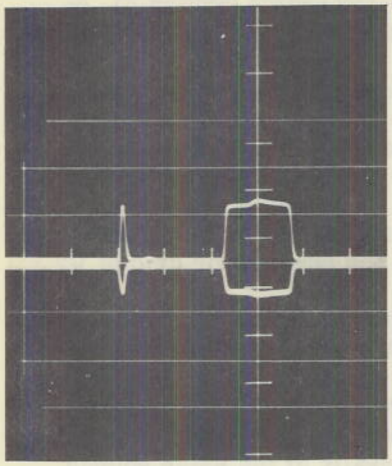

Figure 28 - Double exposure, showing the positive input pulse to the split-load amplifier at test point 8, and the negative output pulse at the plate, test point 9

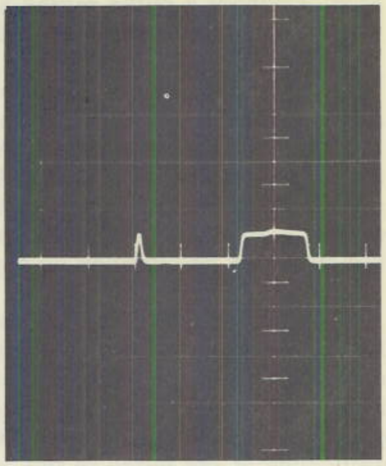

Figure 29 - Positive output pulse, test point 10

[redacted]

Figure 29 illustrates the positive output pulse obtained from the split-load amplifier at test point 10. The sync has been added to show a 22 μsec delay from the sync to the pulse. A photograph illustrating the original sync followed by two pulses with different pulse width is given in Figure 30. This signal (observed at test point 10) is one of the many combinations of widths and delays possible in the unit.

Figure 31 indicates another variation in the arrangement of pulse widths and delays, wherein a pedestal type signal has been simulated. Noise has also been added to the output. The sweep calibration is 10 μ sec/cm.

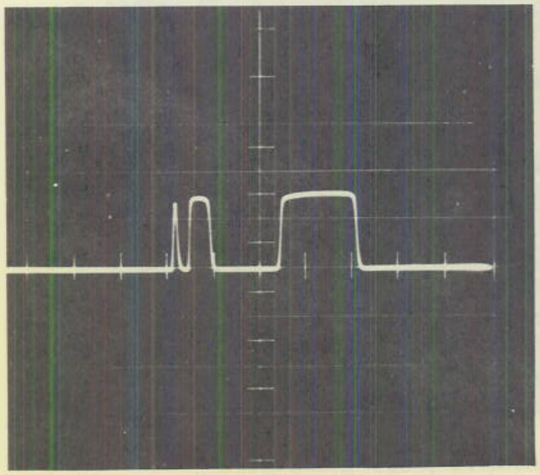

Figure 30 - Output pulses at test point 10 showing second-channel pulse inserted

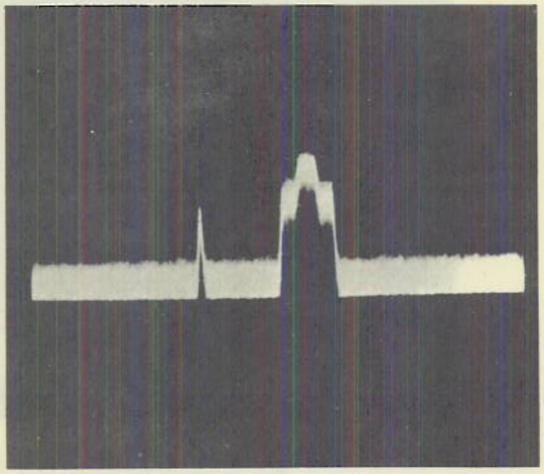

Figure 31 - Pulse width and delays of both channels arranged to give a pedestal type pulse at test point 10, with noise added

Power Supply

The power supply is conventional, and employs a double-section choke-input filter. Figure 32 is a schematic diagram of the power supply. The rectifier tube is a 5V4G. A 10-volt negative voltage is provided by a small dropping resistor of 75 ohms in the negative return to ground. The positive output voltage is about 240 volts, which is sufficient for stable operation of the circuits involved.

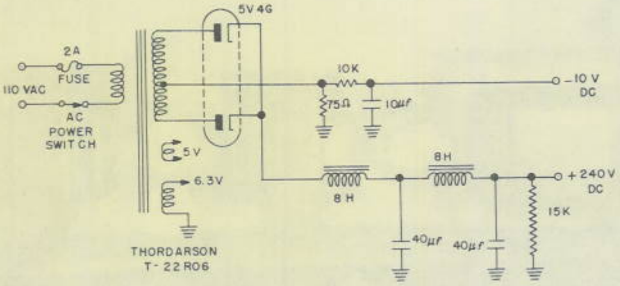

Figure 32 - Power supply for modulated pulse generator

[redacted]

Figures 33 and 34 are photographs of the complete simulator showing a front and a top view.

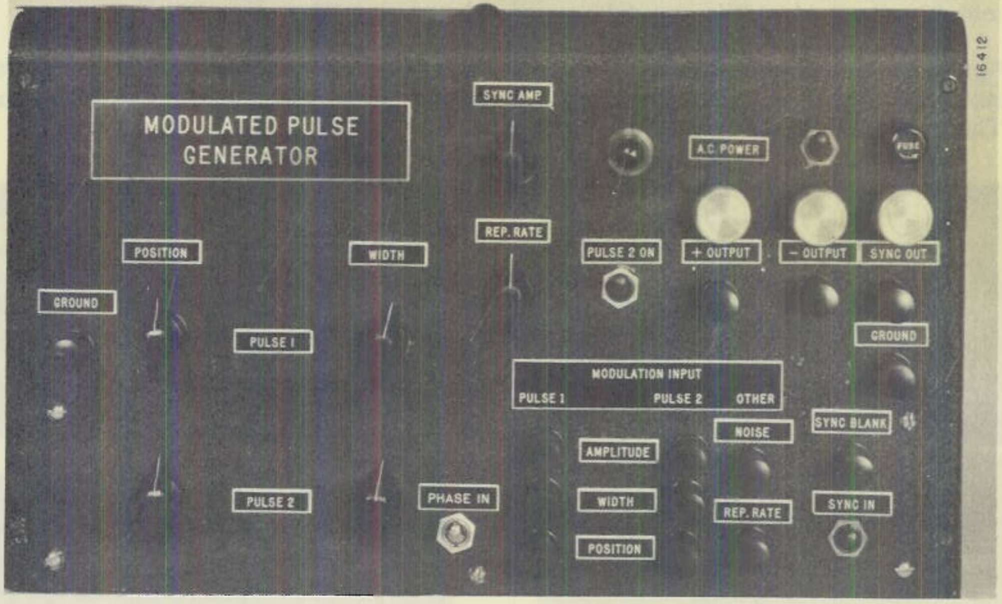

Figure 33 - Front view of modulated pulse generator

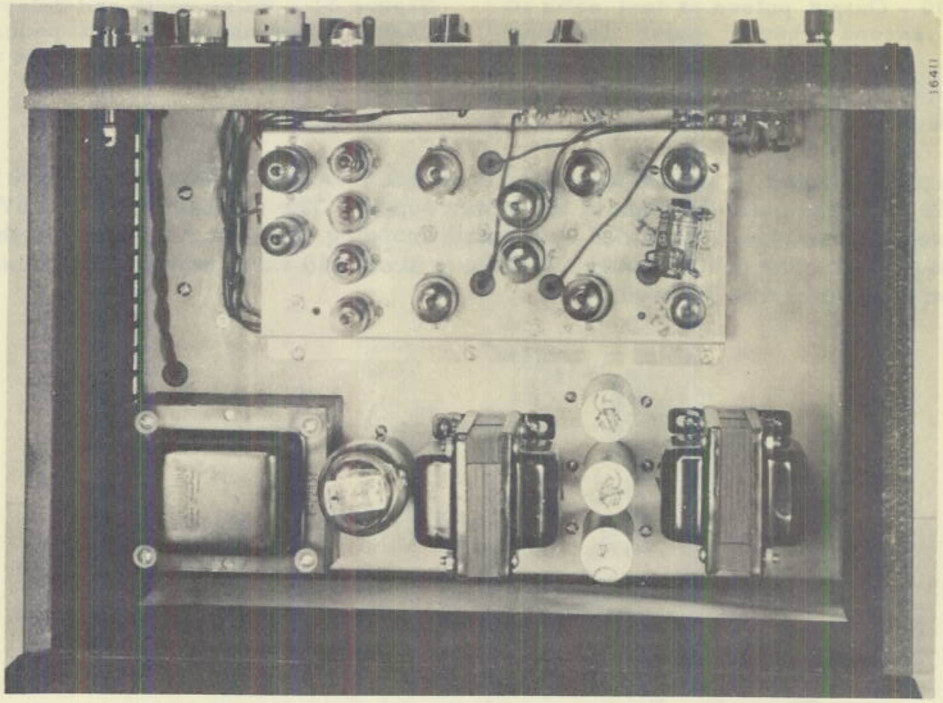

Figure 34 - Top view of modulated pulse generator

[redacted]

AN/SLA TYPE PULSE-ANALYZER DISPLAY

The modulated pulse unit has been used to simulate several different complex pulse signals, the results of which have been displayed on a Navy pulse analyzer, type AN/SLA.[7] This particular analyzer utilizes a multigun cathode-ray tube consisting of five individual gun structures within a single envelope. The incoming signal information is displayed simultaneously on five different sweeps. The five different time bases, as they appear in Figures 35 through 42 are, reading from top to bottom, 5, 50, 500, 5000, and 50,000 μ sec. Since the incoming signal is presented on several time bases simultaneously, much valuable intercept information is obtained that is not available in other types of display. In this particular analyzer the upper two sweeps are used for pulse width measurements and the lower three sweeps are used to measure the pulse repetition-frequency of a signal.

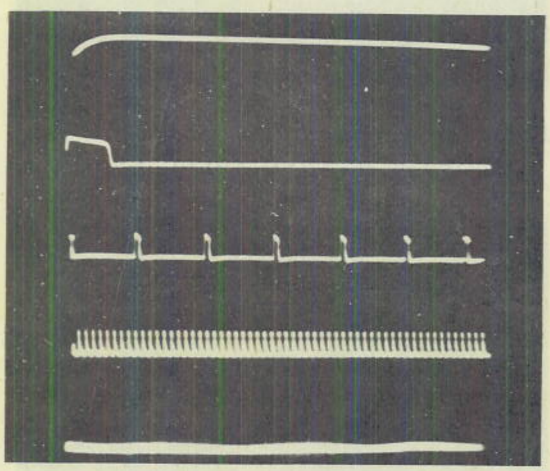

Figure 35 - An unmodulated pulse signal on an AN/SLA type analyzer

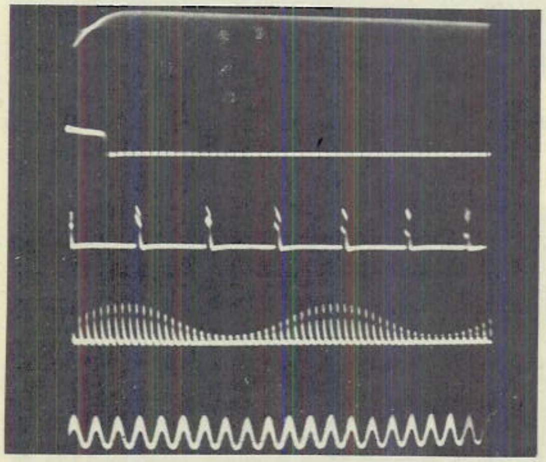

Figure 36 - Pulse amplitude modulation displayed on an AN/SLA type analyzer

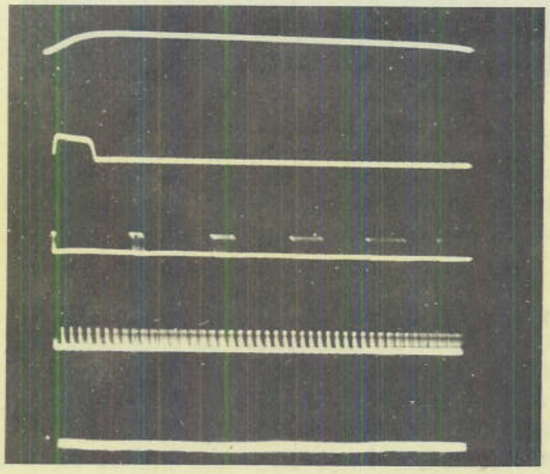

Figure 37 - Pulse repetition-frequency modulation displayed on an AN/SLA type analyzer

---

[7] The AN/SLA type analyzer used for the photographs in this report represents the most modern modification of the technique originally described in NRL Report R-3435, "An Instantaneous Pulse-Signal Analyzer" (Confidential), by J. E. Gall, March 22, 1949. A report is now in progress describing the circuitry and performance of this modified analyzer.

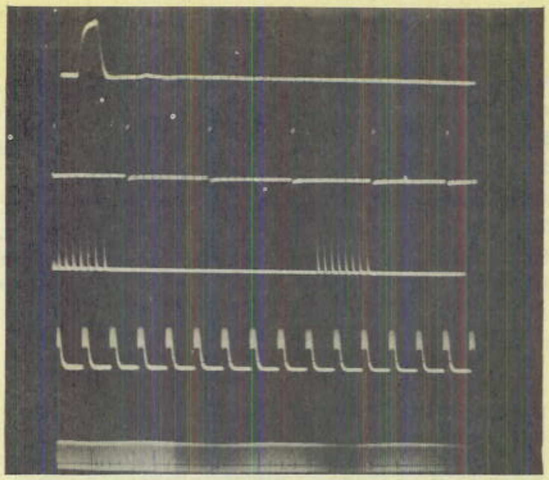

Figure 38 - An unmodulated pulse group displayed on an AN/SLA type analyzer

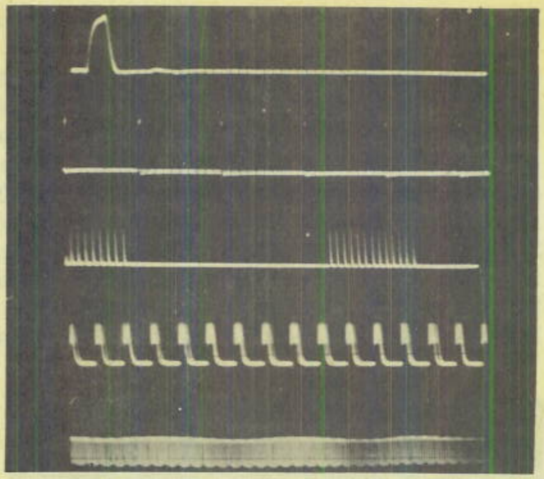

Figure 39 - Pulse group modulation displayed on an AN/SLA type analyzer

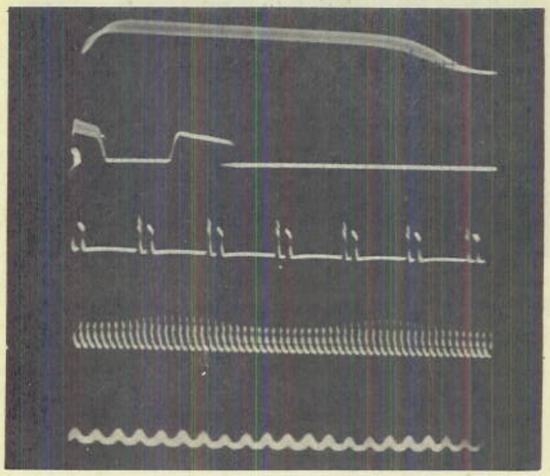

Figure 40 - A double-pulse system displayed on an AN/SLA type analyzer

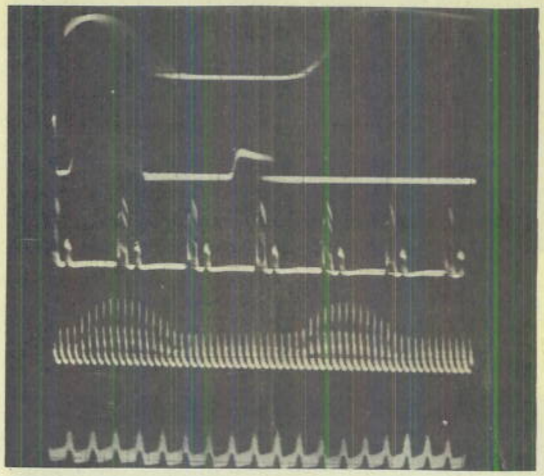

Figure 41 - A multichannel system consisting of a sync, an amplitude-modulated pulse, and a width-modulated pulse; as displayed on an AN/SLA type analyzer

Several photographs taken with a Leica camera show the simulated complex modulation signals as they appear on the pulse analyzer. Figure 35 illustrates an unmodulated pulse signal. The calibrated scales associated with each sweep (which do not appear in the photographs) indicate that the pulse width is about 6 μsec and the recurrence rate is about 14 kc. The same signal has been pulse amplitude modulated in Figure 36. The modulation envelope can be clearly seen on the two slow-speed sweeps at the bottom of the photograph. The degree of modulation is nearly 100 percent. The modulating frequency used is a 400-cycle sine wave.

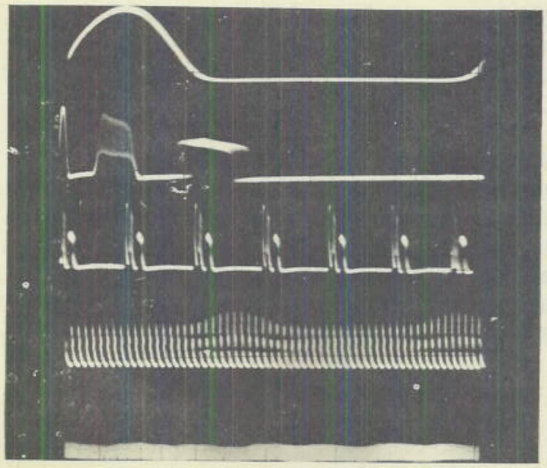

Figure 42 - A multichannel system consisting of a sync, an amplitude-modulated pulse, and a position-modulated pulse; as displayed on an AN/SLA type analyzer

Figure 37 again displays the signal used in Figure 35, this time with prf modulation applied. The 500- and 5000-microsecond time bases clearly illustrate the deviation in pulse position with modulation. The modulating voltage is again a 400-cycle sine wave.

In Figure 38, an unmodulated pulse group has been photographed. The analyzer shows that a 0.5-μ sec pulse with a 10-μ sec pulse spacing within a group, and a group repetition frequency of about 3100 cycles has been used. Figure 39 displays the same signal with pulse group modulation applied. The change in the number of pulses in a particular group is best illustrated on the 500-μ sec time base. The modulating voltage used is a 600-cycle sine wave. The pulse group shown in Figures 38 and 39 have been simulated with a unit of a Pulse Train Control System, discussed in a previous report.[8]

Figure 40 illustrates a double-pulse system wherein the first pulse is amplitude modulated and the second pulse is modulated in width. The 50-μ sec sweep indicates the change in pulse width of the second pulse; the two slow-speed sweeps reveal amplitude modulation patterns of the first pulse. The modulating voltage is a 400-cycle sine wave. The analyzer also indicates that the first pulse is slightly under 5 μsec in width and the second pulse varies from about 7 to 9 μ sec in length. In addition, the spacing from the first to the second pulse is about 13 μ sec and the prf is about 14 kc.

Figure 41 displays a simulated multichannel system. The first sweep shows a sync of about 1.25 μ sec in pulse width. The 50-μ sec sweep reveals a 10-μ sec pulse representing Channel 1, and a 6-μ sec pulse representing Channel 2. The first channel is pulse-amplitude-modulated, the longer time bases clearly showing an outline of the modulation envelope. The second channel is pulse-width-modulated with the width varying between 4 and 8 μ sec. The pulse recurrence frequency, as read on the 500-μ sec sweep, is about 14 kc. The modulating voltage used on both channels is a 400-cycle sine wave.

Figure 42 displays a multichannel system similar to that of Figure 41, with the exception that pulse position modulation has been used on the second channel and amplitude modulation on the first. The position modulation as well as the amplitude modulation can be identified on the 50-μ sec time base. The envelope of the pulse amplitude modulation is easily identified on the 5000-μ sec time base. The modulating voltage used is a 400-cycle sine wave.

SUMMARY

An introduction to various complex pulse modulations has been given along with basic information indicating how they may be recognized and classified. Actually classifying the complex waveforms with an oscilloscope or with a pulse analyzer such as the type AN/SLA, although not extremely complex in most cases, does require a certain amount of fundamental

---

[8] Young, J. D., "A Pulse-Train Control System," NRL Report 3502 (Confidential), July 7, 1949

knowledge and precaution in order to insure proper interpretation of the many modulation patterns obtainable. However, a person with a reasonable amount of electronic experience can be easily trained as an operator on such equipment to classify many of the more common types of complex modulation.

A laboratory method for the simulation of complex pulse modulations has been explained. The electrical details of the unit developed for this use have been systematically given. The simulator is capable of being modulated in several ways, including amplitude, phase or position, width, differential double-pulse, and pulse repetition-frequency modulation. The unit can also be used to represent various combinations of multichannel systems. The equipment is portable, and is self-contained in a small cabinet with a built-in power supply. The actual operation of the unit is simple, direct, and effective—as is evidenced by the photographs.

CONCLUSIONS

The complex pulse generator described is a valuable aid in the laboratory as a signal source for checking operation of complex pulse demodulators, and in the field as a training device for operating personnel. By its use, the appearance of complex pulse modulations on typical intercept indicators, such as the type AN/SLA, can be determined; and it will thereby assist in the classification of unknown signals.

Photographs in this report show that although equipment of the AN/SLA type does permit analysis of the modes of modulation and the time and amplitude characteristics of most signals, it does not always completely analyze the intelligence transmitted nor avoid ambiguity in certain cases. These limitations of present equipment indicate the need for improved methods of analysis.

ACKNOWLEDGMENT

The assistance of Lowell Smith Jr., in the construction of the complex-pulse generator is gratefully acknowledged.

* * *

NAVY-DPPO PRNC. WASH., D.C.