A RECEIVER FOR TIME-MODULATED PULSES

By

RUBEN DAVID KELLY

Bachelor of Science in Electrical Engineering

Oklahoma Agricultural and Mechanical College

Stillwater, Oklahoma

1950

Submitted to the Faculty of the Graduate School of

the Oklahoma Agricultural and Mechanical College

in Partial Fulfillment of the Requirements

for the Degree of

MASTER OF SCIENCE

1951

A RECEIVER FOR TIME-MODULATED PULSES

RUBEN DAVID KELLY

MASTER OF SCIENCE

1951

THESIS AND ABSTRACT APPROVED:

Harold Fristoe
Thesis Adviser

A. Naeter
Faculty Representative

D. C. McIntosh
Dean of the Graduate School

PREFACE

The development of an experimental pulse modulation system was undertaken in February, 1949. Previous pulse communication systems utilized low pulse repetition rate with resulting low modulating frequency response. It was desired to construct a pulse system utilizing a high pulse repetition rate and to find how satisfactory such a system could be in transmitting a number of different channel signals of high quality, each with a high modulating frequency response.

The initial pulse system construction was done by Mr. C. W. Merle, Mr. J. A. B. Bower, and Mr. Thomas King. In February, 1950, Mr. I. E. Lynch and the author continued the development of the pulse system.

A new three-channel pulse transmitter was designed and constructed by Mr. I. E. Lynch, and a three-channel pulse receiver was developed and constructed by the author. Performance tests were made on the completed system and the results were very satisfactory.

ACKNOWLEDGMENT

The author wishes to express his special appreciation for the guidance and cooperation of Professors A. L. Betts and H. T. Fristoe, throughout the development and construction of the project and preparation of the thesis. He is also greatly indebted to Professor D. L. Johnson for his helpful suggestions in overcoming many difficulties.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

CHAPTER I

INTRODUCTION

A system of pulse communication was developed for the transmission of three high fidelity audio signals over a single coaxial cable. In pulse communication the signal to be transmitted is sampled at the pulse repetition rate. Therefore, the more samples taken of the modulating signal, the more accurate the reproduction. The maximum theoretical modulating frequency is 1/2 of the pulse repetition or sampling frequency.[1] To transmit a high fidelity audio signal, consisting of frequencies covering the entire audible range, 20 to 20,000 cycles per second, a high sampling frequency must be selected because maximum theoretical limits cannot ordinarily be obtained. In practical systems the maximum frequency that can be transmitted is about 1/3 of the sampling frequency.[2]

The system developed has a pulse repetition rate of 75 kilocycles; therefore, the practical limit of the audio transmission is about 25 kilocycles, which is 1/3 of this pulse rate. Some existing pulse communication systems have realized a higher ratio of modulating frequency to pulse frequency, but the pulse frequency was low in comparison to this system.[3] The frequency response of this system is practically uniform over the entire audible range, the high frequency half-power point

---

1 L. H. Bedford, "Correspondence," Wireless Engineer, XXIII (February, 1946), 56-57.

2 A. G. Kandoian and A. M. Levine, "Experimental Ultra-High-Frequency Multiplex Broadcasting System," Proceedings of the I. R. E., XXXVII (June, 1949), 694-701.

3 F. F. Roberts and J. C. Simmonds, "Multichannel Communication Systems," Wireless Engineer, XXII (November, 1945), 538-549.

occurring at 25,000 cycles. The total overall distortion from transmitter input to receiver output averages about 2%. The signal to noise ratio at the receiver output is +45 db and the crosstalk between channels is from -38 to -42 db. Therefore, this system is quite adequate for relaying broadcast programs.

Existing telephone systems relay broadcast network programs across the country. Due to strict specifications only one program can be transmitted over a single pair of wires. When the necessity arises for the single pair to be disconnected, a carrier system is sometimes temporarily used. The carrier system, capable of transmitting a number of signals over a single pair of wires, has poor frequency response and objectionable crosstalk. The pulse system developed could possibly be incorporated to transmit three or more broadcast quality programs over a given pair of transmission lines with an excellent response to the audio frequency band and a very low amount of crosstalk and distortion.

The intelligence to be transmitted can be added to the pulse in many different methods. Among the most common methods is pulse-amplitude modulation, pulse-width modulation, and pulse-time modulation.[4] The system developed uses pulse-time modulation, in which a channel pulse is varied in time position with respect to a reference pulse, proportional to the amplitude of the modulating frequency. Only one reference pulse, which will be referred to as the master pulse, is needed and can be used as reference for all three channels. The 75 kilocycle pulse repetition frequency is determined by a crystal controlled oscillator. The sinusoidal crystal oscillator output is converted into

---

4 E. M. Deloraine, "Pulse Modulation," Proceedings of the I. R. E., XXXVII (June, 1949), 702-705.

pulses with a repetition rate of 1/f, 13.33 microseconds. These pulses are used as the reference and delayed through three separate circuits to form the three channel pulses. The three delayed pulses can be placed at any mean position between suceeding master pulses and can be modulated in time position with respect to the master pulse. The three channel pulses and the master pulse are electronically mixed to form the composite signal to be transmitted as seen in Figure 1.

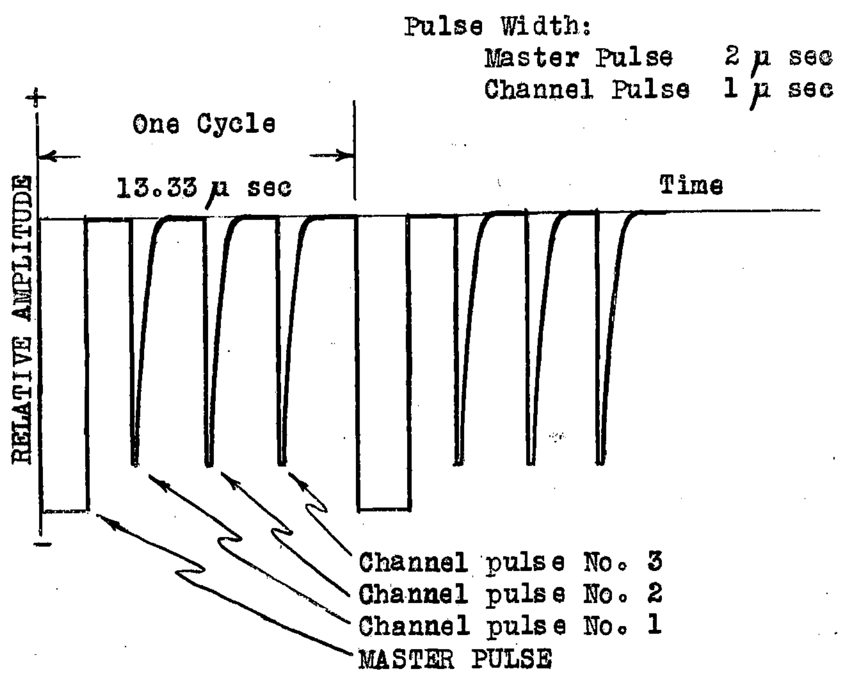

Figure 1. Composite Transmitted Signal.

CHAPTER II

PULSE TERMINOLOGY AND SPECIAL CIRCUITS

In any electronic equipment a basic understanding of each circuit must be mastered before grouping of these basic circuits can be grasped, so it is with pulse-time modulation.

Nine different circuits were tested and developed for use at a pulse repetition rate of 75 kilocycles. The nine basic circuits are as follows:

1. Positive Pulse Amplifier
2. Negative Pulse Amplifier
3. Delay Multivibrator
4. Pulse Mixer
5. Cathode Follower
6. Sync Separator (two types)
7. Grounded-grid Amplifier
8. Channel Selector
9. Flip-Flop Multivibrator

The above circuits are special circuits only. It will be assumed that the reader is familiar with basic Class A audio amplifiers and cathode followers. After the above circuits had been developed for handling pulses at 75 kilocycles, they could be used time and again, as the necessity arose, in the design of both the transmitter and receiver. The basic principles of both the transmitter and receiver were carefully explored before circuits were developed that could accomplish the system requirements. Therefore, the major part of the work was spent in developing the circuits to accomplish the desired results, and in completing the transmitter and receiver units after the final design was established.

A diagram of each pulse-handling circuit is given; also, a voltage waveform, as viewed on an oscilloscope, of both the input and output signals. Any statement pertaining to a waveform seen on a particular circuit element, refers to the waveform as viewed on an oscilloscope.

Positive Pulse Amplifier

Figure 2 is the diagram of the positive pulse amplifier, a pentode biased beyond plate current cutoff. The incoming signal must drive the grid positively into the conduction region before an output signal is seen. If the input consists of both positive and negative going pulses, the amplifier will only respond to the positive going ones; thus, by limiting action, the negative going pulses are eliminated. The only input signal that can be amplified is a positive going one, and the output signal from the plate will have inverted polarity producing a negative going pulse of much greater amplitude. This amplifier will be used when it is necessary to amplify a positive going pulse, separate the positive from a series of both positive and negative going pulses, or for inverting a positive going pulse for some application.

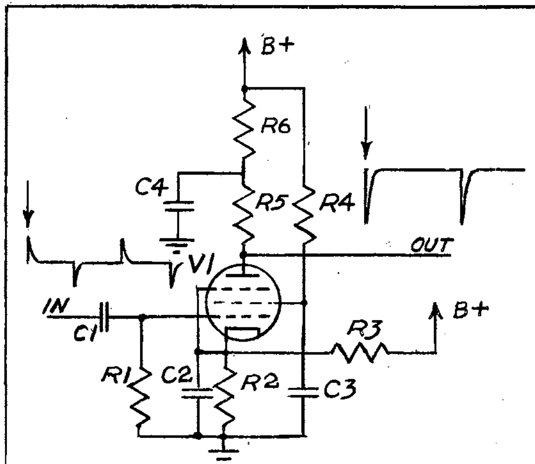

Figure 2. Positive pulse Amplifier.

Negative Pulse Amplifier

The negative pulse amplifier of Figure 3 is a zero-biased pentode. The amplifier, normally at zero bias, will be conducting very heavily and a positive pulse coupled into its grid will not increase plate current greatly; therefore, no appreciable output signal will be experienced. A negative going pulse coupled into the grid will cause a decided decrease in plate current and the output signal from the plate will be a positive going pulse of greater amplitude. This amplifier will be used for amplifying negative going pulses, separating the negative from a series of both positive and negative going pulses, or inverting a negative going pulse for some application.

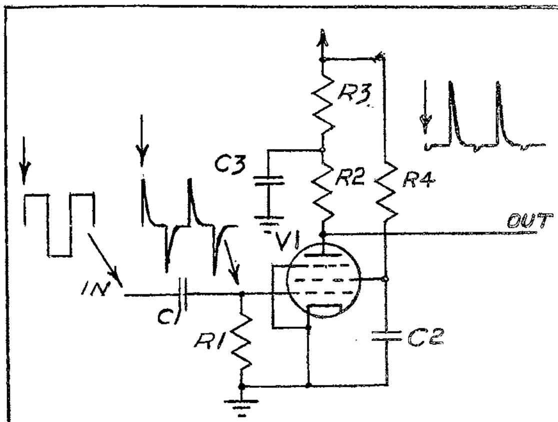

Figure 3. Negative Pulse Amplifier

Delay Multivibrator

Figure 4, the delay multivibrator, consists of two pentodes connected to form a single-shot multivibrator. A negative input pulse is

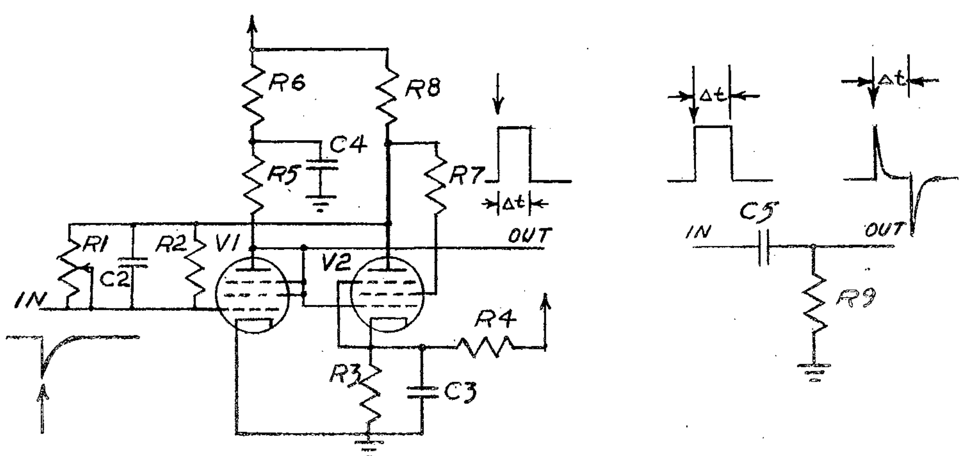

Figure 4. (a) Delay Multivibrator. (b) RC Differentiating Circuit.

used to trigger the single-shot multivibrator and for each triggering pulse input there is a single rectangular pulse output. The triggering pulse causes the leading edge of the rectangular pulse to occur simutaneously. The width of this rectangular pulse is determined by the RC time constant of the grid-plate discharge path -- R1, R2, and C2.

The trailing edge of this timed pulse maybe utilized in obtaining a desired delay, Figure 4b. If the pulse is differentiated, the negative portion of the differentiated wave may be used as a timing pulse to produce a delay with respect to the triggering pulse. Since the delay is dependent on the width of the multivibrator pulse this type of circuit is referred to as the delay multivibrator.

Under static conditions tube V1 is conducting heavily and tube V2 is cutoff by the voltage divider R3 and R4. With the application of a triggering input voltage the tubes reverse operation and will not return to static conditions until after a period determined by the RC discharge. When the RC circuit -- R1, R2, and C2 -- discharges to a certain potential, such that V1 can again start conducting, the tubes will very quickly return to static conditions and await the next trigger pulse. By making the resistor or the condenser in the RC circuit variable, the width of the rectangular pulse can be varied, but the repetition of this pulse is totally dependent upon the triggering pulse. The rectangular pulse is coupled through an RC circuit whose time constant is very short in comparison to the pulse repetition time. The output voltage seen across the resistor is the differentiated rectangular pulse. The output of this RC differentiator will be a series of positive and negative going pulses, the positive going pulse corresponding to the leading edge of the rectangular pulse, and the negative going pulses corresponding to the trailing edge. The negative pulse corresponding to the trailing edge is delayed from the time of triggering by the width of the rectangular pulse. By making the resistor variable in the RC circuit, the position of this pulse can be delayed any amount of time between succeeding triggering pulses. This circuit will be used for generating a variable delayed pulse, or for the generation of a variable width rectangular pulse.

Pulse Mixer

The pulse mixer circuit of Figure 5 consists of two cathode followers with a common cathode resistor. A signal impressed on either grid will appear across the cathode resistor, R3. A series of positive pulses, representing the master pulse, is introduced through C1, and a different positive pulse series, representing a particular channel, is introduced on the other grid through C2. The signal seen across R3 will be the sum of the two series of pulses; that is, alternate master and channel pulses.

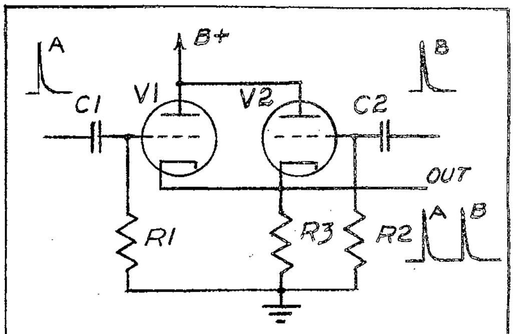

Figure 5. Pulse Mixer

A common plate load resistor, a multi-grid tube, or a common resistor in a voltage divider can be used to accomplish mixing. Each of these principles has disadvantages in pulse applications due to interaction from signals coupled back into the inputs, or the multi-grid tube requiring different amplitude driving pulses. The cathode follower method proved best in eliminating back coupling; thus, the pulse circuits, driving the two grids, are very stable and essentially independent.

Cathode Follower

Shown in Figure 6 is the Cathode Follower, used in this system for matching the output from the transmitter to the 50 ohm coaxial cable. This cathode follower is different in that the cathode resistor is in the receiver and the tube is in the transmitter. In matching to such a low impedance as the 50 ohm coaxial over only 200 feet, it is found more

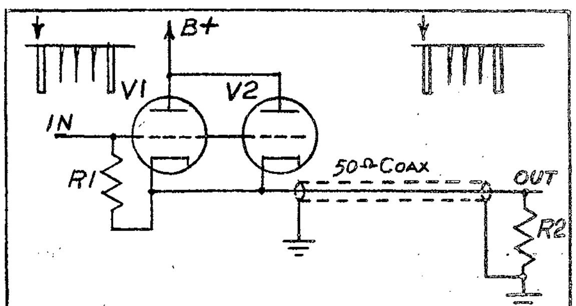

Figure 6. Cathode Follower.

practical to let tube current flow through the entire cable and to place the 50 ohm cathode resistor at the receiver end. Many applications utilize this principle where low impedance cables are used for transmitting pulses over relatively short distances.

Sync Separator

There are two types of sync separators used in the receiver unit—one responding to the pulse amplitude, and the other responding to pulse width. The circuit's job is to separate the master pulse from the composite signal. The master pulse has two distinguishing characteristics; it is of larger amplitude and of longer duration than a channel pulse.

Figure 7 shows the sync separator that operates on pulse amplitude, an ordinary triode biased far below cutoff. The positive going composite signal is coupled into the grid. The cathode is connected to a potentiometer in a voltage divider circuit from B+ to ground. Thus, a bias can be selected, such that tube current flows only when the larger amplitude master pulse is received. The output voltage waveform, seen on its plate, will be a negative going pulse occurring simultaneously with the master pulse. The output is not entirely independent of channel pulses as can be seen from the discontinuities on its trailing edge.

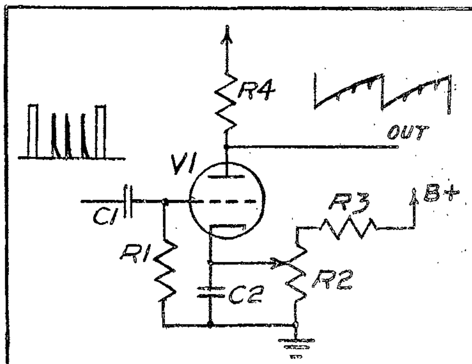

Figure 7. Sync Separator

The sync separator that operates on pulse width, as illustrated in Figure 8, requires more tubes, but the output signal is free from any channel pulse interference . However, the sawtooth output is not of sufficient amplitude; therefore, additional amplification is needed. The incoming positive-going composite signal is integrated by an RC circuit — R1, C1. The signal is taken across the condenser and coupled to the grid of a zero-biased triode with an extremely large plate load resistor and a large grid resistor. The integrated composite signal drives the grid positive just at the time of the master pulse, causing the grid to draw current and charge the coupling capacitor. This charge leaks off slowly, keeping a bias on the triode, sufficient to keep it cutoff except at the time of the master pulse. Due to C3 and the interelectrode capacitance, the voltage on the plate cannot follow the grid signal. At the time of the master pulse the capacitor from plate to ground is discharged due to tube current, but during the rest of the cycle the plate voltage rises slowly due to the large plate resistor. The signal seen on the plate is a sawtooth waveform, with the discontinuity occurring at the time of the master pulse. By coupling this sawtooth voltage to the grid of a negative pulse amplifier through an RC differentiating network a sharp pulse of voltage will be seen on the output of the pulse amplifier. This signal, being free from channel pulse interference, makes circuits employing it very stable even with a high percentage of modulation.

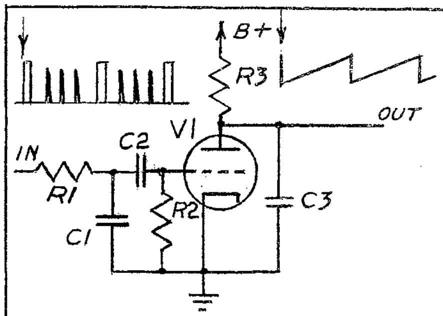

Figure 8. Sync Separator

Grounded-grid Amplifier

A triode grounded-grid amplifier of Figure 9 was employed as a buffer amplifier when signal inversion was undesirable. Ordinarily the grounded-grid amplifier has to be driven by a low impedance source, but in the receiver's particular application a high impedance is preferable. The

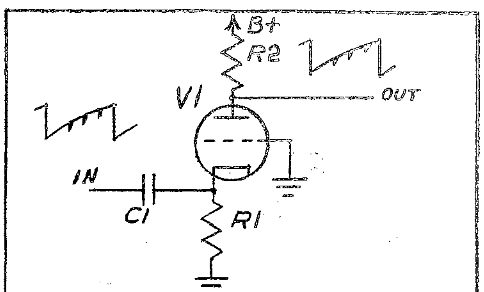

Figure 9. Grounded-Grid Amplifier

cathode resistor was made very large, which would be ridiculous if ordinary signals were to be amplified. In this particular application, though, only a negative going pulse was to be amplified. The large cathode resistor keeps the triode near cutoff, and only a negative going signal, coupled in on the cathode, could make any difference in tube conduction. A negative pulse on the cathode causes tube current to increase. Because of the special buffer's requirements, the grounded-grid amplifier, with an unusually large cathode resistor, was very satisfactory.

Channel Selector

The channel selector is a pentode connected as seen in Figure 10. A positive-going composite pulse signal is coupled to the control grid, and a rectangular pulse of voltage from a delay multivibrator is coupled to the screen grid. Pulses coupled to the control grid, coinciding with the application of screen voltage, will be amplified; pulses not coinciding will not be amplified. If the pulse of screen voltage is selected to coincide with only the No. 1 channel pulse, channel 1 will be amplified on the plate of the channel separator. The time at which the screen voltage pulse is applied and the length of application can be controlled, so any one of the channel pulses can be selected from the composite pulse signal.

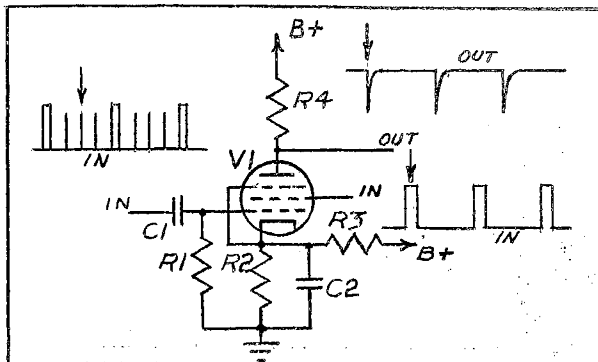

Figure 10. Channel Selector.

Flip-Flop Multivibrator

The flip-flop multivibrator is a basic Eccles-Jordan trigger circuit.[5] Under stable conditions one tube will be conducting heavily and the other will be cutoff. From Figure 11 it can be seen that the bias on V2 is the result of the voltage across R2, the cathode resistor, and the voltage seen by the voltage divider -- R1, R7 -- from the plate of V3 to ground. When V2 is conducting heavily, its plate voltage is quite low because of the voltage drop across its plate load resistor, R4. The tube current through the cathode resistor, R2, will produce a high positive voltage on the cathodes of both tubes. The voltage divider from the plate of V2 to ground causes a low value of positive voltage on the grid of V3. The resultant of the high positive cathode voltage and low positive grid voltage causes V3 to be cutoff. Because V3 is cutoff due to this bias, its plate voltage will rise toward the value of the B+ supply. This high value of plate voltage couples, via the voltage divider -- R1, R7 -- a high positive voltage to the grid of V2. The grid of V2 is positive with respect to its cathode and tends to conduct very heavily. The above condition is stable, but if a trigger voltage is introduced another stable condition will be assumed in which V3 will conduct heavily, thus causing V2 to be cutoff. If a series of triggering pulses are introduced, the circuit will alternate from one stable condition to the other. The plate voltage of one triode, with a series of

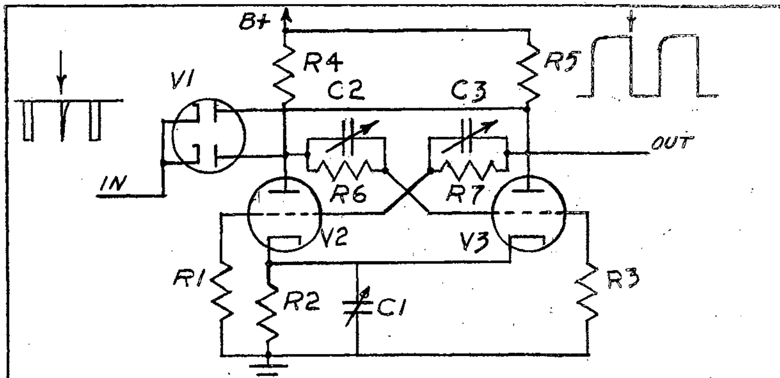

Figure 11. Flip-Flop Multivibrator.

5 Herbert J. Reich, Theory and Applications of Electron Tubes, pp. 353-356.

triggering pulses input, will be a square wave with reversals occurring at the time of the successive triggering pulses. This circuit is employed to produce a square wave when triggered by the master pulse and one channel pulse.

The tube, V1, couples negative triggering pulses into the plates of both tubes, but prohibits the multivibrator from coupling back into the triggering source. The application of the flip-flop multivibrator, as the pulse detector, requires that a series of triggering pulses shall consist of alternate master and channel pulses. The master pulse causes one stable condition to exist, and the channel pulse causes the other stable condition to exist. Under modulating conditions the channel pulse is advanced and retarded, with respect to the master pulse, according to the amplitude of the modulating signal. The square wave coupled from the multivibrator will have a fixed edge and a variable edge. By RC integration of this square wave the modulation can be removed.

CHAPTER III

THE PULSE TRANSMITTER

A new pulse transmitter has been constructed that fulfills the qualifications needed for a versatile system. It was desirable that the channel pulses could be placed at any mean time between succeeding master pulses, and that modulation could be controlled to cause the pulse to vary in position from one to several times pulse width. To obtain the added versatility each pulse had to be separately formed, amplified, positioned, and modulated.

The delay multivibrator serves as a pulse delay and modulating circuit. The audio modulating voltage is added in series with the grid-plate RC discharge circuit. The additional audio voltage causes the trailing edge of the rectangular pulse output to be advanced and retarded. The pulse obtained from the trailing edge is advanced and retarded proportional to the modulating audio's amplitude.

A total of four pulse forming circuits is required -- one for the master pulse, and one for each channel pulse. The four outputs are electronically combined by pulse mixers to form the composite pulse signal. Two pulse mixers each combine a pair of pulses, and the two outputs are combined in a third pulse mixer. The output from the third pulse mixer is the composite pulse signal.

The composite signal from the third pulse mixer is amplified by a positive-pulse amplifier and matched to the 50 ohm coax with the special cathode follower.

The resultant composite signal from the transmitter is negative going, as seen in Figure 1, Page 3. The master pulse is of larger amplitude and of longer duration than a channel pulse. A modulation index of 100% is arbitrarily chosen to be when Δt, the time between maximum delay and minimum delay of a channel pulse, equals twice the pulse width. The composite signal is received with very little loss over the coaxial cable.

The receiver must take the composite pulse signal and obtain the intelligence contained in each channel pulse.

CHAPTER IV

THE PULSE RECEIVER

The composite transmitted signal is the input to the receiver. It is the job of the receiver to select any channel pulse and detect the modulation that it contains. To select a channel pulse, it is necessary to eliminate all but this pulse from the composite signal. The master pulse is the reference for the channel pulse generation; thus, it shall be the reference in the separation of the pulses.

The modulation is removed from the three channel pulses by three identical circuits. For drawing simplicity, the block and circuit diagrams illustrate only one complete channel in the receiver. Signals coupled from mutual circuits to the two other channels are designated on the block diagram, Figure 12. The receiver circuit diagram is shown in Figure 13 and a parts list in Table 1.

A negative pulse amplifier, V1, is used to amplify and invert the negative-going received signals. This circuit is a zero-biased pentode, which responds only to negative going pulses. Its output will be a positive-going, composite pulse signal of large amplitude. The resistor, R5, and the condenser, C3, form a plate decoupling circuit. Tube currents that rapidly vary cause interaction between stages due to the common B+ supply. An RC decoupling circuit is used whenever necessary to help remedy this situation.

The pulse amplifier output is coupled through C4 to V2, an amplitude-discriminating sync-separator. The cathode of V2 is kept at a positive potential determined by the tap on the voltage divider, R11 and R13. Only the larger amplitude master pulse drives the grid of V2 into the conduction region, causing a negative output signal. The output of V2

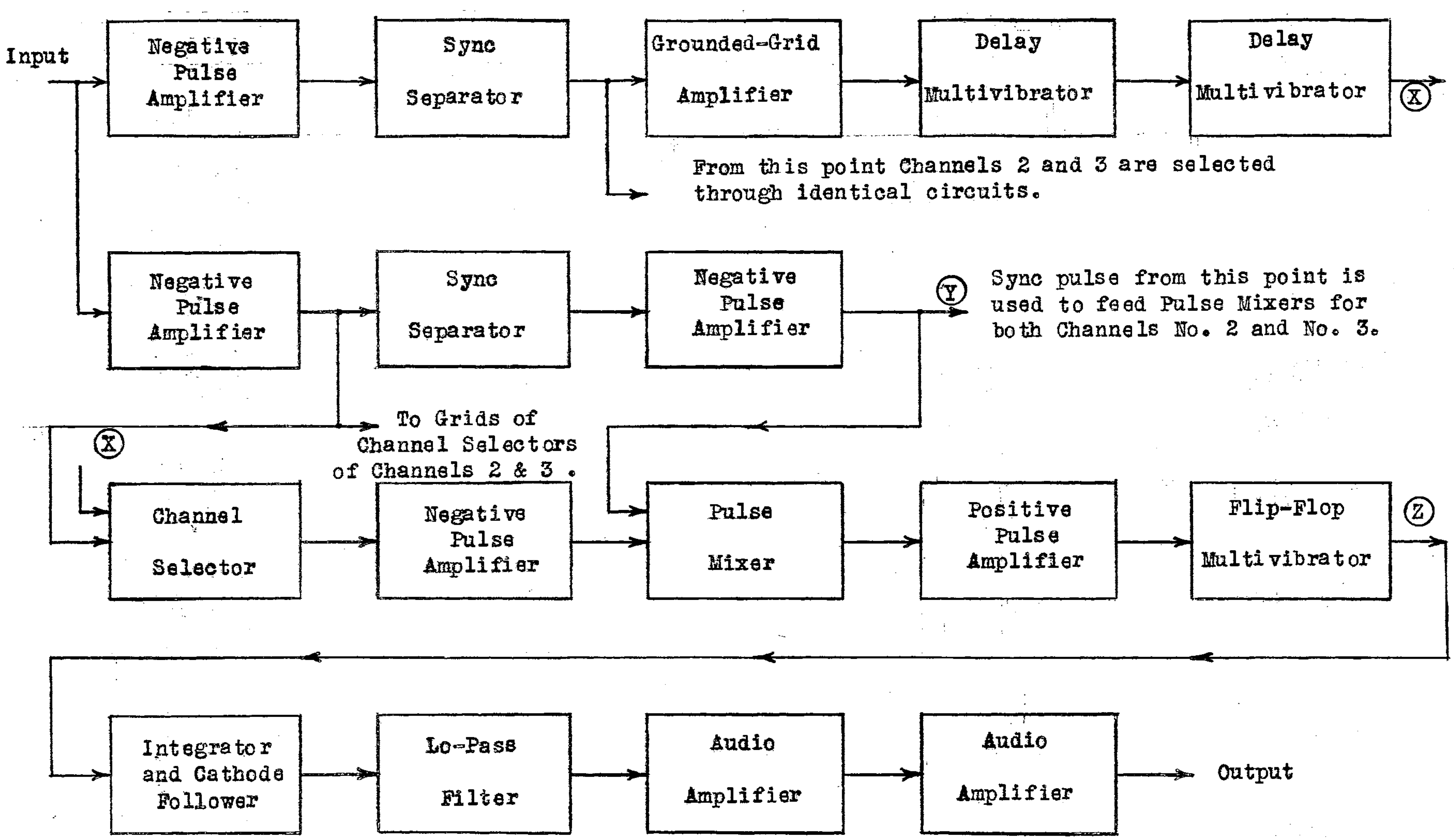

Figure 12. Block Diagram of Pulse-Time Receiver. (Only one channel is represented.)

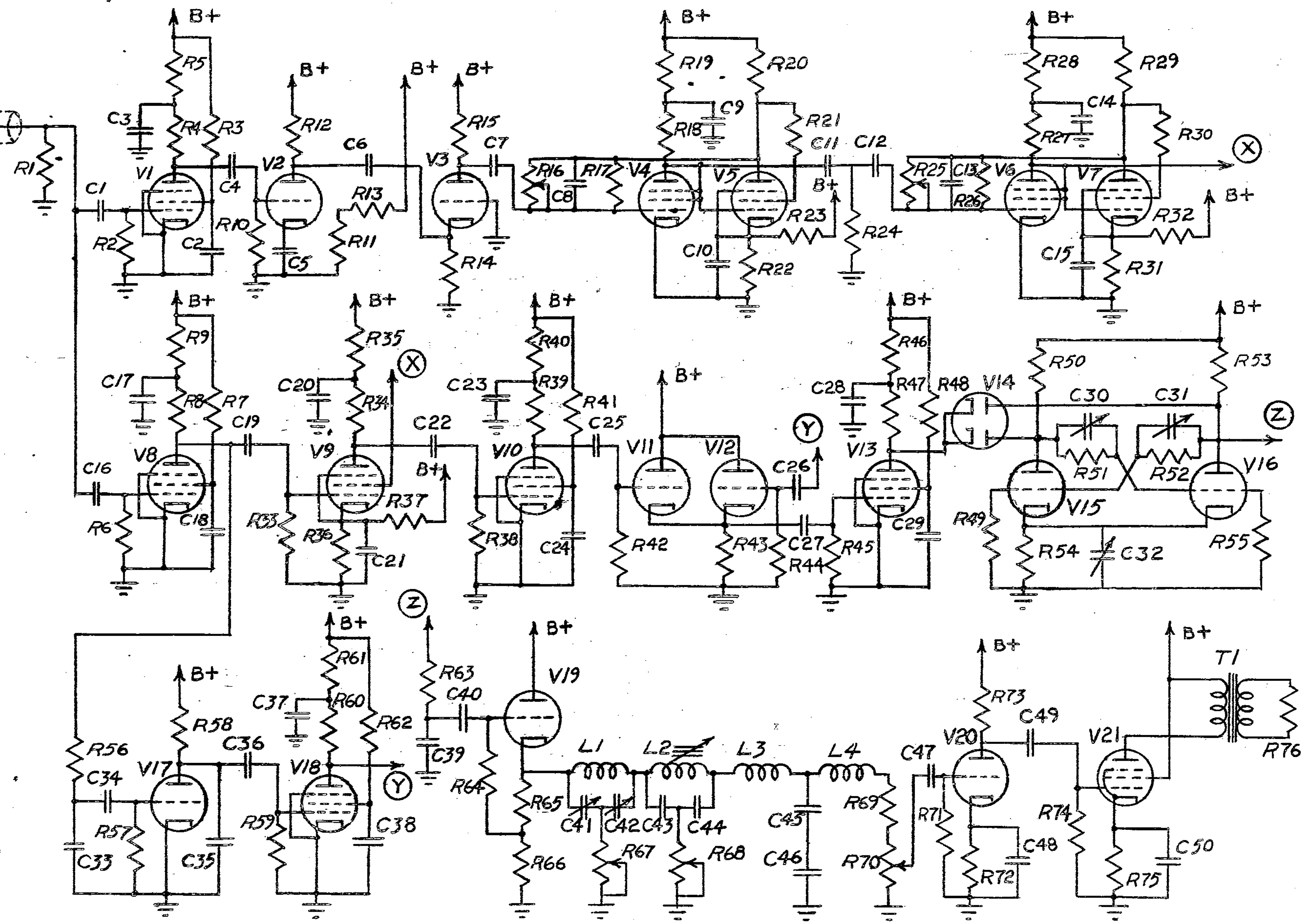

Figure 13. Receiver Diagram for one complete channel.

TABLE I

RECEIVER PARTS LIST

FOR ONE COMPLETE CHANNEL

Capacitors (All capacitances are in microfarads. All capacitors are paper unless otherwise specified.)

C1	0.00005 ceramicon	C26	0.00005 ceramicon
C2	0.1	C27	0.1
C3	0.1	C28	0.1
C4	0.00005 ceramicon	C29	0.1
C5	0.1	C30	0.00003 air variable
C6	0.001	C31	0.00003 air variable
C7	0.005	C32	0.00003 ceramic variable
C8	0.00005 ceramicon	C33	0.00005 ceramicon
C9	0.1	C34	0.1
C10	0.1	C35	
C11	0.00005 ceramicon	C36	0.00005 ceramicon
C12	0.0005 mica	C37	0.1
C13	0.00005 ceramicon	C38	0.1
C14	0.1	C39	0.00005 ceramicon
C15	0.1	C40	0.1
C16	0.00005 ceramicon	C41	0.00015 mica variable
C17	0.1	C42	0.00015 mica variable
C18	0.1	C43	0.002 mica
C19	0.01	C44	0.002 mica
C20	0.1	C45	0.003 moulded paper
C21	0.1	C46	0.003 moulded paper
C22	0.00005 ceramicon	C47	0.1
C23	0.1	C48	5, 25 v. electrolytic
C24	0.1	C49	0.1
C25	0.00005 ceramicon	C50	5, 25 v. electrolytic

Inductors

L1	16 mh air core	L3	8 mh air core
L2	4.8 mh powdered-iron variable	L4	8 mh air core

Resistors (All resistors are in ohms. K represents 1000; meg. represents megohms. All resistors are 1/2 watt carbon unless otherwise specified.)

R1	50	R13	30 K, 2 watt
R2	10 K	R14	100 K
R3	40 K	R15	50 K
R4	25 K	R16	1 meg. potentiometer
R5	2.5 K.	R17	600K
R6	10 K	R18	50 K
R7	40 K	R19	2.5 K
R8	25 K	R20	50 K
R9	2.5 K.	R21	10 K
R10	3.3 meg.	R22	15 K
R11	3 K potentiometer	R23	150 K
R12	50 K	R24	50 K

TABLE I

(Continued)

Resistors

R25	1 meg. potentiometer	R51	200 K
R26	600 K	R52	200 K
R27	50 K	R53	20 K
R28	2.5 K	R54	10 K
R29	50 K	R55	5 meg.
R30	10 K	R56	10 K
R31	15 K	R57	1 meg.
R32	150 K	R58	2.5 meg.
R33	50 K	R59	10 K
R34	25 K	R60	25 K
R35	2.5 K	R61	2.5 K
R36	5 K	R62	40 K
R37	150 K	R63	150 K
R38	10 K	R64	500 K
R39	25 K	R65	1 K
R40	2.5 K	R66	10 K
R41	40 K	R67	1 meg. potentiometer
R42	2 K	R68	1 meg. potentiometer
R43	10 K	R69	25 K
R44	2 K	R70	500 potentiometer
R45	10 K	R71	500 K
R46	2.5 K	R72	1 K
R47	25 K	R73	50 K
R48	40 K	R74	500 K
R49	5 meg.	R75	400; 5 w. wire wound
R50	20 K	R76	5; 5 w. wire wound (see text)

Transformers

T1	output transformer, plate to speaker

Tubes

V1	6AC7	V11	6SN7
V2	6SN7	V12	6SN7
V3	6SN7	V13	6AC7
V4	6AC7	V14	6AL5
V5	6AC7	V15	6SN7
V6	6AC7	V16	6SN7
V7	6AC7	V17	6J5
V8	6AC7	V18	6AC7
V9	6AC7	V19	6SN7
V10	6AC7	V20	6SN7
		V21	6V6

is used by all three channels as reference in channel pulse separation. From the plate of V2 to the audio output, the various channel circuits are identical.

A channel pulse is separated from the composite signal by a channel selector, as discussed in Chapter II, Page 10. A rectangular pulse that can be varied in width and in time position must be generated for applying to the channel selector's screen grid. A channel pulse will be amplified by the selector only when its time of occurrence coincides with the application of the rectangular pulse of screen voltage. Selection of any particular channel is accomplished by varying the occurrence time of the rectangular pulse. The rectangular pulse must be of sufficient duration to cause amplification of the particular channel pulse even when 100% modulation is applied. An index of 100% was chosen to be when Δt, the time between maximum delay and minimum delay, equals twice the channel pulse width. With 1 μ second pulse width, the rectangular pulses must be 2 μ seconds or longer in duration. Indication of sufficient rectangular pulse duration is obtained by observance, on the oscilloscope, of the channel selector's output. The plate signal will be a complete reproduction of the channel pulse, as seen in the composite signal, when proper selection is made.

The output from the sync-separator is used as the reference in generating the variable-positioned, variable-width rectangular pulse needed by the channel selector. V4, V5, V6, and V7 are two delay multivibrators in cascade. The first multivibrator, V4 and V5, is triggered by the sync-separator's output. The width of the resulting rectangular pulse can be varied by R16, and the pulse is differentiated so the trailing edge triggers the second multivibrator. C11 and

R24 form the RC differentiator and C12 serves for pulse coupling to V6 and V7. The output from the plate of V6 is a rectangular pulse whose width is determined by the resistor, R25, and whose occurrence time is controlled by R16.

A rectangular pulse generator of this type is used for each channel selector. The master pulse from the sync-separator is needed for synchronizing all rectangular pulse generators, but a simple condenser coupling to each multivibrator is unsatisfactory. A buffer amplifier that does not invert the required negative-going output from the sync-separator is necessary. The special grounded-grid amplifier, discussed in Chapter II, is used and eliminates interaction between rectangular pulse generators. On the circuit diagram this is V3 and associated components.

The generated rectangular pulse, seen at point X, is directly coupled to the screen grid of V9, the channel selector. V8 is a negative pulse amplifier for feeding a positive-going composite signal to the control grid of the channel selector. The positive composite signal is coupled from the plate of V8 to the control grids of corresponding tubes of the other two channels and to V17, a sync-separator. The signal seen at the plate of V9 will be a negative-going channel pulse, when the rectangular pulse of screen voltage is adjusted to coincide with the channel pulse applied to the control grid.

V10 is a negative pulse amplifier to invert the negative-going channel pulse from the plate of V9. The output of V10 will be a large amplitude positive-going channel pulse.

The positive-going composite signal from V8 is integrated by R56 and C33.

C34 and R57 supply V17 with grid-leak bias. Only when the longer-duration master pulse is integrated by R56 and C33 will the grid of V17 be driven into the conduction region. The grid of V17 quickly draws grid current and charges C34. This charge, leaking off through R57, causes a bias sufficient to make V17 non-conductive, except at the time of the master pulse. R58 and C35 form an RC charging circuit across the B supply. At the time of the master pulse, V17 conducts and discharges C35; then it begins to charge again toward the value of B+. The signal at the plate of V17 will be a sawtooth wave with the discontinuity occurring at the time of the master pulse. The differentiation of the sawtooth wave form, a negative-going master pulse, will be found at the grid of V18 due to the short RC time of C36 and R59. V18 is a negative pulse amplifier to invert the negative-going master pulse for application to V12 in the pulse mixer circuit. The positive-going master pulse at the plate of V18 is point Y on the circuit diagram. The signal at point Y is coupled to corresponding tubes in pulse mixer circuits in the other two channels. V17 is the type of sync-separator shown in Chapter II, Page 9

V11 and V12, a pulse mixer circuit, combine the separated channel pulse with a separated master pulse. The channel pulse selected by V9 is coupled to the grid of V11, and the master pulse is coupled to the grid of V12. The output signal seen across the common cathode resistor, R43, will be the master pulse and the channel pulse electronically mixed. The master pulse and the channel pulse have the same repetition rate, but occur at different times; therefore, the electronically mixed signal will consist of alternate master and channel pulses. This is the basis of a detection system which is almost independent of pulse amplitude.

There are other methods which could be employed to detect the modulation contained in the positioning of a channel pulse. One method of detection is to super-impose the channel pulse on a sawtooth wave form, and as the pulse is advanced and retarded in its position, the resulting output will be a pulse varying in amplitude, proportional to the modulating signal. By simple RC integration the modulation may be recovered. This method is simple, but it defeats the purpose of pulse-time modulation in introducing a low signal to noise ratio, typical of ordinary pulse-amplitude modulation.

Any noise on the pulse signal or variations in its amplitude will be received along with the modulating signal, and harmonic distortion will be introduced if the sawtooth is non-linear. To obtain a high signal to noise ratio -- that should accompany pulse-time modulation -- a system of detection is necessary that is insensitive to pulse amplitude variations. This is accomplished by using the pulse train, consisting of alternate master and channel pulses, to trigger a flip-flop multivibrator. The amplitude of the resulting rectangular wave is nearly constant, even though the triggering pulses may vary in amplitude. RC integration of the constant-amplitude, rectangular wave from the multivibrator recovers the modulation contained in the channel pulse. V15, V16, and associated components form the flip-flop multivibrator, which was discussed in Chapter II, Page 11.

The positive-going pulse train from the cathodes of the pulse mixer is amplified and inverted by V13. The dual-diode, V14, acts as a uni-directional coupling device for coupling the triggering pulses into V15 and V16, but prevents the resulting rectangular wave of the multivibrator from coupling back into V13. The output from the plate of V16 is the constant amplitude rectangular wave, whose width varies as the triggering channel pulse varies. R63 and C39 perform the RC integration and C40 couples the integrated wave to the grid of V19. V19, an ordinary cathode follower[1], is able to accept the high amplitude wave without being over-driven. It also furnishes a low output impedance to drive a filter network. Integration of the rectangular wave produces a triangular wave of the pulse repetition frequency, 75 KC, whose amplitude varies proportional to the modulating signal. The 75 KC triangular component must be eliminated and only the audio modulating component retained. With 100% modulation, the ratio of triangular wave to modulating signal is 14 db.

A simple low-pass filter is insufficient in eliminating the high-amplitude fundamental and harmonic components of the triangular wave. The Fourier[2] analysis of a triangular wave shows it to be composed of the fundamental and an infinite number of odd harmonics. The third harmonic is 1/9 the amplitude of the 75 KC fundamental, which is quite large in comparison to the audio component. Twin "T" filters were quite adequate in suppressing the triangular wave, but the overall audio frequency response, using RC filters, could not be extended past about 12,000 cycles per second. The attenuation of 6 db per octave accompanying RC filtering caused the audio frequency response to be poor.

A combination of several bridged "T"[3] circuits proved best for

---

1 Reich, op. cit., pp. 170-174.

2 Russell M. Kerchner and George F. Corcoran, Alternating-Current Circuits, pp. 150-151.

3 Frederick Emmons Terman, Radio Engineers' Handbook, pp. 918-919.

triangular wave suppression and in obtaining an extended audio frequency response. The bridged "T" consists of a parallel resonant circuit with the condenser divided in two equal sections; the center tap is connected through a resistor to ground. A bridged "T" for suppressing the 75 KC fundamental is L2, C43, and C44, and R68 on the circuit diagram. When the value of R68 equals 1/4 the impedance of the parallel resonant circuit -- L2, C43, and C44 -- there will be an extreme amount of attenuation at the resonant frequency. R68 and the resonant LC circuit were made variable so best results could be obtained in suppressing the 75 KC component. L1, C41, C42, and R67 form another bridged "T" for suppressing the third harmonic, 225 KC, which was still of undesirable amplitude in comparison with the audio. L3, L4, and C45, and C46 form a low-pass filter[4] having a cutoff frequency of 75KC. This low-pass filter furnishes sufficient suppression to the smaller-amplitude, higher-frequency components. C45 and C46 were used in series to obtain the correct value of capacitance. R69 and R70 form a load for the filters and cathode follower. The junction between R69 and R70 can be used to obtain the audio signal with an output impedance of 500 ohms. This point was used for tests of frequency response, intermodulation, and signal to noise ratio.

V20 is an ordinary triode audio stage[5] driving V21, a 6V6 power amplifier.[6] T1 is an output transformer for matching the plate of V21 to the 5 ohm load resistor, R76. R76 can be replaced by a speaker with

---

4 William Littell Everitt, Communication Engineering, pp. 190.

5 Reich, op. cit., pp. 149-161.

6 Ibid, pp. 238-246.

a voice coil impedance from 5 to 8 ohms.

Only two control knobs for a channel selector are brought out to the front panel. Once the receiver is in operation only the rectangular pulse generators need be adjusted to select any one of the three channels. Until one is experienced in adjusting the two knobs, an oscilloscope may be placed on the plate of the channel selector to aid in selection. If the channel selector is properly adjusted all other circuits function properly. This system was made versatile so numerous tests could be performed. A working system could be designed with only one control for channel selection. If this system were used commercially for transmission, a single control would be very desirable.

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

A pulse communication system utilizing pulse-time modulation was designed and constructed for experimentation at a 75 KC pulse repetition rate. The receiver described herein is the final unit necessary to complete the system. The special pulse circuits employed are separately illustrated and discussed in order to simplify presentation of the unit. The complete receiver consists of three identical pulse channels so only one channel illustration is necessary. A brief discussion of the transmitter is also presented, along with the nature of the transmitted signal.

Results of Tests on System

A Barker and Williamson Model 400 Distortion Meter was used for distortion, signal to noise, and intermodulation tests.

Distortion was checked at numerous frequencies in the range of 200 to 15,000 cycles. The total distortion was less than 2%. The principal distortion in this range of tests was due to the incomplete attenuation of the 75 KC triangular wave experienced in the detection system.

Signal to noise ratio was checked throughout a four-hour period, remaining continually at +45 db. This consistency was mainly the result of the detection system. The noise, received along with the pulse, is eliminated by use of the trigger circuit detection system. All noise present at the receiver output is a result of only the circuits past the flip-flop multivibrator. Pulse-time modulation should give good signal to noise ratios.

Intermodulation tests at several frequencies show it to range from -38 to -42 db. As the spacing of channels is decreased, the intermodulation increases. Tests were made when channel pulses were just sufficiently separated so satisfactory selection could be made at the receiver.

The arbitrary modulation index of 100% was maintained throughout the frequency response test. The receiver output remained essentially constant to 25,000 cycles. The modulating signal was sampled only three times per cycle at 25,000 cycles. Distortion increases as the modulating signal approached the high frequency 3 db point, due to the low number of samples taken per cycle.

A hetrodyne effect between the modulating signal and the pulse frequency exists at all times. The filters remove all the undesirable sum and difference frequencies, when the modulating signal frequency is below the 25,000 cycle, 3 db point. Sampling a 37,000 cycle signal produces an effect the same as when a 1,000 cycle signal is sampled. This is the result of hetrodyning; the sampling frequency believes a 1,000 cycle signal is actually being transmitted, due to the few samples taken per cycle of the modulating signal. To eliminate undesirable introduction of frequencies, not present at the transmitter input, a low-pass filter should be employed to limit input frequencies.

A square wave was used as the modulating signal, and satisfactory reproduction resulted up to approximately 1,000 cycles. Satisfactory reproduction of a square wave results when frequencies up to the twenty-first harmonic are present. The system adequately supplied transmission of the necessary harmonics for the 1,000 cycles square wave. Above 1,000 cycles an insufficient number of harmonics are transmitted to give desirable reproduction.

Further tests of the equipment could be made to prove experimentally the theoretical limits to the number of channels. Also, further experimentation with the system and its limitation would prove valuable and interesting.

The maximum ratio of modulating frequency to pulse frequency obtained in this system is 1:3. A higher ratio has been obtained in systems employing low pulse repetition frequencies.[1] Further experimentation with the filters in the detector would possibly improve this ratio.

A purpose of this project was to obtain the practical number of channels that could be employed without adjacent channel interference. With the modulation index chosen, the theoretical maximum number of channels is 5.56. The pulse repetition frequency is 75 KC, which gives 13.33 μ seconds between master pulses. The master pulse is 2 μ seconds in duration, leaving 11.33 μ seconds available for the channels. The channel pulse is 1 μ second in duration. The 100% modulation index permits the channel pulse to be advanced and retarded by an amount Δt, equal to twice pulse width. Under 100% modulating conditions the channel pulse would occupy 2 μ seconds of the time between succeeding master pulses. In the 11.33 μ seconds available 5.56 fully modulated channel pulses could be placed. It is not possible to obtain this in practice because a definite break must be left between channel pulse extremities, so proper selection can be made at the receiver.

It is interesting to note the theoretical maximum if pulse-amplitude modulation were employed. 11.33 μ seconds is available

---

1 Roberts and Simmonds, <u>loc. cit.</u>

between succeeding master pulses and each channel would consume only 1 μ second of time. This would permit the use of 11.33 channels, twice the number possible with pulse-time modulation. A 2:1 ratio is true only for the modulation index chosen.

BIBLIOGRAPHY

Bedford, L. H. "Correspondence." Wireless Engineer, XXIII (February, 1946), 56-57.

Deloraine, E. M. "Pulse Modulation." Proceedings of the I. R. E., XXXVII (June, 1949), 702-705.

Goldberg, H. and C. C. Bath. "Multiplex Employing Pulse-Time and Pulsed-Frequency Modulation." Proceedings of the I. R. E., XXVII (January, 1949), 22-28.

Kandoian, A. G. and A. M. Levine. "Experimental Ultra-High Frequency Multiplex Broadcasting Systems." Proceedings of the I. R. E., XXXVII (June, 1949), 694-701.

Kerchner, R. M. and G. F. Corcoran. Alternating-Current Circuits. New York: John Wiley and Sons, Inc., 1948.

Reich, Herbert J. Theory and Applications of Electron Tubes. New York: McGraw-Hill Book Company, Inc., 1944.

Roberts, F. F. and J. C. Simmonds. "Multichannel Communication Systems." Wireless Engineer, XXII (November, 1949), 538-549.

Terman, Frederick Emmons. Radio Engineers' Handbook. New York: McGraw-Gill Book Company, Inc., 1943.

War Department Technical Manual. TM11-467 Radar System Fundamentals. Washington: United States Government Printing Office, 1944.

THESIS TITLE: A RECEIVER FOR TIME-MODULATED PULSES

NAME OF AUTHOR: RUBEN DAVID KELLY

THESIS ADVISER: HAROLD FRISTOE

The content and form have been checked and approved by the author and thesis adviser. "Instructions for Typing and Arranging the Thesis" are available in the Graduate School office. Changes or corrections in the thesis are not made by the Graduate School office or by any committee. The copies are sent to the bindery just as they are approved by the author and faculty adviser.

NAME OF TYPIST : R. D. KELLY (MRS.)