MULTIPLEX PULSE COMMUNICATION CIRCUITS

By

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PREFACE

Crowding of the available channels for broadcasting, and the need for several different communications over a single coaxial cable at an assigned low frequency made this project possible. For years pulses have been used but at microwave frequencies. Very little work has been done at low frequencies but it was thought that less loss would occur if a lower fundamental frequency were used.

John A. B. Bower and C. W. Merle did the background research and started this project. Mr. Merle left just after the transmitter had been started. Mr. Bower and myself completed the transmitter and started theoretical design of the receiver. At this point Bower wrote the first thesis on this project. The delay system and method of modulation was then revised in the transmitter to obtain better results. Several circuits were tried in the receiver and work on the receiver was discontinued at a point described in this thesis. Ruben Kelly and Ira Lynch constructed another transmitter without as many variables as the first one so they could work more efficiently on the receiver. They have tried many different circuits in the receiver and are in the process of completeing both units at the time this was written. Both students will write theses on this project after completing the two units and running tests on them.

It is hoped that this project will be of benefit to posterity by showing results whereby the communication arts may progress.

ACKNOWLEDGEMENT

Thanks should be given to Professor Attie Betts for the idea that started this project and to his untiring efforts to help make it a success. Thanks to Professor Harold Fristoe for his many suggestions and cooperative attitude. Thanks to the School of Electrical Engineering for the use of its parts and equipment. Also, thanks to my wife, Alberta, who had more patience with this thesis than I.

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INTRODUCTION

PULSE COMMUNICATIONS IN GENERAL

Engineers have been familiar with pulse communication at high frequencies for some time. High frequency pulse communication has many advantages in the conservation of space and bandwidth. Due to the increase in the number of radio stations throughout the nation it may become necessary to convert to pulse communication. Such conversion would make it possible for a local station to transmit all of the major networks with only one fundamental frequency involved. There are already too many stations on the air. Stations now interfere with each other in spite of the rigid Federal Communication Commission controls simply because there is no way to have absolute controls of field patterns.

There are several methods of transmitting intelligence by means of pulses. These are: amplitude modulation, the height variation of pulses; width modulation, the width variation of pulses; frequency modulation, repetition rate variation of pulses; time modulation, variation of the pulse on the time axis; coded modulation, variation of both height and time of the pulse. Experiments with microwave frequencies have shown that pulses may be both amplitude modulated and either time or width modulated. This would enable the number of messages to be doubled with one fundamental frequency involved.

Pulse circuits have an advantage over ordinary circuits in that the intelligence can be sampled instead of it being necessary to transmit the entire wave pattern. Pulse circuits also have a disadvantage in that the Q obtained from tank circuits cannot be utilized. There is no way to transmit pulses at this time with the use of resonant circuits; when a pulse enters a tank circuit it acts only as a transient. This condition is due to the high harmonic content involved in forming a pulse. Although the signal oscillator may be 100 K.C. as is the case of equipment described herein, the steepness in the wave form of the pulse indicates that all pulses must be treated as transients composed of harmonics possibly in the U.H.F. region. Circuit parameters do not behave under these conditions as they do under ordinary conditions. This fact will be demostrated again and again and is the determining factor in the use of non-conventional circuits.

Distortion may occur when the signal is only sampled and not transmitted in its complete form. Shannon[1] demonstrates that the human ear is rather insensitive to a slight amount of distortion. The ears are a non-linear device and it has been proven that non-linear distortion up to ten percent is not noticeable.[2] Phase distortion and intermodulation distortion can be tolerated to a lesser degree. This justifies the statement that although a certain amount of distortion is introduced by the sampling process, it can be tolerated.

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[1] C. E. Shannon, "Communication in the Presence of Noise," _Proceedings of the Institute of Radio Engineers_, XXXVII (January, 1949), 10.

[2] M. I. T. Staff, _Applied Electronics_, p. 425.

Amplitude modulation[3] or pulses was found to be undesirable from the viewpoint of noise elimination, therefore other types of modulation were tried. Pulse width variation of a modulation multivibrator was decided upon for test purposes. A high fidelity system with comparatively little noise was desired. Pulse width modulation is a great waste of space,[4] so the waveform of the multivibrator was differentiated converting the trailing edge into a pulse which was displaced in time instead of in width with applied modulation. With this in mind discussion of the transmitter will follow.

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[3] F. F. Roberts, J. C. Simmonds, "Multi-Channel Communication Systems," Wireless Engineer, XXII (November, 1945), 538.

[4] John A. B. Bower, "Multi-Plex Communication Systems," Thesis (January, 1950).

CHAPTER I

THE TRANSMITTER

A complete schematic diagram of the transmitter in its present form is shown in Figure 1. All components of the completed transmitter are given. Triodes and pentodes in both transmitter and receiver are either 6SN7's or 6AC7's for a more practical design.

Briefly, the operation of the transmitter up to the delay tubes follows:[1] A local crystal controlled oscillator was used to create a signal voltage, sine wave in nature, at an operating frequency of 100 K.C. The oscillator was designed so that any load impedance reflected back in the oscillator circuit would not change its frequency.[2] The signal was than fed through a limiter tube which started the wave shaping operation. There were four pulses in this system: three channel pulses and a reference or marker pulse. From the limiter tube the original signal was fed to four separate circuits. The master pulse was first fed through an overdriven amplifier. This enabled further squaring of the waveforms by both saturation and cut-off limiting. Next, the master pulse was put through a special circuit called a peaker and pulse amplifier. The input to this circuit having an RC time constant of one microsecond, differentiated the nearly square wave. The sharp sides of the

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[1] Ibid., Thesis.

[2] Donald G. Fink, "Loran Receiver Indicator," Electronics, XVIII (December, 1945), 110.

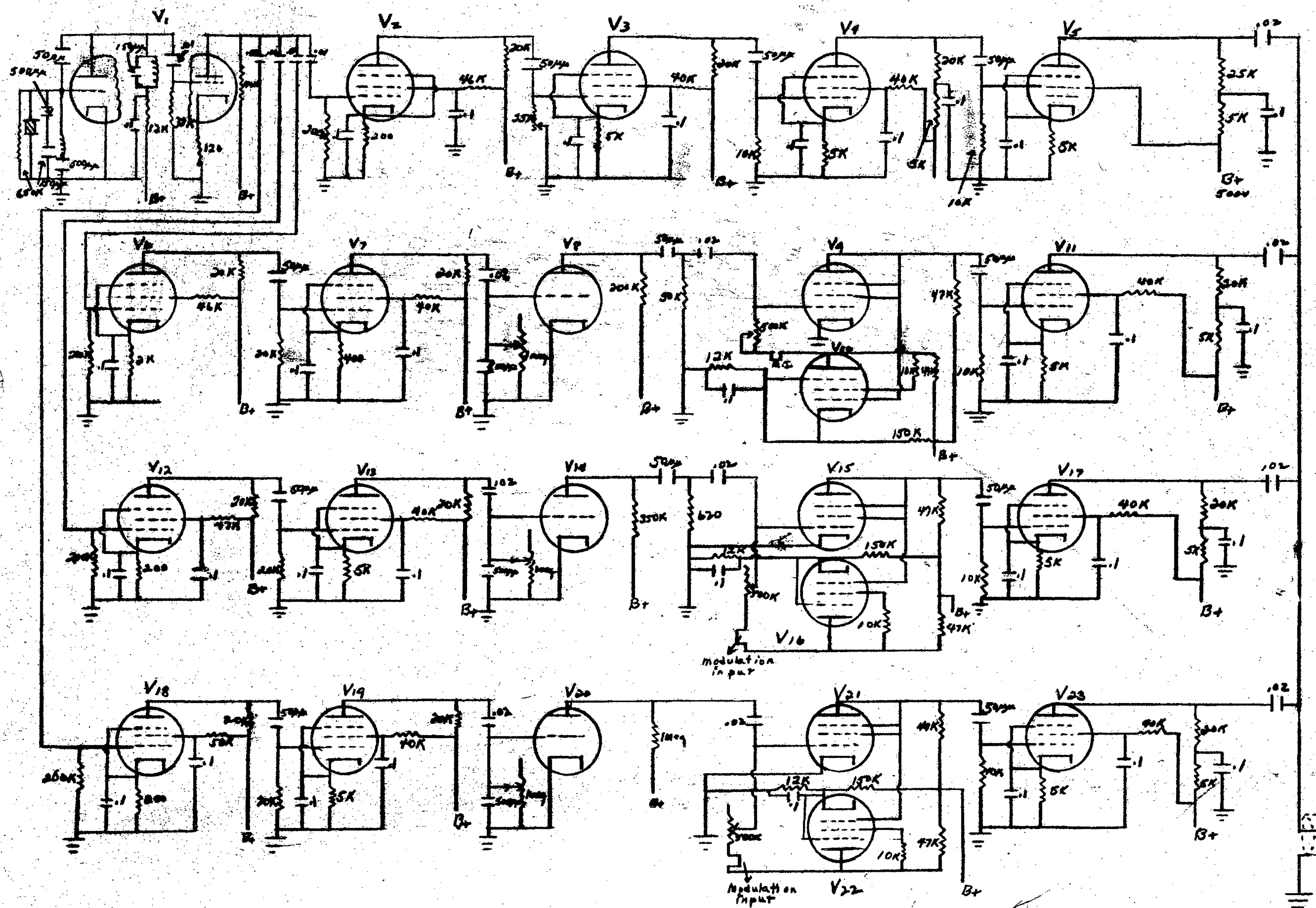

FIG. I PULSE TRANSMITTER

square wave produced a positive and a negative pulse for each square wave. Because of the large capacitive reactance of the coupling condenser to low frequencies there could be no signal applied to the grid of the tube unless a sharp pulse of high harmonic content appeared. Cathode bias of the tube removed the negative pulses, therefore, only the positive pulses were available for amplification. This amplifier itself differed from the conventional voltage amplifier in that it had a very small plate load resistor of 20,000 ohms. It also was decoupled with a 5000 ohm resistor and a .1 microfarad condenser for the purpose of confining the signal to the plate circuit only. The master pulse went through three peakers and pulse amplifiers before it arrived at the output lead.

The other three channel pulses also went through an over-driven amplifier and a peaker and pulse amplifier. At this point all waves including the master pulse were similar in shape, amplitude, and time displacement. From here on each pulse became individual in nature but the height and time displacement were different from that of the master pulse.

It was necessary to make several important changes in the transmitter. The delay circuits formerly used[3] were changed completely as shown in Figure 2 (a), (b), and (c). The previous circuits were not adequate to delay a pulse over one half the distance between master pulses; nor were the previous circuits adequate to prevent pulse amplitude variation when being delayed

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3 John A. B. Bower, loc. cit.

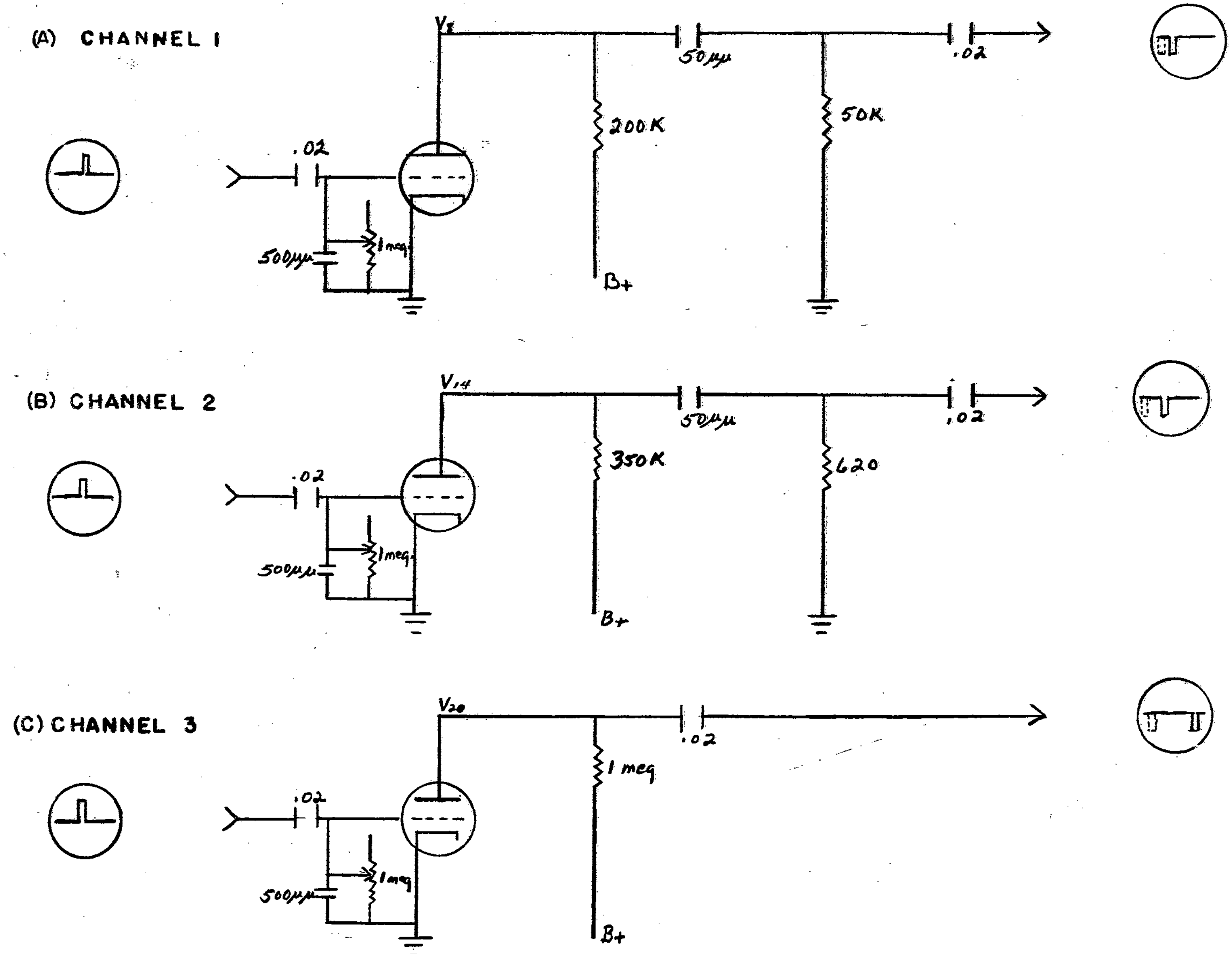

FIG.2 DELAY CIRCUITS

from point to point. By using a combination of variable resistors and variable condensers a satisfactory delay was obtained which varied a single pulse over one half the distance between master pulses. Three different circuits were used because the first pulse had to be delayed from zero to over five microseconds, the second from two to eight, and the third from four to ten. Figure 2 (a), (b), and (c) show the respective circuits for delaying the three channel pulses.

Each channel pulse was then fed into a modulation multivibrator. This method was found to be the best for impressing a modulated signal on the pulse. A previous method[4] of using a reactance tube for modulation was discarded after it was found that the reactance tube would not work as desired. Not only did it not give time displacement modulation but interaction through the power supply upset the functions of the other circuits, and introduced an amplitude modulation of the pulses which could not be removed.

By impressing a modulating voltage on the trailing edge of a multivibrator, a variable width was obtained which in turn was differentiated and thereby connected to a pulse with time displacement. There were two pulses when the square wave was fed through the differentiator but the leading edge pulse was clipped by applying a fixed bias to the peaker and pulse amplifier into which it was fed.

Figure 3 shows the method of modulation used in conjunction

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4 Ibid., Thesis.

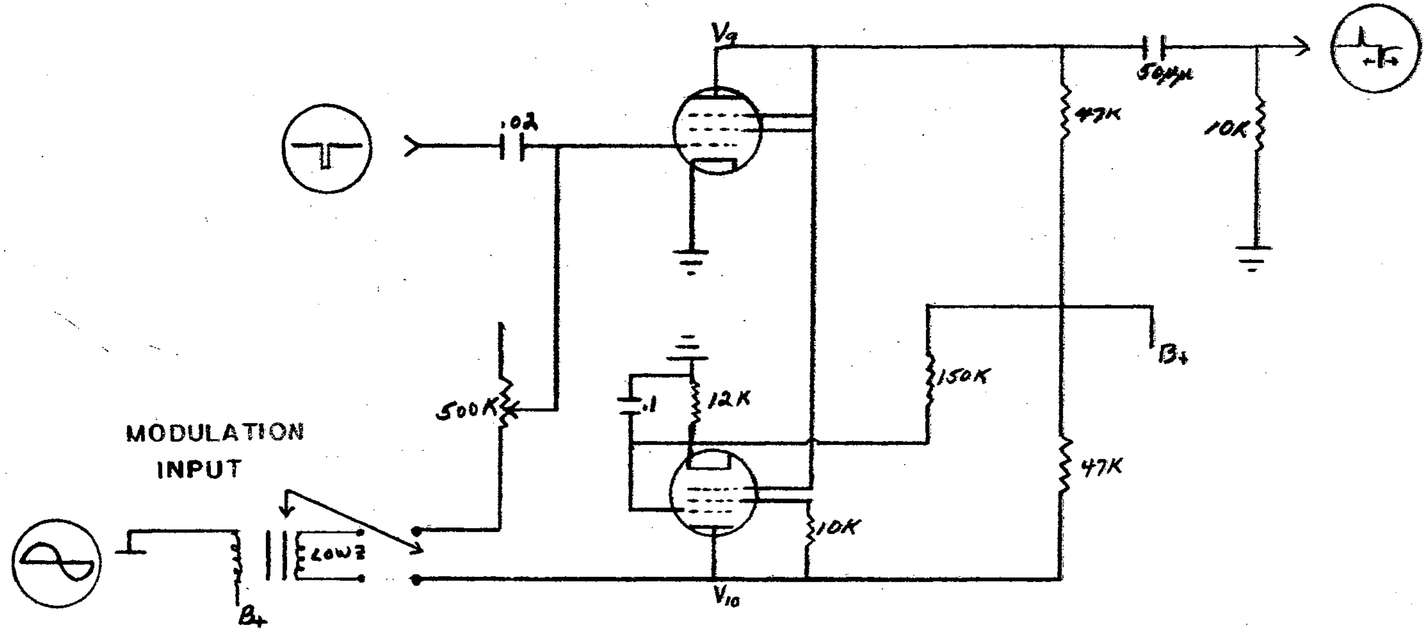

FIG. 3 MODULATED VARIABLE WIDTH MULTIVIBRATOR

with the variable width multivibrator. All three channel modulators were identical, therefore only one circuit is shown.

Mixing of the signals was a relatively easy matter in that they were all coupled through a .02 microfarad condenser to the coaxial cable. A maximum voltage was obtained with the power supply available. In order to produce a master pulse with approximately twice the amplitude of the signal pulses, a higher plate voltage in the order of 500 volts was used on its last peaker and pulse amplifier.

The signal was fed into 220 feet of RG-8/u (52 ohm) coaxial cable. A fifty-two ohm resistor was used to match the characteristic impedance of the cable. This eliminated all transient oscillations set up in the cable due to reflected waves.

CHAPTER II

GENERAL PROBLEM OF DEMODULATION

Very little has been written on the problem of demodulation of multiple channel pulse circuits. A synchronizing circuit was necessary because of the desire to separate the various pulses. It is obvious that the channel pulses must be separated if the intelligence contained in any one channel is to be utilized without interference from the other channels. This must be accomplished without distroying any of the pulses since each must furnish its own part of the completed operation.

A solution to this problem was to send the incoming signals various directions when they entered the receiver. The master pulse alone was obtained through a process of limiting and shaping and therefore became available for tripping delay multivibrators. Each delay multivibrator had a different R-C time constant and started at a different time. The outputs of the various multivibrators were then differentiated and these delayed pulses used to trip another set of multivibrators. Another way to accomplish the same purpose would be by the use of delay lines. This method would not be as variable as the other type and was not used.

The pulses fed in the other direction were taken to the second set of multivibrators, where each channel pulse waited for its chance to go through.

Since each multivibrator was triggered by delay pulses, each operated at a different starting time. The master pulse was first eliminated simply because there was no multivibrator operating at that particular time. The first channel pulse was allowed to pass through the multivibrator controlled by the next shortest delayed pulse, and so on.

After each pulse had been separated there was a need for a system of demodulation. It was possible to recover the modulating signal by means of low pass filters, providing a special separator pulse shape was employed. However, spurious frequencies existed, to the detriment of this system, depending upon the relation between pulse repetition frequency and audio modulating frequency.[1] In another method with a better signal-to-noise ratio, the audio signal was separated from the pulse by charging a capcitor which discharged through a resistor. The voltage across the resistor with a correct time constant adjustment followed at an audio rate.

A delay network could have been used for channel demodulation by producing separate channel pulses for the modulated pulse sequence. An alternate method could have been to have a multivibrator remove the marker pulse and to produce a pedestal pulse delayed to the proper channel in the sequence. The pedestal pulse could have served to separate the appropriate channel pulse with the pedestal pulse slope utilized to translate the time modulated pulses into amplitude modulated pulses. Suitably timed pedestal pulses were required for each channel in the

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[1] F. F. Roberts, J. C. Simmonds, "Multi-Channel Communication Systems," Wireless Engineer, XXII (November, 1945), 538.

sequence.[2]

Any utilization of the pulse time system could become simpler and more efficient by the use of newly developed special purpose multiplexing tubes.[3] Modulation and demodulation devices discussed previously are greatly modified and simplified by the use of these tubes.

It must be pointed out in the discussion on demodulation that use could have been made of limiter and differentiator circuits in the demodulator. An important measure of the protection against noise interference offered by time modulation pulses resulted from the high ratio of peak to average power used. The improvement, in terms of the pulses, was proportional to the build-up to decay time, whichever was the smaller. The threshold of improvement was reached when the peak pulse amplitude was about twice the effective noise peaks. The greatest degree of noise suppression was obtained when the successive stages of limiting and differentiating were incorporated in the receiver. Noise may enter a pulse system by any of the following:

1. Amplitude modulation of pulses
2. Width modulation of pulses
3. Noise between pulses
4. Displacement in time of leading or trailing edge of pulse.

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[2] D. D. Grief and A. M. Levine, "Pulse Time Modulated Multiplex Radio Relay Systems-Terminal Equipment," Electrical Communication, XXIII (June, 1946), 159.

[3] Ibid., p. 159.

Noise arising from (1) and (3) above may be removed by proper limiting if input signal-to-noise is greater than 6 db. A differentiator may extract the proper pulse edge and remove noise from (2) above. This action may not be complete due to the edge-shape variation and the process may be repeated. Noise from (4) is of the same form as the modulating signal and although inherent in the system it is fortunately slight. However, it may be reduced by decreasing the build-up or decay time, i.e., increasing the bandwidth. The limiter application also provides constancy of the signal independent of fading.[4] Figure 4 shows a block diagram of the receiver designed following some of the above ideas.

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[4] Bower, loc. cit.

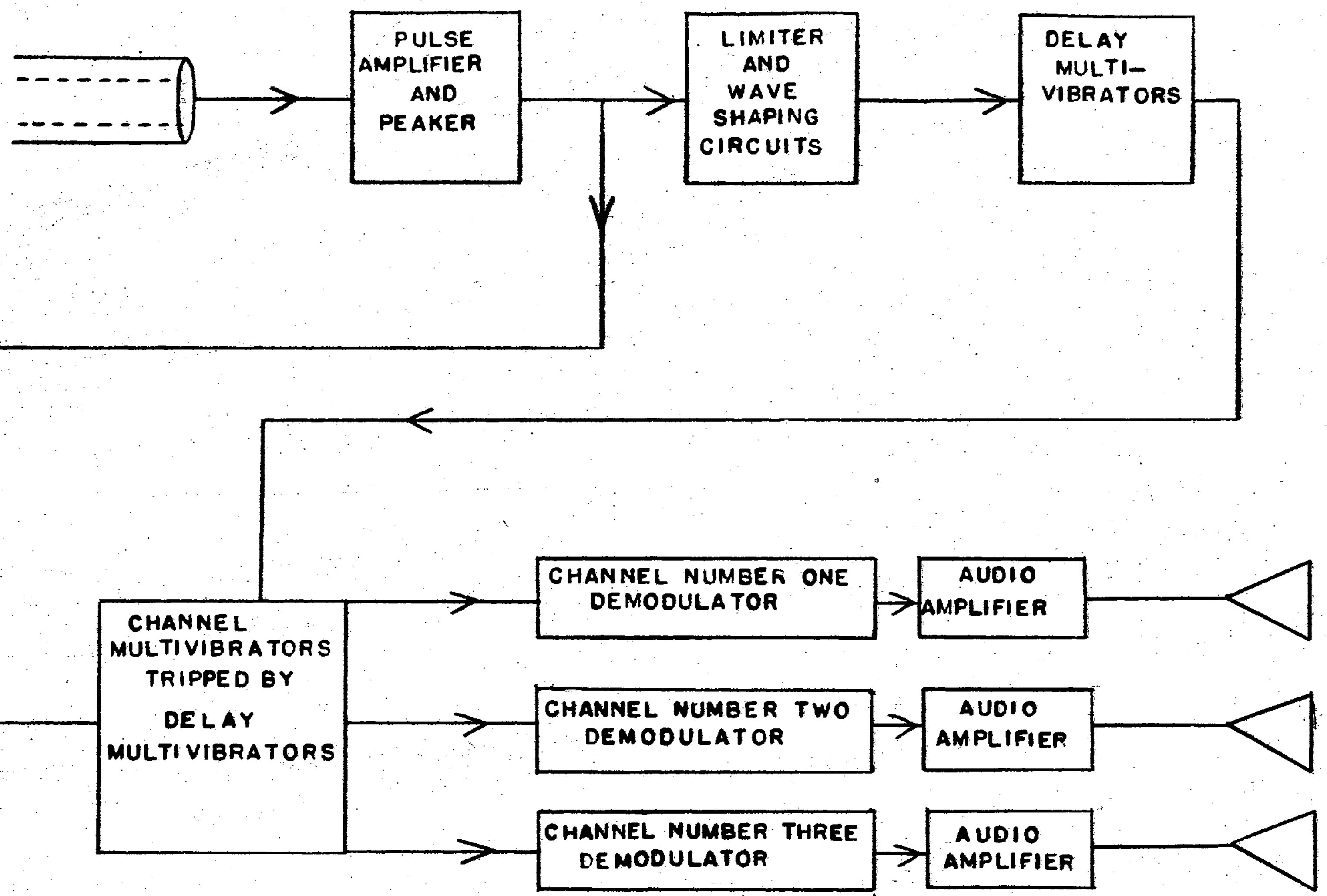

FIG. 4 THE RECEIVER

CHAPTER III

DESIGN OF RECEIVER

The problems which were encountered in the construction of the receiver are:

1. To increase the amplification of all four pulses after they had traveled the length of the coaxial cable.
2. To separate the master pulse from the others for use as a triggering pulse.
3. To separate each channel pulse from the others.
4. To demodulate each channel pulse after it had been separated.
5. To amplify the audio signal obtained after demodulation.

The pulses had to be amplified to a usable value when they reached the receiver because of losses in the cable and losses in the 52 ohm characteristic matching resistor. The characteristic impedance of the line had to be matched, otherwise, transients set up in the cable due to reflected waves would have distorted the pulses beyond recognition. Therefore, four peaker and pulse amplifiers were used, identical in characteristics to those used in the transmitter. This also isolated the various stages from each other as shown in Figure 5.

Before the pulses had been amplified there came a problem of using the master pulse as a triggering device, yet maintaining the channel pulses intact for separation and demodulation. This necessarily meant that the pulses had to be sent

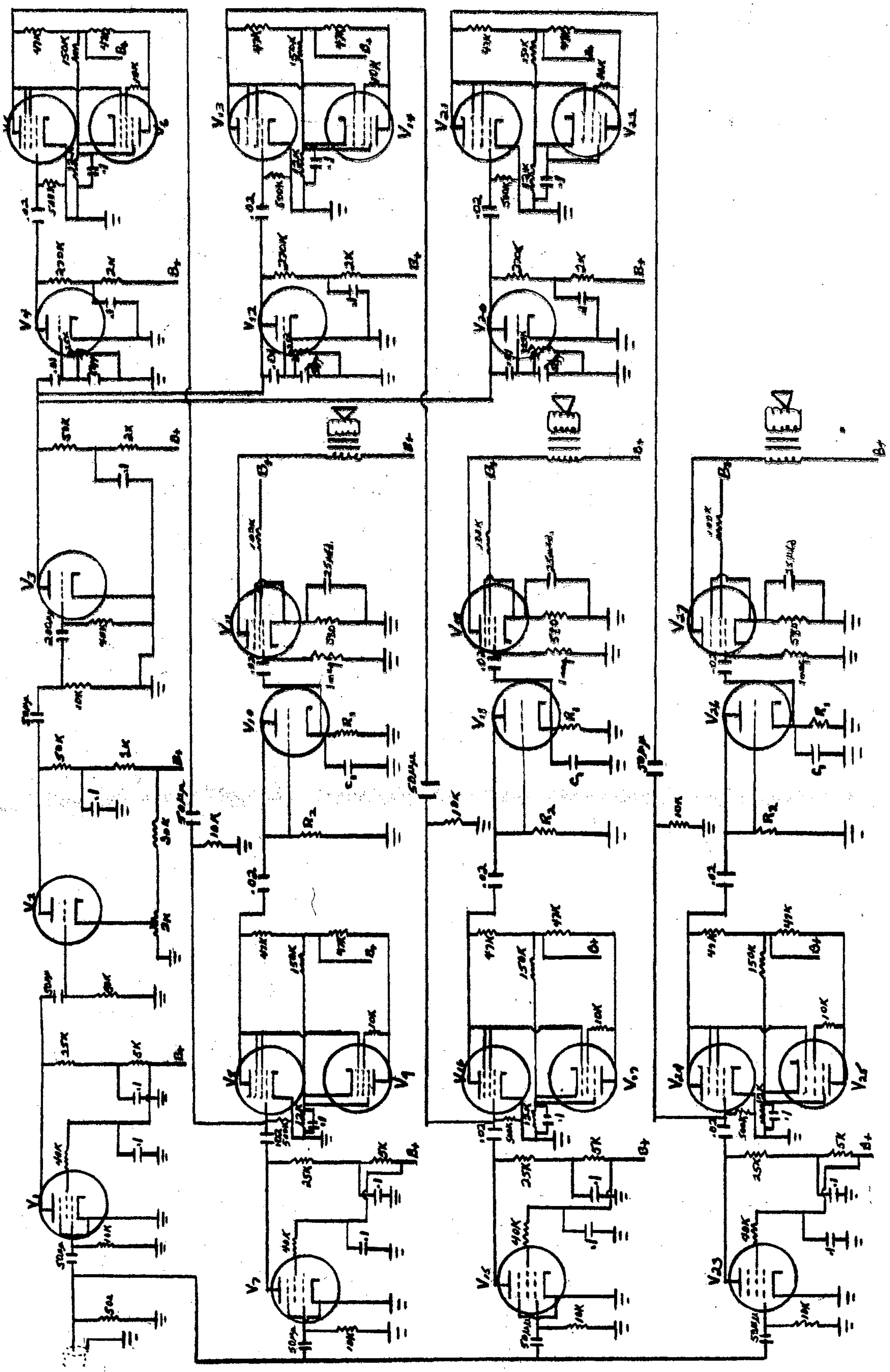

FIG. 5 PULSE RECEIVER

in four directions at the same time, which they were.

The master pulse was separated from the channel pulses through a series of limiting and shaping circuits. It was then fed into a delay circuit which controlled the time it tripped a variable width multivibrator. The multivibrator was similar to those used in the transmitter. The purpose of having a variable width in this case was to provide practical use of the tubes and circuits already available. Any one-shot multivibrator could have been used. After the square wave was obtained from the multivibrator, it was differentiated and sent to trigger another variable width multivibrator. With the aid of the differentiating circuit and the fact that the square wave obtained was nearly power supply voltage, this pulse was approximately five times the height of the other pulses.

The construction as far as this thesis is concerned has ended at this point. Ira Lynch and Ruben Kelly will complete the construction of the receiver and will give a report of the results obtained. Therefore, from this point on further discussion will be theoretical to a certain extent. The rest of the receiver design is based on practical circuits which have already proven satisfactory, so we continue under the assumption that the receiver will work. One channel pulse has been separated and demodulated but only as a rough trial.

The pulses arriving at the separation multivibrator were the three channel pulses, the original marker, and the large variable delayed triggering pulse. The triggering pulse was made to vary in delay from zero to ten microseconds, thus it was allowed to occur at the same time or at a different time than the other four pulses. Since there were three channel pulses to be separated, three triggering pulses were necessary.

The triggering pulse caused the multivibrator to go into operating condition just before the desired pulse was available for flipping the multivibrator. The position of the desired pulse due to modulation caused the multivibrator width to vary. This action caused the negative going side of the multivibrator to vary with modulation of the desired pulse and also blocked the other side.

The demodulation took effect in a diode detector, the audio component being produced across the time constant in the cathode circuit.

The desired number of audio stages may follow the demodulator but no problem is involved here because they conform to conventional circuits.

CHAPTER IV

RECEIVER CIRCUITS AND OPERATION

In order to amplify the incoming signal, four peaker and pulse amplifiers were used in parallel. The design of this circuit primarily came from the Loran receiver design.[1] It was found from designing the transmitter that pulses were amplified better if they were first run through a differentiating circuit. Distortion of the waveform resulted if they were not differentiated. The effect of the input circuit was to make steeper pulses of the signal voltages and therefore would result in a less distorted output. The plate load resistor of this tube was of very small value as compared to conventional tube circuits. Small R_{ℓ} also was to prevent distortion of the pulses. Since pulses behaved as transients, provision had to be made to prevent their complete destruction by interelectrode capacitance and stray fields. A decoupling network consisting of a 5000 ohm resistor and a .1 condenser was employed to keep the signal voltages from feeding into other parts of the receiver. The negative going pulses were reversed 180° through the amplifier tube and were positive going pulses as they entered other circuits. A schematic diagram of this circuit was shown in the thesis by John A. B. Bower and also in Figure 5.

After the master pulse had been amplified it was then fed into a limiter tube to eliminate the channel pulses. The limiter

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1 Bower, loc. cit.

grid was biased below cut-off value and only a large pulse could make it operate. Since the master pulse was approximately twice as large as the channel pulses it alone caused current flow through the tube. The tube caused the waveform to be distorted and therefore had to be differentiated again. Any triode will cause distortion of a pulse because of relatively larger inter-electrode capacitances as compared to a pentode.

Another tube was needed for several purposes before going into the delay circuit. The waveform had to be inverted because a positive pulse was needed for the delay circuit and a negative pulse to trip the variable width multivibrator. Also, as large a pulse as possible was needed, so there was need for an amplifier. By having the pulse go through this additional tube the rest of the distortion, caused partly by the channel pulses, was completely removed. This left only the master pulse at a desired amplitude to be fed into the delay circuits. Figure 6 shows the circuit and waveforms of the limiter and phase inverter.

The delay circuits consisted of three delay tubes and their components. This was necessary because there were three channels to pass and each pulse occurred at a different time. Design and operation was similar to the delay circuits used in the transmitter. The cathode was connected to ground and with no bias the tube was normally conducting. The high amplitude negative pulse drove the delay tube into cutoff since there was no resistance in the charge path of the capacitor between grid and ground. The R-C network between grid and ground determined the amount of delay by fixing the time the tube conducted

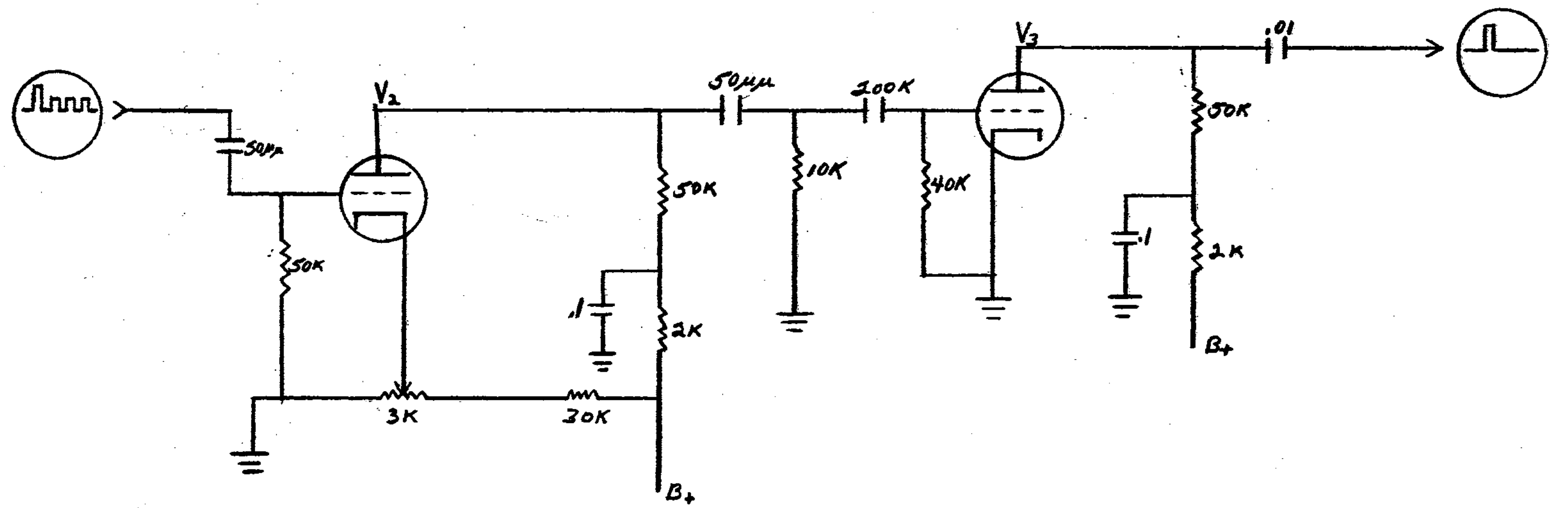

FIG. 6 RECEIVER LIMITER AND PHASE INVERTER

normally. The output, therefore, was a negative going pulse delayed in time determined by the discharge time of the grid R-C time constant. Figure 7 shows this circuit.

It was found through experimentation with the transmitter that the delayed output could trip a multivibrator if the multivibrator were working properly. When it did not work properly it loaded the delay tube circuit and distorted the triggering pulse. A cathode follower was tried without success to isolate the delay circuit. Then, it was found that a faulty multivibrator was the cause of the trouble, and the cathode follower was no longer used (see Figure 1).

Out of each manually delayed circuit came a pulse which triggered a variable width multivibrator. Since all three circuits from this point to the loudspeaker were identical only one channel will be used to demonstrate the action of all three circuits. As pointed out before the first multivibrator acted only as a one-shot multivibrator, which is one that is quiescent until its action is initiated by a pulse of voltage from an external source such as the delayed pulse. V6 was biased below cut-off and V5 was conducting normally. Then when the negative pulse was applied to V5 it caused the current to decrease in its plate load resistor. Since the grid of V6 was connected to the plate of V5 this caused the grid voltage of V6 to become positive enough to overcome its negative self-bias, then start its operation. Then it would make a complete square wave and return to its original position, to await another triggering pulse.

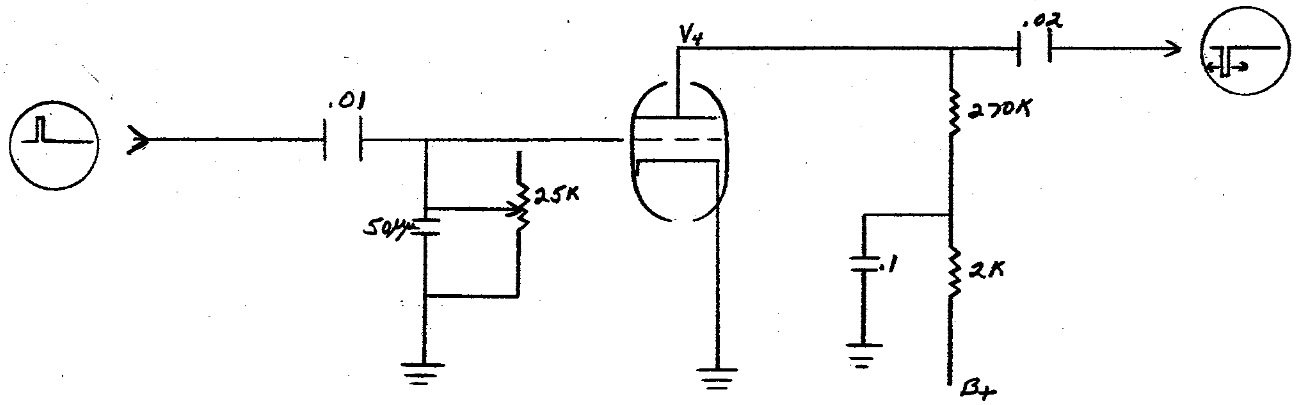

FIG. 7 RECEIVER DELAY CIRCUIT

The square wave obtained was then differentiated and sent to a second multivibrator. One important point to be here noted is; the amplitude of the differentiated pulse was very large, approximately five times the amplitude of the channel pulses. It should be pointed out again, that from this point on, the design is somewhat theoretical since all three channels have not as yet been separated.

At the second multivibrator all four original pulses and the modified and delayed master pulse awaited their chance to go through the multivibrator. Only the first was desired to act upon the variable width multivibrator since that was the channel which was to be used in demonstration. The large triggering pulse was delayed so that it would appear about a microsecond before the channel pulse. It set the multivibrator into action as described above. But instead of making the complete cycle it was made to return to its original position by the positive channel pulse. Since the channel pulse varied in time due to the amplitude of the modulation it caused the multivibrator to reverse directions at different times. This in turn caused the width of the square wave to vary with modulation. The R-C time constants of the multivibrator caused it to not be tripped by any of the other channel pulses. A channel separation system such as shown in Figure 8 would not have been possible except for the peculiar action of a variable width multivibrator. Once started through a cycle it will continue to form a square wave unless interrupted by a restoring pulse, at which time it will instantly reverse in polarity.

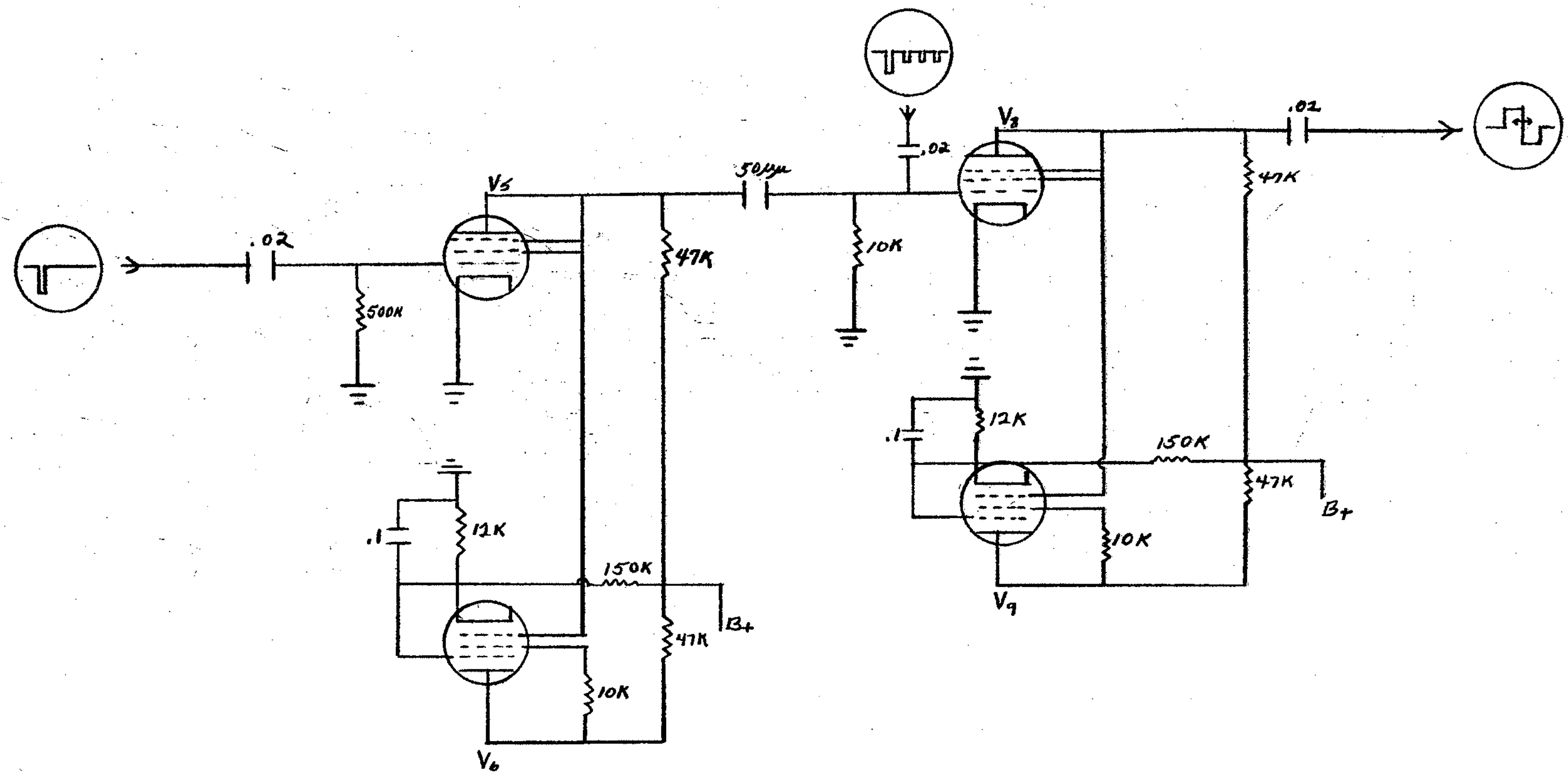

FIG. 8 CHANNEL SEPARATION SYSTEM

The square wave was then fed into a demodulator. Wide positive portions of the square wave caused the diode to draw more current and narrow portions caused it to draw less according to the modulation present. Voltage impressed across R_1 (see Figure 9) will follow the audio signal. C_1 R_1 will not be 10 RC or above as in the case of self-biased cathode circuits but will be a lesser value in order to follow the modulation pattern. As yet R_1, R_2, and C_1 have not been determined to give best results.

Audio stages as may be necessary should follow the demodulation circuit. This would depend upon the power output necessary and is a relatively minor problem. No further consideration of this is necessary.

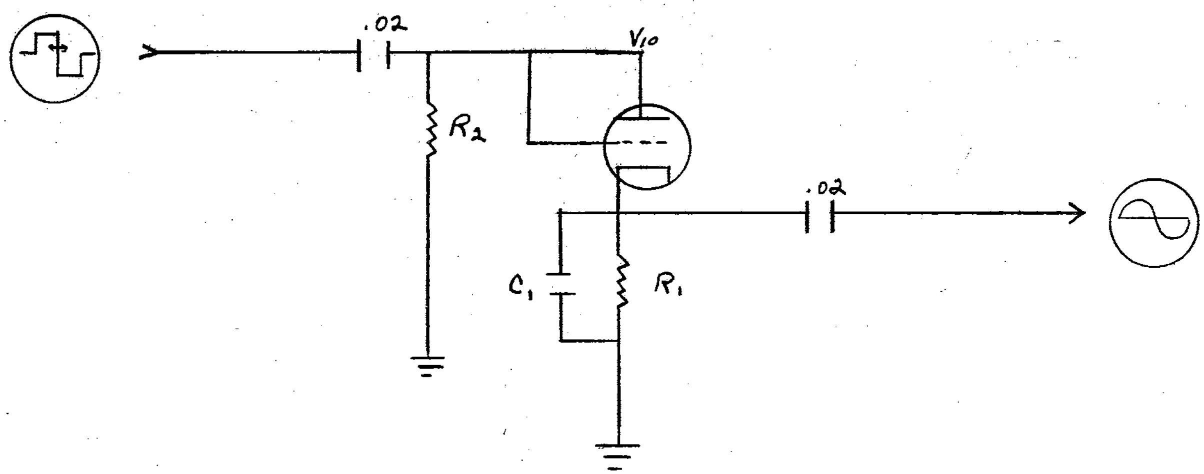

FIG. 9 DEMODULATOR

CONCLUSIONS

This project was set up as a long range objective. With many students involved, changes will and have been made. The object of experimentation is improvement, and this project is no exception. Another complete transmitter already has been built to use in conjunction with the original transmitter. This was done to eliminate too many variables present in the first one. More stability was required in order to obtain proper operation of the receiver, therefore, several circuits were advantageously changed. The delay circuits were improved and the range of delay was widened. More uniform delay response was also achieved. The action of the variable width multivibrators was also improved when modulated. Circuits such as the peaker and pulse amplifier and the fundamental variable width multivibrator have not been changed since they have proven to be very useful circuits where pulse time circuits are concerned.

Circuits such as cathode followers, saw tooth generators, and various limiting circuits have been tried in the receiver. An unstable transmitter caused some of the work to be delayed on the receiver. This trouble was eliminated and the receiver has progressed very rapidly. One channel has actually been through circuits similar to those in Figure 5 and was demodulated.

Improvement had to be made from the beginning. Therefore it was thought that the system should be completely torn down and other circuits tried which would improve the overall response of the receiver. The receiver was at this stage at the time this thesis was written. It has been found with this particular project that it was better not to try for perfection the first time a circuit was constructed. Best results were obtained by making a rough estimation of the general problem and then to go to the beginning and iron out the rough spots. Even a second or third trial did not always give perfect or even satisfactory results. As an example of this, two types of modulation were tried, as shown in Bower's thesis, and plate, or impressed voltage, modulation of the transmitter was tried in this thesis, neither with the desired results. Both methods worked to a certain extent and further progress of both transmitter and receiver was achieved. Overall results could not have been obtained had the project stopped at any particular point to achieve perfection. The stages following the modulated multivibrators largely determined the type of modulation necessary. Now that the receiver has been nearly completed a third type of modulation has proven more satisfactory than either of the two used previously and has shown better results.

Various tests can be performed with both transmitter and receiver. Curves of various parameters may be plotted to secure overall operation of either or both units. Allowable tolerances in performance may be determined. Shielding has not been considered, therefore, tests of this nature may be made in order to strive for improvement.

In the transmitter, conventional tests should be made as well as those adaptable only to this unit. Voltage height of output pulses would be equivalent to power output. Plate input power would mean very little because the pulses constitute only a small amount of the average plate current. Modulation checks similar to conventional tests can be made. Percentage modulation checks, distortion tests, modulation power required and frequency response are some of the tests that may be made. Allowable propinquity of the pulses to either the master pulse or each other would be desirable. Of course, percentage of modulation would determine guard time necessary to prevent cross-talk and distortion. Different fundamental frequencies within a limited range may be tried to determine an optimum point of operation. If another channel should be desired the master pulse could be modulated by any of the mentioned methods of modulation.

In the receiver, sensitivity and selectivity checks should be made. These checks to some extent should determine adjustments to be made on the transmitter for optimum results. Settings made in the delay circuits probably will be critical since the variable width multivibrator must be allowed to start at a particular time.

Tests other than those mentioned will become apparent as soon as both units are functioning properly.

It is felt that these tests herein listed will add to the available information to the extent that the horizons of the communications art may be extended.

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- Patty McAffrey Howell -

Date: May 10, 1950

Name: Thomas A. King, Jr. Position: Student

Institution: Oklahoma A & M College Location: Stillwater, Oklahoma

Title of Study: Multiplex Pulse Communication Circuits

Number of Pages in Study: 32

Under direction of What Department: Electrical Engineering

Scope of Study: Pulse communication at low frequencies required knowledge of pulse circuits and microwave techniques. Extensive work has been performed by pulsing microwaves, but knowledge of pulsing low frequencies is practically unknown. The problem of designing pulse circuits at low frequencies involved modification of radar circuits and knowledge of vacuum tube circuits. Experience of others with pulse circuits and trial and error techniques were useful. Theoretical design was then followed by constructing and testing of the equipment.

Findings and Conclusions: The apparatus consisted of a three channel pulse transmitter and a decoder or receiver. All circuits in both units were made as variable as was practical to enable many test to be performed. Circuits, such as the delay network and the modulation system in the transmitter, have been changed several times for better performance. A relatively large marker or synchronizing pulse and three variable delay channel pulses have been obtained. Tests have shown that the channel pulses are varied on the time axis when modulation is applied to a variable width multivibrator. The output from the transmitter has been fed through 220 feet of RG8/u (52 ohm) coaxial cable. A receiver has been partly constructed to decode the modulated pulse. One channel has been demodulated as a rough trail. Both transmitter and receiver are being revised in which better results are hoped to be attained. It is felt, that when this equipment is completed, a multitude of projects can be undertaken, each adding to our store of knowledge concerning communication systems.

ADVISER'S APPROVAL Attie L. Betts