NEW MEXICO INSTITUTE

of

MINING AND TECHNOLOGY

A Telemetering System for Geophysical Data

A paper submitted in partial satisfaction of the requirements for the degree, Master of Science in Geophysics.

By

C. L. Edwards

February, 1969

ABSTRACT

A TELEMETERING SYSTEM FOR GEOPHYSICAL DATA

By

C. L. Edwards

February, 1969

The first part of the report looks briefly at the different kinds of modulation systems and attempts to choose the best combination from the point of view of simplicity, reliability, and cost. The choice was a pulse-width modulation system and an AM transmitter.

The second part of the paper gives the design of the basic telemetering system consisting of one base station and one remote station.

The third part of the paper evaluates the cost of each component of the system and tries to assign an accurate cost to each remote station and base station.

0.00 TABLE OF CONTENTS ----------- 1

0.10 List of Figures

0.20 List of Tables

1.00 INTRODUCTION

The object of this study is to design a telemetering system capable of transmitting geophysical data from a relatively compact field unit to a base station which can process the data. The basic system would include several remote stations each capable of transmitting three channels of information, that is, the three components of ground motion (east-west, north-south and vertical). The base station would separate first the signals from the remote stations and then separate the three information channels from each station. Once the original analog signal is recovered it can be filtered and then a permanent record made either on tape or strip-chart.

The basic design philosophy is that all system components such as amplifiers, filters, and modulators will be proven electronic circuits. There are thousands of circuits on the market put out by various electronics firms. It is quite simple to locate a schematic which will do a specific job. Some small modifications may be necessary to adapt the particular circuit to perform the job but nothing major which might damage the reliability of the circuit. This means that a particular circuit used might not be the best for the particular job but for reliability, cost, and availability it is the one to be used.

1.10 Requirements of the System

The remote station must be able to amplify the signals from the three seismometers to a level high enough that the three signals can be multiplexed and transmitted. The power used must be small since the units must function for several weeks without servicing. The station should be able to transmit an analog signal with very little distortion. The system should be capable of dc to 100 Hz response. The system should be relatively immune to noise. Some system must be used such that the signals from several remote stations can be received, identified and separated at the base station.

The base station must be able to separate the signals from each remote station and then decode each signal to recover the original information. The base station also must be capable of reproducing the original analog signal with no loss in frequency response. It must also be able to process the information and record it in usable form on either a strip-chart recorder or a tape recorder.

The entire system must of course be reliable and economically feasible.

1.20 Kinds of Systems

Since the analog signals are to be transmitted by radio some method of modulation and multiplexing must be devised such that the signal can be recovered with a minimum of distortion and noise.

1.21 Amplitude Modulation

An amplitude modulated wave is a carrier wave in which the amplitude is varied by a modulating wave. Figure 1-1 shows the relationship between carrier, modulating, and the resultant amplitude modulated waves.

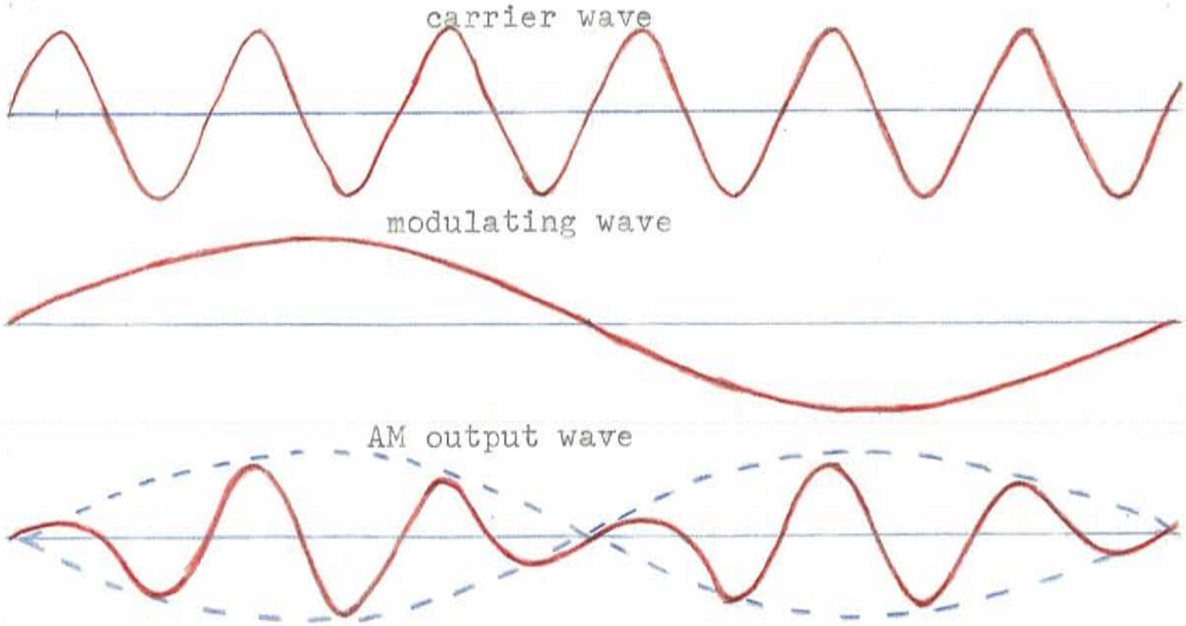


Figure 1-1 Relationship Between Carrier, Modulating, and the Resultant AM Waves

Multiplexing is achieved by allowing each modulating wave to modulate a subcarrier. The subcarriers are then used to modulate the carrier. This is called AM-AM multiplexing.

De-multiplexing is achieved by the use of band pass filters. The band pass filter allows only one subcarrier to pass while rejecting the others. The subcarriers are then filtered out to recover the original modulating wave.

1.22 Frequency Modulation

Frequency modulation is a kind of modulation in which deviation from a carrier frequency is proportional to the amplitude of the modulating wave. Figure 1-2 shows the relationship between carrier, modulating and resultant waves.

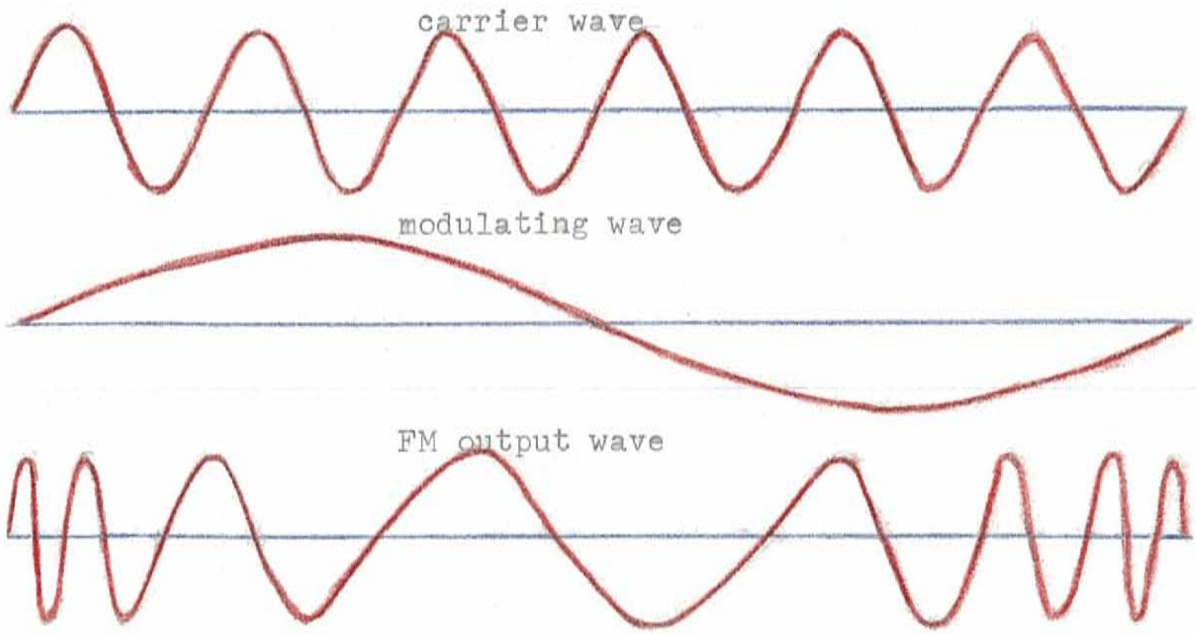


Figure 1-2 Relationship Between Carrier, Modulating, and the Resultant FM Waves

Multiplexing is achieved by allowing each modulating wave to modulate a subcarrier. The subcarriers then are used to modulate the carrier. This is called FM-FM.

De-multiplexing is achieved by using a de-modulator to recover the FM subcarriers. Band pass filters are used to separate the subcarriers and then each is demodulated to recover the modulating wave.

1.23 Pulse Modulation

In pulse-modulation systems the information is transmitted intermittently rather than continuously as in amplitude or frequency modulation. There are three kinds of pulse modulation, pulse-width modulation (PWM), pulse-position modulation (PPM) and pulse-amplitude modulation (PAM). Figure 1-3 shows the relationships between carrier, modulating and modulated waves.

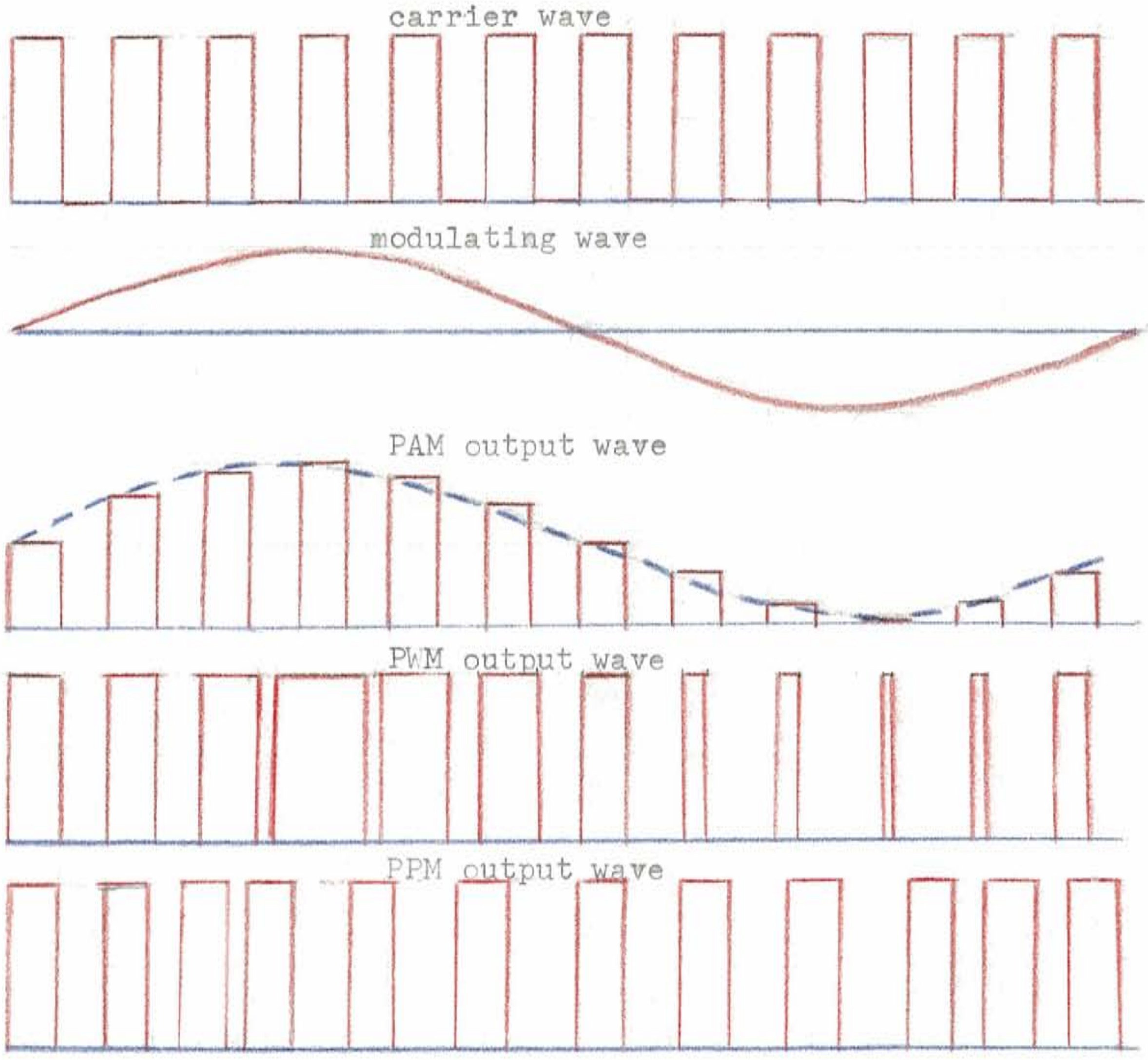


Figure 1-3 Relationship Between Carrier, Modulating, and the Resultant PWD, PPM and PAM waves

Multiplexing is accomplished by allocating a certain amount of time to each channel. For example, a three channel system would serially transmit channel one, then channel two then channel three, then a synchronizing pulse and then repeat the entire cycle. The multiplexed pulse train then amplitude modulates the carrier.

De-multiplexing is accomplished by first identifying the synchronizing pulse and then separating the time between synchronizing pulses into the same number of equal parts as information channels. Each output is switched on when its portion of the pulse train is being received and then switched off when the next channels information begins.

1.30 Choice of Systems

A combination of pulse-width modulation and amplitude modulation (PWM-AM) was chosen as the best possible system considering cost, reliability, and simplicity of design.

Pulse-width modulation is used for the three channels at each remote station because of the ease of multiplexing in the time domain. This greatly simplifies instrumentation by allowing one to use simple switches and gating circuits instead of modulators, demodulators and band pass filters which are ordinarily used in frequency domain multiplexing.

Pulse-width modulation was chosen as opposed to pulse-amplitude modulation even though it is more complex because the signal to noise ratio is much better. Pulse-position modulation offers no advantages over pulse-width modulation and it is more difficult to implement so the initial multiplexing will be done in the time domain with pulse-width modulation.

Pulse-width modulation offers dc response whereas in amplitude modulation and frequency modulation this is very difficult to achieve. It is more difficult to get high frequency response with pulse modulation but since we are not interested in high frequencies, it does not present a problem.

Pulse-width modulation offers better noise rejection than either amplitude modulation or frequency modulation. Also as the number of channels increases the effective noise level decreases. Channel cross talk can be effectively eliminated by allowing a dead-space between multiplexed channels.

The signal transmitted from the remote station is amplitude modulated by a subcarrier which was modulated by the multiplexed pulse train of the three data channels. Different remote stations are multiplexed in the frequency domain by using a different subcarrier.

2.00 SYSTEM DESIGN

2.10 The Remote Station

The function of the remote station is to take the three input channels from the seismometers, amplify each signal to a usable level,and then transmit those signals to the base station.

First each of the signals from the seismometers is amplified by a linear amplifier. Each signal is then fed into a pulse-width modulator. The output of the modulator is a pulse train in which the pulse width is directly proportional to the amplitude of the input signal. The three channels of information are then multiplexed in the time domain. The multiplexed pulse train then gates a subcarrier which amplitude modulates the transmitter.

Figure 2-1 gives the block diagram of the remote station.

2.11 The Input Amplifier

The input amplifier must satisfy several considerations. It must have a very low offset voltage and low drift characteristics. It must have low distortion and a relatively high output current. It also must have a high gain and flat frequency response over the desired frequency range. Since the available power is limited, the amplifier should use as little power as possible without sacrificing stability.

The desired low offset voltage and low drift characteristics can be achieved by using the Fairchild uA702A Linear Amplifier for the first two stages. The high output current can be obtained by

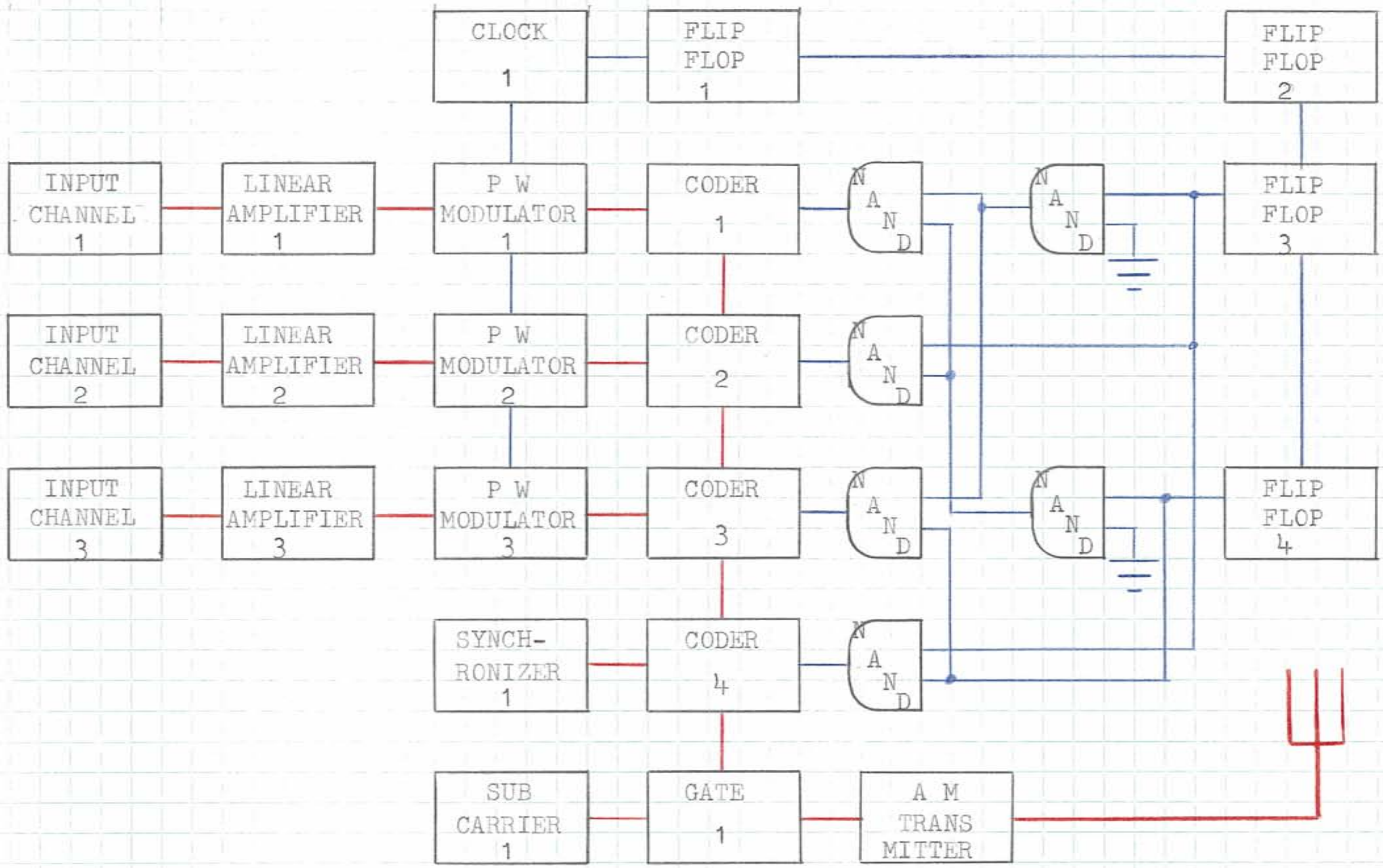


Figure 2-1 Block Diagram of Remote Station

using a Fairchild uA716 which has high current output capability and low distortion.

The composite amplifier can deliver 15 volts peak to peak to a 150 ohm load. The voltage gain of the first stage is determined by the ratio of R2 to R1. The voltage gain of the last two stages is determined by the ratio of R6 to R5. The gain of the composite amplifier is then given by the expression

$$K = \frac{(R2)\,(R6)}{(R1)\,(R5)}$$

The gain of the composite amplifier with the components listed in Table 2-1 is 40,000. The complete schematic is given in Figure 2-2.

Frequency compensation is provided by C1-R4 and C2-R8 for the uA702A. The frequency response is flat from dc to 10 kHz.

The power requirement is a supply of $\pm$ 12 volts dc. The maximum current drain is 100 ma.

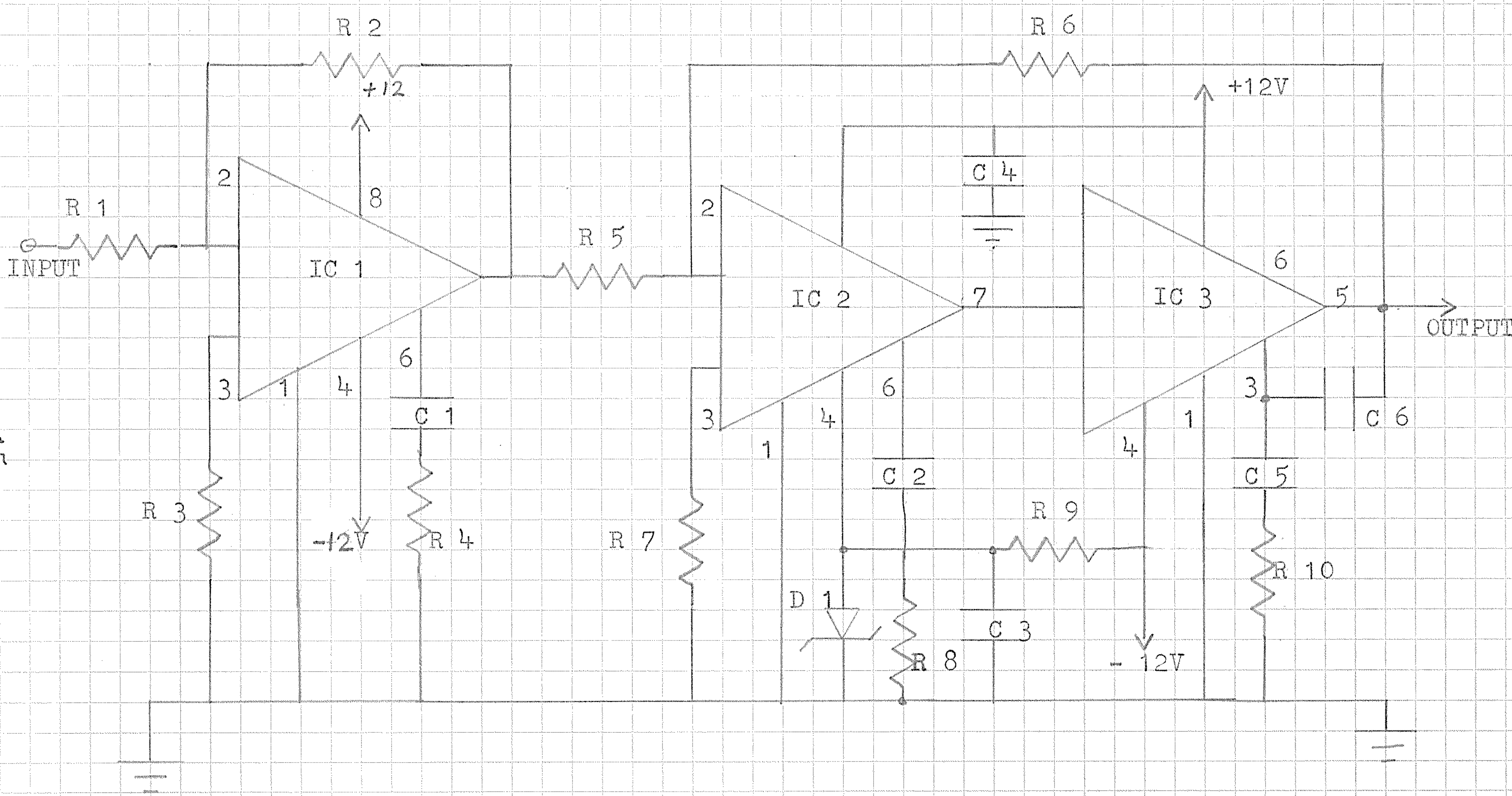


Figure 2-2 Schematic of the Input Amplifier

R1	500
R2	50K
R3	500
R4	100
R5	1K
R6	200K
R7	1K
R8	100
R9	620
R10	75
C1	2nF
C2	2nF
C3	10nF
C4	10nF
C5	68pF
C6	39pF
D1	IN753A
IC1	uA702A
IC2	uA702A
IC3	uA702A

Table 2-1 Components of the Input Amplifier

2.12 Pulse-Width Modulators

A pulse-width modulator develops a pulse train in which the widths of the pulses are directly proportional to the amplitude of the modulating signal.

A square wave carrier is applied to the input of the integrator which converts it into a triangular wave. A comparator switches states when the amplitude of the triangular wave is the same as the amplitude of the modulating signal. This is shown in Figure 2-3.

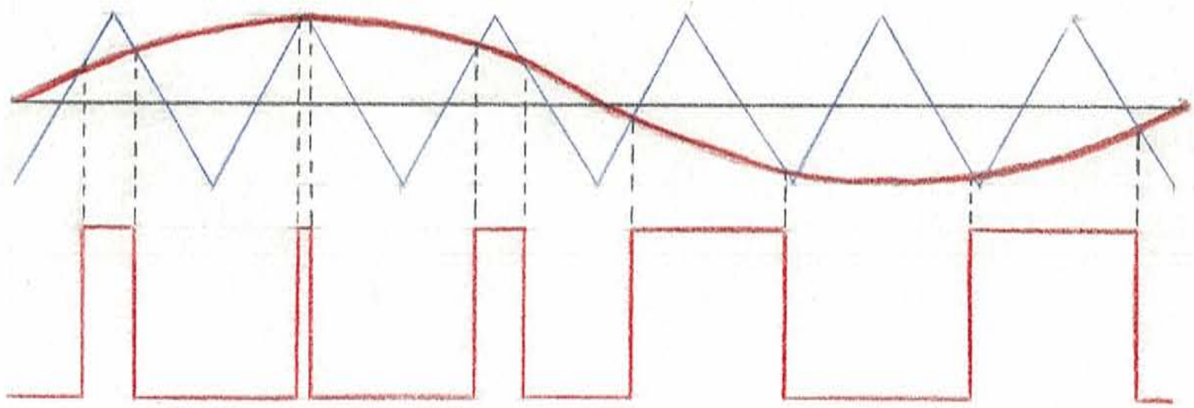


Figure 2-3 Generation of a Pulse-Width Modulated Wave

The effective linearity of the pulse width modulated output is a function of the linearity of the triangular wave and the offset of the comparator. The percentage of modulation is a function of the response time of the comparator.

The circuit in Figure 2-4 will give extremely linear modulation up to 99% with a carrier frequency of 100 kHZ.

Table 2-2 lists the components.

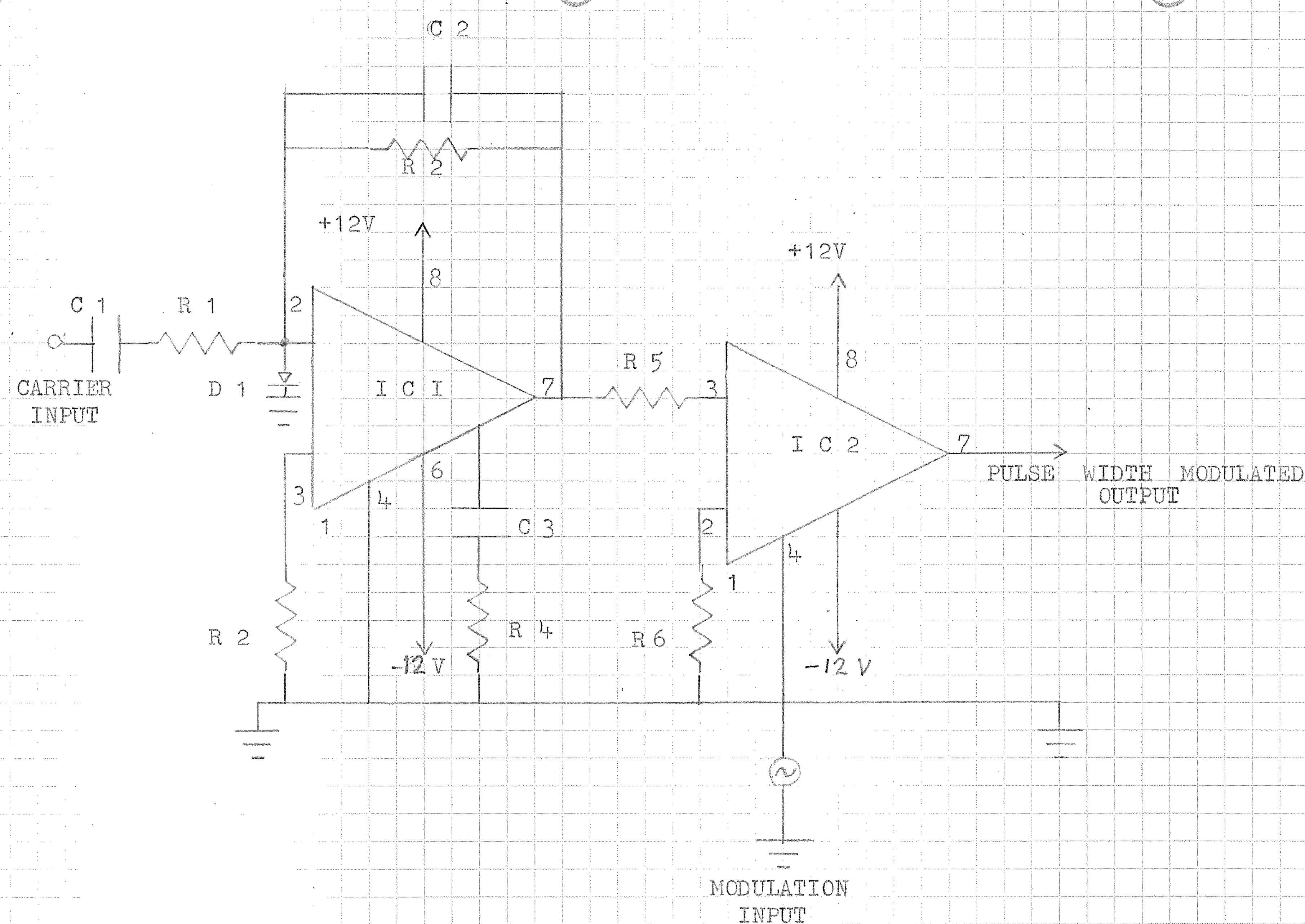


Figure 2-3 Schematic of the Pulse-Width Modulator

R1	2.7K
R2	10K
R3	10K
R4	20K
R5	1K
R6	1K
C1	10nF
C2	91pF
C3	10nF
D1	FD111
IC1	μA702A
IC2	μA702A

Table 2-2 Components of the Pulse-Width Modulator

2.13 Multiplexer

Time-division - multiplexing of three information channels is achieved by using a synchronizing pulse to identify the position of the three information channels. The position of each information channel is determined by a two-bit digital code. If we let the code for the synchronizer be 00, channel 1 be 11, channel 2 be 10 and channel 3 be 01, the codes can be generated by a clock, flipflop, and six two-input Nand gates, arranged in the following manner:

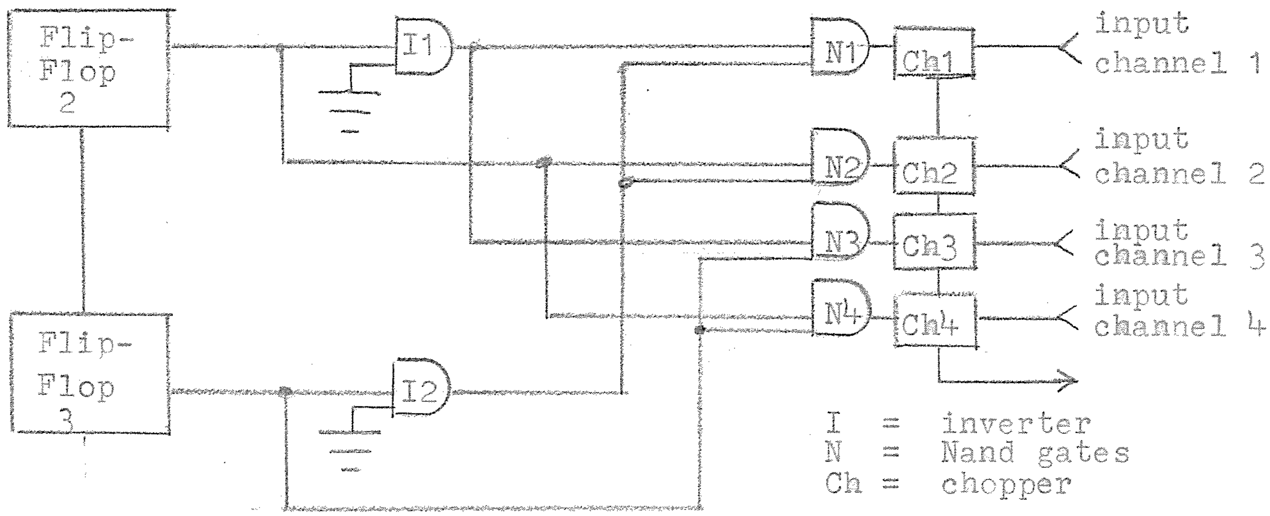


Figure 2-5 Block Diagram of the Multiplexer

The clock generates the basic gating pulse train and the flip-flop divides the frequency by two. The outputs with respect to time of the clock and the flip-flop are as follows:

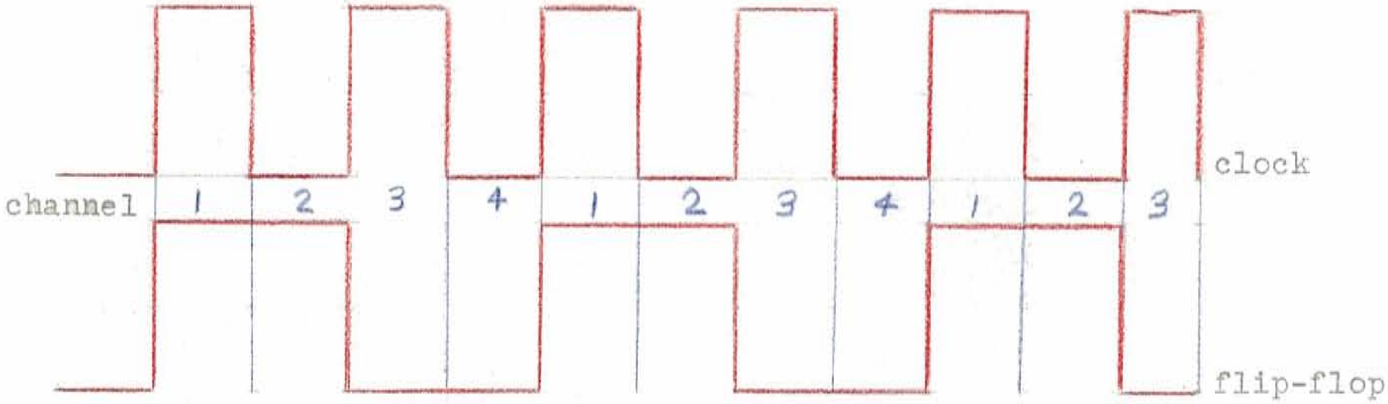


Figure 2-6 The Relationship Between Gating Pulse and Channel Allocation in the Multiplexer

If we let the positive pulse represent the digital 1 and the zero level represent the digital 0, then the output of the clock and flip-flop with respect to channel is:

Channel	Clock	Flip-flop
1	1	1
2	0	1
3	1	0
4	0	0

Table 2-3 Multiplex Coding

Using two Nand gates as inverters we can invert the outputs of the clock and flip-flop. A two input Nand gate has an output only when both inputs are zero. Using the configuration in figure 2-5 we get an output from Nand-1 only when the input code is 11, Nand-2 when the input code is 01, Nand-3 when the input code is 10, and Nand-4 when the input code is 00. The choppers allow the information to pass only if they receive a gating pulse from the appropriate Nand.

The output of the multiplexer with respect to time is as follows:

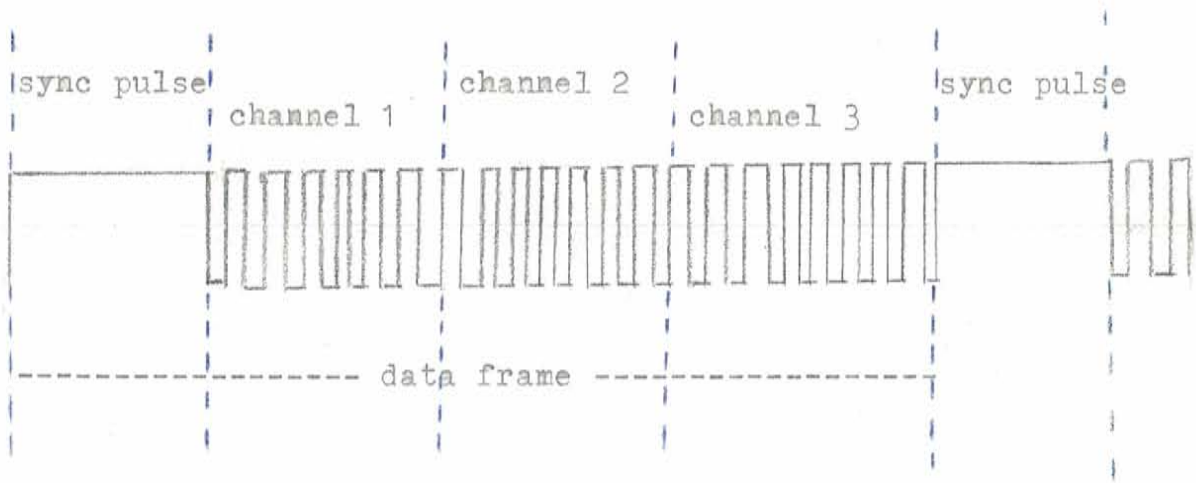


Figure 2-7 Three Channel Multiplexered Output

The components required to build the three-channel multiplexer are listed in Table 2-4.

CH-1	Model-98 *
CH-2	Model-98 *
CH-3	Model-98 *
CH-4	Model-98 *
Nand-1	SN 7400 **
Nand-2	Quadruple
Nand-3	2-Input
Nand-4	Nand
Invert-1	SN 7400
Invert-2	Quadruple 2-Input Nand
Clock and Flip-Flop	(See Figure 2-8, Table 2-5)

* Solid State Electronics Corporation
** Texas Instruments

Table 2-4 Multiplexer Components

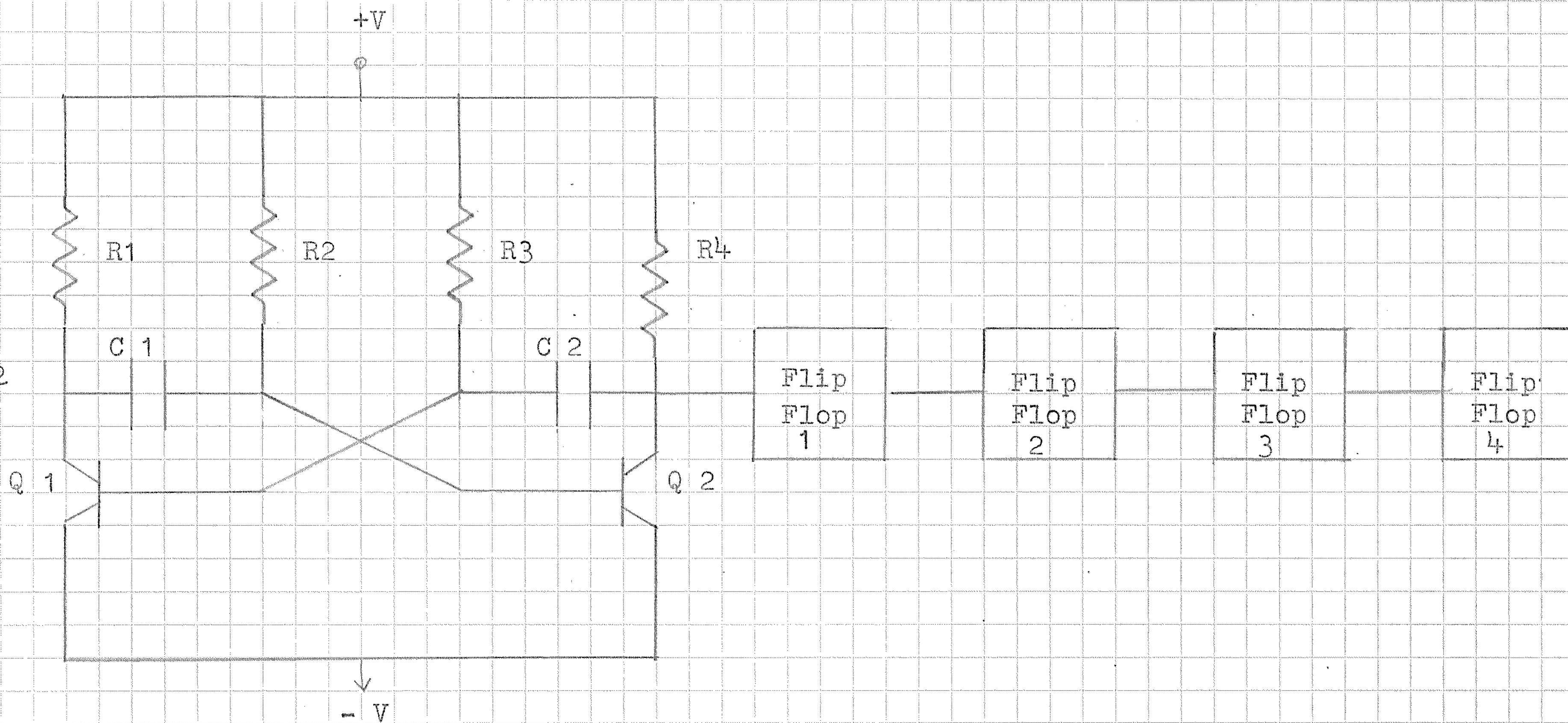


Figure 2-8 Schematic of Clock and Flip Flop

R1	3.3K	
R2	68 K	
R3	68 K	
R4	3.3K	
C1	.002 uF	
C2	.002 uF	
C3	.01 uF	
Q1	2N3904	
Q2	2N3904	
Flip-Flop 1	MC 259 F	(Motorola)
Flip-Flop 2	MC 259 F	
Flip-Flop 3	MC 259 F	
Flip-Flop 4	MC 259 F	

Table 2-4 Components of Clock and Flip-Flop

2.14 The Transmitter

This transmitter will supply 1.5 watts of 120 MHz carrier power. The total current drain from a 12-volt dc source is about 370 mA.

Figure 2-9 gives the schematic and Table 2-5 lists the components.

Figure 2-10 gives the schematic of the oscillator which generates the subcarrier which is the input to the transmitter.

Table 2-6 lists the components.

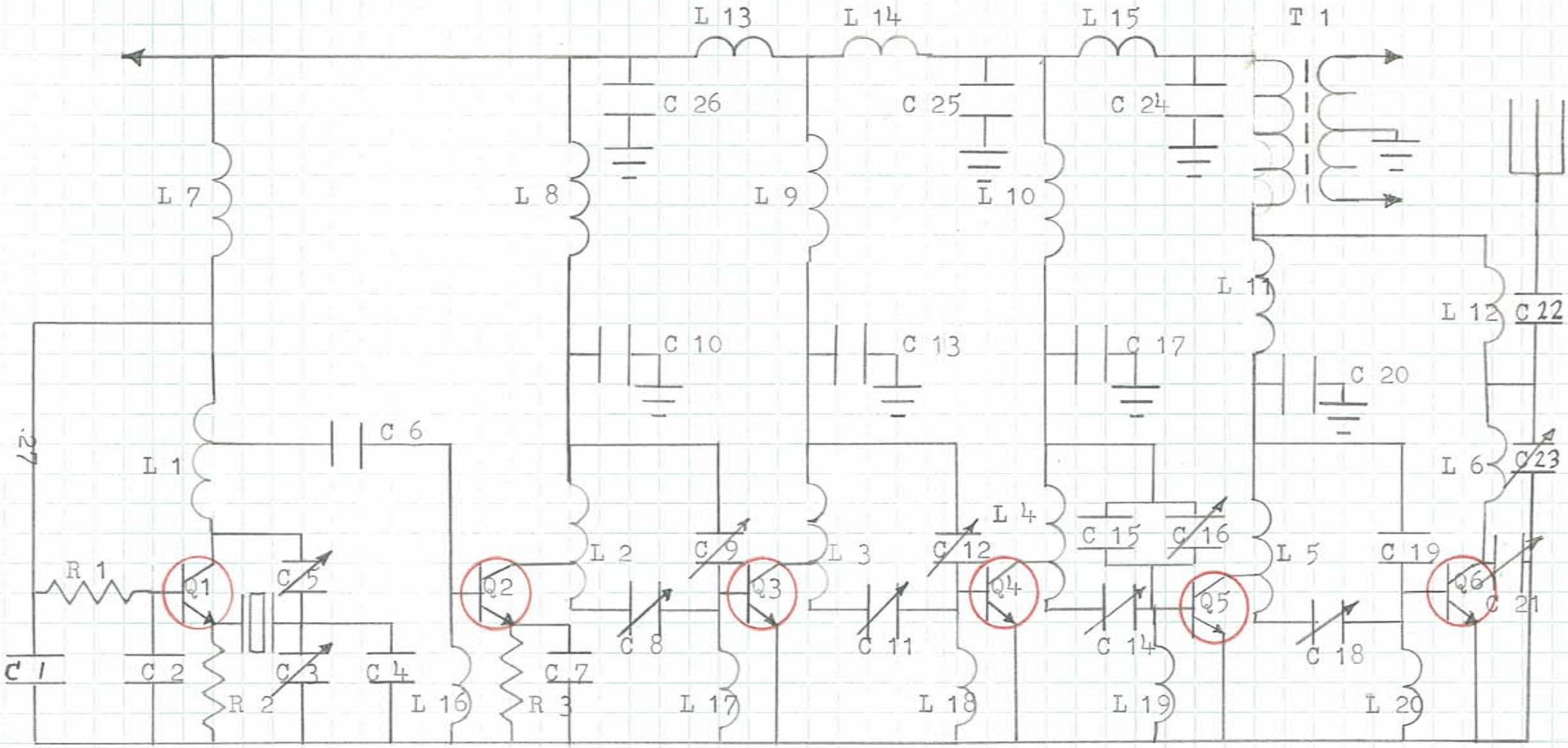


Figure 2-9 Schematic of the 120 MHz AM Transmitter

R1	1K
R2	240
R3	33
RL	50
C1	.002 uF
C2	.01 uF
C3	7 - 45 pF
C4	12 pF
C5	7 - 45 pF
C6	.1 uF
C7	.002 uF
C8	7 - 45 pF
C9	7 - 45 pF
C10	.001 uF
C11	7 - 45 pF
C12	7 - 45 pF
C13	.001 uF
C14	7 - 45 pF
C15	30 pF
C16	7 - 45 pF
C17	.001 uF
C18	7 - 45 pF
C19	22 pF
C20	.001 uF
C21	.4 - 8 pF
C22	.001 uF
C23	4 - 30 pF
C24	10 uF
C25	.01 uF
C26	.01 uF

L1	.14 uh	*
L2	.11 uh	*
L3	.11 uh	*
L4	.11 uh	*
L5	.11 uh	*
L6	.11 uh	*
L7	1.0 uh	RFC
L8	1.0 uh	RFC
L9	1.0 uh	RFC
L10	1.0 uh	RFC
L11	1.0 uh	RFC
L12	1.0 uh	RFC
L13	1.0 uh	RFC
L14	1.0 uh	RFC
L15	1.0 uh	RFC
L16	1.0 uh	RFC
L17	1.0 uh	RFC
L18	1.0 uh	RFC
L19	1.0 uh	RFC
T-1	Thoradson	TR - 58

* Coil	Turns	Wire	Coil ID
L1	6	18	0.25
L2	1.5 CT	14	0.75
L3	1.5 CT	14	0.75
L4	1.5 CT	14	0.75
L5	1.5 CT	14	0.75
L6	1.5 CT	14	0.75

Table 2-5 Components 120 MHz Transmitter

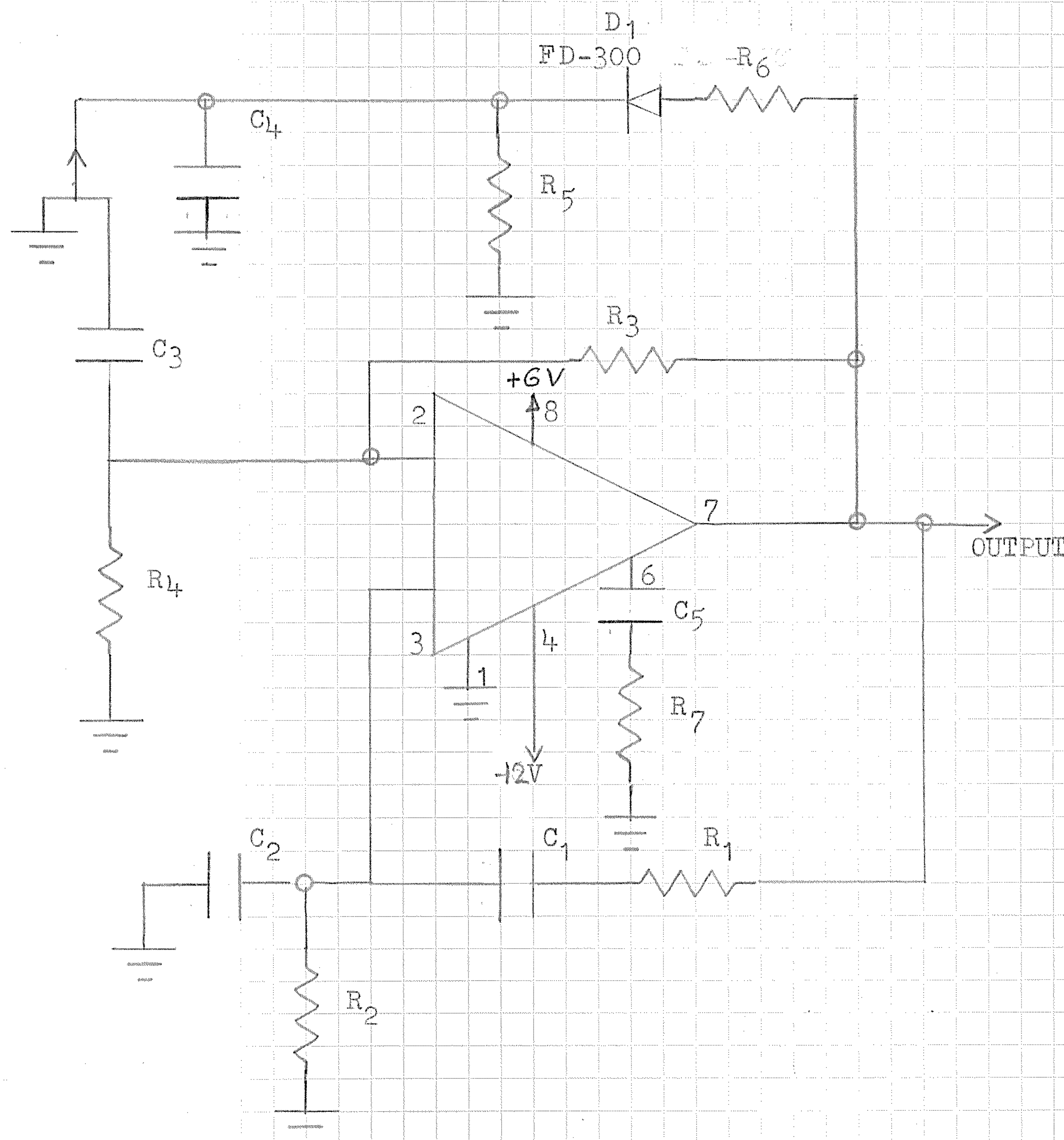


Figure 2-10 Schematic of Subcarrier Oscillator

R1	20K	
R2	2K	
R3	200K	
R4	11K	
R5	1M	
R6	470K	
C1	160 pF	
C2	1600 pF	
C3	.001 uF	
C4	.047 uF	
C5	500 pF	
D1	FD - 300	
Q1	2N 3277	
IC1	uA702A	
Chopper 1	Model 98	(SSEC)

Table 2-6 Components of the Subcarrier Oscillator

2.15 Power Supply

The power supply must be well regulated to keep the calibration of the system from changing. If the supply voltage should change then the clock rates would change; the height of the triangular wave would change and the trigger level of the comparator would be different causing a change in the duty cycle of the pulse-width modulator. This would possibly cause some data loss and most certainly a level change in the signal.

Figure 2-11 gives the schematic and Table 2-7, a list of components of a supply which will deliver 100 mA at 6 volts and 100 mA at 18 volts. Larger currents are available if the values of R4 and R12 are lowered.

In this particular circuit an operational amplifier is used as a buffer between the reference zener and the load. This saves power since the current drawn from a straight zener supply is usually limited to 10% of the bias current. Also the circuit provides a simple means of voltage adjustment over a wide range, whereas a zener supply would have a fixed output voltage equal to the zener voltage.

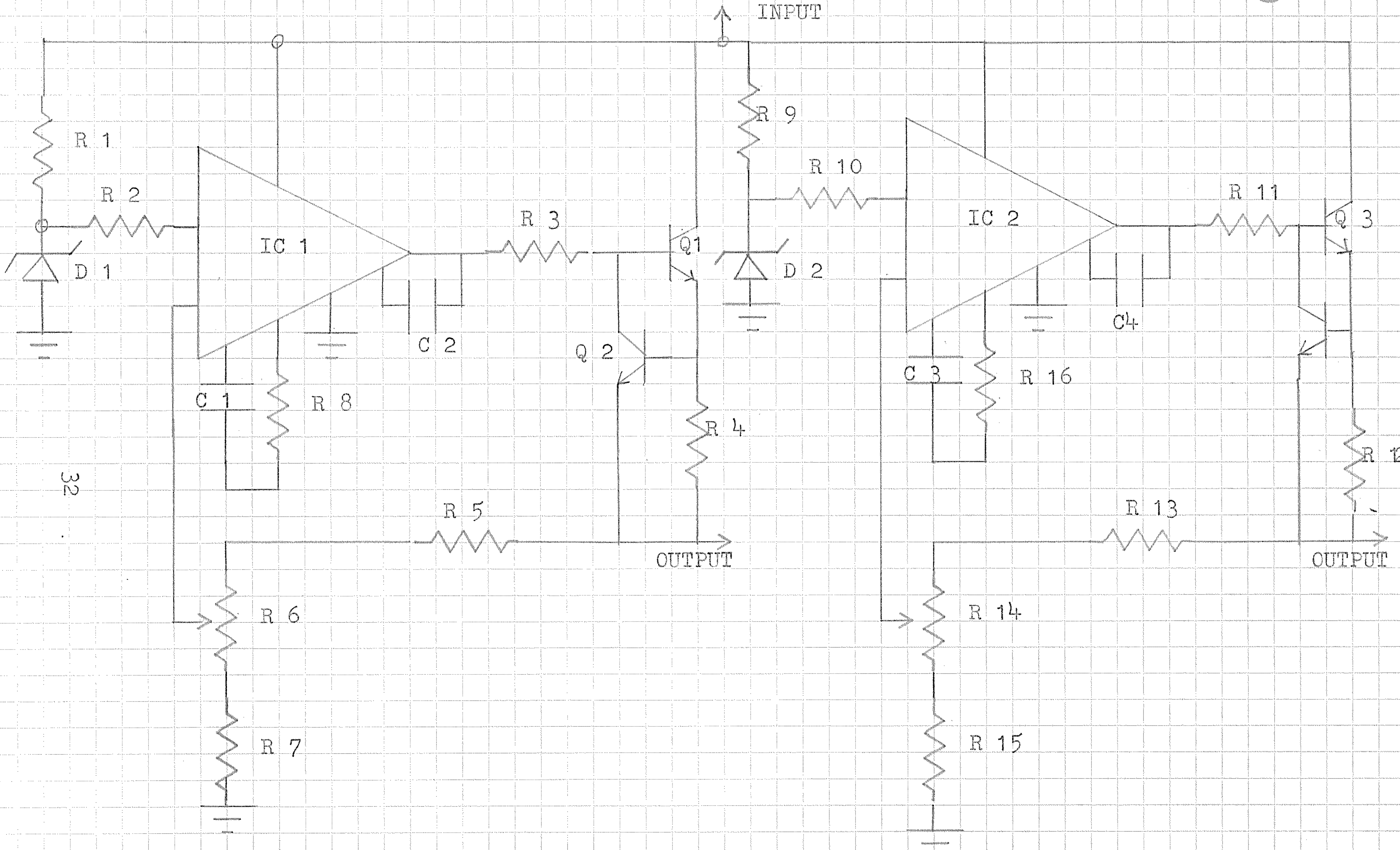


Figure 2-11 Schematic of the Remote Supply

R1	12 K	
R2	3 K	
R3	1 K	
R4	6	
R5	2 K	
R6	2.5 K	Variable
R7	1.6 K	
R8	1.5 K	
R9	12 K	
R10	3 K	
R11	1 K	
R12	6	
R13	2 K	
R14	2.5 K	Variable
R15	1.6 K	
R16	1.5 K	
C1	5 nF	
C2	200 pF	
C3	2 nF	
C4	200 pF	
D1	6.6 Volt	Zener
D2	3.3 Volt	Zener
Q1	SE 3035	
Q2	2N 3567	
Q3	SE 3035	
Q4	2N 3567	

Table 2-7 Components of Remote Power Supply

2.20 The Base Station

The function of the base station is to receive the information transmitted from the remote station and process it such that once again we have three information channels.

First the receiver picks up the transmitted signal and amplifies it. Then the subcarrier is recovered by a band-pass filter in the receiver. Next a fixed-gain pulse amplifier amplifies the pulse train. The output of the pulse amplifier is examined by the pulse-width detector for a synchronizing pulse and then de-multiplexed. Each information channel is then fed to a low-pass filter which recovers the original analog signal from the pulse-width modulated pulse train. Each channel of information is then fed to either a tape deck or a strip-chart recorder.

The block diagram of the base station is given in Figure 2-12.

2.21 The Receiver

The receiver must be tunable over the general frequency range in which the remote stations are transmitting. The receiver must not drift once it is tuned to the correct frequency because then the data will be lost. The different remote stations are multiplexed by using a different subcarrier tone. It is most feasible then to buy a commercial receiver and add the necessary band-pass filters to separate the subcarriers. Figure 2-13 gives the schematic and Table 2-8 lists the components for one such filter.

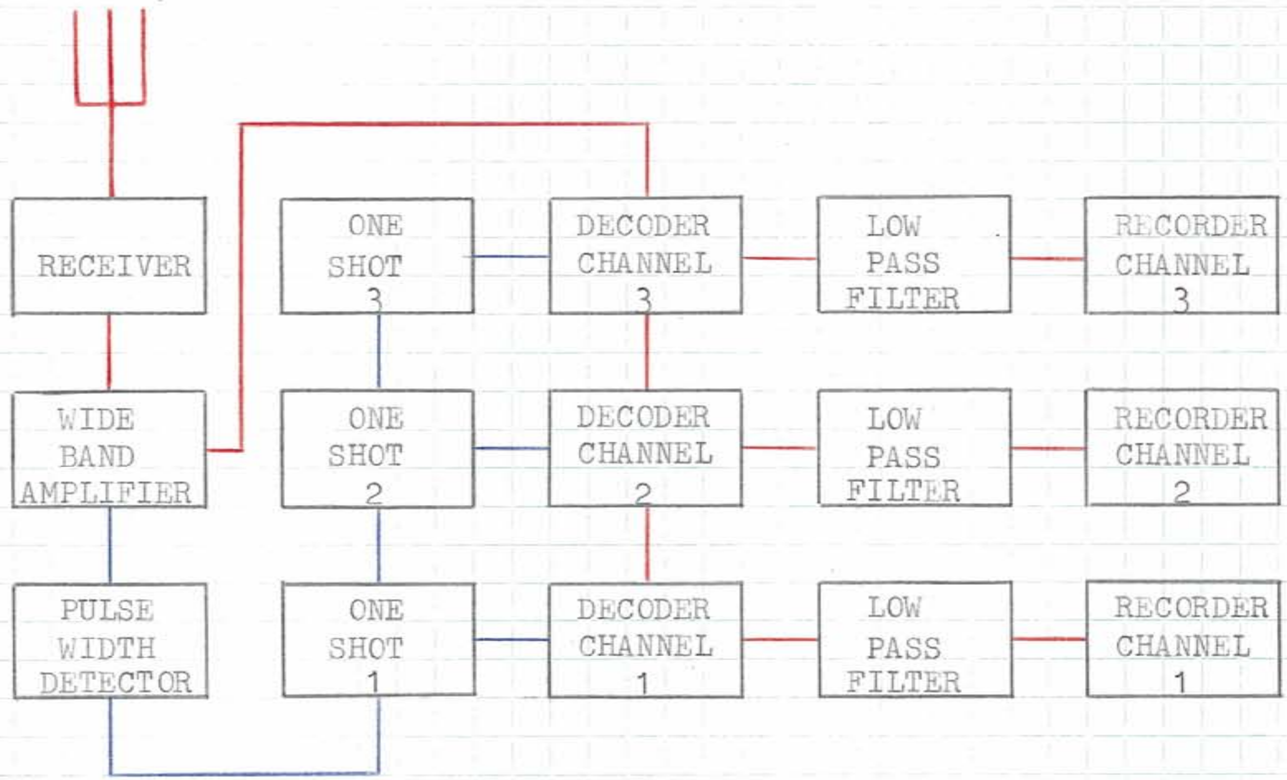


Figure 2-12 Block Diagram of Base Station

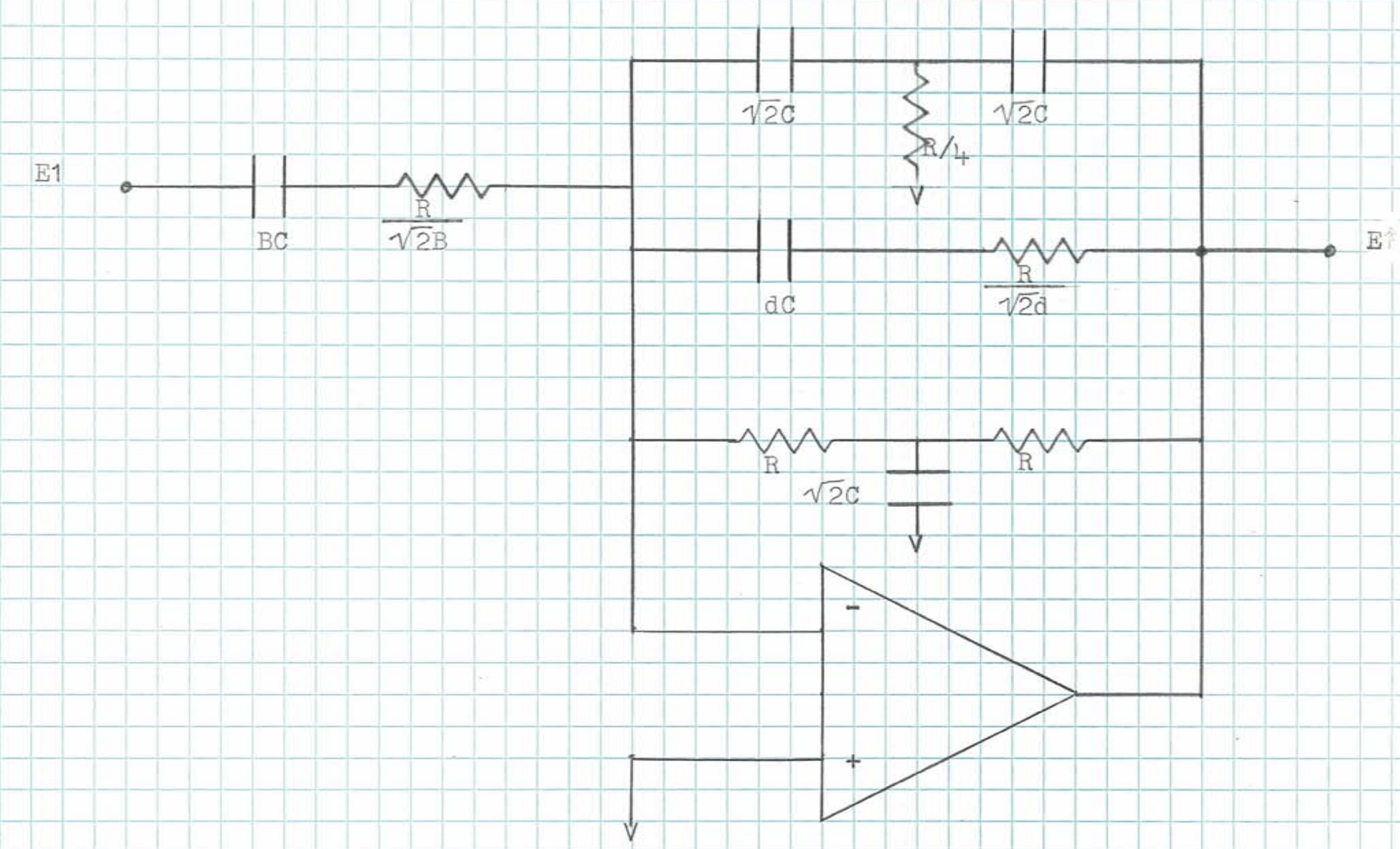


Figure 2-13 Schematic of Band-Pass Filter

fo	50 kHz
fcu	62.5 kHz
fcl	40 kHz
B	.125
d	.0822
BC	.125 uF
C	1 uF
$\sqrt{2}$C	1.414 uF
dc	.0822 uF
R	16 K
R/4	4 K
R/ $\sqrt{2}$ B	90 K
R/ $\sqrt{2}$ d	125 K

Table 2-8 - Components of Band-Pass Filter

2.22 The Pulse Amplifier

The amplification of the incoming pulse train from the receiver is achieved by the wide band amplifier shown in Figure 2-14; Table 2-9 lists the components. The pulse amplifier functions not only as an amplifier but also as a pulse shaper. Due to the loss of some of the high frequency, components of the pulse train during radio transmission and reception the input pulse train to the pulse amplifier may have rounded edges.

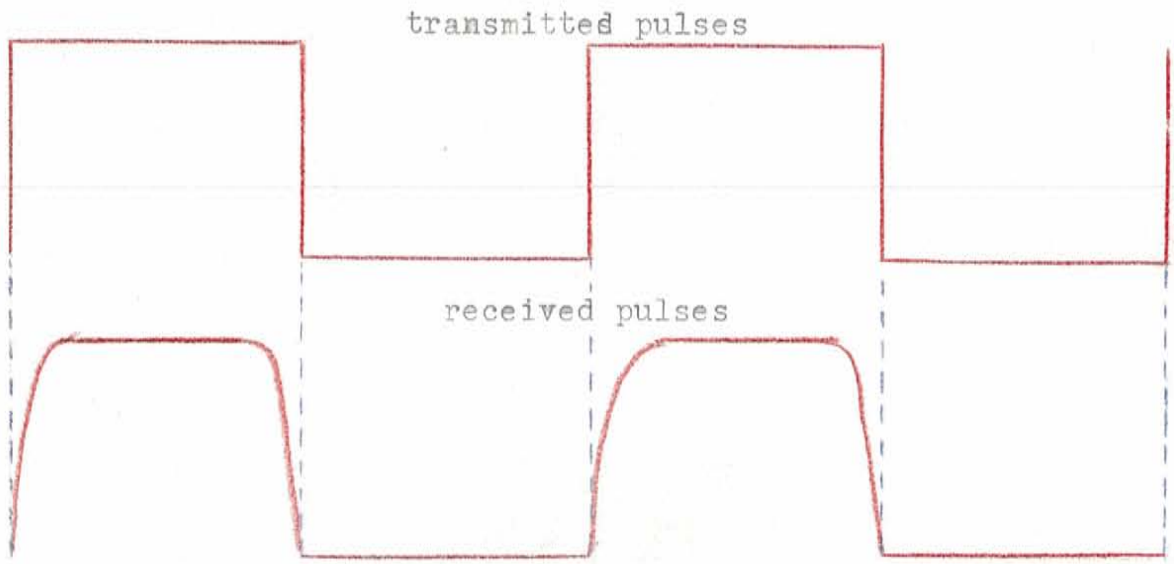
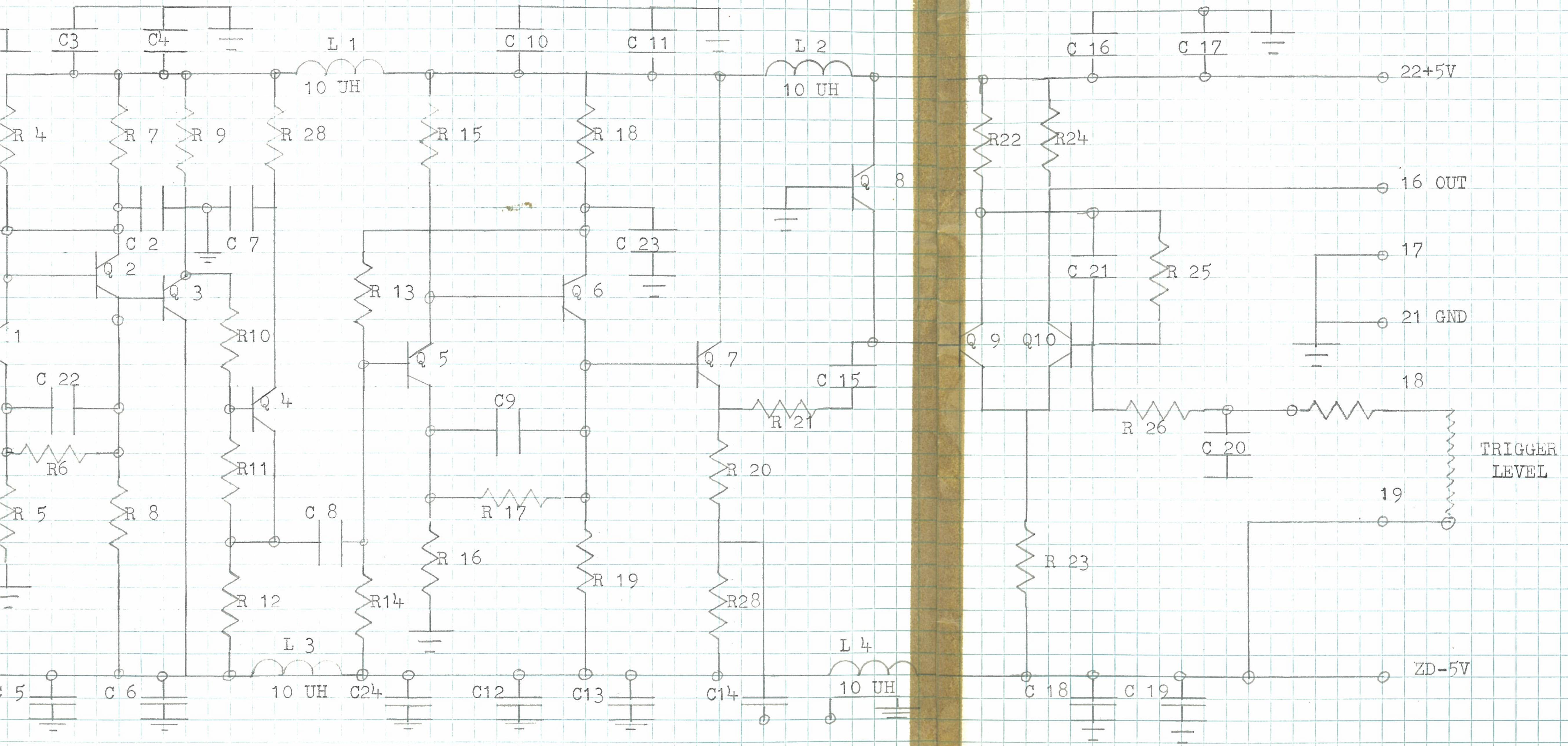


Figure 2-15 Comparison of Transmitted and Received Pulse

The pulse amplifier contains a trigger circuit which can be adjusted such that the level at which the pulse amplifier turns on can be varied from zero to five volts. Figure 2-16 shows how the trigger level can be used to eliminate noise and reconstruct the transmitted pulse.


C3
C4
L 1
10 UH
C 10
C 11
L 2
10 UH
C 16
C 17
22+5V
R 4
R 7
R 9
R 28
R 15
R 18
R22
R24
Q 8
16 OUT
C 2
C 7
C 23
17
C 21
R 25
Q 2
Q 3
R 13
Q 6
21 GND
R10
Q 5
Q 7
Q 9
Q10
C 22
C9
C 15
18
Q 4
R 21
R 26
R6
R11
R 20
C 20
TRIGGER
LEVEL
R 5
R 8
C 8
R 17
19
R 16
R 19
R 23
R 12
R14
R28
L 3
L 4
10 UH
10 UH
ZD-5V
C 6
C24
C12
C13
C14
C 18
C 19

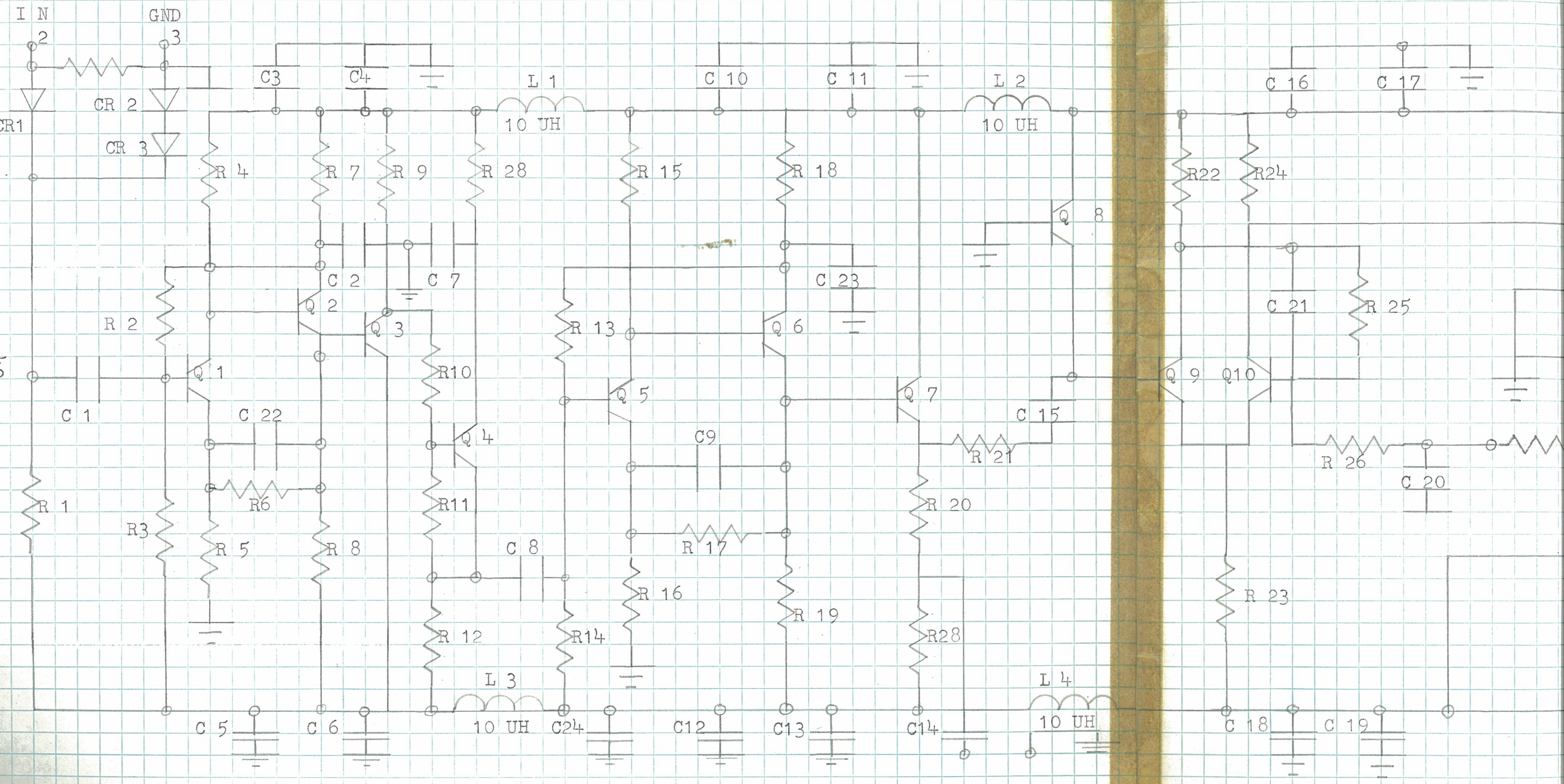


Figure 2-14 Schematic of the Wideband Amplifier

40

R1	5.6 K	C1	.01MF
R2	1.8 K	C2	.1MF
R3	5.6 K	C3	.01MF
R4	470	C4	15MF
R5	33	C5	.01MF
R6	330	C6	15MF
R7	220	C7	.1MF
R8	470	C8	.01MF
R9	390	C9	6.8 pF
R10	100	C10	.01MF
R11	220	C11	15MF
R12	390	C12	.01MF
R13	1.8 K	C13	15MF
R14	5.6 K	C14	.01MF
R15	470	C15	.01MF
R16	33	C16	.01MF
R17	330	C17	15MF
R18	220	C18	.01MF
R19	470	C19	15MF
R20	390	C20	.01MF
R21	33	C21	.01MF
R22	47	C22	6.8 pF
R23	330	C23	.1MF
R24	180	C24	.01MF
R25	390		
R26	390	Diodes	1N914
R27	56		
R28	820	Q (NPN)	2M 3563
R29	56	Q (PNP)	2N 3640

Table 2-9 Components of the Wide Band Amplifier

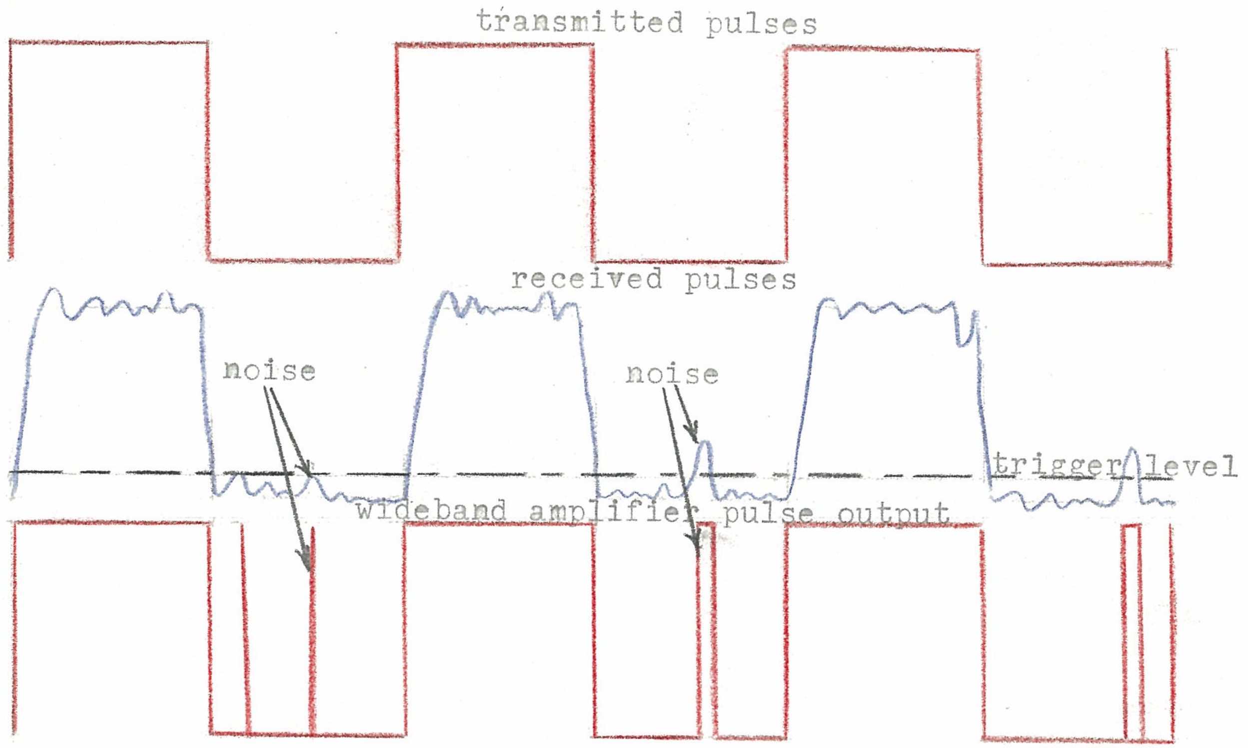


Figure 2-16 - Pulse Shaping

As the trigger level is raised above zero, more and more noise is eliminated, but distortion is introduced since the leading edge of the reconstructed pulse would be moved inward because of the slope of the received pulse. The net effect would be to make the pulse width smaller than that of the transmitted pulse. This distortion would then be a function of the amplitude of the input signal. The higher the amplitude, the more narrow the pulse becomes.

Time - division - de-multiplexing is achieved by identifying the synchronizing pulse and then separating the remaining data frame into three equal parts. Each part depending upon the time from the synchronizing pulse represents a specific information channel.

This is achieved by using a pulse width detector to identify the synchronizing pulse and three series connected one-shots to generate the gating pulses to the decoders. The configuration is shown below.

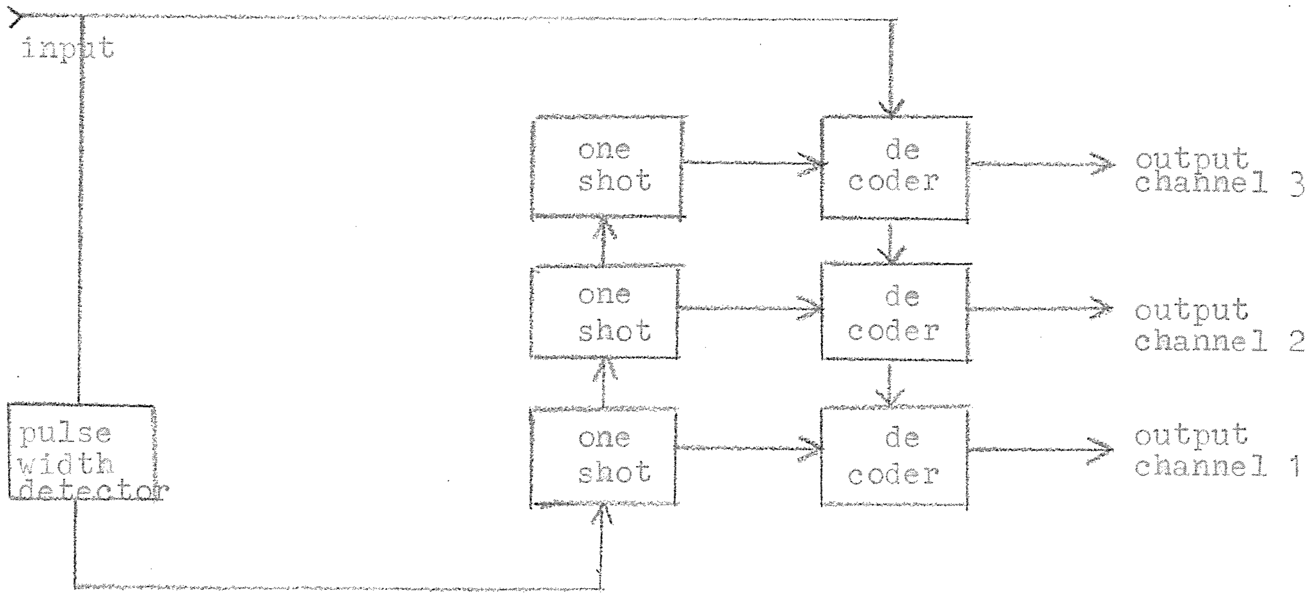


Figure 2-17 - Block Diagram of De-Multiplexer

Figure 2-18 shows each event as it occurs in time.

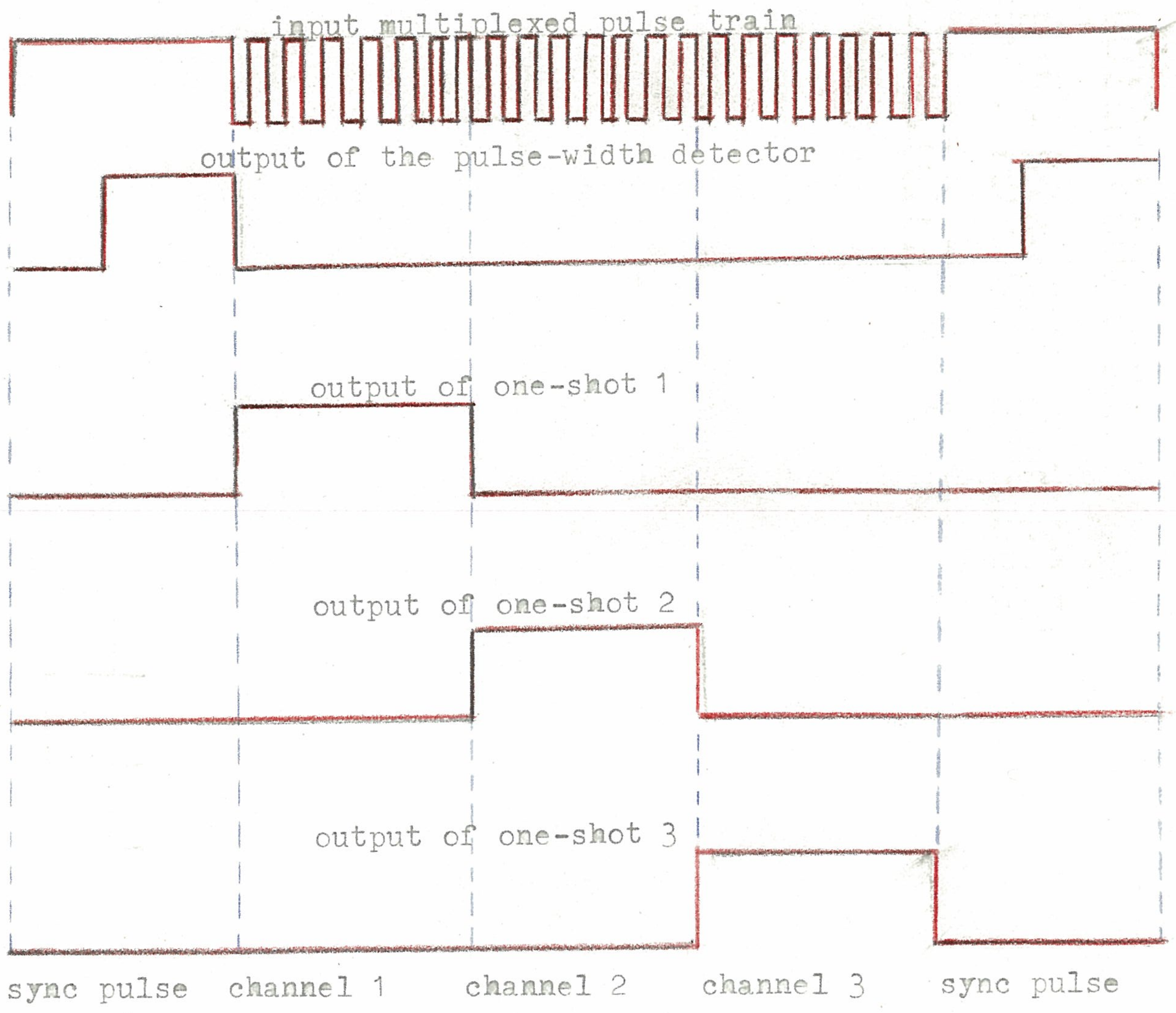


Figure 2-18: Relationship Between Gating Pulse and Channel Allocation in the De-Multiplexer

The decoder functions as a simple switch. Whenever a gating pulse is received the switch closes allowing information to pass through until the gating pulse is removed. This allows clear separation of information with the channel cross talk dependent upon the alignment of the gating pulses.

The pulse-width detector shown in Figure 2-19 gives a pulse output when a pulse of greater width then a reference pulse appears on the input. The output pulse has a width of the difference between the input and reference pulses. Table 2-10 lists the components.

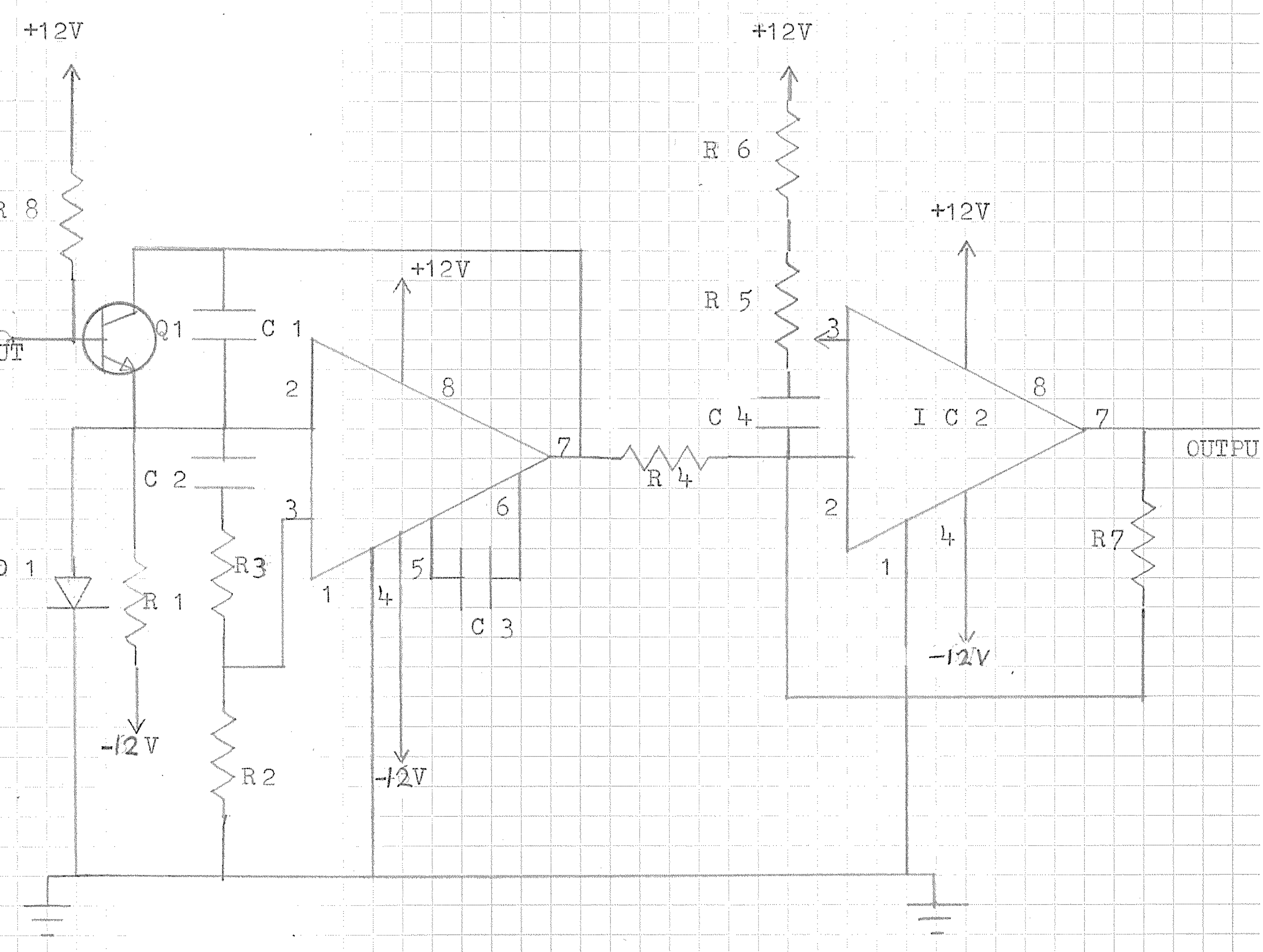


Figure 2-19 Pulse Width Detector

R1	6.2 K
R2	6.2 K
R3	15
R4	1 K
R5	5 K Trimpot
R6	7.5 K
R7	470 K
R8	12 K
C1	20 nF
C2	15 nF
C3	50 pF
D1	FD-300
Q1	2N3015
IC1	MA702A
IC2	MA710

Table 2-10 - Components of The Pulse-Width Detector

The function of the filters is primarily to integrate the incoming pulse train to recover the input analog signal at the remote station. They also serve to limit the frequency response of the system depending upon the frequency range one is interested in. The high frequency cut off is a function of the multiplexing frequency. For example if the multiplexing frequency was 800 hertz, then the limit of a 4 channel system would be 100 hertz.

Active filters were chosen because they eliminate the need for inductors and impedance matching. Also the size, weight and cost is substantially less. Several filters such as the seven listed in Table 2-11 can be made with only one operational amplifier and seven RC networks each of which can be switched in or out of the circuit.

Figure 2-20 shows the schematic and Table lists the necessary components.

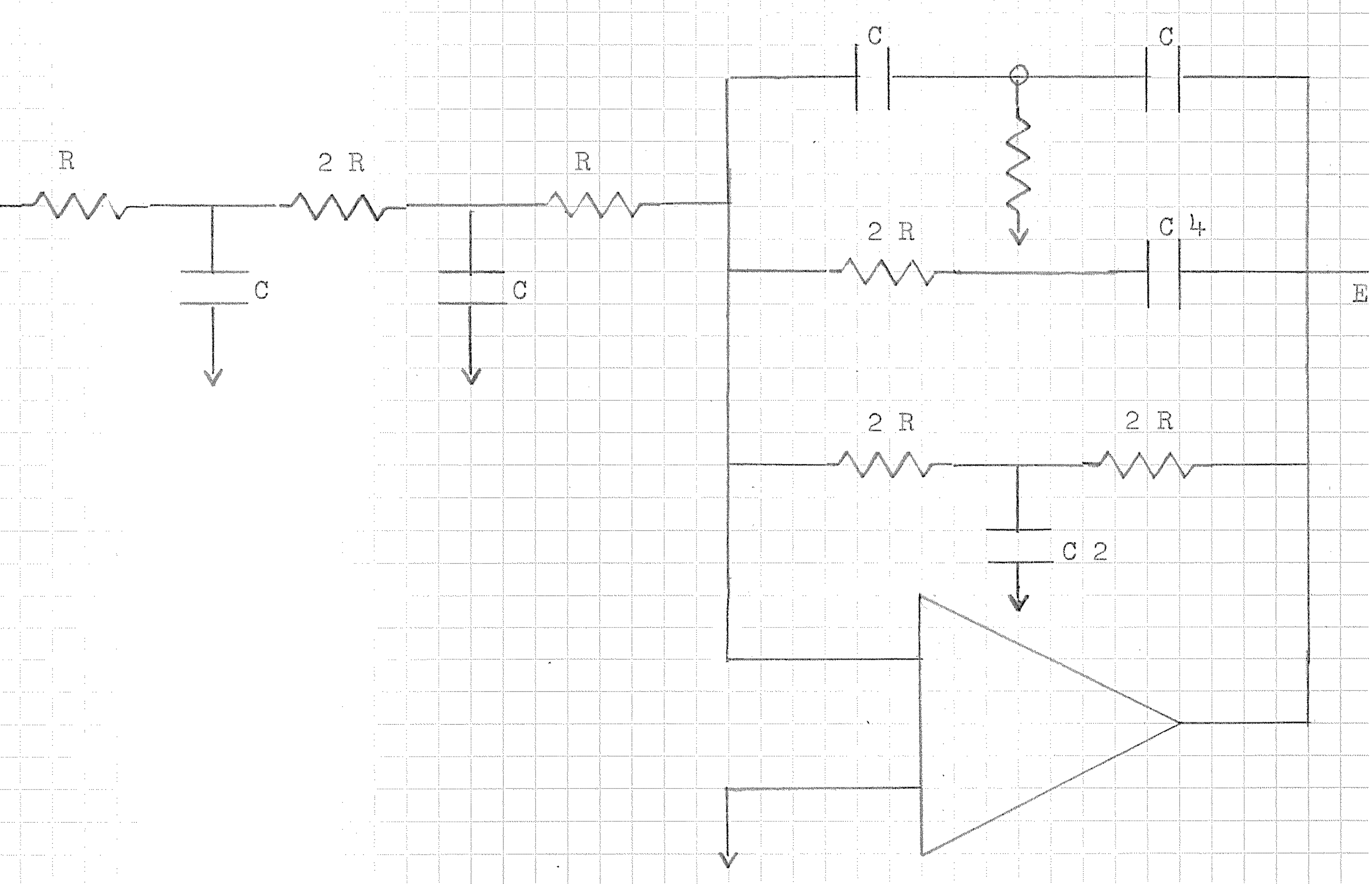


Figure 2-20 Schematic of Low Pass Filter

3dB Point (HZ)	2 R (K)	1 R (K)	R/2 (K)	R/4 (K)	1C (uF)	C/2 (uF)	C/4 (uF)	IC1
10	32	16	8.0	4.0	1.0	0.5	0.25	Philbric
20	16	8.0	4.0	2.0	1.0	0.5	0.25	Philbric
30	12	6.0	3.0	1.5	1.0	0.5	0.25	Philbric
40	8.0	4.0	2.0	1.0	1.0	0.5	0.25	Philbric
60	6.0	3.0	1.5	0.75	1.0	0.5	0.25	Philbric
80	4.0	2.0	1.6	0.50	1.0	0.5	0.25	Philbric
100	3.5	1.75	0.88	0.44	1.0	0.5	0.25	Philbric

Table 2-11 - Components of the Low-Pass Filters

This power supply is essentially the same as the remote supply. The only difference being that the energy sourse is not batteries but an AC to DC converter. Figure 2-21 shows the raw supply and Table 2-12 lists the components. Figure 2-11 gives the schematic shows the components.

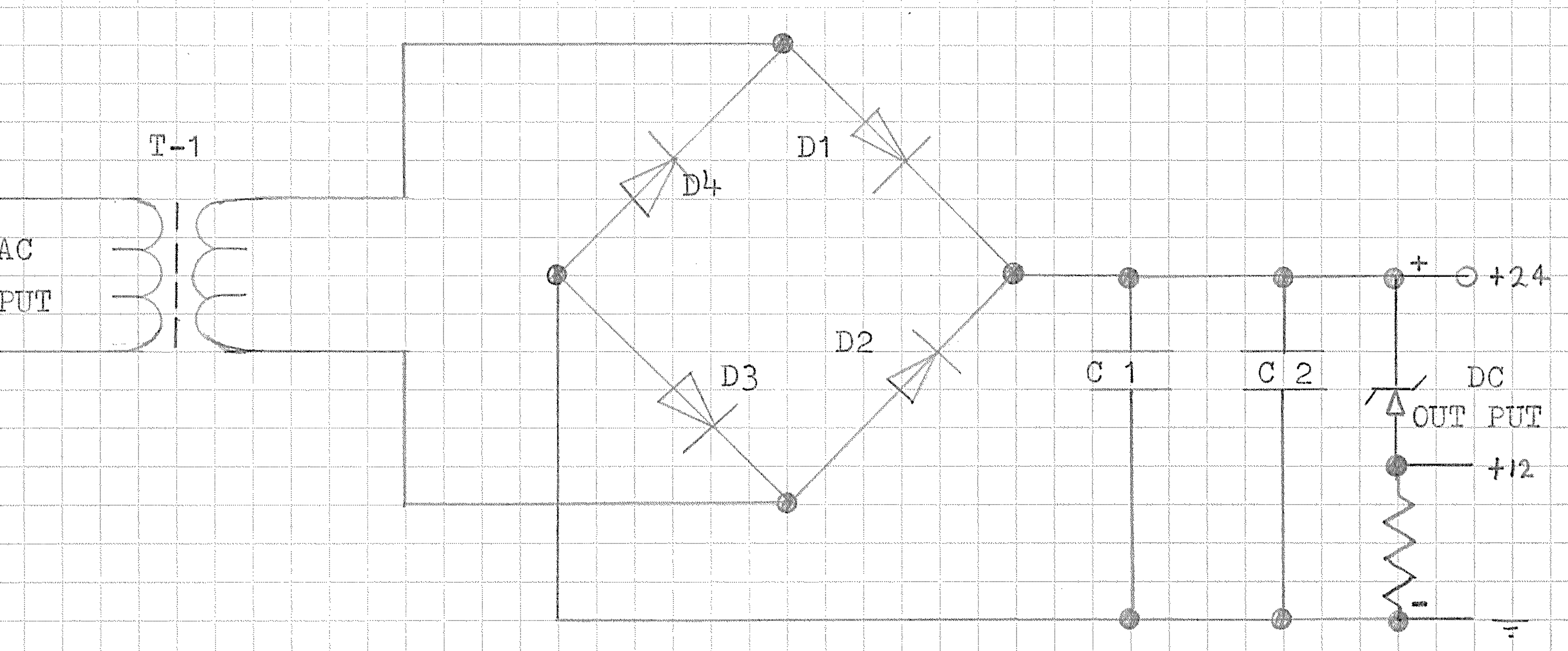


Figure 2-21 Schematic of the Base Power Supply

T-1	F-61 u	(Triad)
D1	IN5060	
D2	IN5060	
D3	IN5060	
D4	IN5060	
C1	100 uF	
C2	100 uF	

Table 2-12 Components of the Base Supply

Component	Item	Number	Cost at	Component Net Cost
Input Amplifier	Resistors	10	0.073	
	Capacitors	6	0.075	
	Diodes	1	0.40	
	Integrated Circuits	3	2.50	9.08
Pulse-Width Modulator	Resistors	6	0.073	
	Capacitors	3	0.075	
	Diodes	1	0.40	
	Integrated Circuits	2	2.50	6.07
Multiplexer	Choppers	4	135.00	
	Nand gates	4	6.35	
	Inverters	2	6.35	
Clock and Flip-flop	Resistors	4	0.073	
	Capacitors	3	0.075	618.26
	Transistors	2	0.82	
	Flip-Flop	4	9.50	
Transmitter	Resistors	3	0.073	
	Capacitors	19	0.075	
	Capacitors	7	0.95	
	Inductors	13	0.60	
	Transformers	1	5.00	
Subcarrier Oscillator	Resistors	6	0.073	
	Capacitors	5	0.075	
	Diodes	1	0.40	
	Chopper	1	135.00	
	Transistors	1	0.82	
	Integrated Circuits	1	2.50	160.93
Power Supply	Resistors	14	0.073	
	Resistors	2	5.00	

Component	Item	Number	Cost at	Component Net Cost
Wide-Band Amplifier	Resistors	29	0.073	
	Capacitors	6	2.02	
	Capacitors	18	1.32	
	Diodes	3	0.40	
	Transistors	10	0.82	47.20
De-Multiplexer	Resistors	8	0.073	
	Capacitors	3	0.075	
	Diodes	1	0.40	
	Transistors	1	0.82	
	Integrated Circuits	2	2.50	
	Choppers	3	135.00	
	One-shots	3	2.50	419.53
Low Pass Filter	Resistors	7	0.073	
	Capacitors	6	1.32	
	Integrated Circuits	1	2.50	10.93
Power Supply				
raw	Capacitors	2	1.32	
	Diodes	4	0.56	
	Transformer	1	10.17	
regulated	Resistors	14	0.073	
	Resistors	2	5.00	
	Capacitors	4	1.32	
	Transistors	4	0.82	
	Diodes	2	2.65	39.93

3.30 Three Channel System

The total cost of each three-channel remote station will be approximately $850.00.

The total cost base station will be approximately $520.00, not including the receiver.

General Information

Black, Harold S., Modulation Theory, D. Van Nostrand Company, Inc., New York, January, 1966.

Geotech, A Teledyne Company, Instrumentation, Catalog, 1966.

Henny, Keith, Radio Engineering Handbook, McGraw-Hill Book Company, Inc., New York, 1950.

Hewlett Packard, Instrumentation, 1967.

Lynch, William A., Principles of Electronic Instrumentation, McGraw-Hill Book Company, Inc., New York, 1962.

Shea, T. E., Transmission Networks and Wave Filters, D. Van Nostrand Company, Inc., New York, 1944.

Design and Cost Analysis

Allied Industral Electronics Catalog 1968

Fairchild Application Notes, 1968, pages 135-179.

Motorola Semiconductor Circuits Manual, Motorola Inc., 1964.

Nichols, Roy Leland, RC Active Filtering, Thesis, University of California, June, 1964.

Credits for help and information:

Richard Carlson	NMIMT	Socorro, New Mexico
Ronald Reynolds	NWCCL	Corona, California
Paul Alexander	NWCCL	Corona, California