"PCM SUBCHANNELS FOR VIDEO MICROWAVE"

BY

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ABSTRACT

A PCM subcarrier system has been developed which will permit video microwave to carry twenty-four 6 kHz channels along with the normal video signal. The channels may be used directly or split into forty-eight 3 kHz voice channels. The subcarrier system uses a differentially coherent quadraphase approach and has a data rate of three megabits.

The paper outlines the frequency requirements of implementing a subcarrier in the presence of video. Then a system block diagram description is given for the channelizing and subcarrier equipment. Performance curves taken from experimental data are given. These include the error rate performance for the system in the presence of differential phase and gain along with thermal noise.

SYSTEM CONSIDERATIONS

Although considerable baseband spectrum is available above the video signal on most microwave systems, it has remained relatively unused. The most notable exceptions are order wire subcarriers, fault reporting, and the addition of a few FM subcarriers for program channels. The reason for this sparse utilization is that the available spectrum above 5 mHz does not lend itself readily to conventional AM or FM subcarriers operating in the presence of the video signal. The nonlinearities of the microwave equipment, principally the differential phase and gain as well as the second harmonic distortion of the video signal all severely limit the achievable signal to noise performance of such subcarrier systems.

Figure 1-A contains a graph of the relative 15 kHz sidebands that are produced on a subcarrier due to differential phase and gain in the microwave system. The presence of these sidebands will show as degraded signal to noise performance for a subcarrier system. The sidebands due to differential gain will limit the performance of an AM subcarrier, and the sidebands due to differential phase will limit the performance of an FM subcarrier. However, if a digitally modulated subcarrier is used, the data stream may be regenerated, and the cross-modulation effects removed. Also, if a phase modulated subcarrier is used and the data stream is recovered by differentially comparing the phase of the subcarrier, then the effects of differential phase can be minimized even further.

If a digitally modulated subcarrier is to be used, some consideration must be given to how many subchannels may be placed in the available bandwidth. For the quadraphase system selected, the available bandwidth was taken to be between 5.0 and 7.0 mHz. This permits a sufficient guard band between the subcarrier and the video on the low side, and on the high side the band edge is sufficiently below the second harmonic of the 3.58 mHz color subcarrier.

To fully utilize the available bandwidth, twenty-four 6 kHz channels were implemented. This number of channels was derived after several considerations. First, a channel should be capable of carrying a 5 kHz AM broadcast station, as this was in fact to be the first application of the equipment. Secondly, a channel should be capable of being split into two 3 kHz channels for standard phone circuitry applications. Therefore, a channel with frequency response slightly above 6 kHz. was selected as a basic channel unit. If additional channel bandwidth is required for a specific application, this can be achieved by occupying more than one basic channel unit.

To meet the signal to noise requirements of 55 dB, each 6 kHz channel has its analogue input signal quantized into 256 levels (8 bits). This number of bits allows for a basic signal to quantizing noise of 59 dB. The eight bit code, together with the fact that the 6 kHz channel would have to be sampled at approximately a 14 kHz rate, indicated that each channel would require about 100 kilobits/sec. The quadraphase system selected could readily handle three megabits in the available bandwidth, so a basic channel number for the subcarrier system was established at twenty-four channels.

Once the approximate sampling rate was selected, the question arose as to whether an optimum sampling frequency near 14 kHz would have minimum interference with the video signal. Subjective tests were made by adding an interference frequency in the 14 kHz range to a video signal. It was found that frequencies which were separated from the 15.734 video sync frequency by an odd multiple of one half the line frequency (60 cycles) produced interference "nulls". These points were subjectively much more tolerable than any other frequency inserted at the same level. A sampling frequency of 14.624 kHz was selected. This frequency is thirty-seven (a prime number) times thirty cycles (one half the line rate) below the 15.734 kHz video sync frequency.

A further requirement of the system was to have the subcarrier frequency synchronous with the data rate. To achieve this, a 17.5488 mHz master oscillator was utilized and divided by three to generate a 5.849600 mHz basic subcarrier frequency. The basic subcarrier frequency is then divided by four hundred to obtain the 14.624 kHz sampling rate.

This basic sampling rate times the eight bits per sample determines the individual channel data rate which is 116 kilobits/sec. Since twenty-five channels are used on the system (twenty-four channels plus one channel for system synchronization purposes) the total data rate is 2.9248 megabits/sec.

To insert this information above the video signal, consideration was given as to which type of modulation is best suited to withstand the problems of the microwave system. After a tentative evaluation of several possibilities, a differentially coherent quadraphase modulation system was selected. This approach has several inherent advantages over other possible implementations. Since the detection process for this system is accomplished by comparing the carrier phase difference between two sequential data bits, the effects of differential phase are minimized. This is because the differential phase is occurring at a slow rate compared to the data stream,and although the total phase shift of the subcarrier may be large over a 15 kHz interval, the amount of phase shift between two adjacent data bits is considerably less.

Another advantage of this approach is that since the modulation information is on the phase of the carrier, it may be amplitude limited to remove the effects of differential gain.

The quadraphase approach was implemented instead of binary phase shift keying in order to meet the bandwidth requirements of the subcarrier system. The occupied bandwidth of the system may be limited to 1.5 mHz, which easily fits into the allotted two mHz band above the video.

SYSTEM DESCRIPTION

Figure one shows a block diagram of how the subcarrier system is implemented on a microwave path. The twenty-four 6 kHz inputs are time division multiplexed by the PCM transmitter. The channels are formed into two binary data lines, each carrying data at one half the overall three megabit rate. The PCM transmitter also generates the synchronization information and the carrier source for the subcarrier transmitter. These signals are supplied to the subcarrier transmitter which modulates the data onto the 5.84 mHz subcarrier. The modulated signal is band limited and added to the normal video signal. The composite signal is then supplied to the microwave baseband.

At the microwave receiver, the composite signal is connected to the subcarrier receiver which removes the subcarrier from the video signal, and demodulates the data stream back into two binary data lines. The binary data lines are connected to the PCM receiver which decodes the data back into twenty-four 6 kHz audio channels.

Figure two contains a block diagram of the PCM transmitter. The 17 mHz crystal oscillator is used to derive all of the timing signals, including the 5.84 mHz subcarrier. The basic data rate of one bit per 700 nanoseconds is exactly one fourth of the subcarrier frequency. A single channel occupies four sequential time slots. There are twenty five channel assignments (twenty four channels plus one channel for synchronization) which total one hundred data intervals per 14 kHz sampling interval. The timing generator divides the basic data rate with a seven bit countdown chain which resets on the one hundreth data pulse. The seven bit timing pulses synchronize the indivual channel encoders onto a common pair of data lines.

The block diagram for the subcarrier transmitter is shown in Figure three. The 5.84 mHz carrier source is split into four phase related sources of the same frequency. The signals are at a 90° spacing, and are supplied to the phase modulator. The arithmetic unit cumulatively adds the data bits prior to transmission. This is necessary since the differentially coherent detection process in the subcarrier receiver is subtractive. Although the cumulative addition could have been done in the subcarrier receiver, this is not the optimum location. If the arithmetic unit is placed in the receiver, a single error in the detection process will cause all of the remaining bits in that sampling interval to be wrong. Therefore, the arithmetic unit was placed in the transmitter which has the data stream at a much higher signal to noise ratio and is essentially error free.

The synchronization channel occupys four data time slots as in the normal information channels. During the first two time intervals of the synchronization period, the 5.84 mHz subcarrier is amplitude modulated to an "off" state. This modulation is AM detected in the subcarrier receiver and used to phase lock the local clock in the PCM receiver. During the third time interval 0^{o} phase reference carrier is transmitted alternately (on different sample intervals) with 180^{o} phase carrier. The fourth time interval is used to always transmit 0^{o} reference phase. In this manner, alternate sampling periods are uniquely identified. The third time interval corresponds to a channel split pulse that is used when a 6 kHz channel is split into two 3 kHz channels. Each 3 kHz channel is alternately sampled by the 14 kHz sampling pulse, which effectively divides the 14 kHz sampling rate in half for each channel.

After the data and synchronization information is added to the subcarrier, the modulated subcarrier is band limited to restrict the occupied bandwidth in the microwave baseband. The incoming video signal is also band limited to 4.5 mHz to remove any harmonics which would fall in the subcarrier channel. The subcarrier is then added to the video signal and the composite signal is connected to the microwave baseband.

Figure four contains a block diagram of the subcarrier receiver. The composite baseband signal from the microwave receiver passes through a splitting filter which removes the subcarrier signal from the video signal. The subcarrier signal is then split to drive both an AM detector and a phase detector. The AM detector recovers the synchronizing pulse that occurs during the first two time intervals of the synchronization channel interval. The detected pulse is used to phase lock the receiver clock.

The phase detection process is accomplished by comparing the phase of the subcarrier during the presently arriving data bit to the phase of the subcarrier during the previous data bit. This process is subtractive, as the recovered data stream is the difference between the two bits. To recover the data stream directly, the bits are cumulatively added in the transmitter, so that the difference operation in the receiver produces the data stream directly.

Figure five contains a block diagram of the PCM receiver. The detected AM sync pulse is phase compared with a 14 kHz sampling pulse generated by dividing down the VCXO in the PCM receiver. The VCXO is at 5.84 mHz and has a countdown chain similar to the one in the transmitter. The phase comparator is enabled only during the first two time slots of the synchronization channel. This prevents spurious sync pulses from entering the phase comparator while the remaining twenty four channels are transmitting. To acquire lock, the sync pulse derived from the local VCXO slowly advances in time through the different channels. When the local sync pulse passes through the synchronization channel, the phase comparator is enabled, and lock is achieved.

The 5.84 mHz VCXO in the receiver generates the same timing signals that were available in the transmitter. Individual channel decoders are enabled for a four bit interval corresponding to their correct encoding channel, and the recovered data is decoded into the original analogue input signal.

SYSTEM PERFORMANCE

To evaluate the system performance in the presence of thermal noise and microwave distortion, a pseudo-random sequence generator which could occupy a single transmitted channel was designed. At the receiver, a channel card which was programmed to accept the known sequence was implemented, and an error count was made between the locally generated sequence and the received sequence. It was found that additional channels did not change the error rate performance, with the exception of the two channels adjacent in time to the error test channel. Therefore, the data was always taken with these adjacent channels fully loaded.

A test set was made which would simulate microwave distortion, as well as add thermal noise to the subcarrier signal. Differential gain was produced by amplitude modulation of the subcarrier at a 15 kHz rate. Differential phase was produced by varactor modulation driven by a 15 kHz full wave rectified sine wave which produced parabolic phase distortion similar to that encountered in microwave systems. The test set was checked by using a video test set which uses a 3.58 mHz test signal. Good agreement was observed between the video test set and the sideband predictions of Figure 1-A when measured on a spectrum analyzer.

Figure six contains error rate performance curves for different values of signal to noise with different amounts of microwave distortion. For no microwave distortion, the subcarrier system achieves an error rate of 10^{-5} for a signal to thermal noise ratio of 17 dB. This would mean an individual 6 kHz channel would have approximately one error per second. Experimental results with 5 kHz music channels indicated that less than ten errors per second would pass for an undegraded music channel.

The outside curve of figure six (on the right hand side) is an error rate versus signal to noise curve where diffential phase and gain have been applied to the subcarrier. Differential gain sufficient to produce 20 dB relative sidebands on the subcarrier, and differential phase also sufficient to produce 20 dB relative sidebands were simultaneously impressed upon the subcarrier. This corresponds to approximately 23° of differential phase and 3.5 dB of differential gain. The microwave distortion has the effect of shifting the error rate curve to the right, that is, it makes apparent signal to noise degradation. To achieve a 10^{-5} error rate, the signal to noise had to be increased to 21 dB as compared to 17 dB without microwave distortion. Otherwise, there was no change in the individual 6 kHz channel performance. This indicates the digital system does eliminate the differential phase and gain effects of the microwave system, but must be operated at a slightly higher signal to noise ratio than would otherwise be expected.

For less than 20 dB differential phase and gain sidebands, the error rate curve shifts to the left toward the thermal noise curve. The two inside curves plotted are for 20 dB differential phase sidebands only, and for 20 db differential gain sidebands only.

Prototype equipment has been evaluated on a four hop back to back microwave system, and through a 500 mile heterodyne repeater system. In both cases, an error rate of 10^{-5} was achieved by operating the subcarrier approximately 17 dB below the composite video signal.

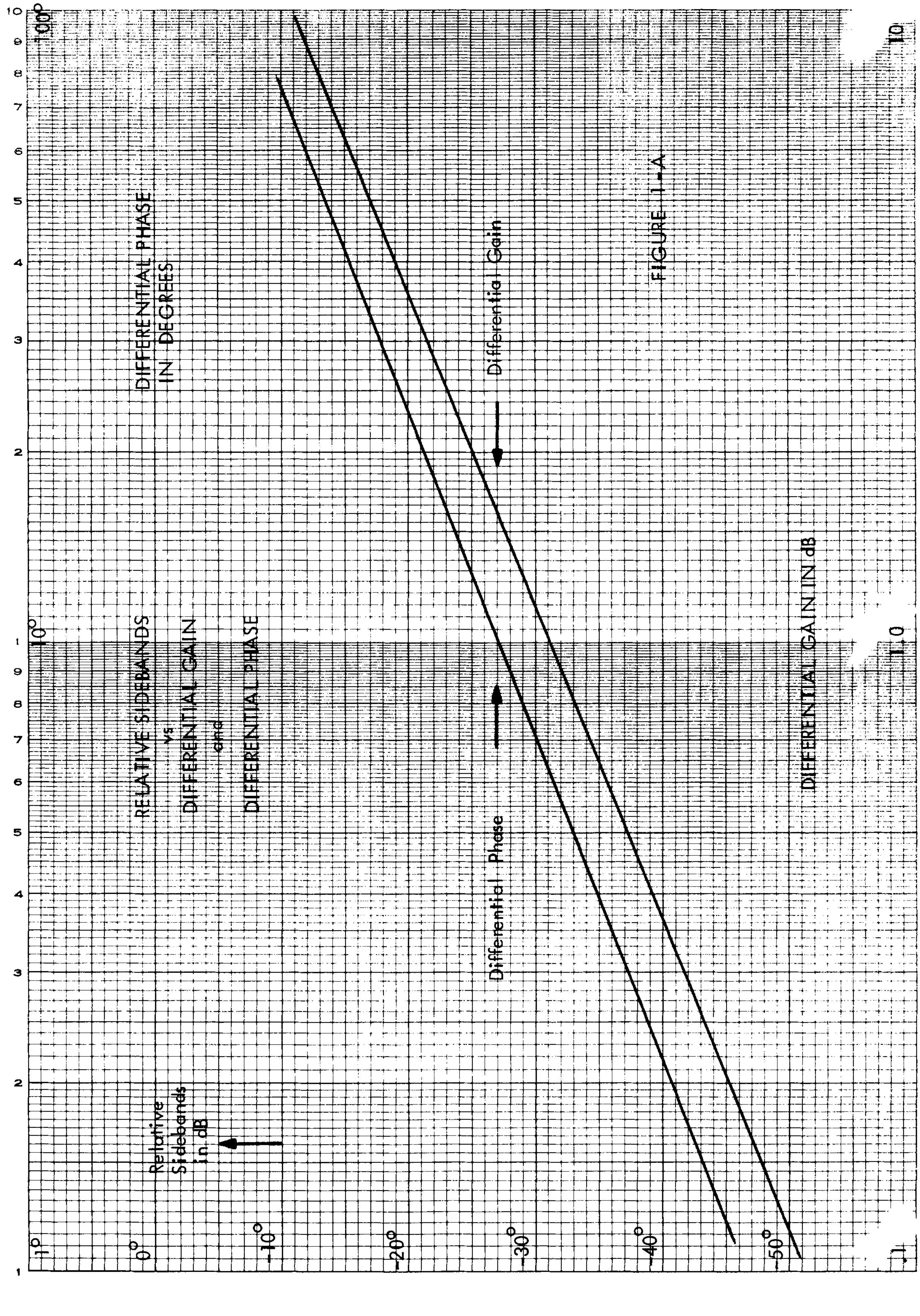

RELATIVE SIDEBANDS
vs
DIFFERENTIAL GAIN
and
DIFFERENTIAL PHASE
DIFFERENTIAL PHASE
IN DEGREES
Differential Gain
Differential Phase
FIGURE 1-A
DIFFERENTIAL GAIN IN dB
Relative
Sidebands
in dB
0°
-10°
-20°
-30°
-40°
-50°
1°
10°
100°
.1
1.0
10

FIGURE ONE

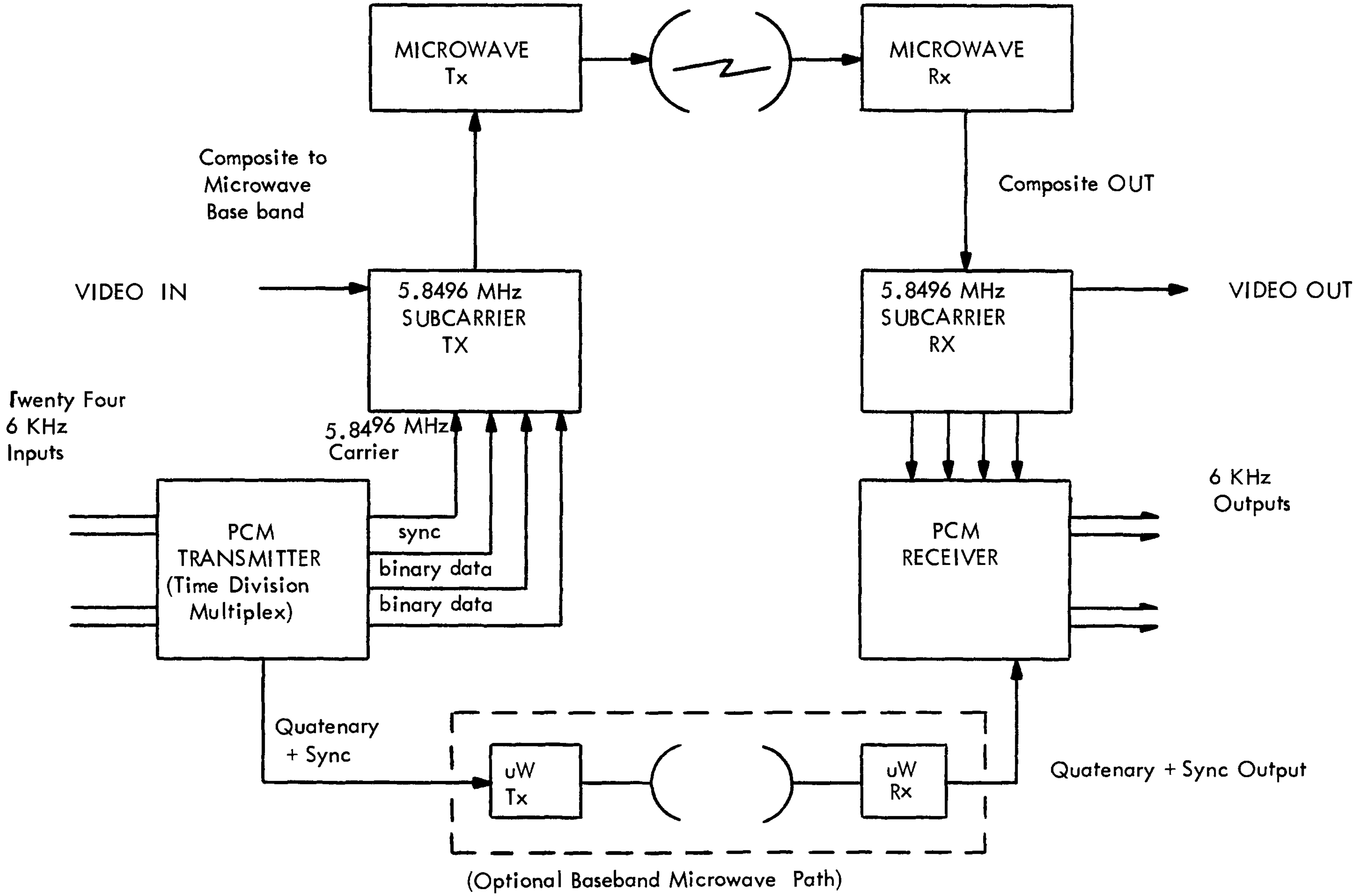
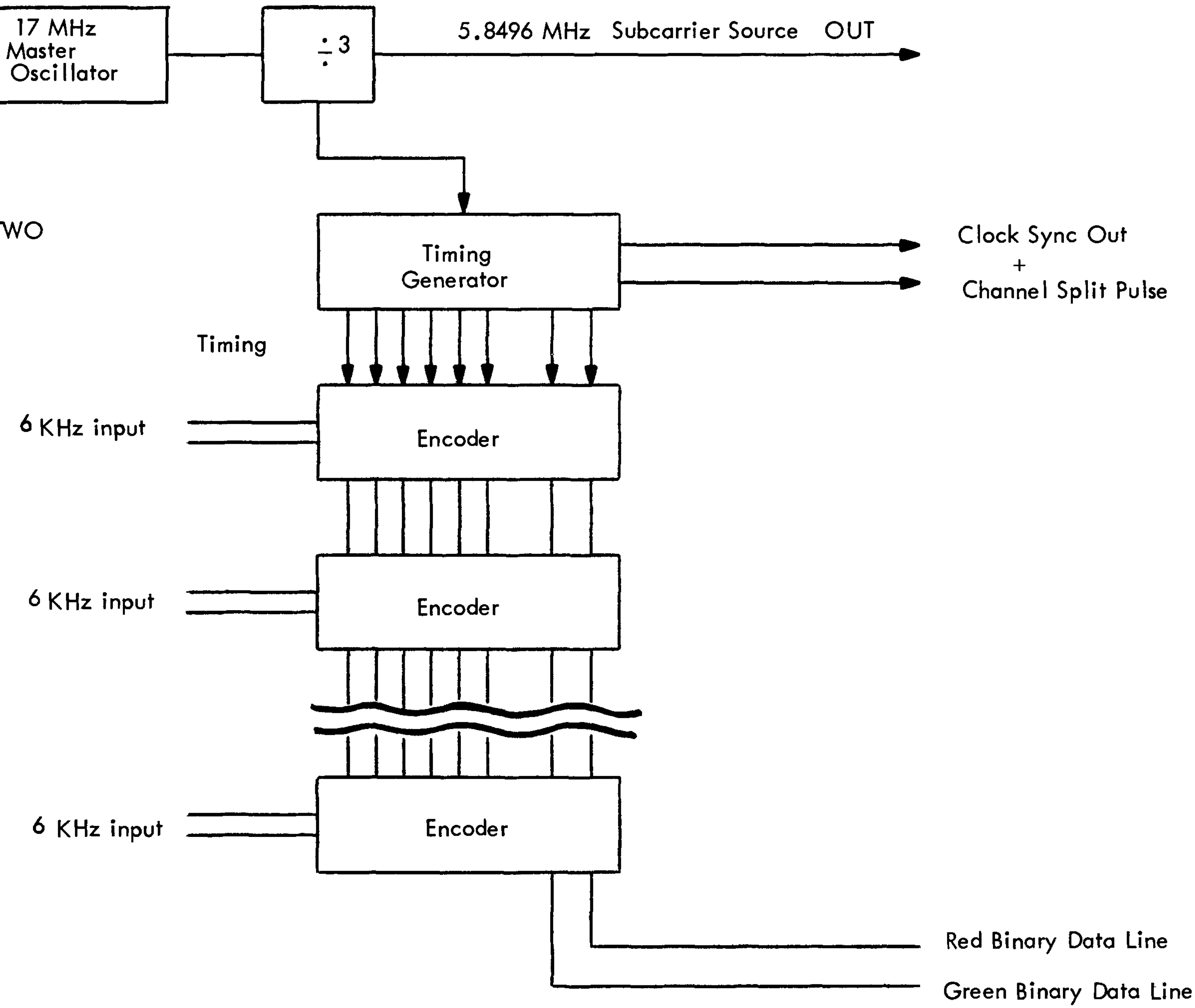
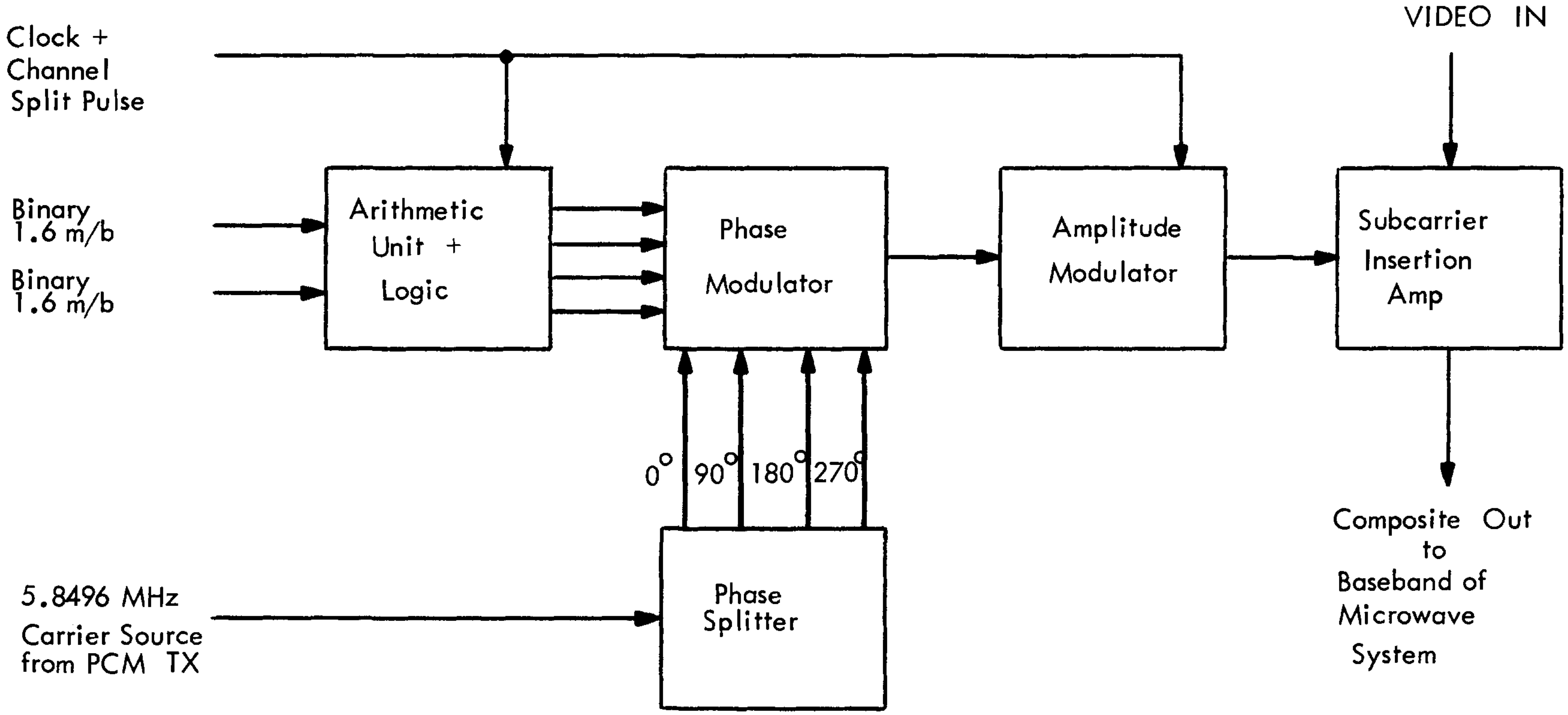

MICROWAVE
Tx
MICROWAVE
Rx
Composite to
Microwave
Base band
Composite OUT
VIDEO IN
5.8496 MHz
SUBCARRIER
TX
5.8496 MHz
SUBCARRIER
RX
VIDEO OUT
Twenty Four
6 KHz
Inputs
5.8496 MHz
Carrier
6 KHz
Outputs
PCM
TRANSMITTER
(Time Division
Multiplex)
sync
binary data
binary data
PCM
RECEIVER
Quatenary
+ Sync
uW
Tx
uW
Rx
Quatenary + Sync Output
(Optional Baseband Microwave Path)

FIGURE TWO



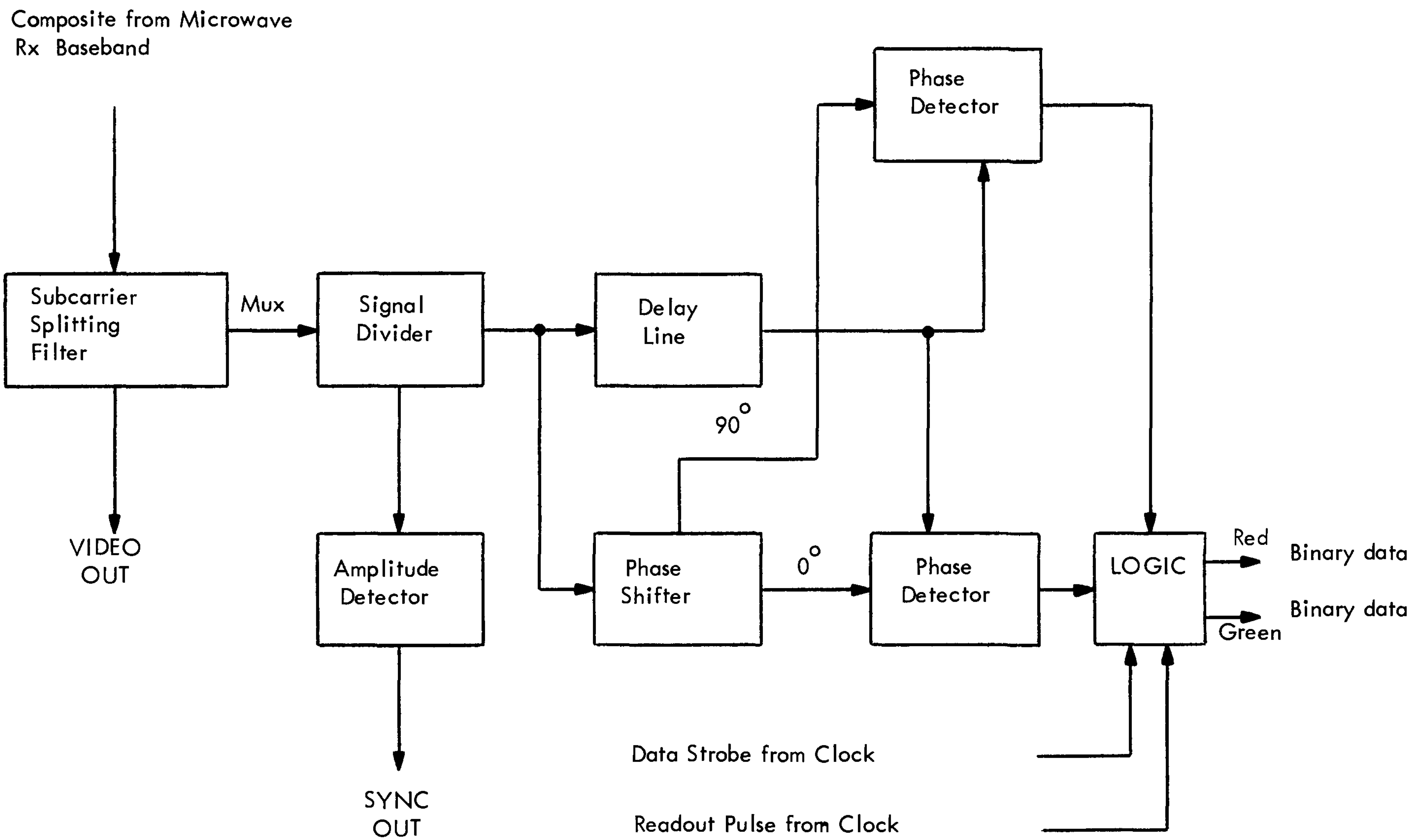
PCM MULTIPLEX TRANSMITTER

FIGURE THREE

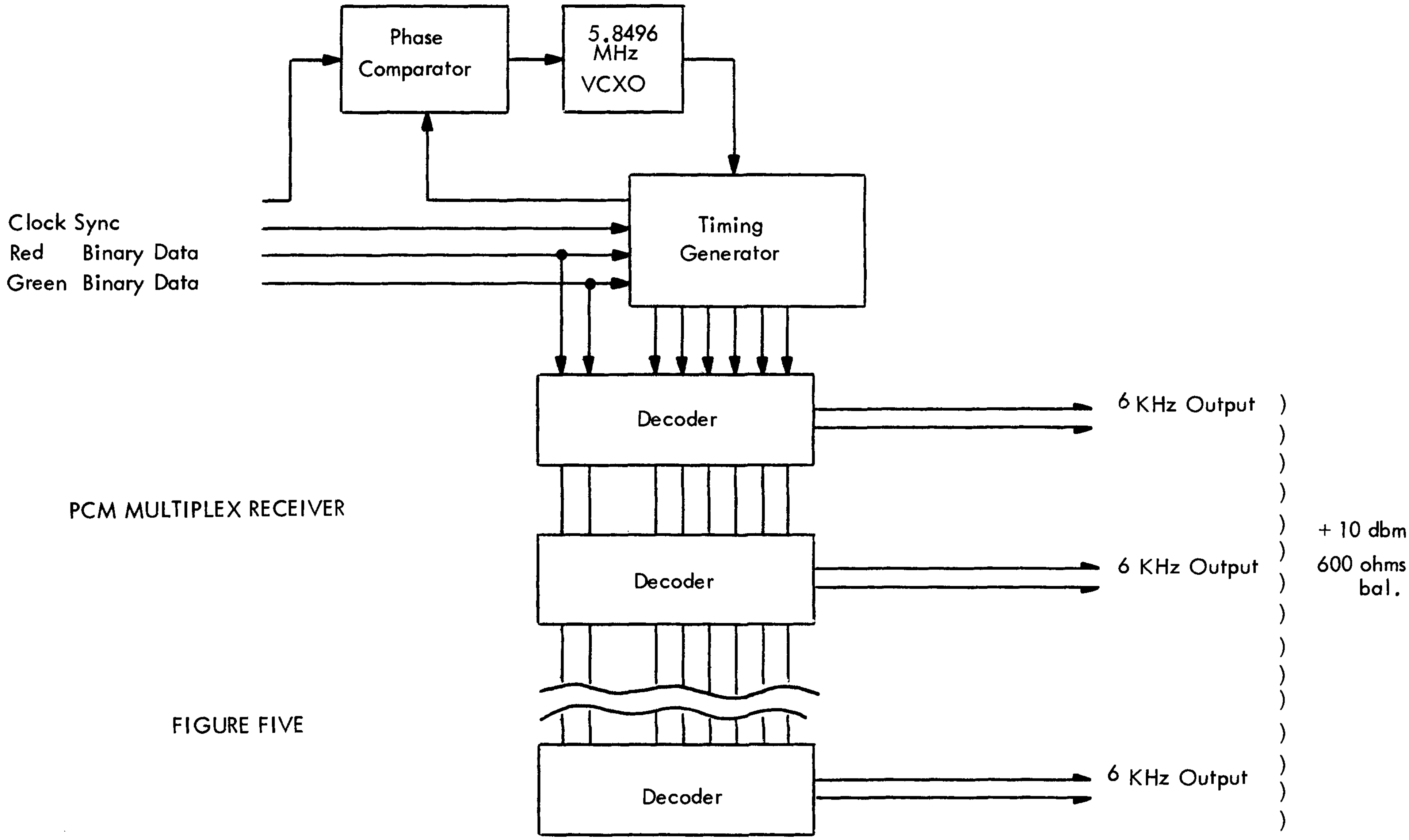


SUBCARRIER TRANSMITTER

FIGURE FOUR



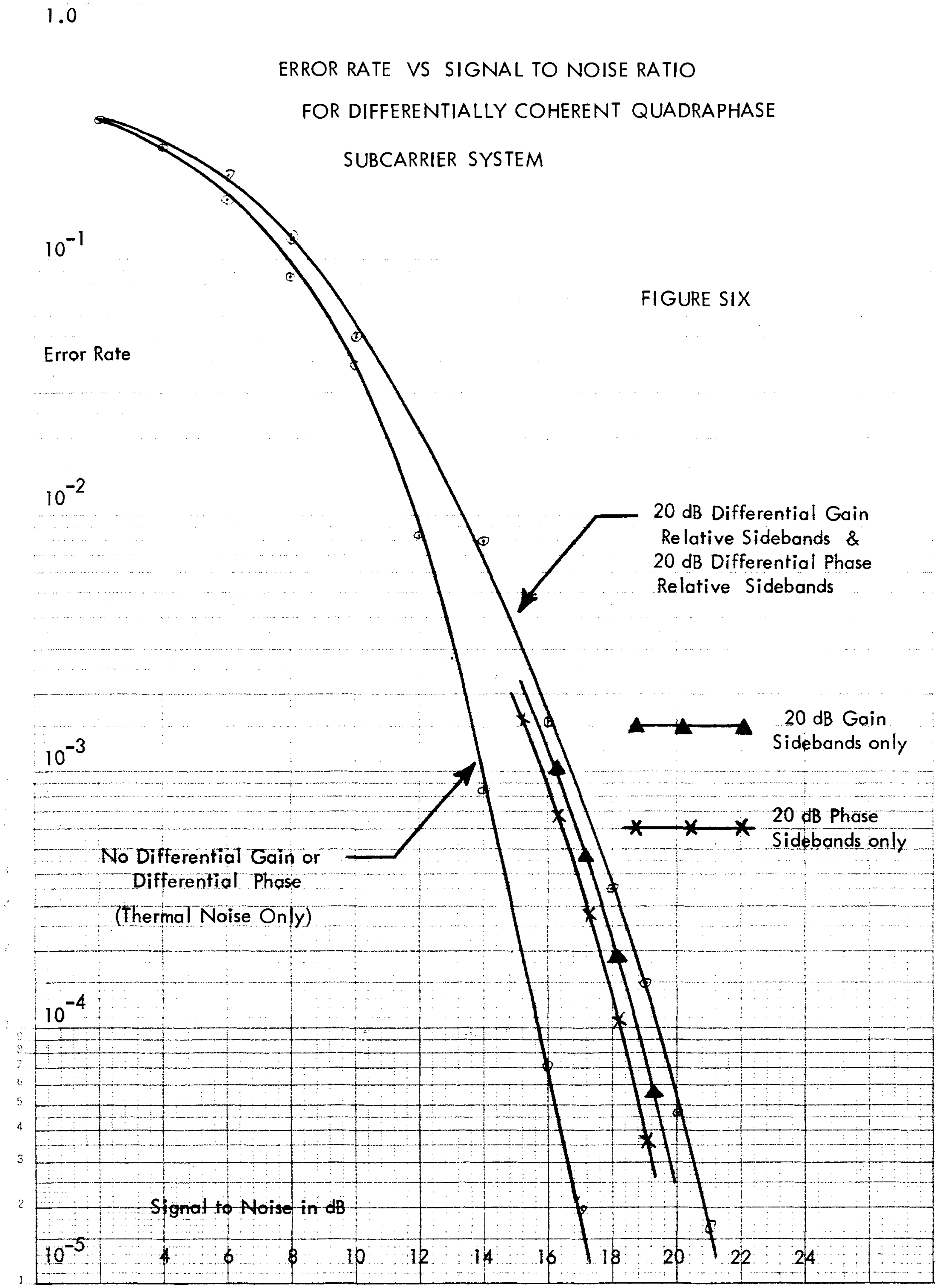
SUBCARRIER RECEIVER



PCM MULTIPLEX RECEIVER

FIGURE FIVE

Harmonic Distortion 2% max.
IM - 60/6000 2% or -34 dB


1.0
ERROR RATE VS SIGNAL TO NOISE RATIO
FOR DIFFERENTIALLY COHERENT QUADRAPHASE
SUBCARRIER SYSTEM
10^-1
FIGURE SIX
Error Rate
10^-2
20 dB Differential Gain Relative Sidebands & 20 dB Differential Phase Relative Sidebands
10^-3
20 dB Gain Sidebands only
20 dB Phase Sidebands only
No Differential Gain or Differential Phase
(Thermal Noise Only)
10^-4
Signal to Noise in dB
10^-5
4
6
8
10
12
14
16
18
20
22
24