DESIGN AND PERFORMANCE OF AN OPTIMAL RATIO COMBINER USING AGC AND AM WEIGHTING

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ABSTRACT

The conventional AGC weighted diversity combiner design experiences performance problems in the presence of fast fade rates of amplitude and phase of RF input signals.

These problems and other needs are discussed by the author in detail along with the design and theory of a new combiner that has been developed. It successfully overcomes these phase and amplitude fading problems and also addresses many other problems such as the need for wider bandwidths, computer control, and many other improvements. These improvements are necessary to increase the state-of-the-art in the telemetry and communications combiner.

The design criteria and realization of the design goals are described in detail accompanied by a block diagram discussion of the theory of operation.

INTRODUCTION

The requirements of the Diversity Combiner for Satellite and Missile Telemetry have increased dramatically in the last decade.

This increase in requirements for Diversity Combiners has prompted many excellent studies on the subject - most notably, those by E. R. Hill. A sample of these papers is indicated in the bibliography. Mr. Hill and others have brought to light the demands that are placed on modern-day Diversity Combiners. Mr. Hill and others have also studied and experimented with new techniques to accomplish these demands. These studies and papers have prompted the design of a completely new commercial Combiner that incorporates many of these new techniques along with many new methods developed during our study and resultant finished design.

Diversity combining has been thoroughly analyzed in the references and no general dissertation will be given in this paper. The purpose of this paper is to point out the improvements in combiner circuitry and analyze the results obtained.

AM/AGC WEIGHTING

The conventional AGC-weighted combiner requires perfect tracking of the AGC vs. the RF fading envelope to properly perform as an optimal ratio combiner. The studies show that receivers cannot supply this function when the RF input envelope is fading rapidly in phase and amplitude.

Mr. Hill devised techniques to overcome this problem in his experimental combiner study entitled Technical Publication TP-78-20 Department of the Navy, Pacific Missile Test Center. (1) He made use of the fact that when a receiver AGC system cannot track a fading FM or PM signal, the resultant output of the IF contains the residual AM component. He devised an AM detector to recover these AM signals, process them through a log amp then sum them with the recovered receiver AGC voltages. This resultant AM/AGC-weighted combiner then more closely tracks the fading RF signal. This technique worked well for Mr. Hill in his experimental combiner. (2) These techniques were later studied with the prospect of incorporating it in a commercial design.

The initial thought was that the AM and AGC voltages could be brought from the receiver and processed in the combiner. This technique creates some human engineering problems with the receiver setup and operation. For example, the receiver AM gain control must never be tampered with once it is set. Also, video filter selection and matching between receivers must be precisely controlled. These extra human engineering problems, coupled with existing combiner setup problems, persuaded us to abandon this technique.

We then went back to consider the basic problem in that the receiver AGC cannot track the RF fade rate. It then seemed reasonable to design another gain-controlled amplifier within the combiner that could track fade rates up to 20 kHz and recover its AGC voltage. By adding the combiner AGC voltage to the receiver’s AGC voltage, a control voltage would be created that would track the fading conditions of the RF at the receiver input. Figure 1 shows a block diagram of the COMPOSITE AGC system of a single channel for the combiner.

This new design produces an AGC liner in respect to the input signal in dBm. A typical response of Ch 1 and Ch 2 AGC tracking and response is shown in Figure 2. Note that the tracking of the two units is nearly identical. This is very important because the AGC response must be a true representation of the RF response. Note the unit is designed to operate at a dynamic range of at least 35 dB to accommodate very large fade depths. This type of system also eliminated the need for a log amp.

This system has one other very important benefit in that it is no longer necessary to set up the combiner RF input signals precisely. In the past, this was a very difficult accomplishment. The combiner AGC loops hold the internal RF level at the combiner circuits at a very precise level regardless of the difference between the two input signals. They can be up to 6 dB different with no system degradation. In other words, with this system, the Ch 1 and Ch 2 receiver IF output signals can be connected to the combiner without any adjustments. The combiner is then controlled by the receiver AGC summed together with the combiner AGC to form a COMPOSITE AGC equal to the RF fade rate.

A complete set of data was taken with this new Combiner design. These tests were conducted using the IRIG Document 118-79 Chapter 5 on Diversity Combiners, in order to simulate actual mission parameters.

The data of most interest for this design was the data taken with random and periodic fading. Figure 3 shows the Bit Error Rate improvement where Ch 1 and Ch 2 BER's were set equal and the Combiner BER was set for a finite BER. Although Ch 1 and Ch 2 BER's were difficult to measure, in almost all cases, they were greater than 100, 000 errors per million. In this case, the Ch 1 and Ch 2 signals were fading in phase and amplitude with the amplitude fading at 20 dB depth. At 50 Hz fade rate, Ch 1 and Ch 2 modulating signals are 180° out-of-phase with one another.

Figure 4 represents the action within the Combiner. When Ch 1 peaks, the Ch 1 control is max and the Ch 2 RF and control signal is min. The combiner will instantaneously select only Ch 1 data in this case. As the Ch 1 RF decreases, the Ch 2 RF increases, and the combiner will start to combine the two channels during this time and will peak at a 3 dB improvement when Ch 1 is equal to Ch 2. Then the process will reverse where when Ch 2 has its maximum level, the combiner has instantaneously selected the Ch 2 signal.

The combined data improvement is very dramatic over the individual channels. The Combiner is selecting and combining the best data according to the Ch 1 and Ch 2 composite control signals. This data was taken using only a 50 Hz fade rate and you could expect an AGC ONLY combiner to perform as well with this slow fade if the receiver AGC time constants were set fast enough to track the fade rate.

A comparison of data was done with an AGC ONLY combiner vs. a combiner with COMPOSITE AGC and the data is shown as Figure 5. Once again, the fades were 20 dB in depth and 180° out-of-phase with one another but, in this case, the fade rate was varied from a few Hz to 20 kHz. The Ch 1 and Ch 2 BER's were adjusted to keep the combined

BER at one error per million bits. The AGC ONLY combiner is totally dependent on the receiver AGC time constants for tracking capability and there are two curves - the first one, the time constant was set for 10 msec and the second one was set for 0.1 msec. The receiver AGC time constant for the new combiner with COMPOSITE AGC was set for 10 msec.

Note that the new Combiner with COMPOSITE AGC maintained a BER of one error per million when Ch 1 and Ch 2 are set for 30, 000 errors per million from a few Hz to about 10 kHz and then degrades to about 17, 000 errors at a fade rate of 20 kHz. The COMPOSITE ACC is able to track the fade rate out past 10, 000 Hz.

Next, refer to the two curves for the AGC ONLY combiner. Curve 1 had the receiver AGC set to 10 msec. Note the combined error rate was one error per million at fade rates up to 15 Hz which was equal to the performance of the composite unit. However, note that the error rate climbs very sharply after 15 Hz. This is the point where the receiver AGC can no longer track the fade rate and the combiner is not proportioning back and forth between the channels with the highest carrier-to-noise ratio. It is also important to note that at about 22 Hz, the combined errors exceed the Ch 1 and Ch 2 errors. This is the point where the AGC of the receiver is being wiped off and being shifted in phase relative to the RF fade rate, due to the RC filter action of the receiver AGC loop components. As the fade rate continues up from 20 Hz, the BER begins to decrease as the receiver AGC response decays toward an average DC component until about 1,000 Hz where the combined errors level out to about 5,000 errors or to about a 3 dB expected improvement.

Curve 2 had the receiver AGC time constants set to 0.1 msec and yielded about the same result except that the errors didn’t begin to increase until reaching 150 Hz fade rate, then the response was similar to Curve 1.

An important aspect of the new Combiner with COMPOSITE AGC is that the receiver AGC time constant settings are not important since the combiner AGC will always pick up a residual AM component left by the receiver. Even if the receiver AGC time constants are each set for a different time constant, the combiner COMPOSITE AGC will still duplicate the RF fading at the receiver input. This leaves the receiver AGC time constants available for other mission parameters.

A pictorial diagram of COMPOSITE AGC vs. AGC ONLY is shown as Figure 6.

Figure 6a shows a dual trace scope display of the input RF envelope and the recovered AGC response at the AGC output of a receiver. Note the top trace is a logarithmic AGC response of the RF envelope and is tracking the RF envelope very well. This recovered

AGC is sent to the combiner and controls the combining ratio properly which allows the data improvement as shown in Figure 5 for 50 Hz fade rate.

The next picture shows the fade rate increased to 1500 Hz. Note that the recovered AGC signal is lowered in amplitude, but even worse, it was shifted in phase relative to the RF envelope. This AGC signal was improperly controlling the combining ratio and the result is a serious degradation of the data improvement.

The last photograph shows the AGC back in sync and displays the correct amplitude with the RF envelope. In this case, the receiver AGC of Figure 6 had been combined with the combiner internal AGC to form a COMPOSITE AGC that supplies the combiner with the proper combining information.

The COMPOSITE AGC keeps the AGC in sync and at the proper level for fade rates up to 20 kHz and never degrades the data improvement shown on Figure 5.

AM/AGC CONCLUSION

The data taken during tests of this new combiner design bear out the same conclusions obtained by Mr. Hill and others in that it is necessary to supplement the normal receiver AGC control of a combiner with an additional control signal when it is necessary to gather maximum data under conditions where fast phase and amplitude fade rates are present.

The data indicates that the Composite Receiver and Combiner AGC System used in this design successfully performs this function.

PHASE LOCK LOOP BANDWIDTH

Studies have also indicated that the Phase Lock Loop Bandwidth should be increased to accommodate the fast amplitude and phase fading experienced by such things as flame attenuation and missile rotation. It was decided that a switchable loop bandwidth would be most desirable. Three loop bandwidths were designed to be switched depending on the combiner applications. The Slow sweep mode was designed for a sweep time of 10 seconds. This position is designed to sweep very slowly so as to acquire phase lock on a signal with a very low carrier-to-noise ratio. The Medium sweep mode was designed for a sweep time of one second. The Fast sweep mode was designed for a sweep time of 0.1 second. The Fast poisition was used for all the data taken in this paper. No noticeable degradation of data was noticed due to selecting this loop bandwidth during our tests. A further study of loop bandwidth requirements for various mission parameters is planned to better determine optimum loop bandwidths.

The curve of most interest is shown as Figure 7. This curve shows the Pre-D combined error improvement when the Ch 1 and Ch 2 signals were modulated in amplitude and phase using random noise. Separate noise sources were used for Ch 1 and Ch 2 and Ch 1 and Ch 2 errors were set equal and set to a combined bit error rate of one error per million. The noise bandwidth was then varied from 100 Hz to 10 kHz while maintaining the same modulation power. The curve shows the combined error improvement to be constant from a low noise band with up to 10 kHz noise bandwidth. The combiner phase lock loop bandwidth was set to the Fast position of 0.1 or about 7 kHz at the -3 dB point. The data shows that the combiner was easily able to maintain phase lock with these widely varying parameters.

PHASE LOCK LOOP CONCLUSION

The data taken from other studies of phase lock loops in combiners (see bibliography) indicates that the loop bandwidth needs to be increased to accommodate the fast phase rates encountered under actual operating conditions.

The fast loop bandwidth in this design was increased for a sweep time of 100 milliseconds and two other selectable loop bandwidths were provided to allow for as many different applications as possible.

The data curves in this paper indicate that the fast loop bandwidth in this design was sufficient for all applications considered.

OTHER DESIGN REQUIREMENTS

PREDETECTION BANDWIDTH

The center frequency of the two IF inputs of this combiner is 20.0 MHz. This frequency was selected during the initial study of the needs of the telemetry industry. Intermediate frequency bandwidth up to 10 MHz and higher were indicated. Therefore, it was necessary to increase the center frequency of the IF inputs. This allowed us to design a predetection combiner with a bandwidth of 15 MHz. This increased bandwidth allows a down converted center frequency of up to 5 MHz in order to accommodate wideband down converted data.

POST-DETECTION VIDEO BANDWIDTH

New telemetry receivers have video bandwidths in excess of 5 MHz. This necessitated a post detection combiner design that is capable of combining two video signals with a frequency response up to or in excess of 5 MHz. This new design incorporating new state-of-the-art high speed, high power op amps has resulted in a video combiner design capable of greater than 4V p-p into a 75Ω load, that is, flat to 5.0 MHz and usable to almost 10 MHz.

This increased video bandwidth would also allow combining of television-type video signal formats.

THEORY OF OPERATION

A simplified block diagram is included in this paper for reference. Figure 8.

Predetection Combining

Two 20 MHz signals are fed into the Combiner from the linear IF outputs of separate receivers. These inputs must be linear so as to contain the AM information generated by fast fade rates that the receiver AGC cannot wipe off.

The 20 MHz gain control amps contain extremely fast AM detectors and logarithmic AGC circuits that process the AM component of the fading signal. The processed AM/AGC voltage is summed together with the AGC from the receivers and produces a COMPOSITE AGC that is a replica of the AM fading at the receiver RF input. This COMPOSITE AGC controls the optimal ratio combining of the Pre- and Post-Detection Combiners. The gain control circuits were designed to track one another very closely.

The output of the gain control amps is leveled and held constant by the AGC loops. This AGC loop allows the operator to connect the linear IF inputs without regard for their respective levels so long as they are within 6 dB of one another. This further eliminates a very tedious and difficult setup procedure.

The gain control amps output is 20 MHz which is upconverted to 80 MHz in each channel by the 60 MHz crystal oscillator. This 80 MHz signal is down converted to 20 MHz by the 60 MHz crystal signal in Channel 2 and sent to the phase det circuit. The Ch 1, 20 MHz input to the phase det is down converted from 80 MHz by the 60 MHz VCO. The Ch 1 signal is compared with the Ch 2 reference and an error voltage is fed to the VCO which changes the Ch 1, 20 MHz frequency and causes Ch 1 to phase lock to Ch 2. When Ch 1 and Ch 2 are phase locked to one another, the lock detector outputs a lock logic signal that allows the combining of Ch 1 and Ch 2 RF signals. When the two signals are not phase locked, the unit acts as a switching combiner, selecting the channel with the better signal-to-noise ratio as determined by the logic circuits.

The combined predetected signal is fed to the down converters where the combined signal is down converted to various center frequencies determined by the operator. Ch 1 and Ch 2 down converted outputs are also provided. However, the combined output automatically provides Ch 1 or Ch 2 outputs when the unit is not in the combined logic condition. The channel with the best signal-to-noise is present at the combined output.

The post-detection combiner circuits also function as a switching combiner in the same fashion as the predetection previously described.

The post-detection combiner is supplied with video from the Ch 1 and Ch 2 receiver. The levels are set up by front panel switches in conjunction with the digital panel meter to allow for very precise video level setting. The two signals are then routed to the post-detection combiner where they are optimal ratio combined by the AM/AGC signal. The post-detection combiner will also provide combining at very fast fade rates. A switch is provided for those who wish to use the post-detection section without IF input signals.

This has been a very simplified discussion of some very complicated circuits. We have designed into this unit state-of-the-art circuits that will handle immediate needs as well as those that may be required far into the future.

REFERENCES

1. E. R. Hill, “Techniques and Circuits for Implementing Predetection Diversity Combiners,” Technical Publication TP-78-20, 15 September 1978, Pacific Missile Test Center, Point Mugu, California.

2. E. R. Hill, “AM/AGC Weighted Predetection Diversity Combining,” Proc. International Telemetering Conference, Volume 13, pp. 215-238, October, 1977.

3. D. G. Brennan, “Linear Diversity Combining Tchniques,” Proc. IRE, June, 1959.

4. E. R. Hill, “Time Domain Analysis of an AGC Weighted Combiner,” Proc. International Telemetering Conference, Volume 9, pp. 475-494, October, 1973.

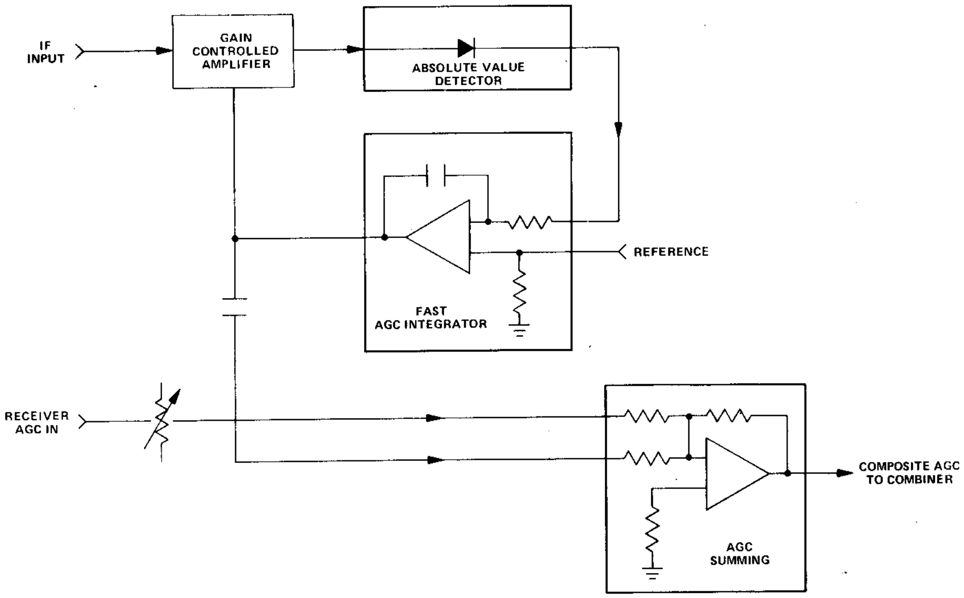

FIGURE 1. BLOCK DIAGRAM, COMPOSITE AGC SYSTEM FOR A SINGLE CHANNEL 3200 PC COMBINER

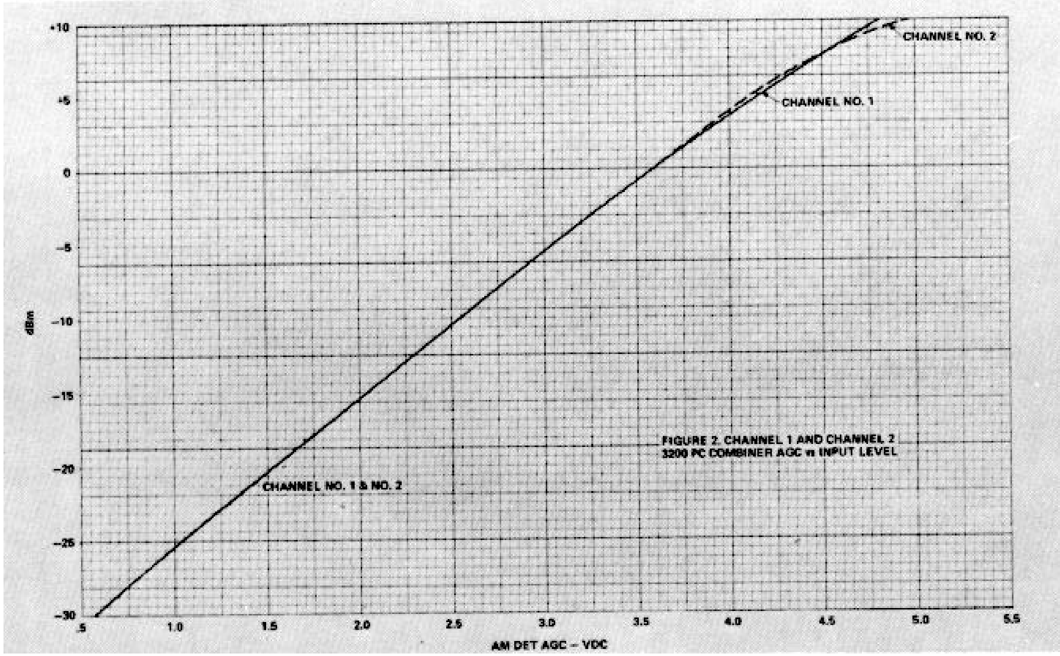

FIGURE 2. CHANNEL 1 AND CHANNEL 2 3200 PC COMBINER AGC vs INPUT LEVEL

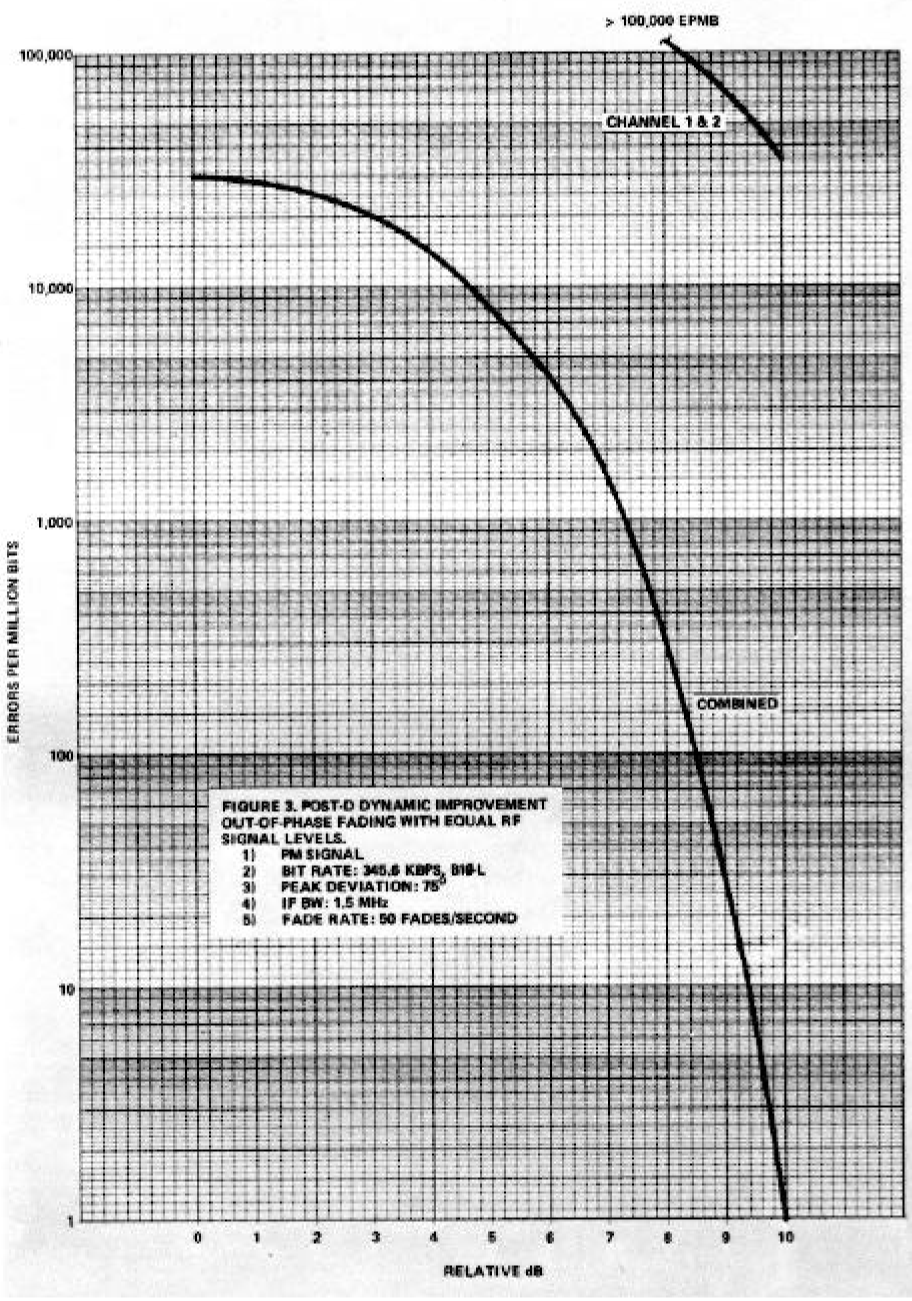

FIGURE 3. POST-D DYNAMIC IMPROVEMENT OUT-OF-PHASE FADING WITH EQUAL RF SIGNAL LEVELS.

1) PM SIGNAL
2) BIT RATE: 345.6 KBPS, BIΦ-L
3) PEAK DEVIATION: 75°
4) IF BW: 1.5 MHz
5) FADE RATE: 50 FADES/SECOND

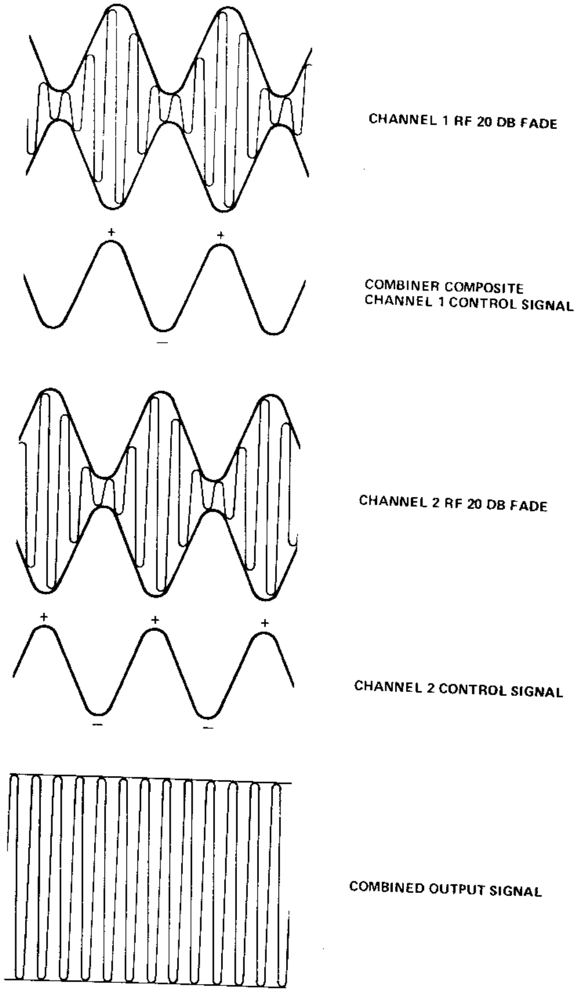

FIGURE 4, CHANNEL 1 AND 2 RF vs AGC CONTROL SIGNAL

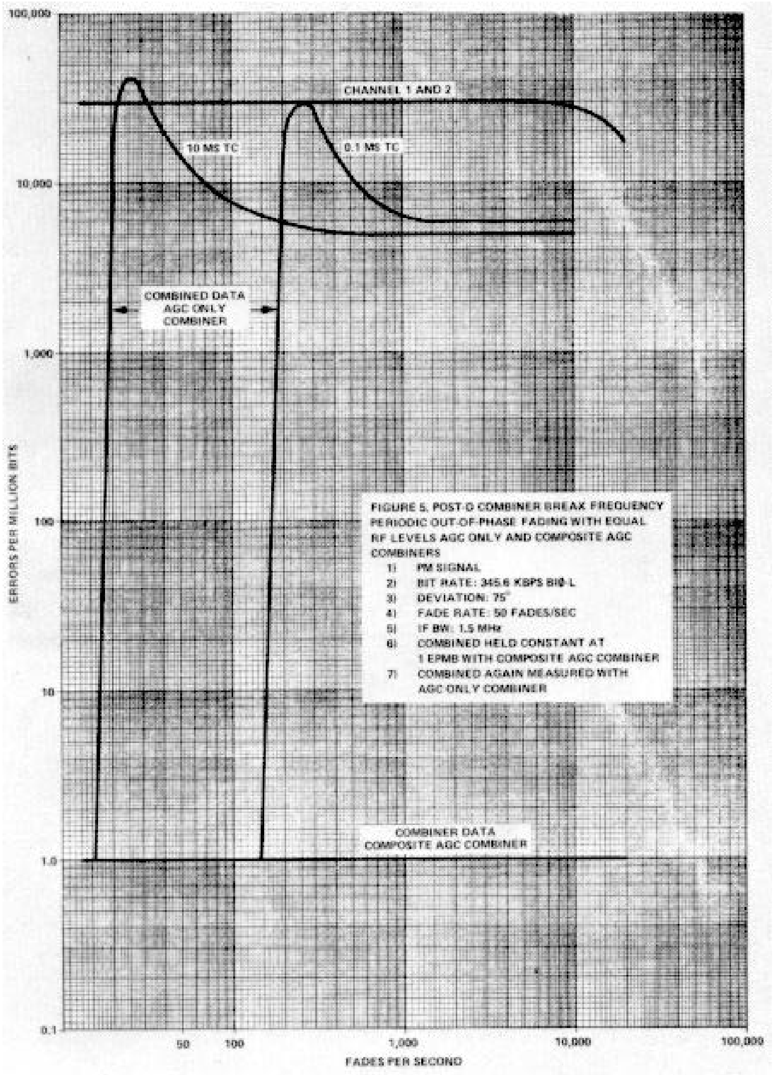

FIGURE 5, POST-D COMBINER BREAK FREQUENCY PERIODIC OUT-OF-PHASE FADING WITH EQUAL RF LEVELS AGC ONLY AND COMPOSITE AGC COMBINERS

1) PM SIGNAL
2) BIT RATE: 345.6 KBPS BIØ-L
3) DEVIATION: 75°
4) FADE RATE: 50 FADES/SEC
5) IF BW: 1.5 MHz
6) COMBINED HELD CONSTANT AT 1 EPMB WITH COMPOSITE AGC COMBINER
7) COMBINED AGAIN MEASURED WITH AGC ONLY COMBINER

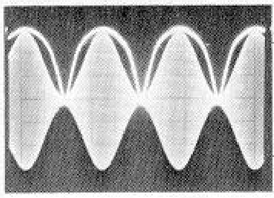

FIGURE 6A
AGC ONLY
50 Hz RATE
AGC TC=100 μSECONDS

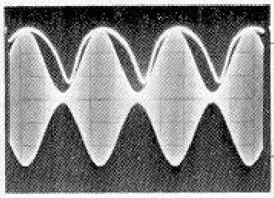

FIGURE 6B
AGC ONLY
1500 Hz FADE RATE
AGC TC=100 μSECONDS

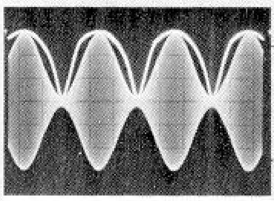

FIGURE 6C
AGC AND AM CONTRIBUTION
1500 Hz FADE RATE
AGC TC=100 μSECONDS

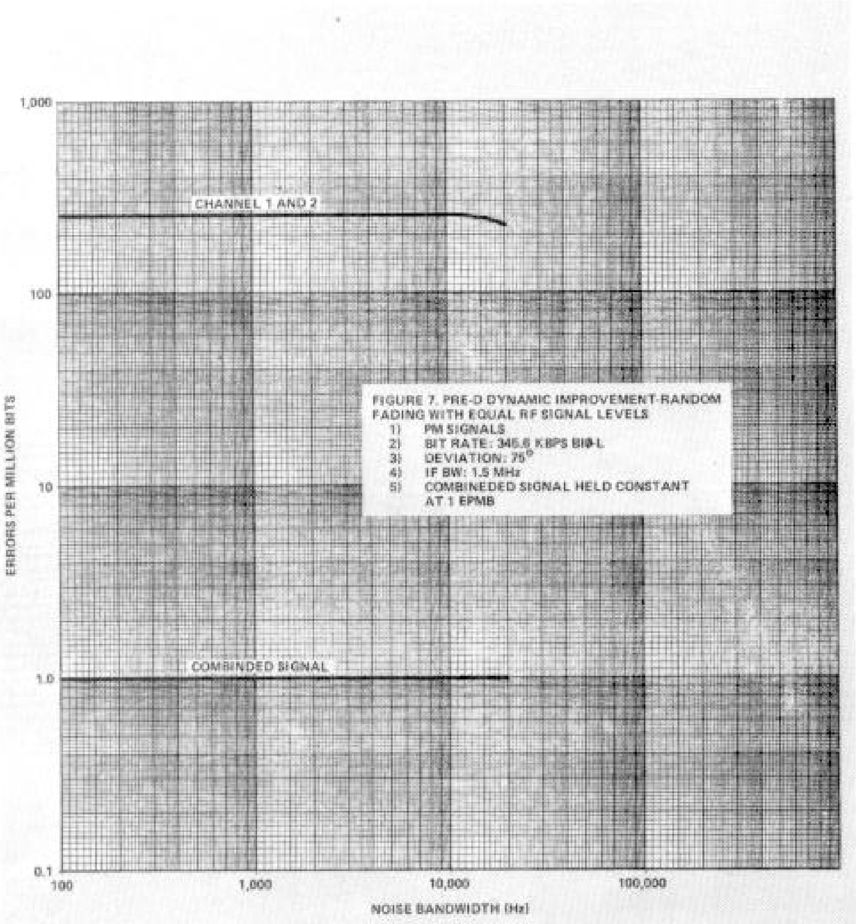

FIGURE 7. PRE-D DYNAMIC IMPROVEMENT-RANDOM FADING WITH EQUAL RF SIGNAL LEVELS

1) PM SIGNALS
2) BIT RATE: 345.6 KBPS BIØ-L
3) DEVIATION: 75°
4) IF BW: 1.5 MHz
5) COMBINEDED SIGNAL HELD CONSTANT AT 1 EPMB

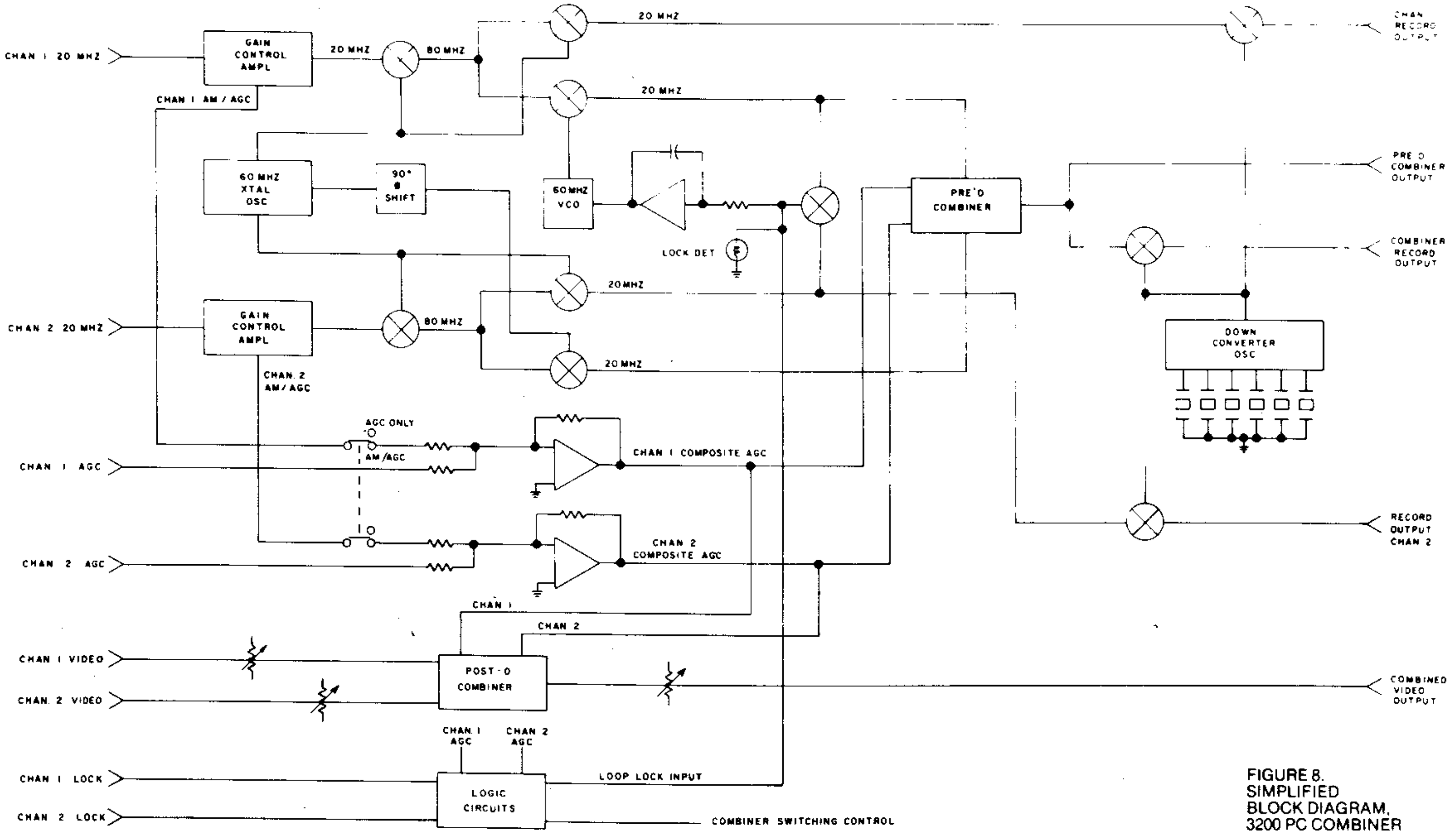

FIGURE 8.
SIMPLIFIED
BLOCK DIAGRAM,
3200 PC COMBINER

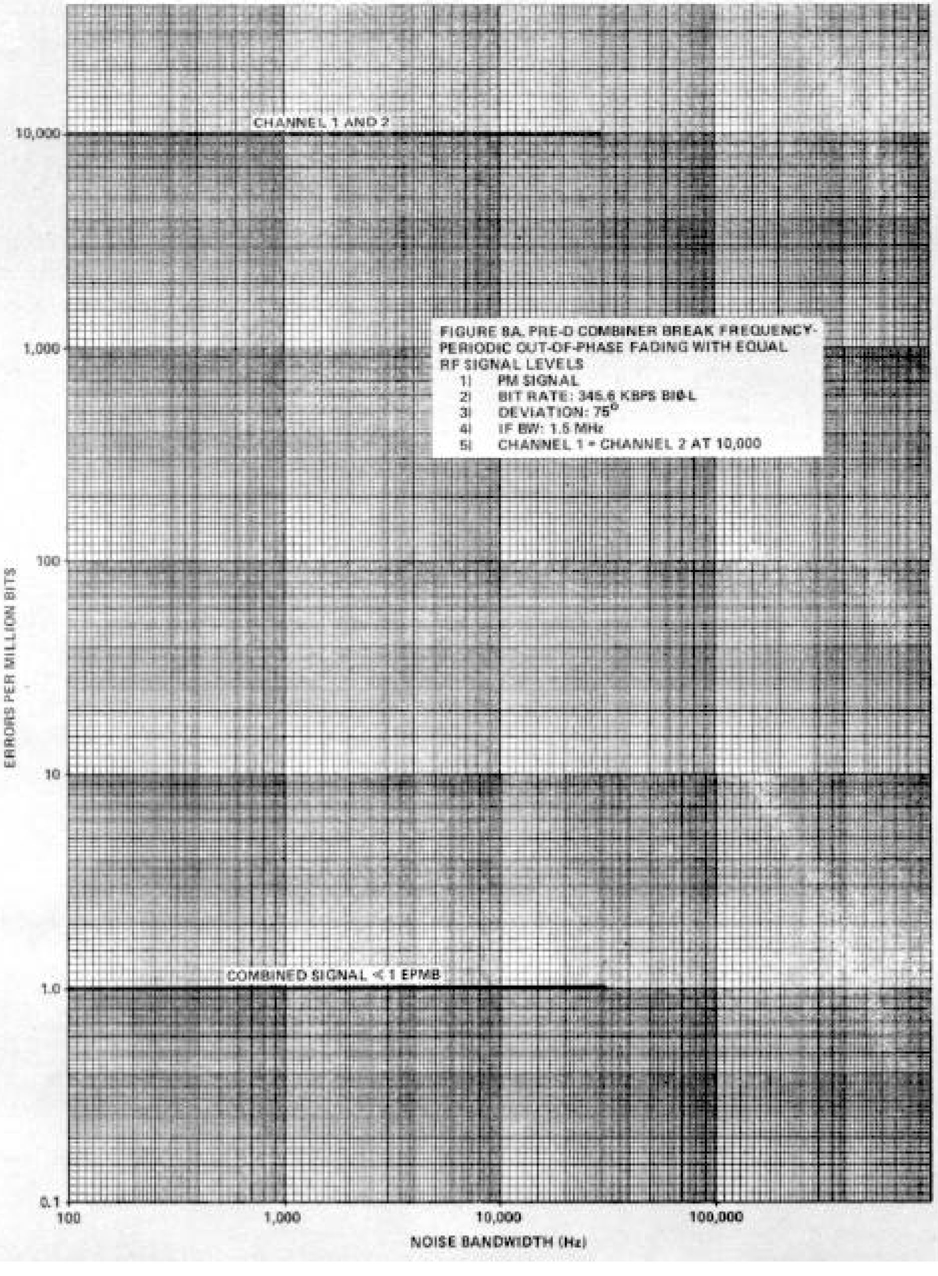

FIGURE 8A. PRE-D COMBINER BREAK FREQUENCY-PERIODIC OUT-OF-PHASE FADING WITH EQUAL RF SIGNAL LEVELS

1) PM SIGNAL
2) BIT RATE: 345.6 KBPS BIØ-L
3) DEVIATION: 75°
4) IF BW: 1.5 MHz
5) CHANNEL 1 = CHANNEL 2 AT 10,000