DYNAMIC REQUIREMENTS FOR DIVERSITY COMBINERS

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Summary In order to provide nearly continuous data on missile and Space launches, polarization diversity is utilized at acquisition sites. Diversity signals are also combined to further reduce data dropouts. It is shown in this report that the right hand circular (RHC) and left hand circular (LHC) signals undergo rapid transients during certain portions of the flight, and that the channel dropouts are sometimes independent. The nature of the transients is described and a test set which simulates the transients discussed. Finally bench test data is compared with flight test data to verify that combiners with rapid transient response are required to cope with the RF transients.

Introduction Range instrumentation stations are commonly configured with receiving antennas having right and left hand circular feeds. The RHC and LHC signals are down converted by local oscillators to 10 MHz where predetection combining occurs. The combining is intended to provide signal-to-noise improvement or best channel selection. However, analysis of launch data indicates that the combined output is often degraded in comparison with the inputs. Consequently, a study was undertaken to determine the nature of the input transients in order to specify combiner performance requirements. The study included three primary areas:

1) Measurement of the transients which occur during actual missions.

2) Simulation of transients with a test set.

3) Verification of the hypothesis that combiners capable of providing rapid transient response are required for range support.

The study progressed in accordance with suggestions made by Dr. M. H. Nichols. The test set illustrated in Figure 2 is a slightly modified version of a set designed by Dr. Nichols.

Nature of RF Signal Perturbations There are specific periods during a missile flight which correlate with data dropouts. For example, an ionized gas cloud in the vicinity of the missile antennas causes data loss. This occurs most frequently at launch separation, staging or where the aspect angle to the missile causes the transmission path to fall within the flame plasma of some ascending stage. H. A. Poehler (Reference 1) examined the AM and PM effects of flame noise at AFETR using a CW transmission from the launch vehicle. He concluded that flame plasma caused amplitude modulation (attenuation) and phase modulation (flame noise). M. H. Nichols (Reference 2) has pointed out that most of today's missiles have two or more antennas transmitting the same signal. The missile can maneuver in such a manner that the phase of the antennas causes a complete signal cancellation. (Missile maneuvering is the reason multiple antennas are employed.) He also points out that combiners are the primary tool for retrieving data when cancellation occurs in one received polarization but not the other.

Since flame noise appeared to be a much more severe cause of phase cancellation, it was assumed that a combiner which could respond to flame noise transients would be able to handle the phase cancellation due to antenna positioning during maneuvers.

In order to measure the frequency and duration of actual phase noise transients, pre-D mission tapes were made of the RHC and LHC combiner inputs. The data receiver AGC time constant was set to one second. Consequently, the receiver could not respond to rapid signal changes, and high speed transients were retained on the recorder input. Mag tape recordings were made at 120 ips; but played back at 15 ips with the playback receiver in the 0.1 millisecond AGC mode. Thus, the playback AGC could respond to realtime dropouts as short as 0.2 millisecond or as long as 0.1 second. The playback AGC voltage was recorded on high speed oscillographs showing the signal dropouts. Typical responses are shown in Figure 1. Analysis of many such plots indicates that fades occur randomly over a range of 500 Hz to 25 kHz with fade durations as small as 0.04 milliseconds but averaging 0.1 milliseconds. Of vital importance is the observation that RHC and LHC signal fades are sometimes independent.

From this data, two conclusions were drawn. First, that the combiner must be able to rapidly recover from simultaneous dropouts of 0.04 to 1 millisecond duration. Secondly, that the combiner circuitry must be able to correctly determine and select the best channel at a very high sampling rate in order to recognize independent channel dropouts of perhaps 0.04 milliseconds duration.

Simulation of Transients with a Test Set It was assumed that the mission signal fades could be simulated by phase cancellation. The test set shown in Figure 2 provides fades in excess of 30 db, and simultaneous 180 degree phase changes as described below.

Referring to Figure 2, the S-band signal generator is modulated by a PN (pseudonoise) sequence P04 serial data stream at deviations and bit rates used on the major missile programs. The combiner test set then simulates the RF signal perturbations caused by the transmission path. The working principles of the combiner test set are:

1) The RF signal is split by a 50 ohm termination power divider into two identical, coherent signals. The two signals can be thought of as RHC and LHC.

2) Since both channels function the same, only one will be reviewed. The signal (S1) enters a 3 db hybrid to be split into two equal signals (S2 and S3) which are 180 degrees out of phase.

3) Signals S2 and S3 pass through separate, identical voltage controlled phase shifters. The two signals are then summed in a power divider. The output of (S4) is the RF test signal representing either the RHC or LHC signal.

4) The phase shifter through which S2 passes was inserted only to ensure that S2 is attenuated the same amount as S3. (The phase shifter turned out to be less expensive than a nonstandard, precision attenuator.)

5) During fabrication a cable carrying S2 was cut so that phase cancellation caused a power null in S4 when the control voltage to the phase shifter was at 15 volts. The audio oscillator out-put level was then set to produce a 30 volt peak as shown in Figure 3. The 180 degree phase shift as the control voltage passes through 15 volts is essentially instantaneous and occurs at the same instant as the null. The phase and amplitude of the resultant RF signal in relation to the control voltage is shown in Figure 3. Notice that the variables, fade rate, fade slope and duration, and the time between the end of a fade on one channel and the beginning of a fade on the other channel, are all interdependent. All these variables can be controlled by the control voltage frequency.

The two RF channel outputs of the combiner tester feed directly into a dual channel downconverter which replaces the receiving antenna system for test purposes.

The receiver was a dual channel receiver with a common first and second local oscillator. The 10 MHz IF signals of the two receiver channels were carefully measured with a power meter and found to be balanced within a few tenths of a db as were the downconverter inputs.

The combined 10 MHz predetection output of the combiner was connected to the IF input of a playback receiver (a standard telemetry receiver without a tuner). Demodulators were inserted in the playback receiver as required by the data format.

To test a combiner, the control voltage was first turned off, and a bit error rate of 1×10^{-4} established for each channel. This results in an error rate of about 1×10^{-6} when the signals are combined. Next, the control voltage was turned on, and the frequency slowly increased. An ideal combiner would have provided an error rate less than 1×10^{-4} for any control frequency, as one channel is always restored before the other begins to fade. However, with actual combiners, an abrupt "breakpoint" occurred. Virtually no data was obtained above the "breakpoint" frequency.

Combiner Test Configurations Several modulation formats were tested including PCM-FM-NRZ at 44, 684, and 950 kbit. However, the most conclusive results were obtained on PCM-PM-Bi-ϕ at 350 kbit, as actual flight testing was performed in this format. Three basic configurations were tested on the bench, and then used for mission support. They are as follows:

1) **AGC Controlled Phase Lock Loop Combiner [*], Receiver with PM Demodulators** This was the combiner and configuration normally used for support which has proven unsatisfactory. Because of hardware limitations, the AGC setting must be one millisecond.

2) **AGC Controlled Phase Lock Lou Combiner *, Receiver with FM Demodulators** This was configuration identical to (1), except that FM demodulators were used. The AGC time constant could be decreased to 0.1 millisecond. It was believed that these changes would increase the transient response.

3) **Synthetic Phase Isolator Combiner** This type of unit uses only the linear IF receiver output. Phase and frequency coherence are obtained through the use of a synthetic phase isolation (SPI) (Reference 3). The unit does not utilize a VCO reference as do conventional combiners, but instead uses a loop composed of two balanced mixers and two bandpass filters. The primary advantage of this system is that reacquisition time is limited only by the bandpass filter.

Test Results The control voltage frequency "breakpoint," as discussed earlier in the paper, is given below for each configuration.

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[*] This type of combiner utilizes a phase lock loop to achieve phase coherency between the input signals. If phase lock is lost, a sweep circuit is enabled to control the VCO until reacquisition occurs. The loop bandwidth, sweep rate, and reacquisition time are performance limiting factors. The combiner logic is also dependent on AGC response, and the worst imput may be selected during rapid fades, depending on the nature of the transient. The PM demodulator logic also controls the combiner, and allows combining action only after the demodulator achieves lock.

Combiner Configuration	Control Voltage Frequency Which Produced the “Breakpoint,” Hz
1) AGC Combiner, PM Demod 1.0 millisecond AGC 25 kHz Loop Bandwidth	18
2) AGC Combiner, FM Demod 0.1 millisecond AGC 25 kHz Loop Bandwidth	350
3) SPI Combiner 20 kHz Filter Bandwidth	800

It should be possible to further improve the transient response, without unduly affecting signal-to-noise improvement, on the 350 kbit Bi-ϕ format, by changing the (2) configuration to 0.01 millisecond AGC and 100 kHz loop bandwidth; and the (3) configuration to 100 kHz filter bandwidth. However, these options were not available when tests were conducted.

The same combiner configurations were used to support a launch mission with a modulation format similar to the bench test format. Recordings were made of the combiner inputs individually, and of each combiner output. Playbacks were made, and plots of frame sync and word sync obtained. Bit errors were counted and plotted in Figure 4. As predicted, only the combiners with good transient response (Configurations 2 and 3) provided a data improvement, and the combiner with the best transient response, as determined by the test set, provided the best data.

Conclusions The authors of this paper concluded that missile signals received by telemetry tracking stations frequently experience rapid transients. These transients and accompanying loss of data are most often caused by flame plasma (ionized gases). To effectively process such signals, diversity combiners capable of coping with these transients must be used. The test set described herein provided a simple method of comparing the transient response of several combiners.

The combiner with the best transient response under bench test conditions provided the best data during mission support.

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References

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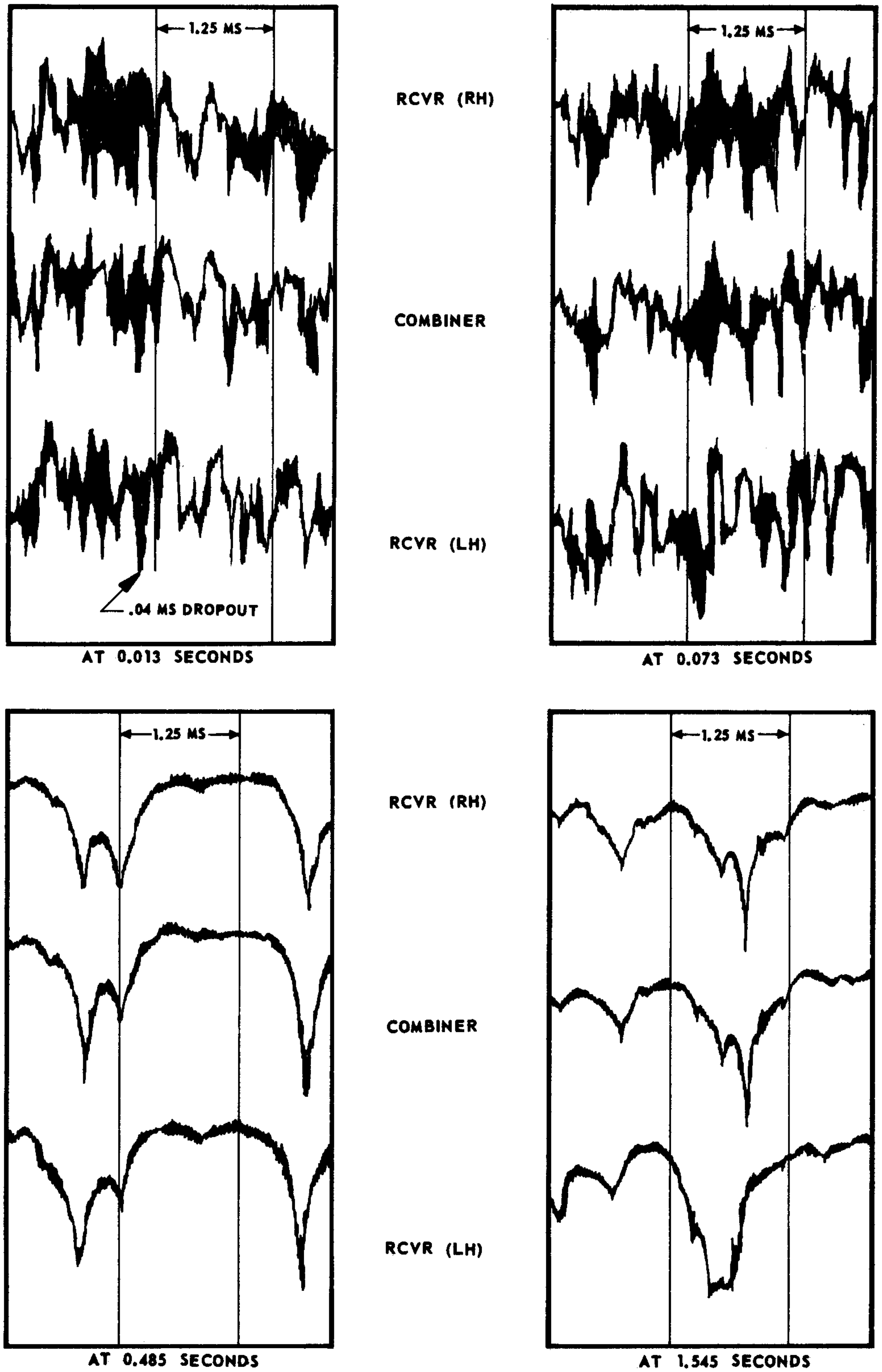

FIGURE 1
S-BAND TELEMETRY S/S FLUCTUATIONS AFTER THIRD STAGE IGNITION

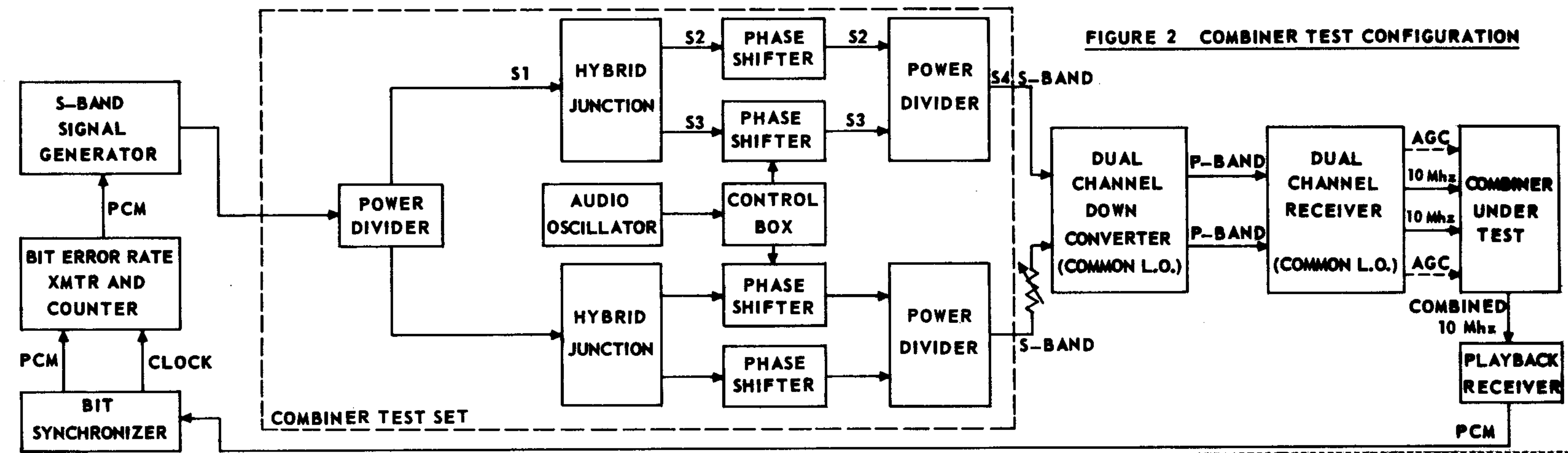

FIGURE 2 COMBINER TEST CONFIGURATION

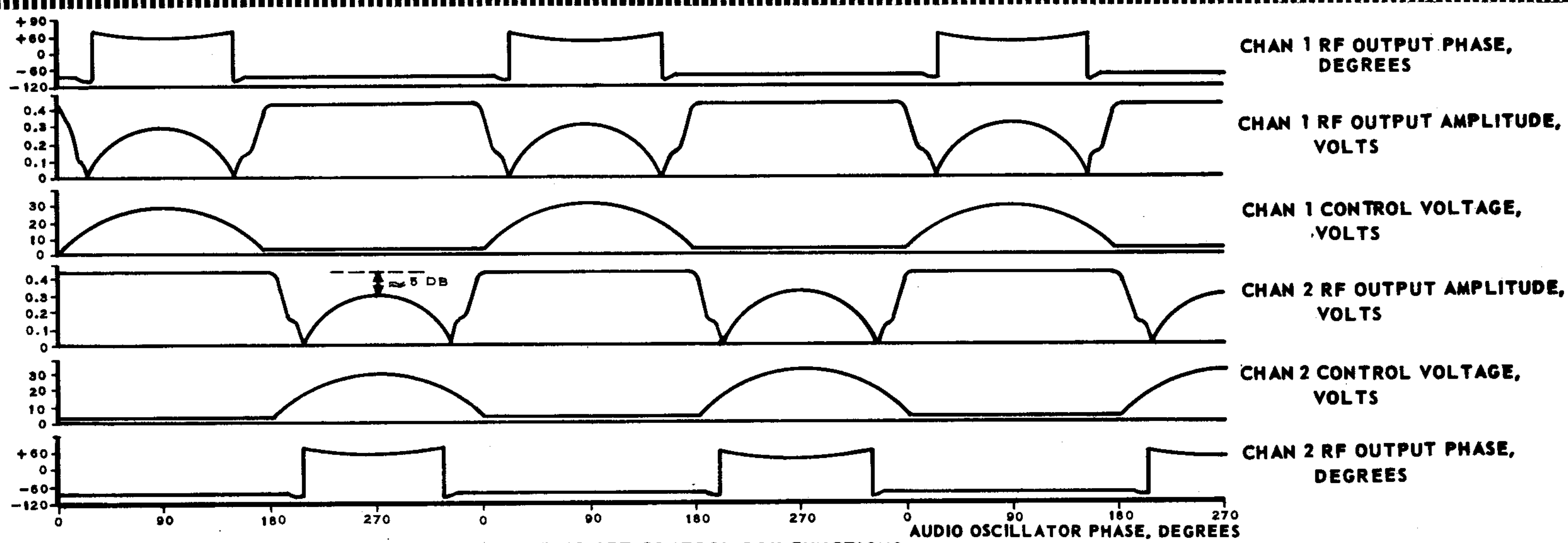

FIGURE 3 COMBINER TEST SET CONTROL BOX FUNCTIONS

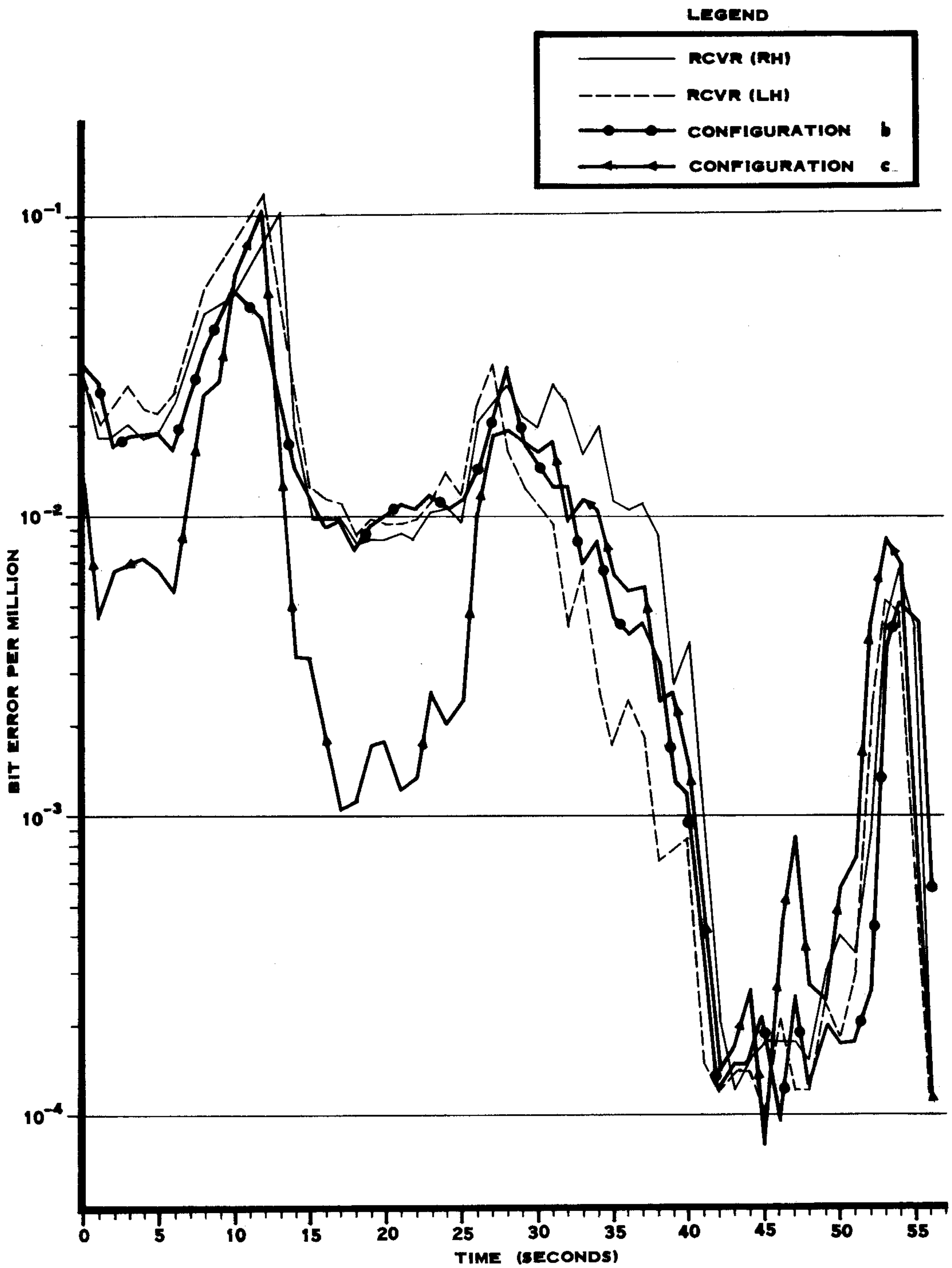

FIGURE 4 THIRD STAGE BURN PERIOD