United States

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Geological Survey

Increasing Dynamic Range in Analog Seismic Data Systems Used in Alaska

by

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Introduction

The retrieval of seismic data using analog telemetry and instrumentation is generally limited to slightly better than two orders of magnitude although earthquake signals cover at least eight orders of magnitude from the smallest to the largest. The ratio of these two magnitudes, expressed in decibels (dB), is defined as the dynamic range of the signal of interest. For example, a signal which could range over 5 orders of magnitude would have a dynamic range of 100 dB. Since seismic electronics and telemetry have such a small dynamic range most of the larger earthquakes are lost due to clipping in the amplifier stages.

A common way this problem has been overcome is to install two stations at the same location each having a different gain. Although straightforward, this approach is wasteful of bandwidth since only one of the stations will actually have useful data while the other would either be clipped or appear very quiet. A more economical approach is to change the gain of a single station so that the signal is on-scale over a greater range. This scheme complicates the data analysis somewhat since gain changes neccesitate special codes to indicate the current gain value. However, if these complications are acceptable, the hardware described in this report can significantly increase the dynamic range recordable from a single station.

A1VCO Gain-Ranging Considerations

A voltage-controlled oscillator, gain-ranging amplifier and calibrator (A1VCO) designed at the USGS has been used in Alaska since 1978 for seismic data acquisition. The unit also incorporates many advanced features such as digital channel selection, low noise synthesized FM output, firmware-based calibration cycle, crystal-referenced center frequency, and expansion capability (via an empty card slot) which are fully described by Rogers and others (1980).

The initial A1VCO units deployed did not use the expansion capability, but in 1983-1985 a multi-function expansion board was designed and field tested which provides increased dynamic range, trigger-time pulses of a co-located strong-motion recorder and monitoring of a solar-charged battery voltage.

The sensor used with the A1VCO is the L-4 geophone made by Mark Products which has a dynamic range of about 100dB of which 50-60dB is unused in non-gain-ranging VCOs. The exact dynamic range depends on telemetry noise, hence the 10dB ambiguity. Although the original A1VCO configuration had an added 20 dB of dynamic range due to single gain-ranging for a total of at least 60dB, it is still for below the dynamic range of the L-4 geophone. With the expansion card however, the A1VCO approaches the dynamic range of the geophone.

Other Design Considerations

Another problem the expansion card addresses is recovering accurate (.05 sec) trigger times from remote SMA-1 strong motion event recorders. Normally, the recorder's timing is only good to several seconds per year due to drift of the internal clock. This drift connot be corrected locally using WWVB radio as the signal is too weak for reliable reception in Alaska. The expansion card however, allows the recorder to be connected to the A1VCO so that a trigger causes a unique timing mark to be transmitted to the central recording facility which has accurate time.

The third feature of this card is the monitoring of the voltage of a solar-charged battery. This voltage tends to drop during the dark winter months due to lack of sufficient charging current from the solar panel. To correctly design or "size" a solar-powered site just enough battery storage and solar panel power should be provided. This decision has to be based on the predicted amount of sunlight available during the winter darkness and on the reduced light level on the panel due to snow, ice, and cloud cover. Unfortunately, this data is not available for many remote regions in Alaska, so fairly conservative estimates were made. By transmitting back the battery voltage, information is indirectly gathered on solar insolation which could indicate that less conservative sizing of future sites would be adequate.

Gain-Ranging Operation

Figure 1 shows the three possible gain states of the A1VCO. The state of highest gain ("NO GAIN RANGE" or NGR) occurs when both GR1 and GR2 are off or logic state 0. "GAIN RANGE 1" (GR1) referes to the first gain-range state described by Rogers and others (1980) while "GAIN RANGE 2" (GR2) is the extra gain-range state introduced by the expansion card. When in the NGR state the amplifier gain is 340*2**n, where n is between 0 and 7 and selected via a switch on the amplifier board. Usually the background signal is less than 10 percent of full-scale if the switch has been set properly.

When an event occurs, the signal will have to be 6dB into the clipping region of the NGR state before going into the GR1 state. While in GR1 state the gain is now 34*2**n, or one-tenth of the original gain. If the signal increases 20dB into the clipping region of GR1, then the GR2 state is entered. This causes another drop in gain such that the gain is now 0.68*2**n or one-five hundreth of the original gain.

Figure 1 indicates that although the ratio in dB of the smallest signal to the largest signal that can be linearly recorded is over 90dB, there exist two regions of clipping within this large dynamic range. This does not mean, for example, that any signal above 40dB but less than 46dB will be clipped. The explanation of this has to do with the hysteresis of gain-range states as discussed below.

A signal is amplified linearly until it momentarily exceeds a value 6dB above the clipping level for GR1. At that time the gain is reduced by a factor of ten and will stay reduced until the signal remains strictly below one-half of the old threshold for six seconds. To indicate the changed gain state a pulse is output onto the record three seconds after entering GR1. If the signal continues to increase, it will encounter the second clipping region which is 20dB wide. Once again if the signal momentarily exceeds this 20dB threshold, GR2 will be entered. This reduces the gain by an additional factor of fifty. The system will leave this lowest gain state if the signal stays 6dB below the threshold for entering GR2 for 48 seconds. A unique code for GR2 occurs 45 seconds after GR2 is entered. Initially the system will return from GR2 to the NGR state, but if the amplitude is still high enough the GR1 state may be entered again instanteously. The 6dB of hysteresis used in GR1 and GR2 adds stability to the gain by preventing excessive gain switching. Table 1 summarizes the exact values of the various thresholds,

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Note: ** means exponentiation

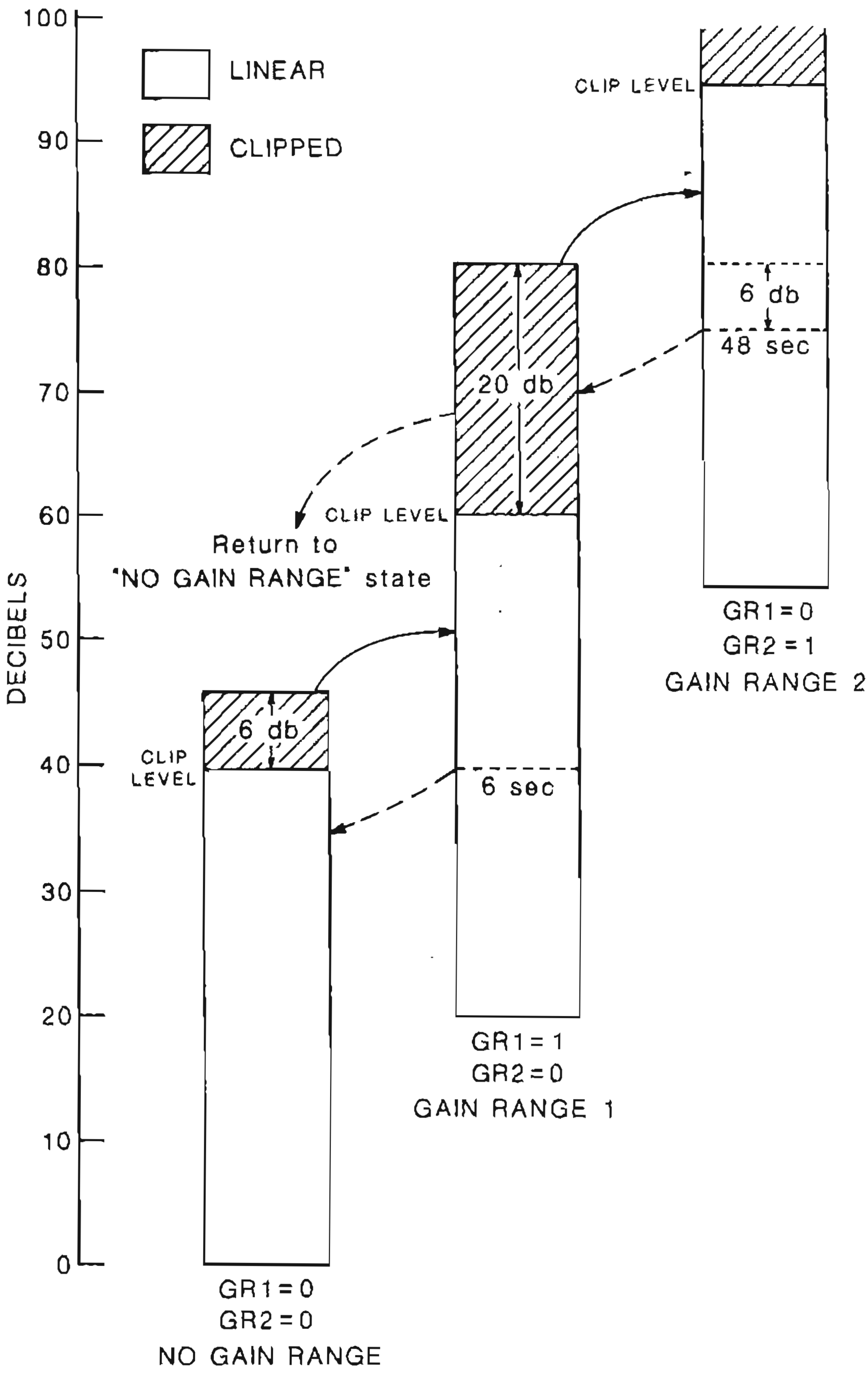


FIG. 1 A1VCO GAIN RANGE DIAGRAM

	GR1	GR2
Enter	> 6dB above clip level	> 20dB above clip level
Leave	< clip level for 6.02 s	< 14dB above clip level for 48.18 s
Min. Time	6.02 seconds	48.18 seconds
Code onset	after 3.01 seconds	after 45.18 seconds
Code duration	0.188 second	1.51 second
Code Freq.	pulse*	5.3 Hz
Gain Reduction	10	50 (from GR1)

*Note: pulse polarity corresponds to signal causing GR1

TABLE 1 - Gain-Range Constants

delays and characteristic signals described above while Figure 2 displays the action of both gain-range steps on a seismogram and test signal.

Although both gain states occur instantaneously, GR2 cannot force the amplifier into the linear region instantaneously as GR1 does due to limitations (described below) in the amplifier. A period of several seconds is needed before the amplifier settles during which time the signal is biased towards one of the supply voltages.

Finally, a second mode of operation is possible which allows the user to choose the signal level required for GR2 without regard to the gain setting of the amplifier. One use for this feature would be to have a network of stations all trigger at the same point regardless of gain setting. Of course, when this mode is used the dynamic range of the system depends on the trigger point selected. This mode is activated by jumpering the "SEL" pins on the header and selecting the proper code for the threshold desired. The threshold will be determined by the code produced via the other three jumper wires. In general, this voltage will be 0.8*2**(-G) volts, where G is the decimal value of the binary code. For example, with all three code jumpers present the code value is 0, so the threshold voltage will be 800 millivolts.

Circuit Operation

1. Gain-Ranging. The signal from the L-4 geophone is imput to U8, a differential amplifier as shown in Figure 3. This amplifier has a gain of unity and is used mainly as a buffer. The output of U8 goes to the threshold detection circuitry and to another amplifier with a gain of 0.432. The two operational amplifiers (opamps) U19 and U20 detect any signal which exceeds the thresholds -VTH and +VTH. As soon as this occurs, flip-flop U12 is set which releases the reset on counters U16 and U5. These counters keep track of the time interval since the last time either threshold was exceeded. If 48 seconds is reached, U5 will output a pulse to U12 and GR2 will be reset.

Several other things happen when GR2 goes high. The OVERIDE line goes high which causes the amplifier to switch inputs to auxillary channel "H" from the normal geophone input. AUX H is the geophone signal reduced by the gain of U13. Also GR1 is disabled by GREN1, the output of AND gate U25. When all these changes are taken into account, the system gain is reduced by a factor of 500 relative to GR1 = 0 or no gain range. Finally, GR2 causes a -6dB change in VTH by switching R68 out of the feedback loop.

Normally, the reference voltage of diode D4 is attenuated by U21 to 800 millivolts. When R687 is switched in, the output is reduced to 400 millivolts. This causes the 6dB change in threshold for leaving GR2. In either case, the output of U21 is fed to the resistor ladder network of U7. The output of U7 (VTH) is controlled by either the jumper wires on the header plug or by the gain switch on the amplifier board. These thresholds are set to produce the gain switching action shown in Figure 1.

Although this gain switching is instantaneous, the signal out of the amplifier will tend to be at either power supply rail for two or three seconds due to saturation of opamp U4 on the amplifier board. This saturation effect is due to the blocking capacitor before the opamp being unable to instantaneously change voltage when the input is switched to the lower gain channel.

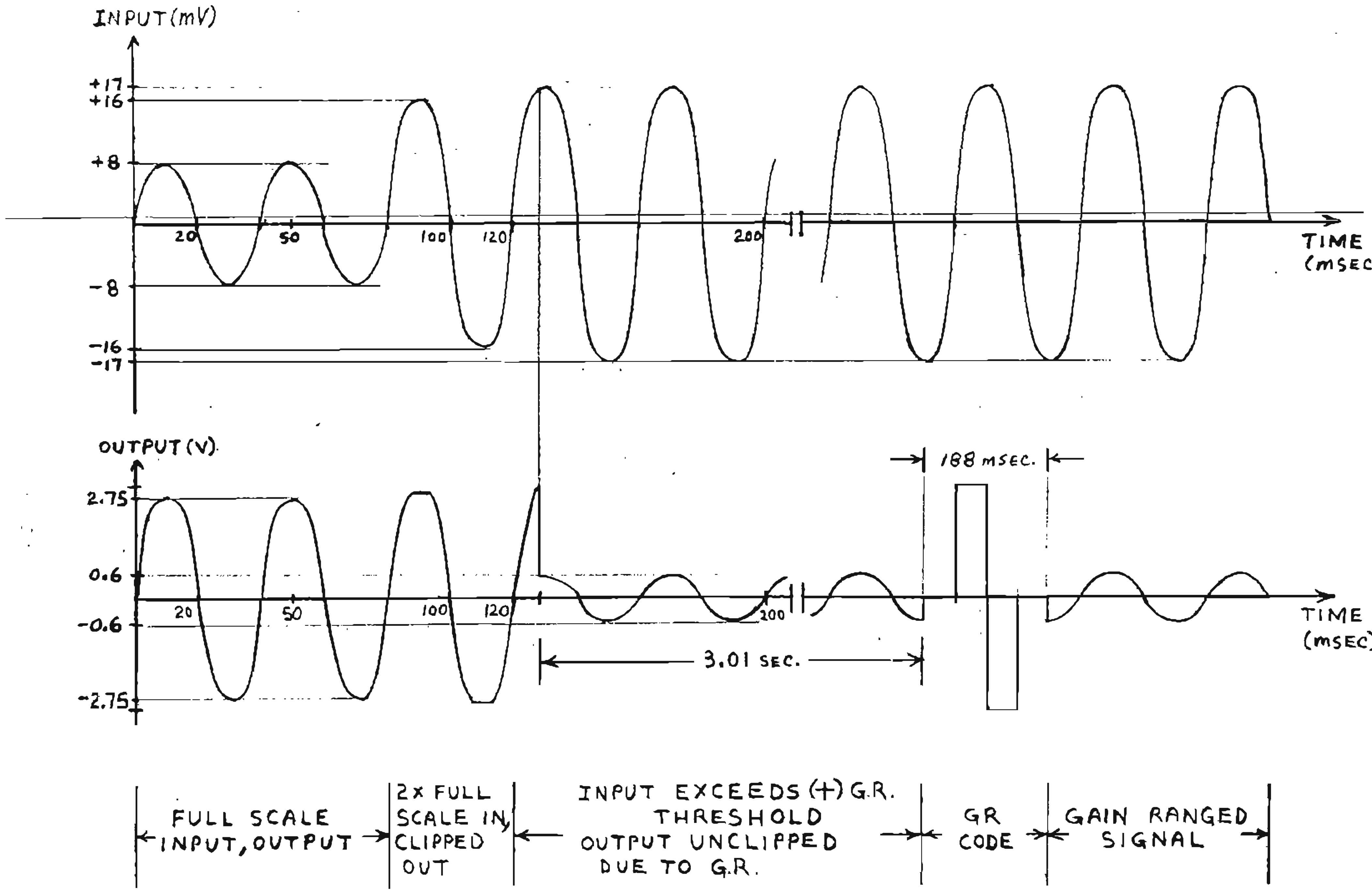


FIG 2a
WAVEFORMS DEMONSTRATING GAIN RANGE AND GAIN RANGE CODE
FOR POSITIVE EXCURSION (G=0)

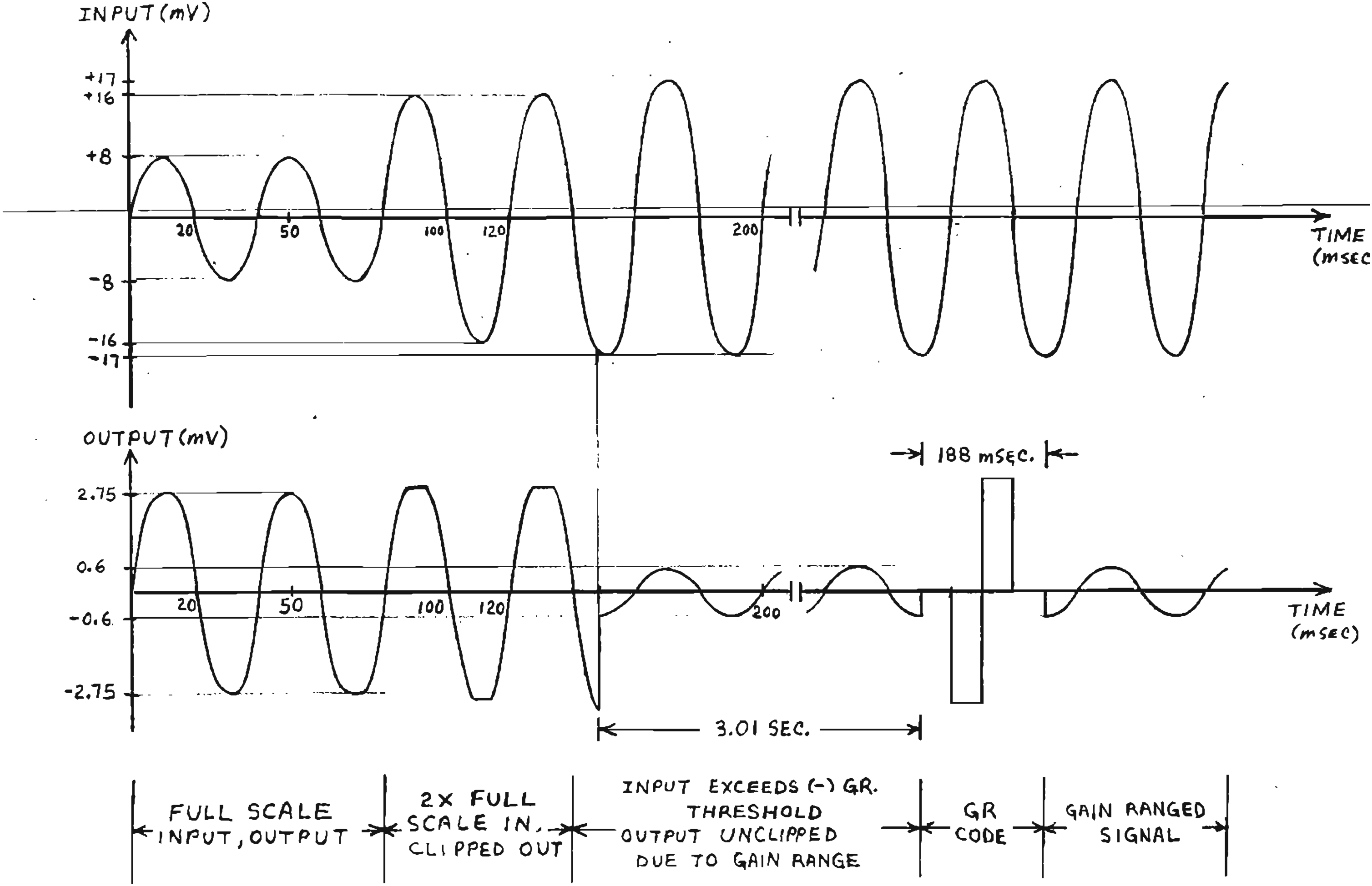


FIG. 2b
WAVEFORMS DEMONSTRATING GAIN RANGE AND GAIN RANGE CODE FOR NEGATIVE EXCURSION (G=0)

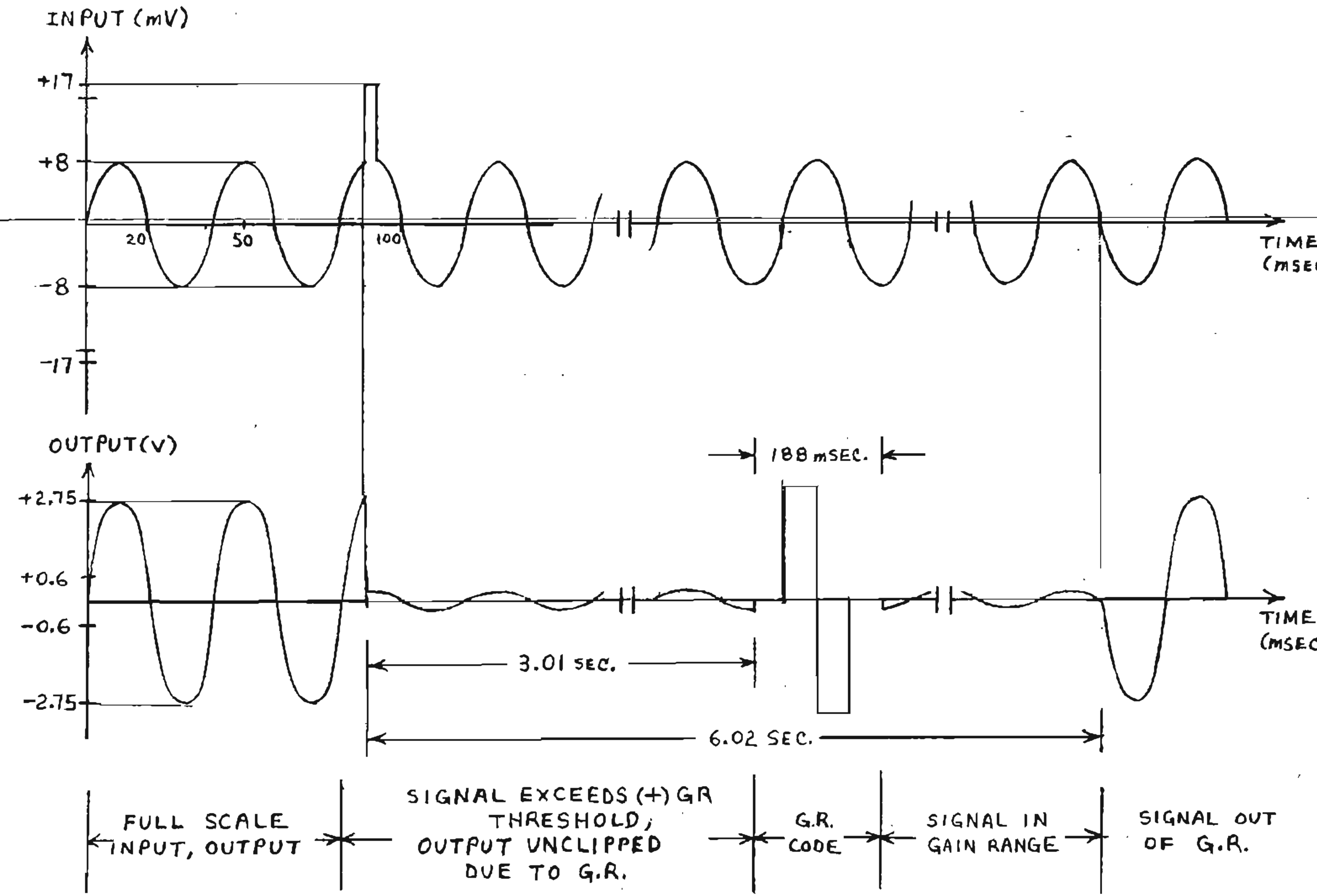


FIG. 2C
WAVEFORMS DEMONSTRATING MINIMUM GAIN RANGE TIME

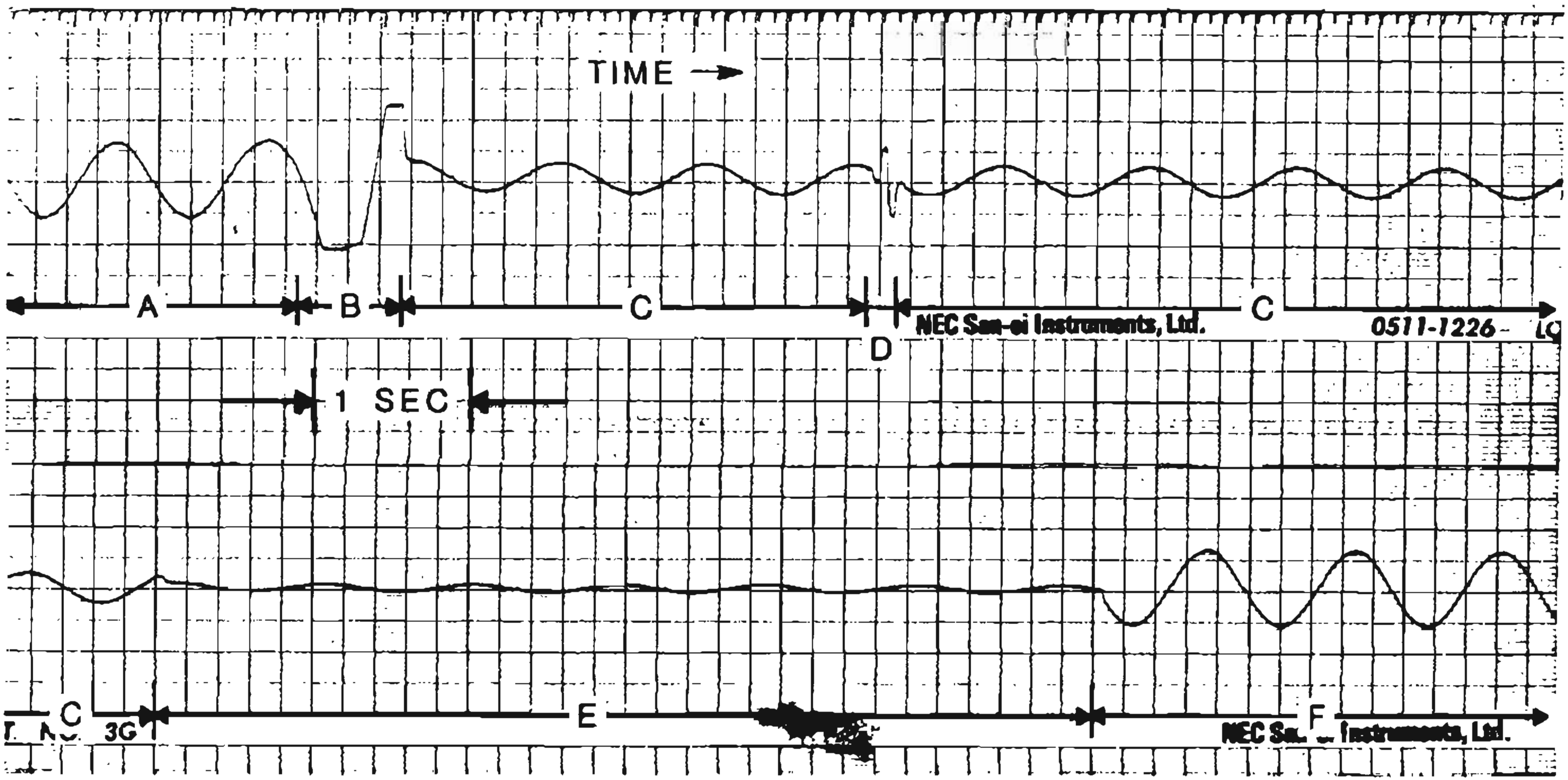


Fig. 2D
Strip Chart Demonstrating GR1

Region A:	GR1 = 0, Unclipped
B:	GR1 = 0, Clipped, input increased
C:	GR1 = 1, Unclipped, input same as "B"
D:	Gain range code (positive going)
E:	GR1 = 1, Input decreased to 1/3 of "C"
F:	GR1 = 0, Input same at "E"

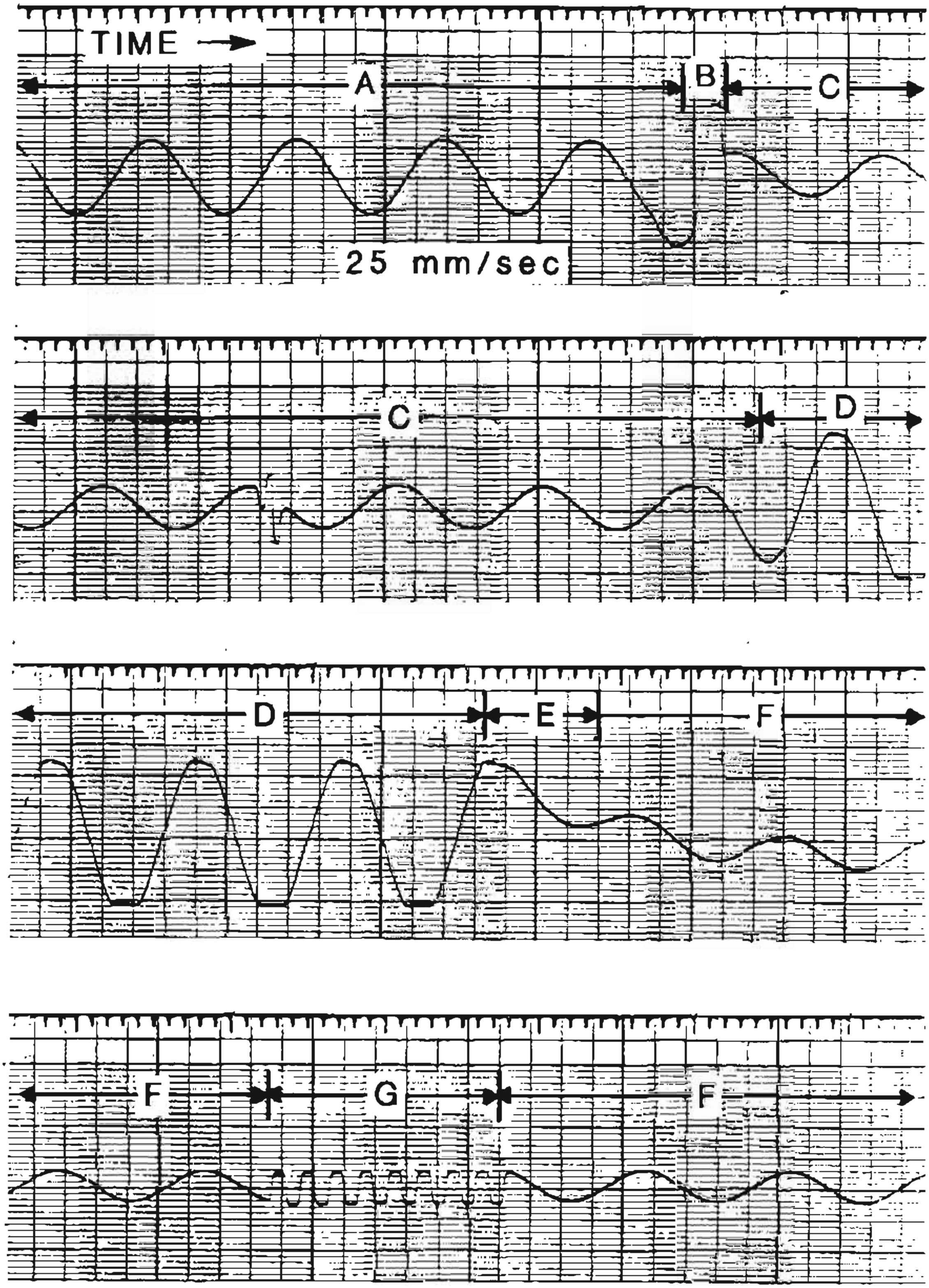


Fig. 2E
Strip Chart Recording Demonstrating GR1, GR2
(Record is not continuous)

Region	Gain State	GR1	GR2	Comment
A	No gain range	0	0	Unclipped
B	No gain range	0	0	Clipped
C	GR1	1	0	Unclipped
D	GR1	1	0	Clipped
E	GR2	0	1	Biased toward positive supply
F	GR2	0	1	Unbiased, unclipped
G	GR2	0	1	GR2 Code

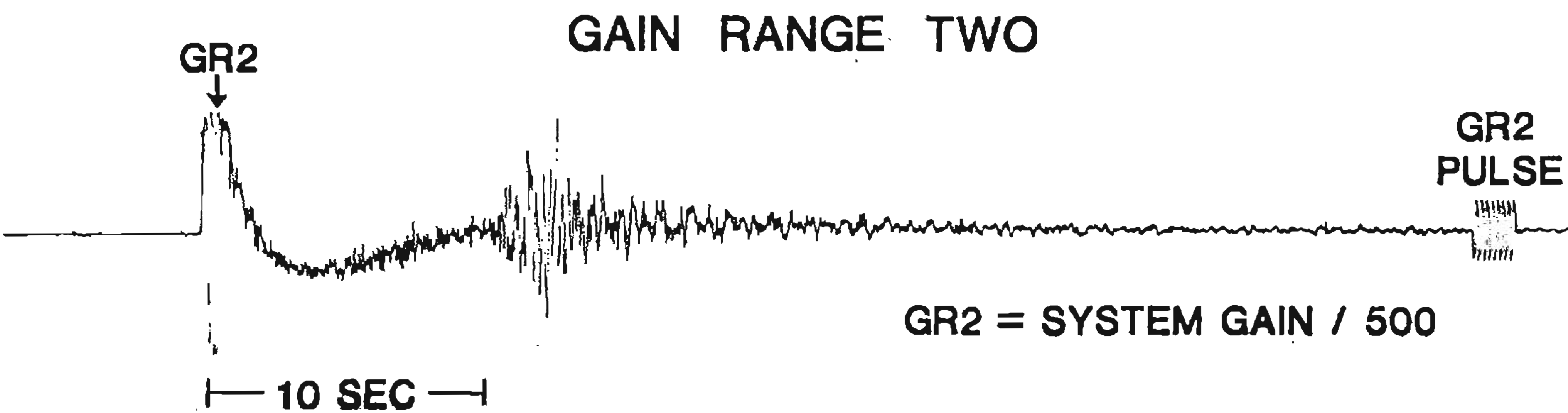


FIG. 2F
GR2 PLAYBACK

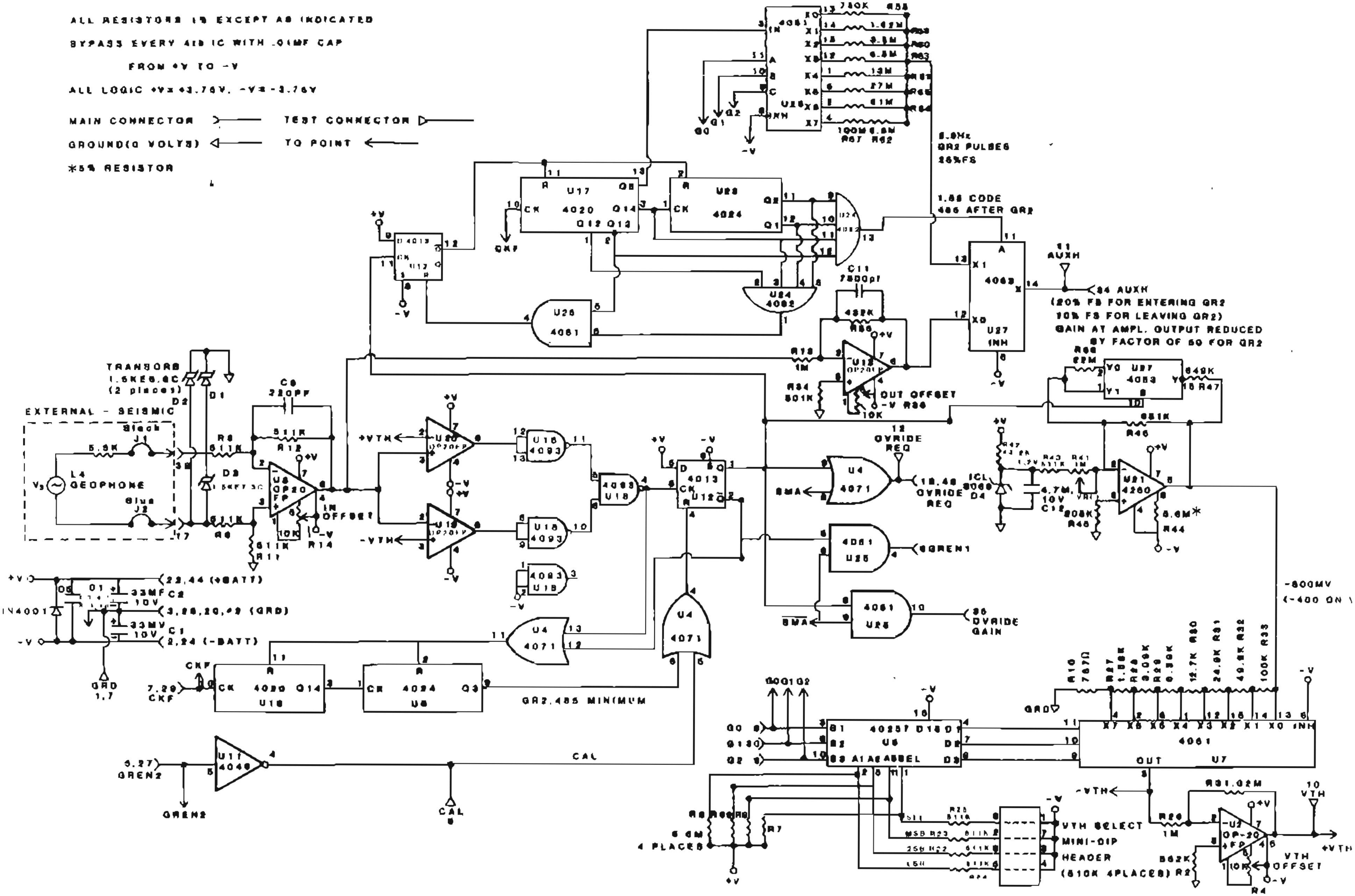
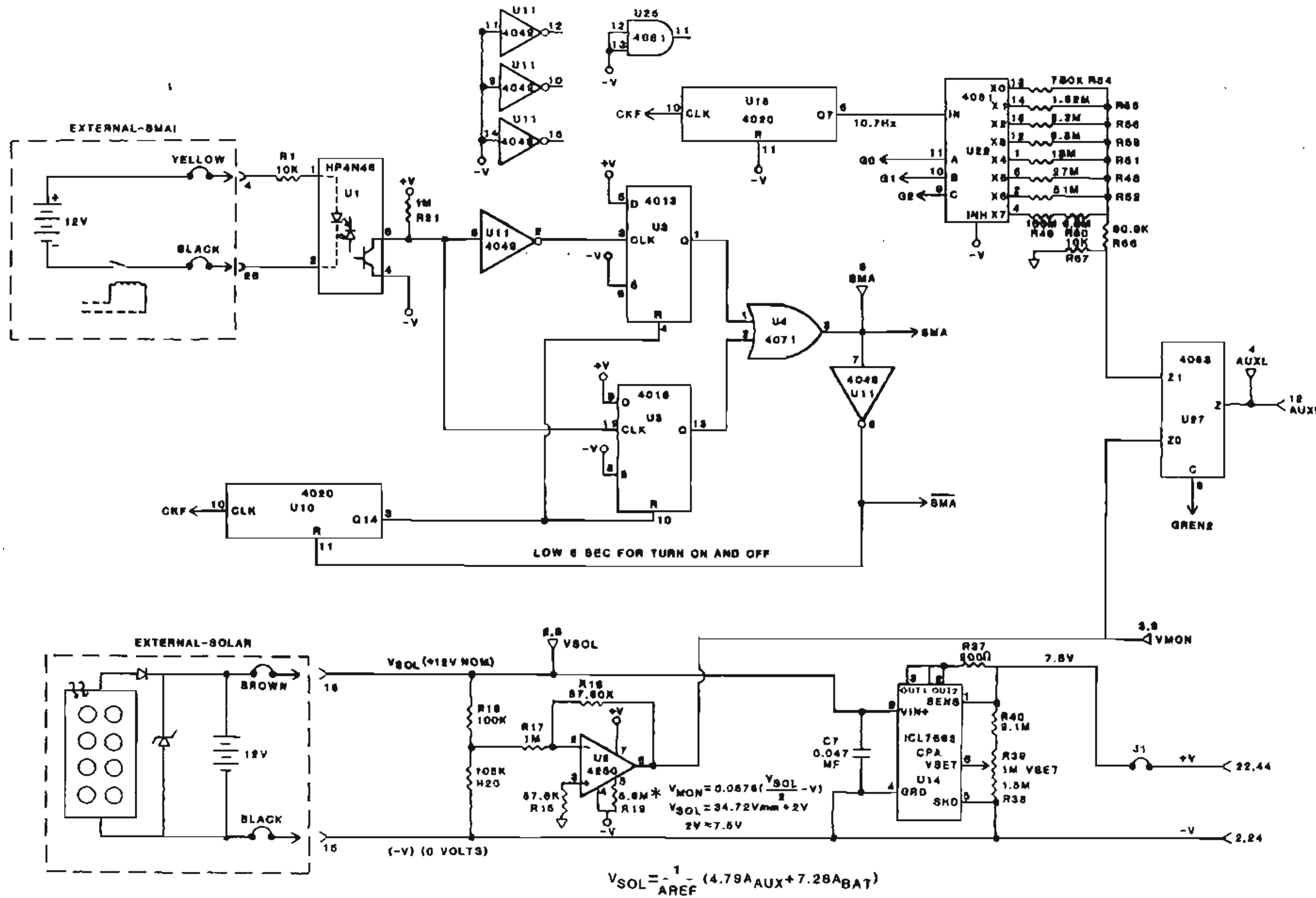


FIG.3 A AIVCO OVRIDE CONTROLLER-GR2 SECTION



$V_{SOL} = -\frac{1}{A_{REF}}(4.79A_{AUX} + 7.28A_{BAT})$

FIG. 3B AIVCO OVRIDE CONTROLLER-EXT SOLAR POWER, SMAI SIGNALLING SECTION

Finally, GR2 also causes a characteristic code to be generated. When GR2 goes high, U12 is set which enables counters U17 and U23. After counting CKF for 45 seconds, AND gate U24 goes high switching the output of U27 from the normal seismic signal to the 5.3Hz signal from U17-Q8. This signal is attenuated by U26 and its resistor ladder network to compensate for the various amplifier gains. After 1.5 seconds, the other section of U24 causes U12 to be reset which switches the output back to the seismic line.

2. SMA-1 Interface. The SMA-1 produces a 12 volt signal on a wire pair whenever the unit is recording. This signal is coupled through U1, an opto-isolator, to flip-flops U3. This arrangement will produce a set pulse on one flip-flop when the SMA turns on and a set pulse on the other flip-flop when it shuts down. For either set pulse, the corresponding Q-output causes the reset to be released on U10 and a pulse train output to appear on AUX L This pulse train shown in Figure 4 will replace the normal seismic output until U10-Q14 goes high which resets the two flip-flops. The pulse train is a characteristic signal of 10.7 Hz of 6 second duration and will be present twice for each activation of the SMA.

3. Solar Monitor. The solar battery voltage is processed by U9 such that its output voltage is 0.0576* (VSOL/2-VBATT) where VSOL is the solar battery voltage and VBATT is the VCO voltage from ground to the positive supply. Normally, VMON is present on AUX L. During the calibration cycle the voltage is included and can be calculated by comparison to the reference voltage of 138 millivolts.

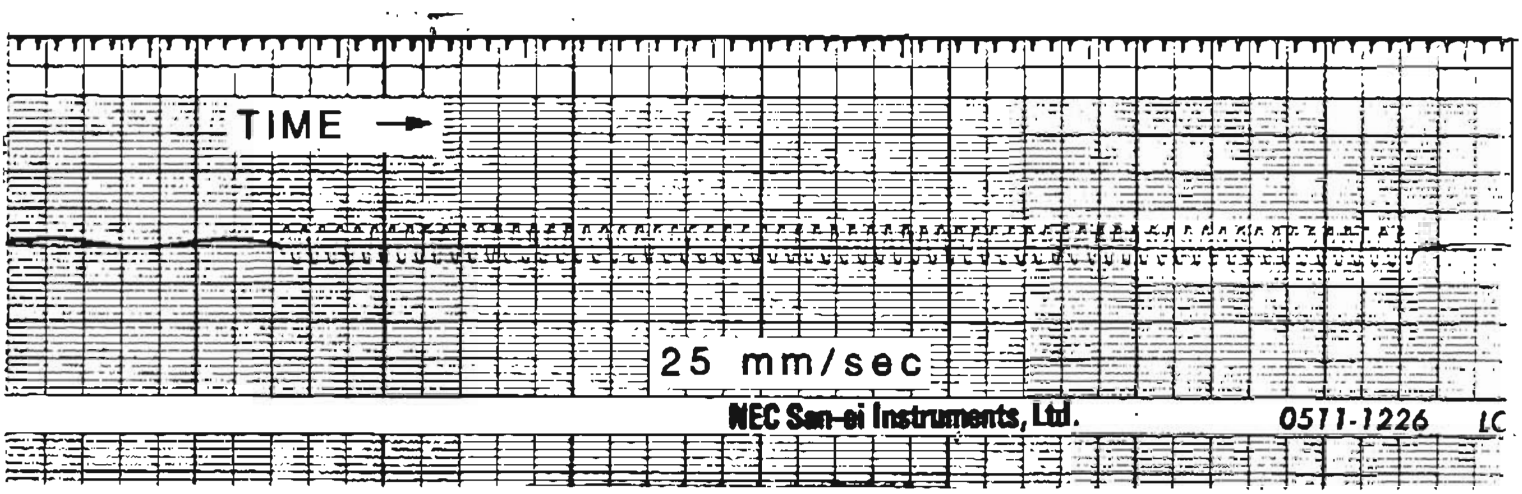


Fig. 4
SMA Trigger Signal

1. Rogers, J. A., and Maslak, S., Lahr, J. C., 1980, A Seismic Electronic System with Automatic Calibration and Crystal Reference, U.S. Geological Survey Open-File Report 80-324, 130 p.