THE DEVELOPMENT OF A TELEMETRY SHOCK MEASURING SYSTEM

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ABSTRACT

THE DEVELOPMENT OF A TELEMETRY SHOCK MEASURING SYSTEM

by Stephen Russell Pierce

A self-contained telemetry shock measuring system has been developed for use in the measurement of package environment. A description of the operation and components of the system is presented. The system is capable of measuring shocks of 10 to 250 g's with durations of 0.24 millisecond to 250 milliseconds.

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INTRODUCTION

With the increased demand for sophisticated packaging, the need has arisen to measure the environment through which a package travels on its way to the ultimate consumer. This environment includes both the handling and the in-transit environments. This paper is concerned with the development of instrumentation capable of measuring the mechanical shock components of these environments. The intransit environment is defined as those shocks occurring while the package is being moved by any transport vehicle other than a handling vehicle such as a lift truck. Those shocks occurring during loading, unloading, and physical movement into and out of storage are defined as the handling environment. Once the packaging designer knows the shocks encountered in these environments, he will be better prepared to develop a package that will provide protection for the product.

The development of instrumentation for measuring the shock components of the environment was undertaken with the understanding that such instrumentation should be self-contained, of minimum size, and capable of measuring the shocks encountered in the package environment. After studying the instruments available for measuring shock, it was decided that accelerometers having a frequency response from 2 to 5,000 cycles per second were adequate for measuring shocks in the package environment. Other types of instrumentation were discounted due to their inadequate frequency response. Although an accelerometer had adequate frequency response for measuring the shock environment, it lacked the requirement of being self-contained. The accelerometer is not capable of recording within itself. This brought about the problem of finding a way to record the output from the accelerometer, which is the measurement of the shock, and an adequate way to get the signal from the accelerometer to equipment capable of recording the shocks.

The Shock And Vibration Handbook defines telemetry "as the indication, measurement, or integration of a quantity at a distance by electrical translating means." [1] It goes on to say that "this definition implies a complete system: transducers to convert the measurand to an electrical equivalent, encoding and transmitting equipment, and receiving and decoding equipment capable of providing an indication or record of events as they occur at the remote location." [2]

There are two types of telemetering systems available. They are designated as the FM/FM system and the PDM/FM system. The FM/FM system is a frequency division system. A PDM/FM system is a time division system.

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[1] Cyril M. Harris and Charles E. Crede, Shock And Vibration Handbook (New York: McGraw-Hill, Inc., 1961), p. 19-76.

[2] Ibid, p. 19-76.

A PDM/FM system is a pulse duration modulation on a frequency modulated carrier. [3] Data channels are sequentially sampled by commutation. This type of system was not used because of its low frequency response. The maximum frequency response of a PDM/FM system is from 1 to 3 cycles per second, which is much lower than the required frequency response.

An FM/FM system is a frequency division of frequency modulated subcarriers transmitted by a frequency modulated radio-frequency carrier. [4] All this means is that one modulated frequency is used to modulate another frequency. This system of telemetry was chosen because of its frequency response capabilities. FM/FM telemetry offers frequency response capabilities from 0 to 2,100 cycles per second.

FM/FM telemetry can be used in either a single channel system or a multiplex system. A multiplexing FM/FM telemetry system utilizes two or more different subcarrier frequencies to modulate one transmitter. Each channel in the system has a different subcarrier frequency that is linearly mixed with the other subcarriers of the system by a mixing amplifier. The mixing amplifier, which is sometimes called an adder network, performs an arithmetic addition of the voltages of the subcarrier frequencies. The output from the adder network goes into a single transmitter whose

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[3]Ibid, p. 19-77.

[4]Elliot L. Gruenberg, Handbook Of Telemetry And Remote Control (New York: McGraw-Hill, Inc., 1967), p. 6-3.

carrier frequency transmits all the subcarrier frequencies. With multiplexing, only one receiver is needed because there is only one radio-frequency carrier involved. The output of the receiver is fed in parallel to subcarrier discriminators which select the subcarrier for which they are set and translate it back into analog input. Using all the IRIG (see Appendix 2) FM/FM telemetry subcarrier oscillator bands available, 18 different subcarrier oscillators could be used to simultaneously frequency modulate one radio-frequency transmitter. With each channel of telemetry in a multiplexing system having a different subcarrier center frequency, the frequency response of each channel will be different. The IRIG FM/FM telemetry subcarrier oscillator bands are arranged so that there is no overlap from one band to another.

When using multiplexing telemetry, one cannot utilize the maximum frequency response available with single channel telemetry. The frequency response of a given band of telemetry is based on the maximum deviation of the subcarrier frequency from its center frequency and a modulation index of five.[5] Therefore, with a lower subcarrier center frequency, one has a lower frequency response.

Single channel telemetry was decided upon because of its high frequency response capabilities. Single channel telemetry has one radio-frequency carrier for each sub-

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[5] Harris and Crede, p. 19-79.

carrier frequency and one receiver for each radio-frequency carrier. This system enables one to use the subcarrier oscillator with the highest center frequency and frequency response for each channel in the system.

DEVELOPMENT OF THE TELEMETRY SHOCK MEASURING SYSTEM

Description of system operation

The operation of one complete channel of the telemetry shock system will be described by the output from each component in the system. All channels operate in the same manner, therefore, the description of one channel of the telemetry shock system will be adequate for the whole system. Shown in figure 1 is a diagram of the outputs from each component in the system.

The first component in the system is an accelerometer. The accelerometer measures shock and has an output voltage proportionate to the magnitude of the shock. Assume that some external force applies a sinusodial shock of 250 g's for 10 milliseconds to the base of the accelerometer. Any shock applied to the base of the accelerometer is defined as a positive shock and a shock applied to the top of the accelerometer is defined as a negative shock. An 18 volt battery is used to supply power to the accelerometer. The 18 volts from the battery flow through a coupler before entering the accelerometer. The coupler consists of a 10,000 ohm source resistor and a capacitor. The resistor provides a current limiting device for the accelerometer and the capacitor prevents d-c feedback into the accelerometer from other components in the system. The sensitivity of the accelerometer in this system is 10 millivolts per g. Therefore, with a positive shock of

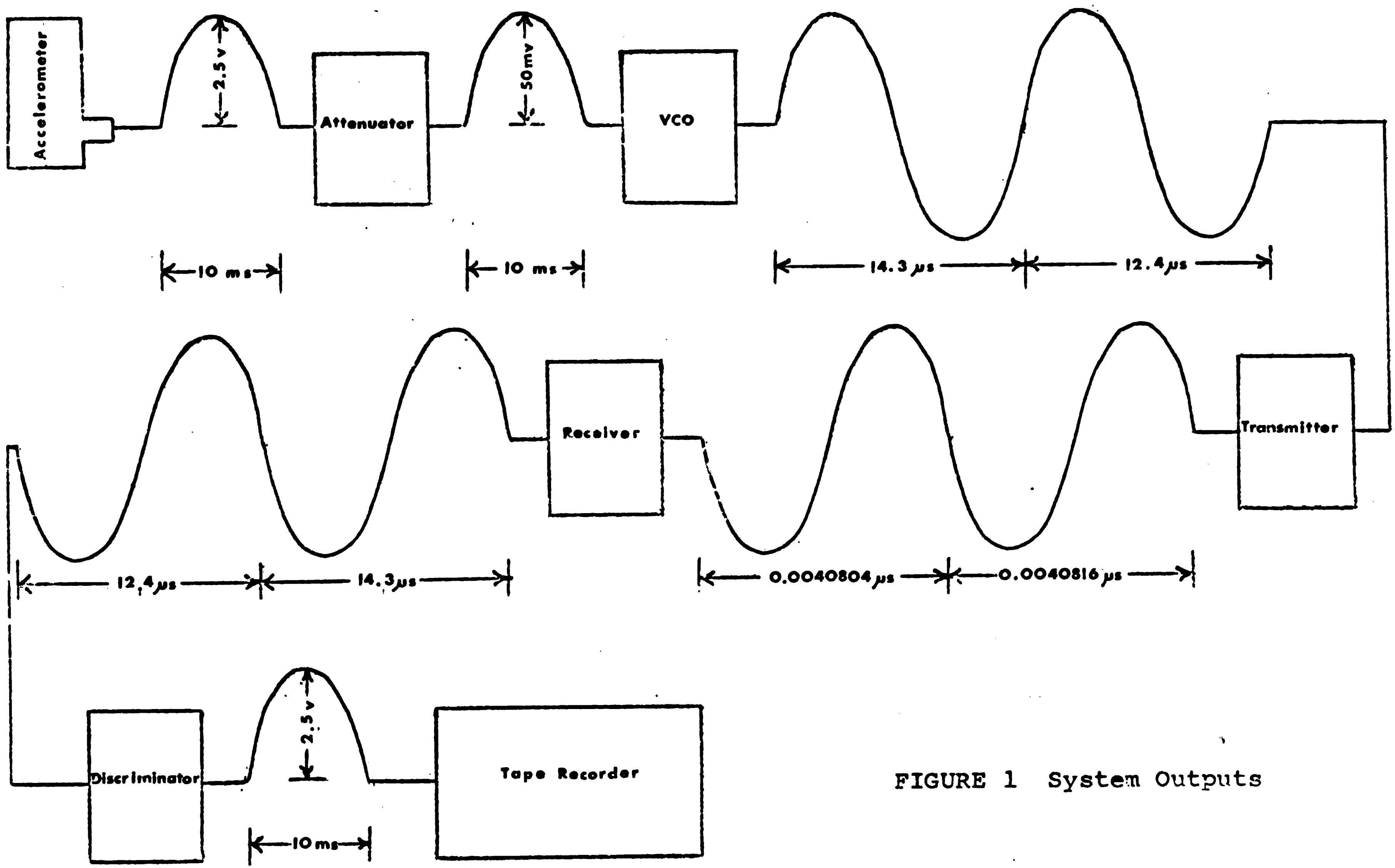


FIGURE 1 System Outputs

250 g's, the output of the accelerometer will be a plus 2.5 volts. The output of the accelerometer increases from 0 volts to 2.5 volts in 5 milliseconds and then decreases to 0 volts again in another 5 milliseconds when the 250 g-10 millisecond shock is applied. This is shown in figure 1.

The voltage output from the accelerometer is too large to be compatible with the input sensitivity of the voltage controlled subcarrier oscillator. Therefore, the voltage is reduced by a ratio of 50 to 1 by running it through an attenuator. The attenuator consists of two resistances in series to ground that simply reduce the voltage input by some factor depending on the resistances. The output voltage from the attenuator is a plus 50 millivolts for the 250 g shock under consideration.

This plus 50 millivolts then goes into a voltage controlled subcarrier oscillator (VCO). The function of the VCO is to convert the input voltage to a subcarrier frequency. An 8.4 volt battery supplies power to the VCO and a transmitter. With a 0 volt input the subcarrier oscillator has an output of 70,000 cycles per second. This is called its center frequency. The input sensitivity of the VCO is a ± 50 millivolts. The ± 50 millivolt input will vary the center frequency by ± 15 per cent. Hence, the plus 50 millivolts input into the VCO will give an output signal from the VCO of 80,500 cycles per second. (15% of 70,000 cps = 10,500; 70,000 cps +

10,500 cps = 80,500 cps). The change in frequency output from the VCO is presented in figure 1 by showing one cycle of each frequency and the period of the frequencies. The first cycle of output represents 0 volts input into the VCO and the second cycle shows 50 millivolts input. The intermediate frequencies between the 70,000 cycles per second center frequency and the 80,500 cycles per second modulated frequency are not shown in the diagram. However, the frequency is increased proportionately from the center frequency as the voltage increases until the maximum 80,500 cycles per second frequency is reached. Then the frequency is decreased to the center frequency as the voltage drops back to 0 volts. It takes 5 milliseconds for the frequency to reach its maximum and 5 milliseconds for the frequency to decrease to the original subcarrier oscillator center frequency. This maintains the duration factor of the shock recorded for later reduction. All of the above mentioned frequencies are called subcarrier frequencies because they will be used to modulate another carrier frequency. The carrier frequency modulated will be that of the transmitter.

The transmitter in this system has a carrier frequency or center frequency of 245 megacycles per second. This carrier is a radio-frequency carrier which means it is capable of sending signals without a connecting wire. The radio-frequency carrier is modulated ± 75 kilocycles per second with a ± 15 per cent modulation of the subcarrier frequency. Therefore, with the subcarrier frequency output of 80,500 cycles per second, the radio-frequency carrier will be modulated to 245,080,500 cycles per second. This change in frequency output is shown in figure 1 in the same manner it was shown for the output of the VCO. The radio-frequency carrier is increased to its maximum frequency by an increase input from the subcarrier frequency and then is decreased to its center frequency as the subcarrier frequency decreases to its center frequency. A shield was built into the transmitter to reduce proximity effects on the carrier frequency. This same shield is arranged to act as the radiating element eliminating the need for an external antenna. The signal radiated from the shield is sent through the air to a receiver located remotely from the transmitter.

From this point in the system, it is the function of the components to reduce the transmitted frequency to the original voltage output of the accelerometer. The receiver's function is to select the carrier frequency of the transmitter, to reject all other frequencies received by the antenna and to reduce the carrier frequency to the original subcarrier frequency. The output of the receiver is shown in figure 1. This output is the same as the output from the voltage controlled subcarrier oscillator. The receiver simply reverses the process of the transmitter. Output from the receiver is then fed into a subcarrier discriminator.

The function of the subcarrier discriminator is to reduce the subcarrier frequency to a voltage. This component functions in reverse of the VCO. Therefore, the output of the subcarrier discriminator will be the ± 2.5 volt signal output from the accelerometer.

In summary, the voltage output signal of the accelerometer, which is a measure of the shock, is converted to frequencies and then changed back from the frequencies to the original voltage output of the accelerometer. This system performs the function of accurately measuring shock from a remote location without the aid of wires.

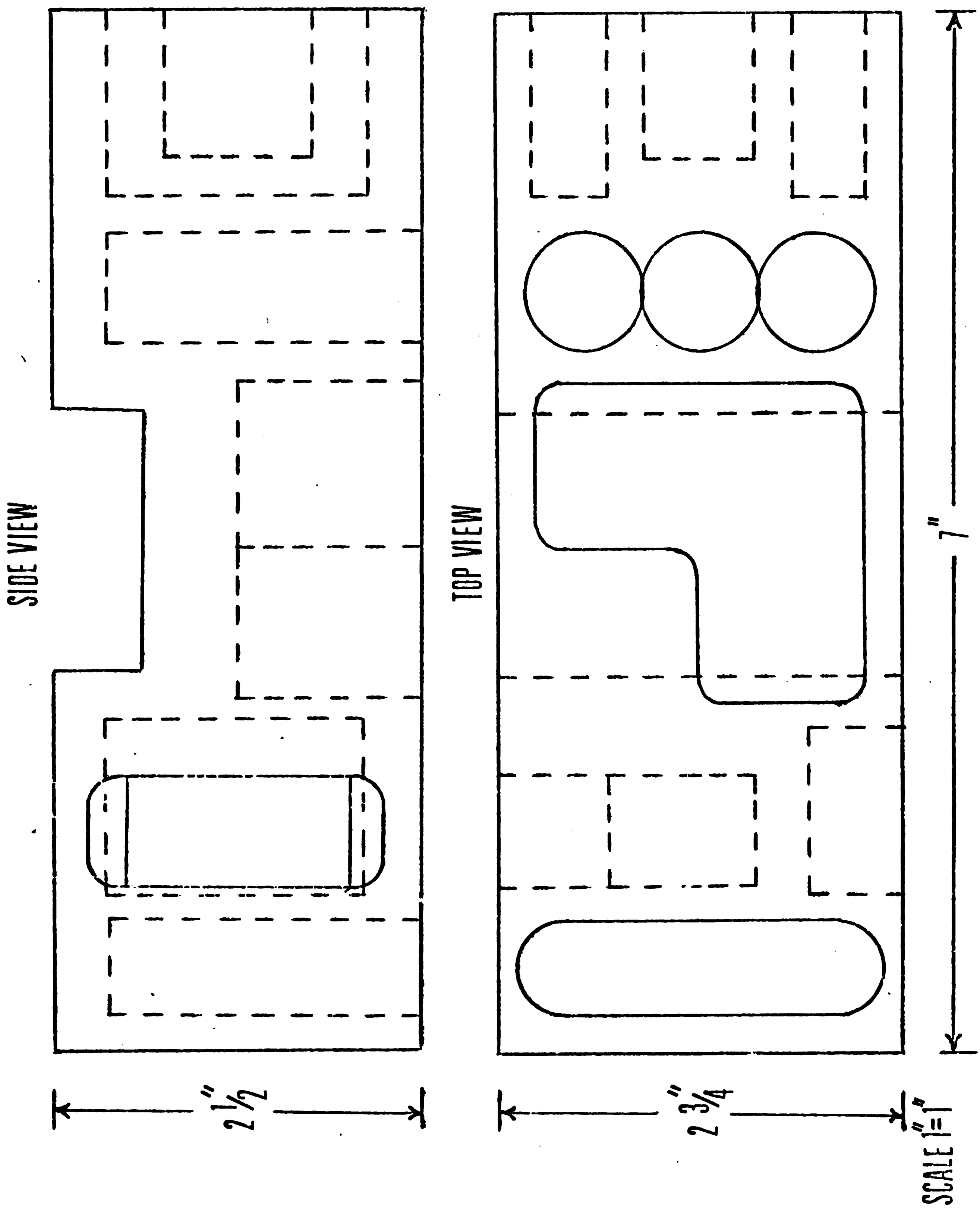
Component description

The development of a telemetering shock measuring system was undertaken to provide a system capable of measuring shocks occurring inside the package as well as shocks transmitted to the package as a whole. A package was needed that could house and protect the internal components of the system. A mahogany wood block was selected for the package because of its shock properties (see Appendix 1). The wood block was cut to the desired size and shaped to accomodate the components of the system. The block is shown in figure 2.

A block diagram of the overall system is shown in figure 3. The first components in the system are three Kistler Model 818 Piezotron accelerometers which are used to measure the shock. The accelerometers are mounted triaxially in the mahogany block which permits the system

Figure 2

Telemetry Package



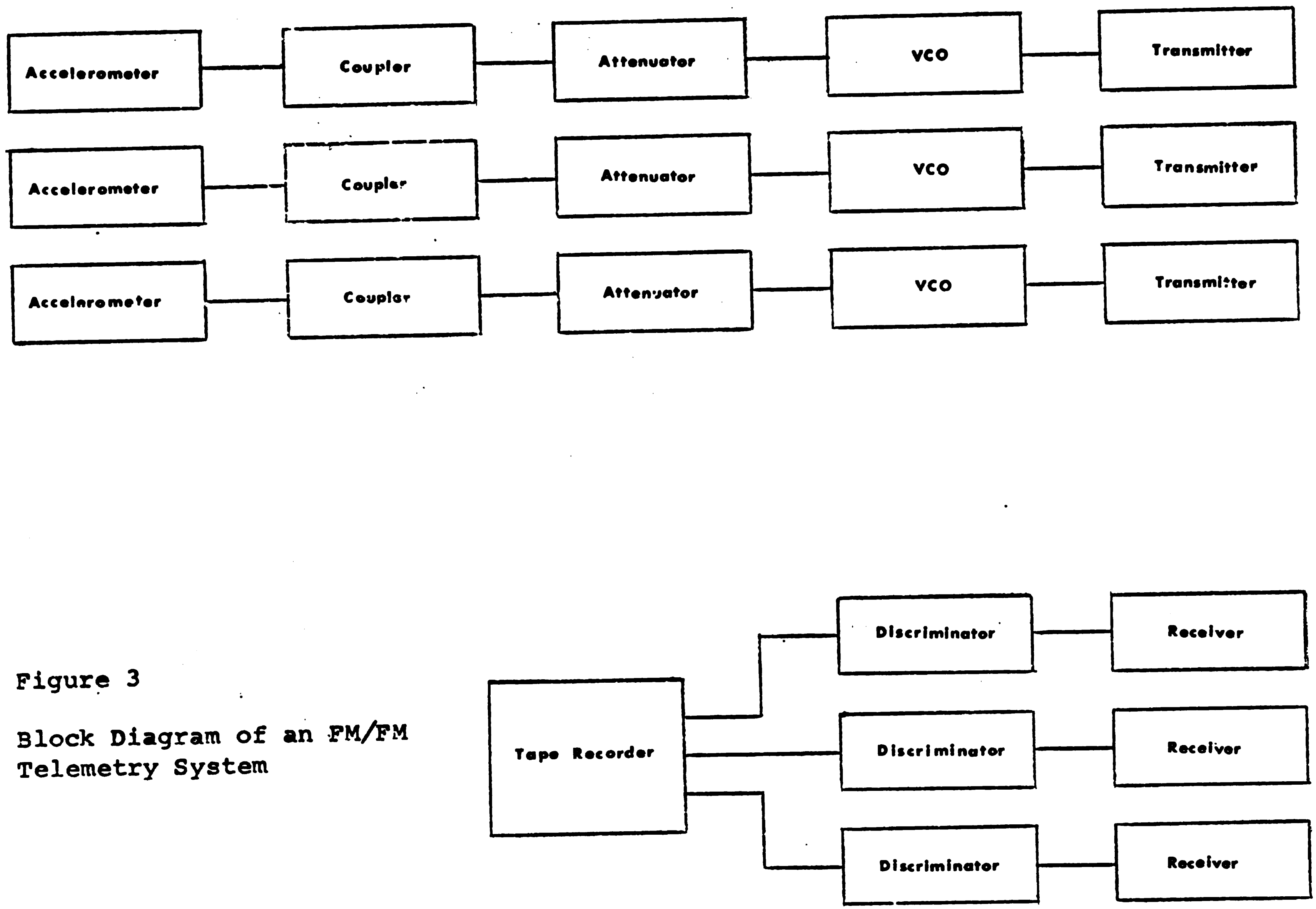


Figure 3

Block Diagram of an FM/FM Telemetry System to measure a shock in any direction.

A Kistler Model 818 Piezotron accelerometer is a low impedance piezoelectric accelerometer which utilizes the advantages of exceptionally high open-circuit voltage sensitivity and the stability of quartz crystal elements. When power is supplied to the accelerometer, the quartz crystal inside is saturated with electrons. When an externally applied force deforms the quartz crystal, electrons flow to a capacitor. Depending on the quantity of electrons released and the size of the capacitor, a voltage of some magnitude is produced. All Piezotrons have a standardized voltage sensitivity of 10 millivolts per g which simplifies the multichannel operation of the system.

The second components in the system are couplers. A coupler consisting of a 10,000 ohm source resistor and a coupling capacitor is required for each accelerometer. The 10,000 ohm resistor is used for reference sensitivity and the coupling capacitor is used in series with the output lead to block the bias voltage from the direct coupled (d-c) equipment used in the rest of the system. An 18 volt power supply is connected to the couplers which supply the Piezotrons with 1.8 milliamps. The output from this accelerometer coupler system is $\pm$ 2.5 volts. The input sensitivity of the voltage controlled subcarrier oscillator

(VCO) into which the signals are to be fed is ± 50 millivolts. Therefore, the output voltage of the accelerometer signal had to be attenuated to be acceptable for the VCO.

Attenuators comprise the third series of components. An attenuator consists of two resistances in series with one of the resistances grounded. These attenuators reduce the voltage output of the accelerometers by a ratio of 50 to 1. In this system, the voltage flows from the accelerometer system into a 27,400 ohm resistor. This resistor is in series with a 547 ohm resistor which is in parallel with the output voltage lead to the VCO. The lead to the VCO takes the voltage output from the 27,400 ohm resistor which is 1/50 of the input voltage to that resistor.

The fourth components shown in the block diagram are voltage controlled subcarrier oscillators (VCO). The VCO units used in this system are Model 1125-E's, manufactured by Signatron, Inc. of Gardena, California. Voltage controlled oscillators are used to convert analog voltages to FM subcarrier frequencies. Any IRIG band is available for use with a VCO. The frequency response required dictates which IRIG band is needed. IRIG band E was selected for this system because of its high frequency response, 0 to 2,100 cycles per second. IRIG band E has a center frequency of 70,000 cycles per second and a ± 15 per cent deviation of the center frequency for ± 50 millivolts input. The subcarrier frequency is dependent on the voltage input to the VCO. With a 0 volt input, the subcarrier frequency will be 70,000 cycles per second and with a + 50 millivolts input the subcarrier frequency will be 80,500 cycles per second (15% of 70,000 cps = 10,500 cps; 70,000 cps + 10,500 cps = 80,500 cps). The output of the voltage controlled oscillator, the subcarrier frequency, is fed into mixing amplifiers or what is sometimes called adder networks.

When FM multiplexing telemetry is used, the adder network linearly mixes the frequency modulated output voltage from all the subcarrier oscillators in the system. This linear mixing is just an addition of the voltages. In this system, only single channels are used for each transmitter. Therefore, the adder network does not function as a linear mixer. The only function it serves in single channel systems is the prevention of feedback into the VCO.

Model 201 low powered transmitters manufactured by Signatron, Inc. comprise the fifth series of components. The purpose of the transmitter is to provide a modulated radio-frequency signal of sufficient power to reach a remote receiver. For typical environments, the usable distance is 50 feet. For more ideal environments, distances up to 300 feet can be obtained. These transmitters are available in the frequency range of 215 to 260 megacycles per second and are frequency modulated by the subcarrier frequency from the VCO. Plus or minus 100 per cent modulation of the subcarrier frequency will modulate the transmitter frequency $\pm$ 75 kilocycles per second. This modulated frequency is sent through the air waves to be picked up by a receiver.

The last three series of components in the system, the receiver, the discriminators, and the recording equipment, are external to the mahogany block and require external power.

The receivers in this system are Model 4200 manufactured by Signatron, Inc. They provide reception of signals in the 215 to 260 megacycle FM band which makes them compatible with the transmitters used. The receivers perform three functions. One, they select the desired radio-frequency from the other signals that are received by the antenna. Second, they amplify the selected radio-frequency carrier to a usable level. Third, they demodulate the radio-frequency to retrieve the subcarrier frequency that was the output of the voltage controlled subcarrier oscillators.[6]

The first function of a telemetry receiver is performed with two components. The first component is a tuning condenser similar to the tuning condenser in a home radio. This component allows one to tune in the carrier frequency. The second component is a radio-frequency amplifier filter which amplifies the signal and filters out frequencies other than the carrier frequency. The signal then goes

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[6]Gruenberg, p. 6-28.

through two intermediate frequency amplifiers that further amplify the signal and narrow the frequency band. The three amplifier-filter components serve the second function. Finally, the signal enters a demodulator which reduces the signal to the transmitted base band waveform.

The subcarrier frequency output from the receivers goes into the next series of components in the block diagram, the subcarrier discriminators. The subcarrier discriminators in this system are Model 3100-E manufactured by Signatron, Inc. They have an output of ± 2.5 volts which is the same as the output of the accelerometers. A subcarrier discriminator consists of four main components: a band pass input filter, limiter, demodulator, and a low-pass output filter.[7] The band pass input filter acts somewhat like the tuning condenser of the receiver in that it selects the desired frequency band and rejects all other frequencies. The signal then goes into the limiter/discriminator which demodulates the FM subcarrier frequency. After demodulation, the output goes through the low-pass output filter which removes undesirable noise from the signal. The signal is then amplified to a suitable output level.

The last block in the diagram is a magnetic tape recorder which is used for recording and storing the signals. The signals on the tape can be monitored at

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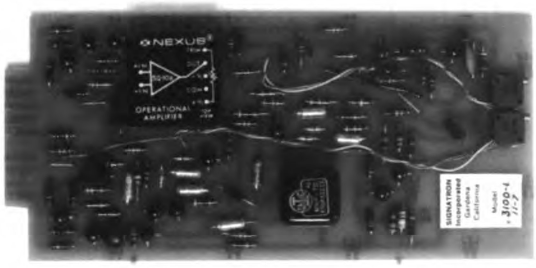
[7]Gruenberg, p. 6-40.

some later time with an oscilliscope. Pictures of the desired signals can be taken or the signals can be recorded on an oscillograph for permanent records.

The assembled shock measuring telemetry block is shown in figure 4. This block contains all the components in the block diagram up to the receivers. A subcarrier discriminator and receiver are illustrated in figure 5.

Figure 4

Assembled shock measuring telemetry package.



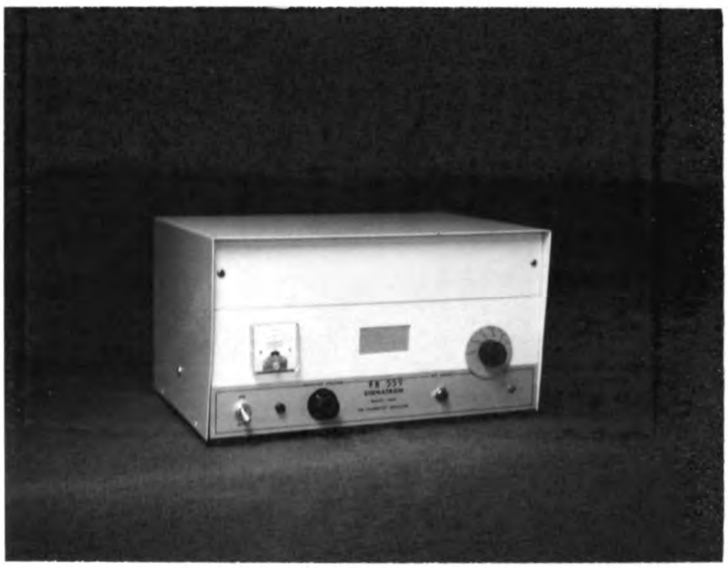


Figure 5

Subcarrier discriminator (top) and receiver (bottom).

CONCLUSIONS

The telemetry shock measuring system developed has been calibrated (see Appendix 1) and successfully used in both drop testing and inclined impact testing. The system has a frequency response from 2 to 2,100 cycles per second which makes it capable of measuring half sine shock pulses with durations from 0.24 millisecond to 250 milliseconds. The system is capable of measuring shocks with magnitudes from 10 g's to 250 g's. Shown in Table 4 are the results of a frequency calibration for the telemetry components of the system. As the frequency of a constant input signal was increased, the output voltage of the subcarrier discriminators decreased. All channels had a flat frequency response from 2 to 250 cycles per second. Therefore, half sine shock pulses with durations from 2 milliseconds to 250 milliseconds could be measured without any extra calibrations. Half sine shock pulses with durations from 0.24 millisecond to 2 milliseconds can also be measured, but the magnitude of the shock will have to be corrected using a calibration factor for the frequency of the shock. Complex shock pulses containing no components representing frequencies above 250 cycles per second will be accurately presented.

In additional studies, an attempt should be made to reduce the noise level of the system. If the noise level could be reduced to less than 5 millivolts, shocks and vibrations with magnitudes greater than 0.5 g could be measured.

APPENDICES

APPENDIX I

TELEMETRY SHOCK MEASURING SYSTEM CALIBRATION

In the development of the telemetry shock measuring system, each component was individually calibrated whenever possible and the system as a whole was calibrated. This appendix will present the procedure and results of these calibrations.

Instrumentation package

The instrumentation package was made from Honduras mahogany wood. The wood block was cut to the desired size and shaped to accomodate the measuring and transmitting components of the system. Honduras mahogany wood had been tested for shock transmissibility and the results revealed that this material had little effect on shock transmission. [8]

Test procedure

The instrumented package was fastened to the drop head of a L.A.B. Model 16-42-100 free fall shock machine as shown in figure 6. Sides and ends of the block were subjected to a series of shock pulses of known magnitude, duration and waveshape. A Kistler Model 808 S/N 128

[8] Stephen Pierce and Robert Fiedler, "A Determination of The Shock Transmission Characteristics of Mahogany" (unpublished technical research paper, School of Packaging, Michigan State University, 1967).

Figure 6

Telemetry package calibration mounting.

quartz accelerometer was mounted directly to the drop head as a control accelerometer. The three Kistler Model 818 piezotron accelerometers mounted triaxially in the block were the test accelerometers. The signals were monitored from the accelerometers without telemetry.

Half sine shock pulses of short duration were achieved with a rubber Vibra-Check deceleration pad (Lowell Ind.). Half sine pulses of long duration were achieved with a No. 1265 Pure Gum rubber pad (Queen City Rubber Co.). Saw tooth wave shapes were produced using lead pellets (molded in the School of Packaging laboratories, Michigan State University).

Signals from the control accelerometer were fed through a Kistler Model 565 S/N 193 charge amplifier into one channel of a Tektronix Model 564 storage oscilloscope. Signals from the test accelerometers were fed through Kistler Model 548B couplers into the other three channels of the same scope. A Tektronix oscilloscope camera C-12 was used to record the shock pulses.

Test results

Readings from the control accelerometer and the test accelerometers are listed in tables 1, 2, and 3. The data is presented with reference to the side or end of the block which was in contact with the drop head. Referring to figure 6, the end shown in contact with the drop head is defined as end 1 and the end not in contact with the drop head is defined as end 2. Side 1 is defined as the face having the accelerometer opening. Side 2 is the right side of the block. Side 3 is the side opposite side 1 and side 4 is opposite side 2. Side 1 could not be tested because of the wires from the accelerometers. The data presented indicate practically no effect on shock transmission by the instrumented block.

TABLE 2

RECORDED SHOCKS AND DURATIONS
FOR THE NO. 1265 PURE GUM RUBBER PAD

	Control Accelerometer (Kistler 808)		Test Accelerometer (Kistler 818)	
	Deceleration (in g's)	Duration (in ms)	Deceleration (in g's)	Duration (in ms)
END 1	40	11	40	11
	75	9	75	9
	110	8.5	110	8.5
END 2	48	12.5	48	12.5
	85	9	85	9
	110	8	112	8
SIDE 2	44	12	44	12
	90	9.5	90	9.5
	110	9	110	9
SIDE 3	40	11	40	11
	69	10	70	10
	120	9	118	9
SIDE 4	39	10	40	10
	65	9	65	9
	98	8	97	8

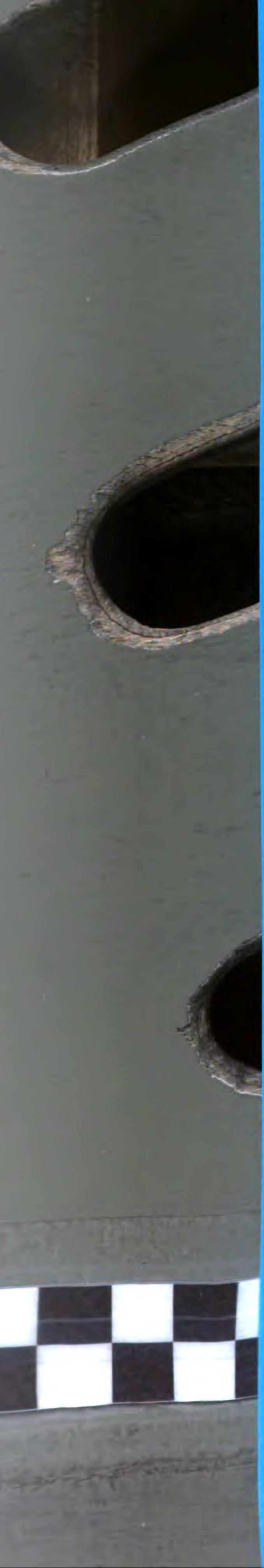


TABLE 3

RECORDED SHOCKS AND DURATIONS
FOR THE LEAD PELLETS

	Control Accelerometer (Kistler 808)		Test Accelerometer (Kistler 818)	
	Deceleration (in g's)	Duration (in ms)	Deceleration (in g's)	Duration (in ms)
END 1	38	6.4	40	6.4
	50	6	50	6
	55	6	55	6
END 2	38	6.4	40	6.4
	55	6	52	6
	60	6	60	6
SIDE 2	42	5.6	44	5.6
	55	5.6	52	5.6
	65	7	63	7
SIDE 3	42	6	42	6
	50	6	50	6
	65	5.6	65	5.6
SIDE 4	42	6.6	44	6.6
	55	6	55	6
	60	6	60	6

Attenuators

The attenuators are used to reduce the voltage from the accelerometers by a factor of 50. The exact value of the resistors used for the attenuator was found by using a type 1650-A impedance bridge manufactured by General Radio Company. The results of the calibration demonstrated that the attenuators reduced the input voltage by a factor of 50.

Test procedure

A Hewlett Packard 3300 A function generator was used to supply a sinusodial input to the attenuators. A voltage from 0 to 2.5 volts was applied to the attenuator. The output from the attenuator was fed into one channel of a Tektronix Model 564 storage oscilloscope. The input to the attenuators was also monitored on another channel of the same scope. A Tektronix oscilloscope camera C-12 was used to record the data. The frequency of the input was varied from 0 to 5,000 cycles per second. The frequency had no effect on the output voltage.

VCO, transmitter, receiver, and discriminator

The VCO, transmitter, receiver, and discriminator were tested together for calibration. They were tested to determine the effect of frequency on voltage output from the discriminator. It was found that the frequency of the input signal had no effect of the output voltage of the discriminator. As the frequency was increased

TABLE 4

RECORDED VOLTAGE OUTPUTS
OF SUBCARRIER DISCRIMINATORS
FOR DIFFERENT FREQUENCY INPUTS

Channel 1		Channel 2		Channel 3	
Frequency Input (in cps)	Voltage Output (in volts)	Frequency Input (in cps)	Voltage Output (in volts)	Frequency Input (in cps)	Voltage Output (in volts)
0	2.5	0	2.5	0	2.5
50	2.5	50	2.5	50	2.5
100	2.5	100	2.5	100	2.5
150	2.5	150	2.5	150	2.5
200	2.5	200	2.5	200	2.5
250	2.5	250	2.5	250	2.5
300	2.5	300	2.5	300	2.45
350	2.45	350	2.5	350	2.40
400	2.40	400	2.45	400	2.35
450	2.37	450	2.20	450	2.33
500	2.35	500	2.40	500	2.30
600	2.25	600	2.35	600	2.25
700	2.15	700	2.25	700	2.1
800	2.05	800	2.15	800	2.0
900	1.95	900	2.10	900	1.95
1000	1.85	1000	2.00	1000	1.80
1100	1.75	1100	1.90	1100	1.70
1200	1.65	1200	1.85	1200	1.65
1300	1.55	1300	1.80	1300	1.55
1400	1.45	1400	1.75	1400	1.45
1500	1.40	1500	1.65	1500	1.35
1600	1.30	1600	1.60	1600	1.30
1700	1.25	1700	1.55	1700	1.2
1800	1.20	1800	1.45	1800	1.15
1900	1.10	1900	1.40	1900	1.1
2000	1.05	2000	1.35	2000	1.05
2100	1.00	2100	1.3	2100	1.00

Total system

In this calibration the accelerometer output was the input to the VCO. The system was assembled as it would be used in field testing.

Test procedure

The instrumented package was fastened to the drop head of a L.A.B. Model 16-42-100 free fall shock machine. Each side and end of the block was subjected to a series of shock pulses of known magnitude, duration and waveshape. Sinusoidal shock pulses from 3 to 12 milliseconds duration were used in the calibration. A Kistler Model 818 piezotron accelerometer, mounted directly on the drop head, was used as a control accelerometer.

Signals from the subcarrier discriminators were recorded on a Tektronix Model 564 storage oscilloscope as was the signal from the control accelerometer.

Test results

Readings from the control accelerometer and the test accelerometer are are listed in tables 5, 6, and 7. Channel 1, positive, has been referred to as side 3 in the instrumentation package calibration. Channel 2, positive, would be end 1. Channel 2, negative, would be end 2. Channel 3, positive, would be side 2. Channel 3, negative, would be side 4.

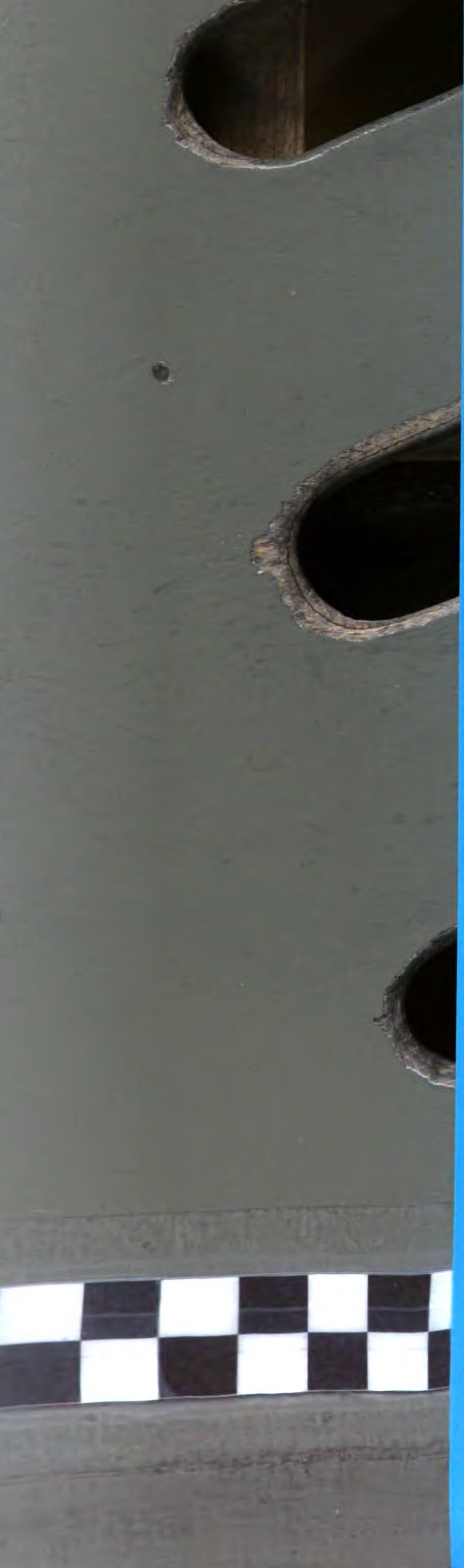


TABLE 5

CHANNEL 1
TOTAL SYSTEM CALIBRATION

Control Accelerometer Deceleration (in g's)	Test Accelerometer Deceleration (in g's)
	Positive Direction (side 3)
30	30
40	40
60	65
65	65
90	90
100	100
115	115
140	140
165	170
180	180
195	195
200	200
220	220
230	225
	Negative Direction (side 1)
25	25
50	50
70	70
75	75
90	85
95	95
110	110
135	130
150	140
240	220

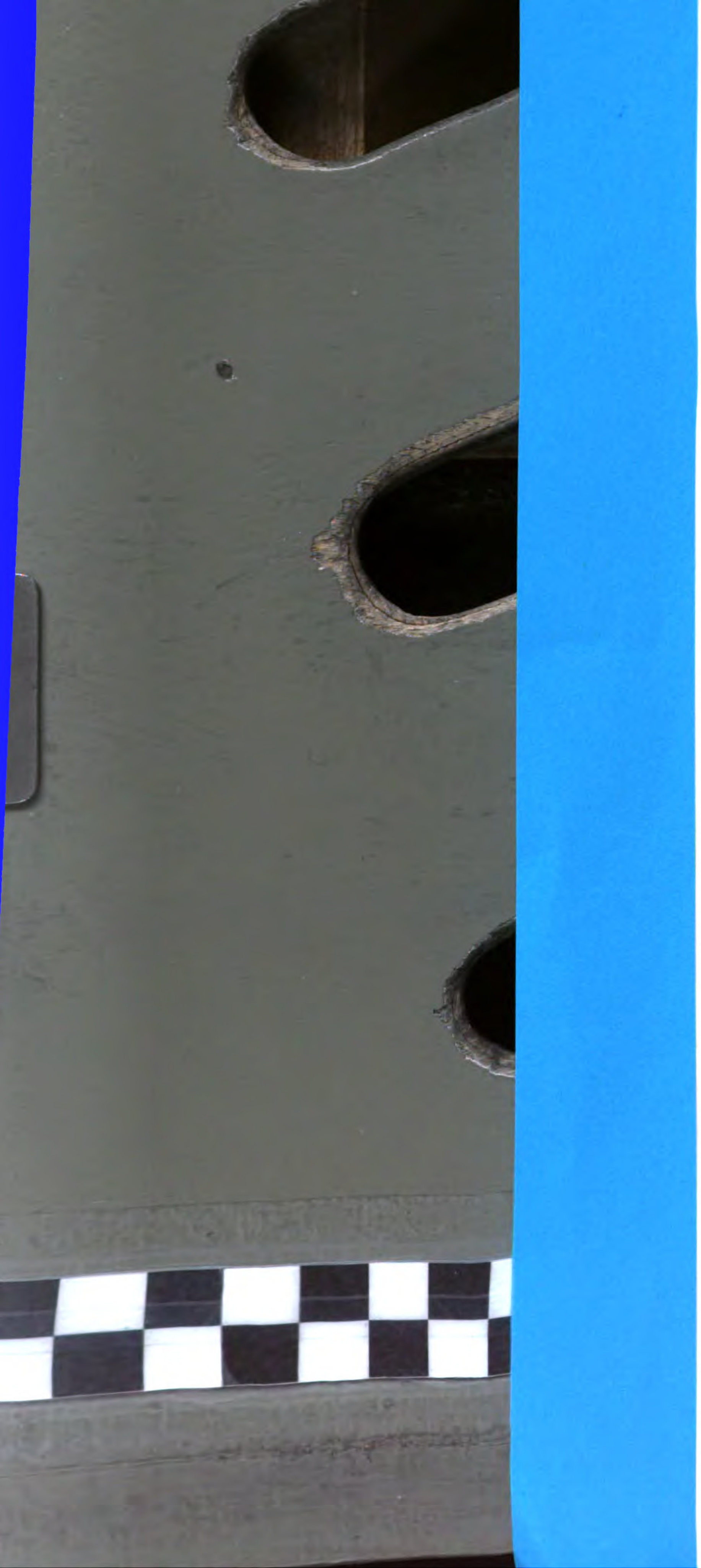


TABLE 6

CHANNEL 2
TOTAL SYSTEM CALIBRATION

Control Accelerometer Deceleration (in g's)	Test Accelerometer Deceleration (in g's)
	Positive Direction (end 1)
30	30
40	40
60	67
70	70
90	92
130	135
190	190
200	200
230	230
240	240
	Negative Direction (end 2)
30	30
50	50
60	60
65	70
80	85
100	100
130	130
150	150
160	160
200	195
230	225

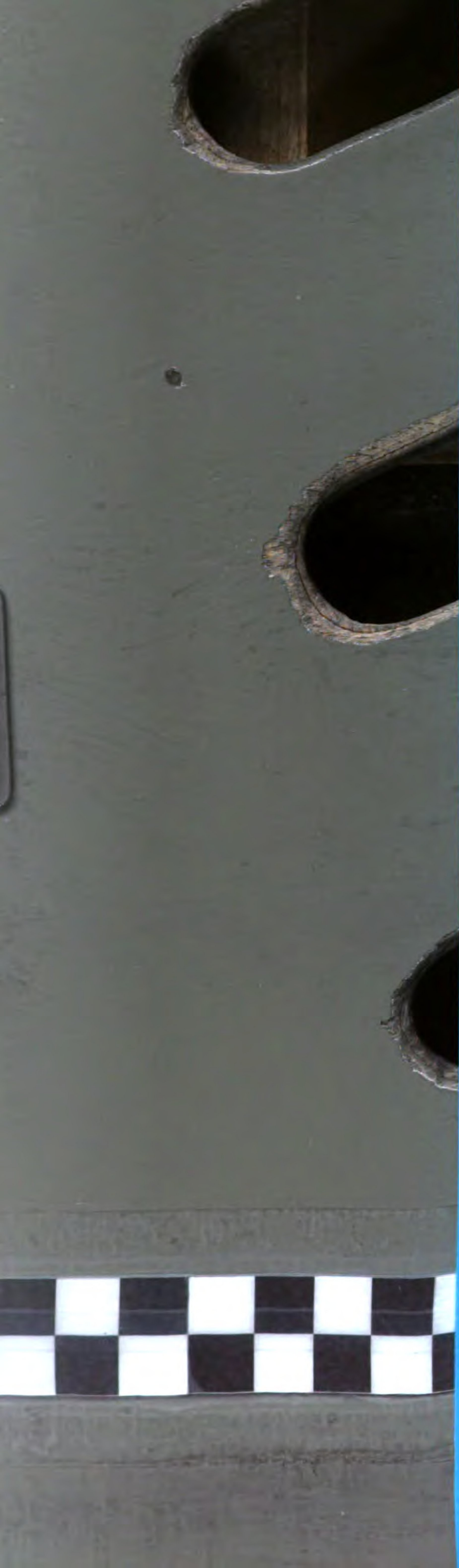


TABLE 7

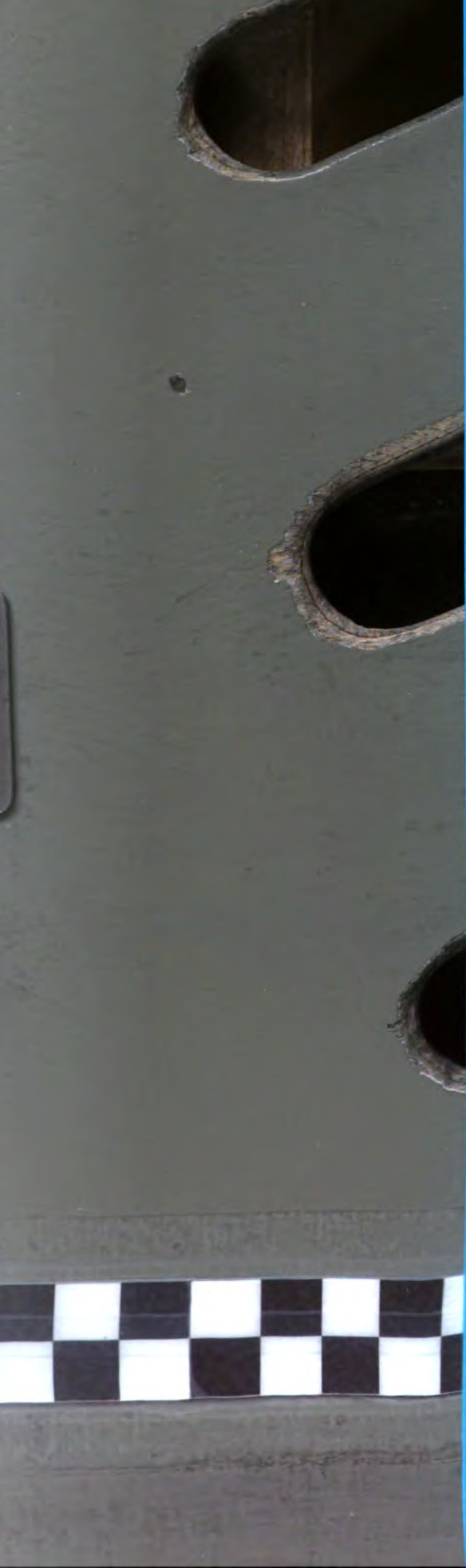
CHANNEL 3
TOTAL SYSTEM CALIBRATION

Control Accelerometer Deceleration (in g's)	Test Accelerometer Deceleration (in g's)
	Positive Direction (side 2)
10	8
45	43
70	70
80	80
140	136
180	180
210	210
240	240
	Negative Direction (side 4)
18	16
45	43
70	66
90	90
110	110
140	140
160	158
190	190
210	210
230	235

APPENDIX II

INTER-RANGE INSTRUMENTATION GROUP

IRIG (Inter-Range Instrumentation Group) is an organization composed of representatives from several guided missile ranges. There are 10 working groups within IRIG that work in different areas, one of which is the Telemetry Working Group (TWG). IRIG has done extensive work in the standardization of radio telemetry. They have published IRIG Document 106-60 entitled "Telemetry Standards." IRIG Document 106-60 contains information on instrumentation, magnetic recording, frequency utilization parameters, as well as definitions of terms and descriptions and uses of the different types of telemetry system.



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