WARHEAD IMPACT TELEMETRY SYSTEM

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ABSTRACT

The retrieval of telemetry data during and after High-G (greater than 1000 g's) testing has presented numerous problems. In an attempt to address some of the more critical problems associated with High-G testing the Telemetry/ Test Engineering Divison of the Naval Weapons Center (NAVWPNCEN) developed and tested a High-G telemetry system to 10K g's with expectations of achieving values up to 50K g's. Innovative shock reduction techniques were applied to reduce the direct shock seen by the individual telemetry system components Major shock reduction was seen through the selection and proper orientation of system materials and components, as well as, the utilization of glass beads and various foam densities as shock absorption medias.

SYSTEM DESCRIPTION

The telemetry system is a frequency modulated/phase modulated system (FM/PM). This indicates that the subcarrier oscillator, which is being frequency modulated, is phase modulating the transmitter. The system transmits at a 200 milliwatt minimum power in the frequency range of 1435 MHz to 1540 MHz band. There are twelve subcarrier oscillators allowing for twelve data channels. figures (1.1) through (1.4) are pictures of the holding fixtures and assembled system.

Mechanically the system has been designed to withstand 50K G's for 11 milliseconds. Aluminum holding fixtures were chosen because of their machinability and high strength to weight ratio. All components were mounted to withstand their maximum shock and placed in 1/8" printed wiring board.

Two types of devices were used for successful shock absorbtion. These were: 1. variable density foams and 2. glass microspheres.

Figure (2) shows the telemetry system with foam layers housed within the airframe.

In dealing with the various density foam layers, the problem becomes that of a boundary type problem.

For a pulse incident on a system with a higher impedance, as shown in Figure (2), where $Z_1 < Z_2$, a transmitted and a reflected pulse will result. In this case of a lower to higher impedance boundary, the reflected pulse will be out of phase, with less amplitude, than the incident pulse. A transmitted pulse with less amplitude than the incident pulse will also result.

If the problem were such that a low to infinite boundary existed, reflection would be 180° out of phase and of equal amplitude. There would be no transmitted pulse.

In this situation the pulse is transmitted through the layers of low to higher densities with lessening amplitudes. Reflection and transmission between the foam layers (boundaries) and between the total foam package will result in dissipation of much of the shock pulse.

As the telemetry system approaches the end of foam layer three as depicted in Figure (2), the hollow glass microspheres come completely into play. This further dissipated the shock pulse.

Once the telemetry system was assembled, the hollow glass microspheres could be poured into the housing while the unit was shaking on a vibration table. This type of shock absorbing material also allowed for easy removal of the spheres after the test for inspection purposes.

Emerson and Cuming hollow glass microspheres were used in this project. Some characteristics are listed as follows for the 1G-101 Emerson and Cuming Microsphere.

Size: 44-175 microns (56% by weight being in the range of 62-125 microns)
Average particle diameter by weight: 80 microns
Average wall thickness: 2 microns
Material: Sodium Borosilicate Glass
Bulk density (tamped): 12.1 lb/ft^3
True density (liquid displacement): 19.4 lb/ft^3
Strength under hydrostatic pressure at 1500 psi yields 47% sphere survivability.
By way of physical explanation a .125 pound (W) circuit board mounted within the telemetry package will be accelerated to 15,000 G’s (a). This combination yields a force (F_0) of 1,875 pounds. A diagram of force distribution and vector representation is found in Figure (3A) and (3B) respectively. This represents an ideal situation with homogeneous sphere discrepancies although this still yields a fair approximation. By way of example, if equal sphere diameters are assumed, the incident force F_0 is divided in two parts, (F_1),

each 30° to the side of F_0, F_0 thus dispersing the shock pulse. Using the law of sines, the component forces (F_1) can be calculated.

$$\frac{F_1}{\sin 30^o} = \frac{F_0}{\sin 120^o} \longrightarrow F_1 = \frac{1875 \sin 30^o}{\sin 120^o} = 1083 \text{ lbs.}$$

Adding the two vector components of F_1 together at the next row of spheres, F_0 is again reached, so centrally each sphere sees F_0.

When the shock pulse amplitude reaches the point where the spheres compress and break, the shock pulse will be absorbed to a great degree.

TEST METHODOLOGY

Since the main concern was whether the system could withstand high shock levels several shock tests were conducted. Each subcarrier oscillator was fed a sine wave in order to establish any distortion at the output during actual shock. A control accelerometer was placed on the shock table and an accelerometer was placed on the outside housing of the telemetry system. The control accelerometer was hardwired to the shock analyzer while the accelerometer on the telemetry housing was processed through the telemetry system with the other channels and transmitted to the shock analyzer. A plot of (G's of acceleration vs time) and the fourier spectral analysis of the shock wave for the hardwired and telemetry system is presented in figures 4.1 through 4.8.

SYSTEM ELECTRICAL DESIGN

The following is the analytical system design for the telemetry system. Two assumptions are made: 1. The receiver input signal to noise ratio $(S/N)_c$ is assigned 10 dB which is 1 dB above theorectical threshold; 2. The discriminator output signal to noise ratio $(S/N)_d$ is 40 dB which allows a 1% noise contribution. With the previous assumptions made the receiver IF bandwidth, SCO preemphasis, and the total transmitter modulation can be determined.

To determine the receiver IF bandwidth the highest frequency SCO, f'_{dc} value equal to "1". The other f'_{dc} values are normalized by dividing the highest SCO ($f'_{dc400\ KHz}$) into the next lowest value ($f'_{dc225\ KHz}$) and proceed until all values are ca cu ate .

Example:

$$\frac{f'dc(225\ KHz)}{f'dc(400\ KHz)} = \frac{135.12 \times 10^6}{320.28 \times 10^6} = .42$$

$$f'dc(PBW) = \frac{C_2 \times (K)^{1/2}(f_s)^{3/2}}{N^{3/2}}$$

$$f'dc\ (400\ KHz) = \frac{(36.54)(1.5)^{1/2}(400\ KHz)^{3/2}}{5^{3/2}} = 320.25 \times 10^6\ Hz$$

$$f'dc(225\ KHz) = \frac{(36.54)(4K)^{1/2}(400\ KHz)^{3/2}}{5^{3/2}} = 135.12 \times 10^6 Hz$$

$$f'dc(CBW) = \frac{C_2(f_{ds})^{1/2} f_s}{N^{3/2}}$$

$$f'dc(CBW) = \frac{(36.54)(4K)^{1/2}(176\ KHz)}{5^{3/2}} = 36.38 \times 10^6 Hz$$

$$f'dc(144\ KHz) = \frac{(36.54)(4K)^{1/2}(144\ KHz)}{5^{3/2}} = 29.77 \times 10^6 Hz$$

$$f'dc(128\ KHz) = \frac{(36.54)(4K)^{1/2}(128\ KHz)}{5^{3/2}} = 26.46 \times 10^6 Hz$$

$$f'dc(112\ KHz) = \frac{(36.54)(4K)^{1/2}(112\ KHz)}{5^{3/2}} = 23.15 \times 10^6 Hz$$

$$f'dc(96\ KHz) = \frac{(36.54)(4K)^{1/2}(96\ KHz)}{5^{3/2}} = 19.84 \times 10^6 Hz$$

$$f'dc(80\ KHz) = \frac{(36.54)(4K)^{1/2}(80\ KHz)}{5^{3/2}} = 16.54 \times 10^6 Hz$$

$$f'dc(64\ KHz) = \frac{(36.54)(4K)^{1/2}(64\ KHz)}{5^{3/2}} = 13.23 \times 10^6\ Hz$$

$$f'dc(48\ KHz) = \frac{(36.54)(4K)^{1/2}(48\ KHz)}{5^{3/2}} = 9.92 \times 10^6\ Hz$$

$$f'dc(32\ KHz) = \frac{(36.54)(4K)^{1/2}(32\ KHz)}{5^{3/2}} = 6.61 \times 10^6\ Hz$$

By adding the normalized values listed in Table B-1 the “A” factor is determined A = 1.98. The Modulation Index (M) can now be calculated from equation 5.

Equation 5 is derived by combining equations 1, 2, 4, and 5.

$$B_c = 2(\Delta f + f_{su}) = 2(Af_{dcu} + f_{su}) \quad \text{- Eq. 1}$$

$$M = \frac{f_{dc}}{f_s} \text{ or } f_{dc} = Mf_{ds} \quad \text{- Eq. 2}$$

$$f_{dc(PBW)} = \frac{C_2 \times K^{1/2} \times (f_s)^{3/2}}{B_c^{1/2} \times (N)^{3/2}} \quad \text{- Eq. 3}$$

Therefore, by substitution:

$$Mf_s = \frac{C_2 \times K^{1/2}(f_s)^{3/2}}{B_c^{1/2} \times (N)^{3/2}}$$

$$Mf_s = \frac{C_2 \times K^{1/2}(f_s)^{3/2}}{2(Af_{dcu} \; f_{su})^{1/2} \times N^{3/2}}$$

Square both sides and solve for M at the highest SCO frequency.

$$f_s = f_{su} \qquad f_{dcu} = f_{dc} \quad \text{- Eq. 4}$$

$$M^2 f_s^2 = \frac{C_2^2 K f_s^3}{2(Af_{dc} + f_s) \times N^3} = \frac{C_2^2 K f_s^3}{2(AMf_s + f_s) \times N^3}$$

$$M^2(AM + 1) = \frac{C_2^2 K}{2N^3}$$

$$\boxed{AM^3 + M^2 = \frac{C_2^2 K}{2N^3}} \quad \text{-Eq. 5}$$

$K = f_{ds} / f_s$ @ SCO = 400 KHz ±15% deviation
K = 60 KHz/400 KHz = .15
A = 1.98
N = 5
$C2 = (S/N)_d / (S/N)_R \times (3/4)^{1/2}$ Voltage Ratio
$(S/N)_R$ = 10 dB 1 dB above theorectical threshold of receiver
$(S/N)_d$ = 40 dB 1% Noise contribution of discriminator
C_2 = 40 dB voltage ratio = $\frac{100}{(3.16)(.866)}$ = 36.54

$$1.98M^3 + M^2 = \frac{(36.54)^2(.15)}{2(5)^3} = .801$$

$1.98M^3 + M^2 = .801$
$M^2 (1.98M + 1) = .801$

Method of Iteration (Successive Substitution)

let M = .5
.25{l.98(.5) + 1} = .4975
.4975 < .801

let M = .8
.64 {1.98(8) + 1} = 1.653
1.653 > .801

let M = .6
.36 {1.98(.6) + 1} = .7876
.7876 < .801

let M = .61
.3721 1.98(.61) + 1 = .8215
.8215 > .801

let M = .605
.3660 {1.98(,650) + 1} = .804

M = .605

The receiver IF bandwidth can now be determined.

f_{dcu} = highest SCO channel deviation
$f_{dcu} = M f_{su}$
f_{su} = center freq. of highest SCO
f_{su} = 400 KHz
f_{dcu} = (.605)(400 KHz) = 242 KHz

ΔF_u = Total peak deviation of RF carrier by the highes SCO channel in the system
$\Delta F_u = A\, f_{dcu}$
$\Delta F_u = (1.98)(242 \text{ KHz}) = 479.16 \text{ KHz}$
$B_{c(cal)} = 2(F_u + f_{su})$
$B_{c(cal)} = 2(479.16 + 400K) = 1758.32 \text{ KHz}$
Select available receiver IF > $B_{c(cal)}$

IF = 2 MHz

The total peak deviation of the RF carrier by all the SCO oscillators is calculated to insure the transmitter isn't over deviated.

$f_{dc} = f_{dcu}$ x Normalized Value
$f_{dcu} = M\, f_{su}$ $\qquad M = .605$
$f_{dcu} = .605 \times 400 \text{ KHz} = 242 \text{ KHz}$
$f_{dc(400)} = (242 \text{ KHz})(1.0) = 242.00 \text{ KHz}$
$f_{dc(225)} = (242 \text{ KHz})(.42) = 101.64 \text{ KHz}$
$f_{dc(176)} = (242 \text{ KHz})(.11) = 26.62 \text{ KHz}$
$f_{dc(160)} = (242 \text{ KHz})(.10) = 24.00 \text{ KHz}$
$f_{dc(144)} = (242 \text{ KHz})(.09) = 21.78 \text{ KHz}$
$f_{dc(128)} = (242 \text{ KHz})(.08) = 19.36 \text{ KHz}$
$f_{dc(112)} = (242 \text{ KHz})(.07) = 16.94 \text{ KHz}$
$f_{dc(96)} = (242 \text{ KHz})(.06) = 14.52 \text{ KHz}$
$f_{dc(80)} = (242 \text{ KHz})(.05) = 12.10 \text{ KHz}$
$f_{dc(64)} = (242 \text{ KHz})(.04) = 9.68 \text{ KHz}$
$f_{dc(48)} = (242 \text{ KHz})(.03) = 7.26 \text{ KHz}$
$f_{dc(32)} = (242 \text{ KHz})(.02) = \underline{4.84 \text{ KHz}}$
500.74 KHz

$$\Delta f = Af_{dc_T} = 1.98(500.74 \text{ KHz}) = 991.46 \text{ KHz}$$

Once the system has been designed check factors are calculated to insure t selected bandwidths and SCO preemphasis are correct for the desired signal to noise ratio.

Channel Check Factor

$$(S/N)_{in} = \frac{(S/N)_{out}}{\sqrt{3N^3}}$$

$(S/N)in$ = Receiver carrier to noise ratio expressed as a voltage ratio related to baseband.
$(S/N)_{out}$ = Receiver data output noise ratio expressed as a voltage out ratio related to baseband modulation.

$$(S/N)_{in} = \frac{100}{\sqrt{3(5)^3}} = \frac{100}{19.36}$$

$(S/N)_{in}$ = 5.165 = 14.26 dB

$$C_{Kt} = \frac{(S/N)_{in}}{3.16}$$

$$C_{Kt} = \frac{5.165}{3.16} = 1.63$$

C_{Kt} is determined by comparing computed $(S/N)_{in}$ to that of the receive threshold (10 dB).

Computed channel check factor

$$\left[\frac{B_{c(sel)}}{2B_{out}}\right]^{1/2} \times \frac{f_{dc}}{f_s} \geq 1.63$$

f_s = 400 KHz ± 15% deviation

$$\left[\frac{B_{c(select)}}{2B_{out}}\right]^{1/2} \times \frac{f_{dc}}{f_s} = \left[\frac{200\ KHz}{2(120\ KHz)}\right]^{1/2} \times \frac{242\ KHz}{400\ KHz} = 1.746$$

f_s = 225 KHz ± 15% deviation

$$\left[\frac{B_{c(select)}}{2B_{out}}\right]^{1/2} \times \frac{f_{dc}}{f_s} = \left[\frac{200\ KHz}{2(67.5)}\right]^{1/2} \times \frac{101.64\ KHz}{225\ KHz} = 1.738$$

f_s = 176 KHz ± 4 KHz deviation

$$\left[\frac{B_{c(select)}}{2B_{out}}\right]^{1/2} \times \frac{f_{dc}}{f_s} = \left[\frac{200\ KHz}{2(8)}\right]^{1/2} \times \frac{30.08\ KHz}{176\ KHz} = 1.91$$

Due to the linear taper of the constant bandwidth subcarrier oscillators the remaining B channel subcarriers also have a check factor of 1.91.

Because the telemetry system utilizes a phase modulated transmitter it's necessary to calculate the total system modulation index to insure the transmitter isn't over modulated.

$M = f_{dcf}\ f_s$
f_{dcf} = SCO channel transmitter deviation resulting from $B_{c(sel)}$
$M_{400} = f_{dcf}\ f_s = 273.46/400 = .68$
$M_{225} = f_{dcf}/f_s = 114.85/225 = .51$
$M_{176} = f_{dcf}/f_s = 30/176 = .17$
$M_{160} = f_{dcf}/f_s = 27.12/160 = .17$
$M_{144} = f_{dcf}/f_s = 24.6/144 = .17$
$M_{128} = f_{dcf}/f_s = 21.87/128 = .17$
$M_{112} = f_{dcf}/f_s = 19.14/112 = .17$
$M_{96} = f_{dcf}/f_s = 16.4/96 = .17$
$M_{80} = f_{dcf}/f_s = 13.67/80 = .17$
$M_{64} = f_{dcf}/f_s = 10.94/64 = .17$
$M_{48} = f_{dcf}/f_s = 8.2/48 = .17$
$M_{32} = f_{dcf}/f_s = 5.16/32 = \underline{.17}$
2.898

The selected transmitter (Microm model number T4-X0) has a deviation sensitivity of .35 volts rms for a modulation index of 5 with a maximum modulation index of 15. The total design modulation index of 2.898 is well within the limit to prevent any distortion due to wver modulation.

The system perameters which have been calculated are all tabulated in Table B-1.

CONCLUSION

Through the utilization of component orientation, shock absorption foams, and glass beads it appears that 50K G's shock levels for 11 milliseconds can be survivable by telemetry systems. Other approaches are being investigate by the Telemetry/Test Engineering Division. Some of the more promising systems are using solid state storage devices to replace the RF link.

DEFINITION OF TERMS

$(S/N)_{in}$ = Receiver carrier to noise ratio expressed as a voltage ratio related to baseband modulation.
$(S/N)_{out}$ = Receiver data output noise ratio expressed as a voltage ratio
B_c = (Receiver IF bandwidth)
B_{out} = Receiver output narrow band filter (3dB frequency points)

M = Modulation index as related to transmitter modulation.
SCO = Subcarrier Oscillator
$(S/N)_d$ = Data or discriminator output RMS signal to noise ratio, expressed as a voltage ratio related to the FM multiplex system.
f_{dc} = RF carrier peak deviation due to any particular SCO modulation signal.
f_{dc} = Relative modulation amplitude of an SCO Channel.
$(S/N)_c$ = Receiver carrier to noise ratio, expressed as a voltage ratio related to the FM multiplex system.
f_{ds} = SCO peak deviation due to data modulation.
f_s = SCO center frequency
N = Modulation index as related to SCO modulation
Δf = Total peak deviation of RF carrier by all the SCO channels in the system.
$\Delta f = Af_{dc}$.
C_2 = Constant, $\frac{S/N)_d}{(S/N)_c(3/4)^{1/2}}$

A = The sum of the ratios of the SCO channels modulating a transmitter, where the deviation of each SCO is normalized with respect to the deviation of the highest frequency SCO modulating an RF carrier.

$K = \frac{f_{ds}}{f_s}$ = Percentage modulation of an SCO.

f_{su} = Highest frequency channel in an SCO mix.
f_{dcu} = Highest SCO channel transmitter deviation.
C_{Kt} = Channel check numbers to insure threshold performance.
$B_{c(cal)}$ = Receiver IF bandwidth selected from IRIG standards.

$B = \frac{B_{c(cal)}}{B_{c(sel)}}$ multiplier factor.

f_{dcf} = Final SCO channel transmitter deviation resulting from B_c (sel)
ΔF_u = Total peak deviation of an RF carrier by the highest SCO channel in the system.

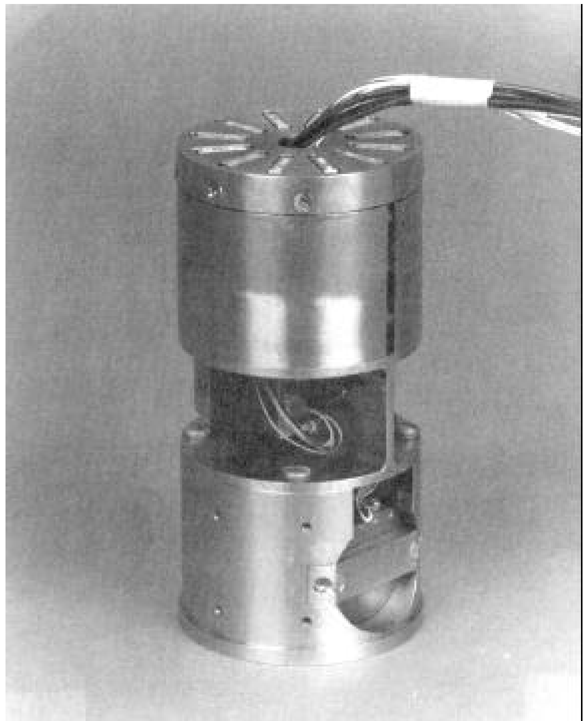

Figure 1.1 - ASSEMBLED TELEMETRY SYSTEM

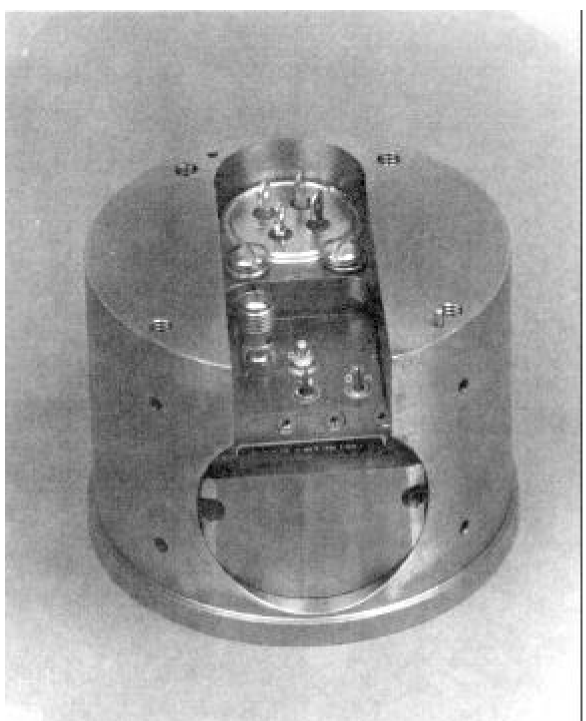

Figure 1.2 - HOLDING FIXTURE FOR TRANSMITTER AND THERMAL BATTERY

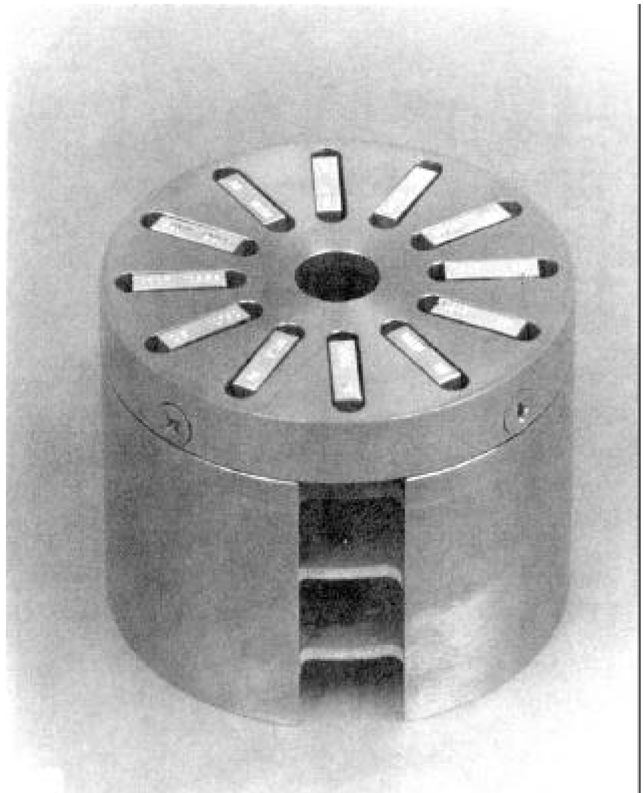

Figure 1.3 - HOLDING FIXTURES FOR SUBCARRIER OSCILLATOR AND SIGNAL CONDITIONING BOARDS

Figure 1.4 - OUTER HOUSING

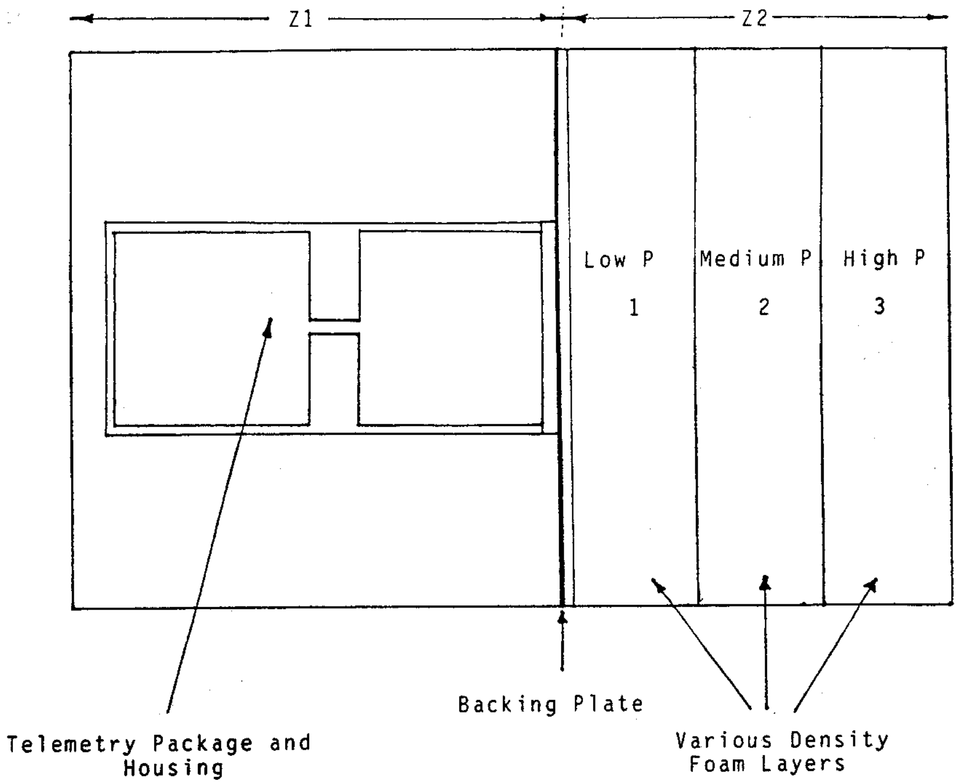

Figure 2 - Telemetry Assembly Within Missile Airframe

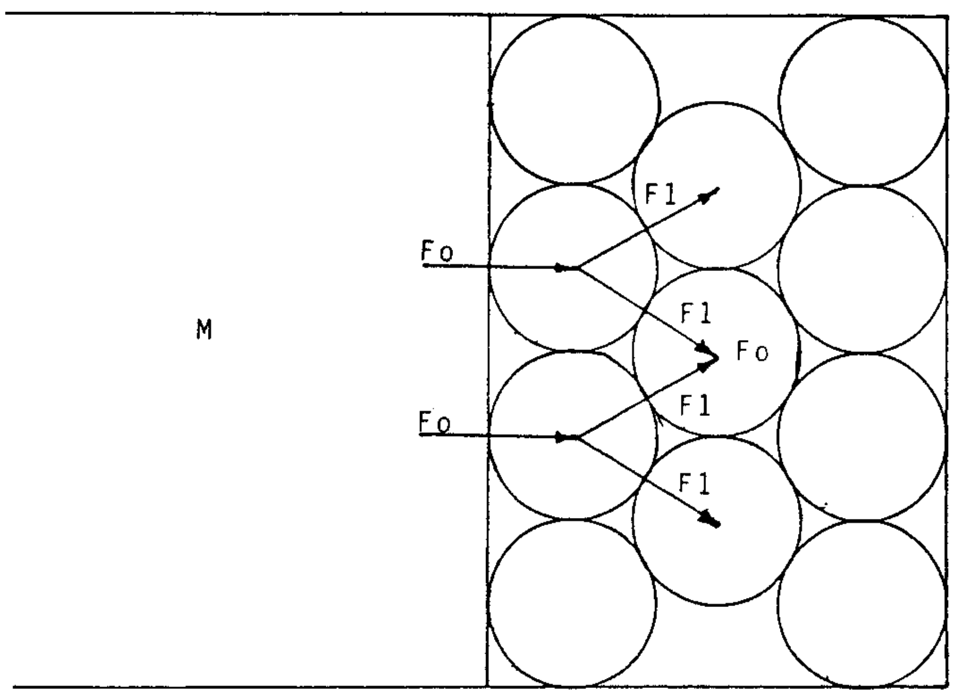

Figure 3a - Glass Sphere Tamped Arrangement (Ideal)

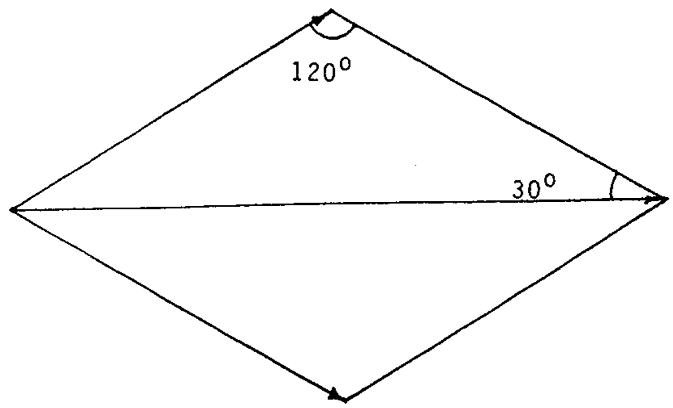

Figure 3b - Force Vector Parallelogram

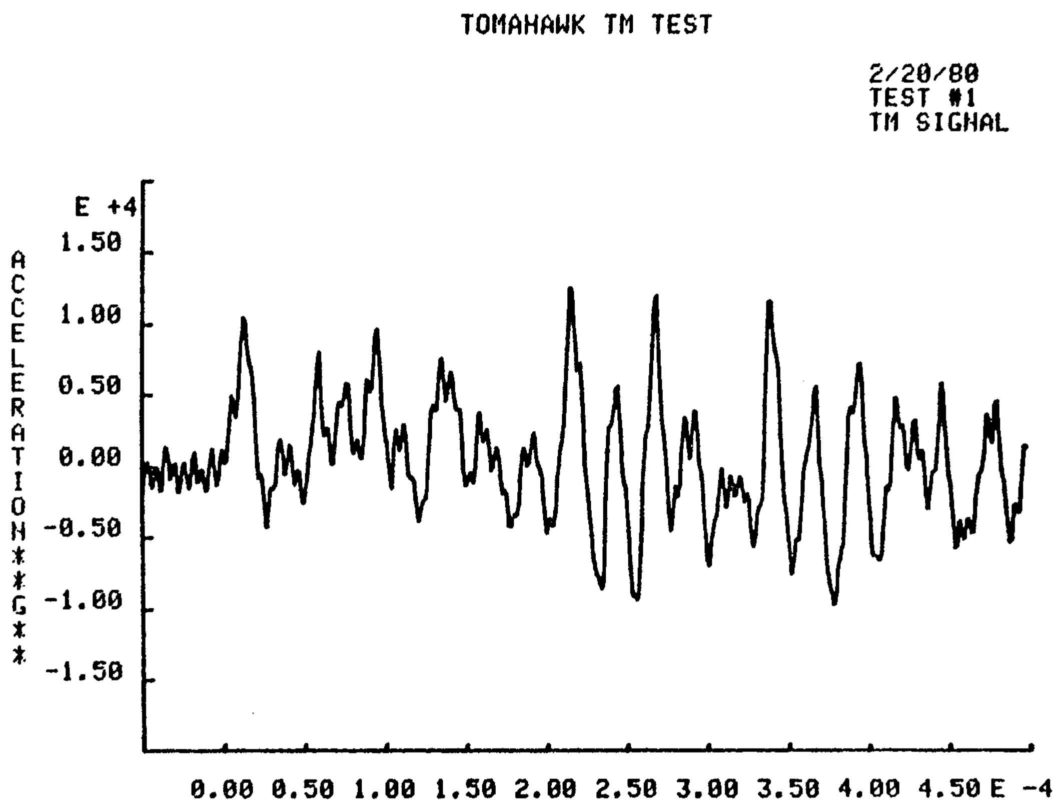

Figure 4.1

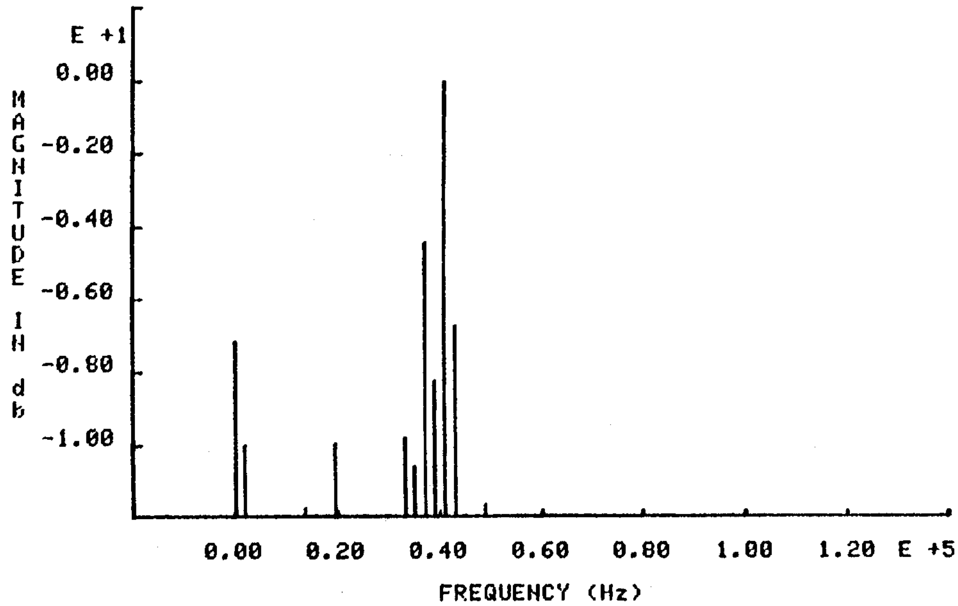

Figure 4.2

FREQUENCY	REAL	IMAGINARY	MAGNITUDE
0	+1.68E-001	0.00E+000	+1.68E-001
1953	+5.83E-002	-1.06E-001	+1.21E-001
3906	-7.27E-003	-5.34E-002	+5.39E-002
5859	-3.47E-002	-2.66E-002	+4.37E-002
7813	+7.52E-004	-1.64E-002	+1.64E-002
9766	+7.45E-002	+1.16E-002	+7.54E-002
11719	+1.99E-002	+6.19E-003	+2.08E-002
13672	-7.33E-002	+6.61E-002	+9.87E-002
15625	+2.10E-002	-2.81E-002	+3.51E-002
17578	-1.15E-002	+2.43E-002	+2.69E-002
19531	+6.73E-002	+1.02E-001	+1.22E-001
21484	+4.37E-002	-5.60E-002	+7.10E-002
23438	+3.76E-003	+3.11E-002	+3.13E-002
25391	-1.76E-002	-5.12E-003	+1.83E-002
27344	+5.45E-002	-1.65E-002	+5.69E-002
29297	-2.59E-002	-2.76E-002	+3.78E-002
31250	+1.12E-002	-5.44E-002	+5.56E-002
33203	-9.05E-002	+8.48E-002	+1.24E-001
35156	-1.36E-002	+1.12E-001	+1.13E-001
37109	-6.15E-002	-2.22E-001	+2.30E-001
39063	-1.48E-001	+8.12E-003	+1.48E-001
41016	+3.68E-001	-1.07E-001	+3.83E-001
42969	+1.13E-001	-1.35E-001	+1.76E-001
44922	+1.91E-002	+3.18E-002	+3.71E-002
46875	-2.10E-003	-9.59E-002	+9.59E-002
48828	-9.79E-002	-1.98E-002	+9.99E-002
50781	+1.16E-002	-3.57E-002	+3.76E-002
52734	+1.14E-002	+4.66E-003	+1.24E-002
54688	-3.04E-002	+3.06E-002	+4.32E-002
56641	-1.57E-002	+3.24E-002	+3.60E-002
58594	+3.03E-002	-5.33E-002	+6.13E-002
60547	+5.17E-002	+1.37E-003	+5.17E-002
62500	+8.20E-003	-6.56E-003	+1.05E-002
64453	-1.53E-002	-1.65E-002	+2.24E-002

Figure 4.3

FREQUENCY	REAL	IMAGINARY	MAGNITUDE
66406	+5.53E-002	-3.47E-002	+6.53E-002
68359	+2.09E-002	+1.61E-003	+2.09E-002
70313	+1.43E-002	-6.02E-003	+1.55E-002
72266	+1.70E-002	+3.42E-002	+3.82E-002
74219	+4.55E-003	-3.30E-003	+5.62E-003
76172	+3.62E-002	+2.37E-002	+4.33E-002
78125	+4.03E-002	+5.36E-003	+4.06E-002
80078	-1.26E-002	-1.37E-002	+1.86E-002
82031	+8.86E-003	-2.79E-002	+2.93E-002
83984	+3.06E-002	-1.88E-002	+3.59E-002
85938	+2.24E-002	-1.50E-002	+2.70E-002
87891	+4.83E-002	+1.43E-002	+5.03E-002
89844	-4.74E-002	+3.37E-002	+5.82E-002
91797	+4.56E-002	+7.78E-003	+4.63E-002
93750	+1.76E-002	+1.83E-002	+2.54E-002
95703	+2.20E-003	+7.10E-003	+7.44E-003
97656	+8.83E-005	-1.96E-002	+1.96E-002
99609	+2.58E-002	+2.45E-002	+3.56E-002
101563	-1.17E-002	-4.90E-002	+5.04E-002
103516	-4.46E-003	+3.72E-002	+3.75E-002
105469	-2.00E-002	-9.97E-003	+2.24E-002
107422	+9.80E-003	+9.24E-003	+1.35E-002
109375	+7.10E-003	-1.32E-002	+1.50E-002
111328	-9.77E-003	-4.10E-003	+1.06E-002
113281	+2.51E-003	-1.79E-002	+1.81E-002
115234	+2.81E-002	-5.44E-003	+2.86E-002
117188	-2.21E-004	+1.87E-003	+1.88E-003
119141	+1.14E-002	+1.86E-002	+2.18E-002
121094	+1.69E-002	+2.85E-002	+3.31E-002
123047	-5.51E-003	+2.41E-002	+2.47E-002
125000	-1.12E-002	0.00E+000	+1.12E-002

Figure 4.4

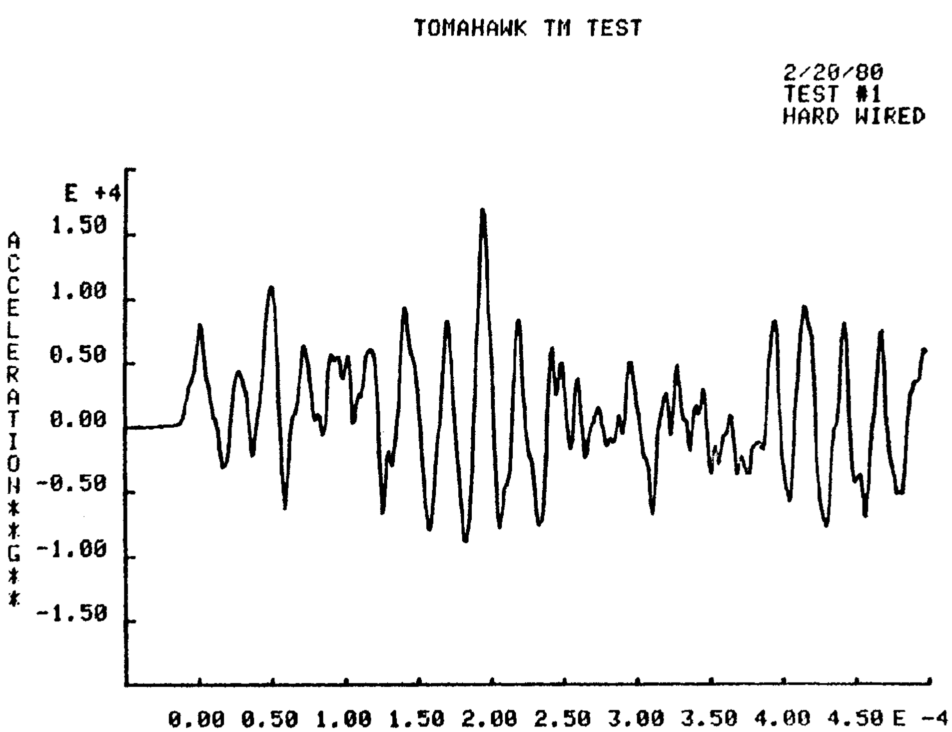

Figure 4.5

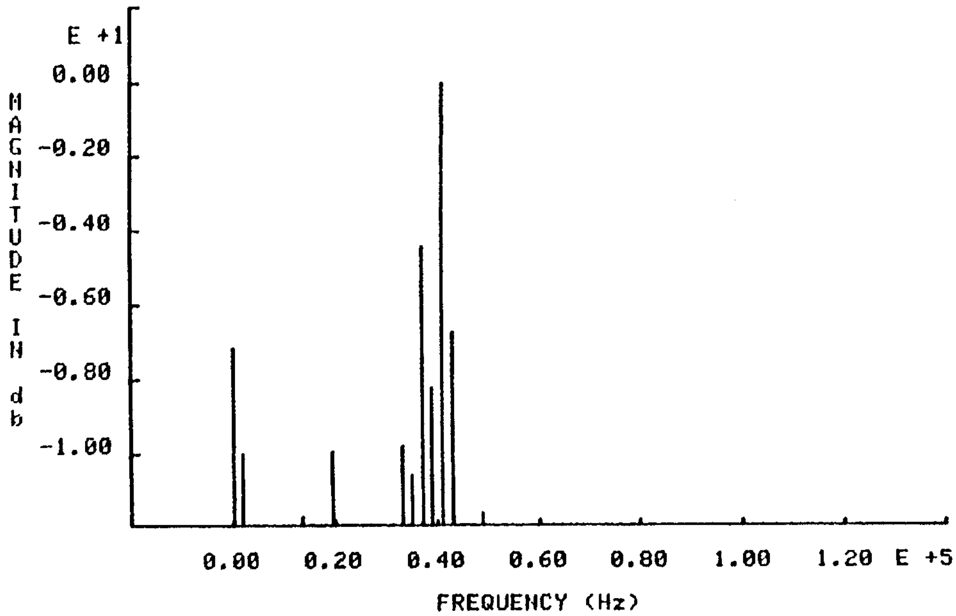

Figure 4.6

FREQUENCY	REAL	IMAGINARY	MAGNITUDE
0	+1.68E-001	0.00E+000	+1.68E-001
1953	+5.83E-002	-1.06E-001	+1.21E-001
3906	-7.27E-003	-5.34E-002	+5.39E-002
5859	-3.47E-002	-2.66E-002	+4.37E-002
7813	+7.52E-004	-1.64E-002	+1.64E-002
9766	+7.45E-002	+1.16E-002	+7.54E-002
11719	+1.99E-002	+6.19E-003	+2.08E-002
13672	-7.33E-002	+6.61E-002	+9.87E-002
15625	+2.10E-002	-2.81E-002	+3.51E-002
17578	-1.15E-002	+2.43E-002	+2.69E-002
19531	+6.73E-002	+1.02E-001	+1.22E-001
21484	+4.37E-002	-5.60E-002	+7.10E-002
23438	+3.76E-003	+3.11E-002	+3.13E-002
25391	-1.76E-002	-5.12E-003	+1.83E-002
27344	+5.45E-002	-1.65E-002	+5.69E-002
29297	-2.59E-002	-2.76E-002	+3.78E-002
31250	+1.12E-002	-5.44E-002	+5.56E-002
33203	-9.05E-002	+8.48E-002	+1.24E-001
35156	-1.36E-002	+1.12E-001	+1.13E-001
37109	-6.15E-002	-2.22E-001	+2.30E-001
39063	-1.48E-001	+8.12E-003	+1.48E-001
41016	+3.68E-001	-1.07E-001	+3.83E-001
42969	+1.13E-001	-1.35E-001	+1.76E-001
44922	+1.91E-002	+3.18E-002	+3.71E-002
46875	-2.10E-003	-9.59E-002	+9.59E-002
48828	-9.79E-002	-1.98E-002	+9.99E-002
50781	+1.16E-002	-3.57E-002	+3.76E-002
52734	+1.14E-002	+4.66E-003	+1.24E-002
54688	-3.04E-002	+3.06E-002	+4.32E-002
56641	-1.57E-002	+3.24E-002	+3.60E-002
58594	+3.03E-002	-5.33E-002	+6.13E-002
60547	+5.17E-002	+1.37E-003	+5.17E-002
62500	+8.20E-003	-6.56E-003	+1.05E-002
64453	-1.53E-002	-1.65E-002	+2.24E-002

Figure 4.7

FREQUENCY	REAL	IMAGINARY	MAGNITUDE
66406	+5.53E-002	-3.47E-002	+6.53E-002
68359	+2.09E-002	+1.61E-003	+2.09E-002
70313	+1.43E-002	-6.02E-003	+1.55E-002
72266	+1.70E-002	+3.42E-002	+3.82E-002
74219	+4.55E-003	-3.30E-003	+5.62E-003
76172	+3.62E-002	+2.37E-002	+4.33E-002
78125	+4.03E-002	+5.36E-003	+4.06E-002
80078	-1.26E-002	-1.37E-002	+1.86E-002
82031	+8.86E-003	-2.79E-002	+2.93E-002
83984	+3.06E-002	-1.88E-002	+3.59E-002
85938	+2.24E-002	-1.50E-002	+2.70E-002
87891	+4.83E-002	+1.43E-002	+5.03E-002
89844	-4.74E-002	+3.37E-002	+5.82E-002
91797	+4.56E-002	+7.78E-003	+4.63E-002
93750	+1.76E-002	+1.83E-002	+2.54E-002
95703	+2.20E-003	+7.10E-003	+7.44E-003
97656	+8.83E-005	-1.96E-002	+1.96E-002
99609	+2.58E-002	+2.45E-002	+3.56E-002
101563	-1.17E-002	-4.90E-002	+5.04E-002
103516	-4.46E-003	+3.72E-002	+3.75E-002
105469	-2.00E-002	-9.97E-003	+2.24E-002
107422	+9.80E-003	+9.24E-003	+1.35E-002
109375	+7.10E-003	-1.32E-002	+1.50E-002
111328	-9.77E-003	-4.10E-003	+1.06E-002
113281	+2.51E-003	-1.79E-002	+1.81E-002
115234	+2.81E-002	-5.44E-003	+2.86E-002
117188	-2.21E-004	+1.87E-003	+1.88E-003
119141	+1.14E-002	+1.86E-002	+2.18E-002
121094	+1.69E-002	+2.85E-002	+3.31E-002
123047	-5.51E-003	+2.41E-002	+2.47E-002
125000	-1.12E-002	0.00E+000	+1.12E-002

Figure 4.8

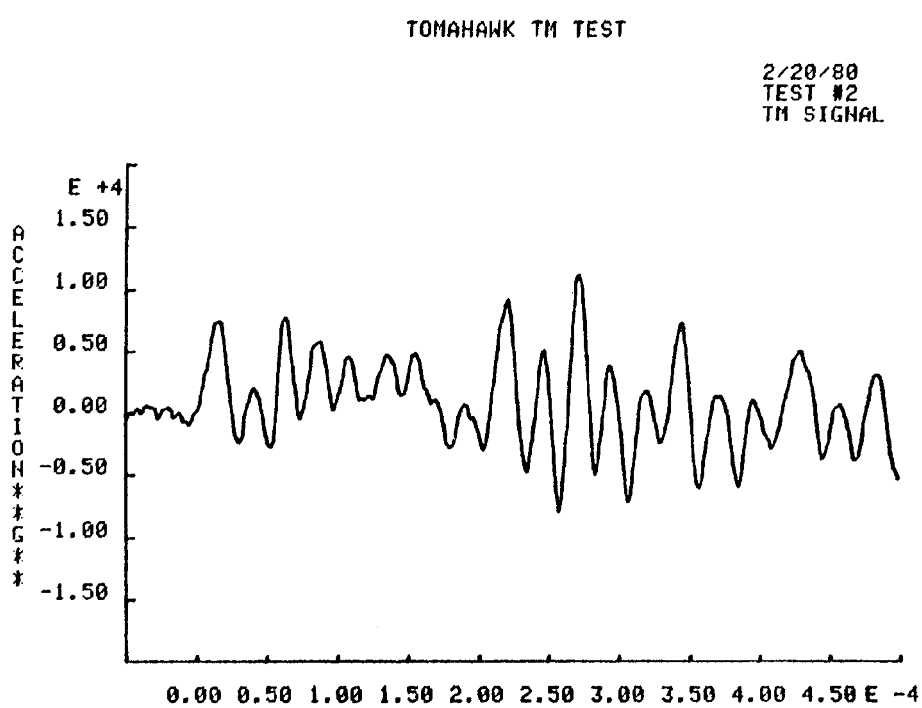

Figure 4.9

IRIG Channel	f_s (KHz)	f_{as} (KHz)	M.I. N	f'_{dc} (10^6Hz)	f'_{dc} (Norm.)	f_{dc} (khz)	f_{dcf}(KHz) B = 1.13	Channel Check Factor	Comp	MI M
K	400	±15	5	320.28	1	242.00	273.46	1.6	1.75	.68
I	225	±15	5	135.12	.42	101.64	114.85	1.6	1.74	.51
21B	176	±4	5	36.38	.11	26.62	30.08	1.6	1.91	.17
19B	160	±4	5	33.07	.10	24.00	27.12	1.6	1.91	.17
17B	144	±4	5	29.77	.09	21.78	24.61	1.6	1.91	.17
15B	128	±4	5	26.46	.08	19.36	21.87	1.6	1.91	.17
13B	112	±4	5	23.15	.07	16.94	19.14	1.6	1.91	.17
11B	96	±4	5	19.84	.06	14.52	16.40	1.6	1.91	.17
9B	80	±4	5	16.54	.05	12.10	13.67	1.6	1.91	.17
7B	64	±4	5	13.23	.04	9.68	10.94	1.6	1.91	.17
5B	48	±4	5	9.92	.03	7.26	8.20	1.6	1.91	.17
3B	32	±4	5	6.61	.02	4.84	5.46	1.6	1.91	.17
					A = 1.98	500.74	596.98KHz			Total M = 2.898

$F = Af_{dc} = 991.46$ KHz

Table B-1 Analytical Tabulations