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6 NON-LINEAR JUNCTION CHARACTERIZATION.

by

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ABSTRACT

The phenomena of non-linear junctions formed by contacting metal surfaces was investigated and a method to characterize these junctions is described.

RÉSUMÉ

Des recherches ont été meneés sur le phénomène de la jonction non-linéaire qui se produit au contact de deux surfaces métalliques et ce travail décrit une méthode pour caractériser ces jonctions.

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1. INTRODUCTION

Normally linear components, such as points of contact, can become nonlinear elements. These can occur in coupling hardware of coaxial transmission lines, in flanged joints of wave guides and in other waveguide components that are bolted together.

Chemical compounds build up on metal contact surfaces exposed to the atmosphere. The compounds, oxides and sulphides for example, are semiconductive and tend to increase contact resistance. They have a non-linear current-voltage characteristic that can be used to characterize Metal-Oxide-Metal junctions by non-linear measurements.

When a pure sinusoidal current flows through a component (point of contact) the voltage across it is distorted by any nonlinearities present. The distorted voltage can be considered the sum of a fundamental frequency voltage and a number of voltages at harmonic frequencies. The magnitude of these harmonic voltages can serve as a measure of the nonlinearity present in the contact. For convenience, the third harmonic is usually chosen since it has the largest magnitude and therefore is easiest to measure. (1)

2. HISTORICAL REVIEW

2.1 MECHANICS

The absolute distortion level depends very much on which parts of the contact surfaces touch. Nonlinear generation is strongly dependent on the contact geometry, pressure and physical condition of the surfaces. (4,3)

The nonlinearity of a contact will depend on the relative proportion of the conductance and displacement currents and on the nonlinearity of the specific conduction mechanisms. Even optically ground surfaces have more irregularities (ripples) than flat areas. Figure 1 illustrates the microscopic conditions at a metal-to-metal junction.

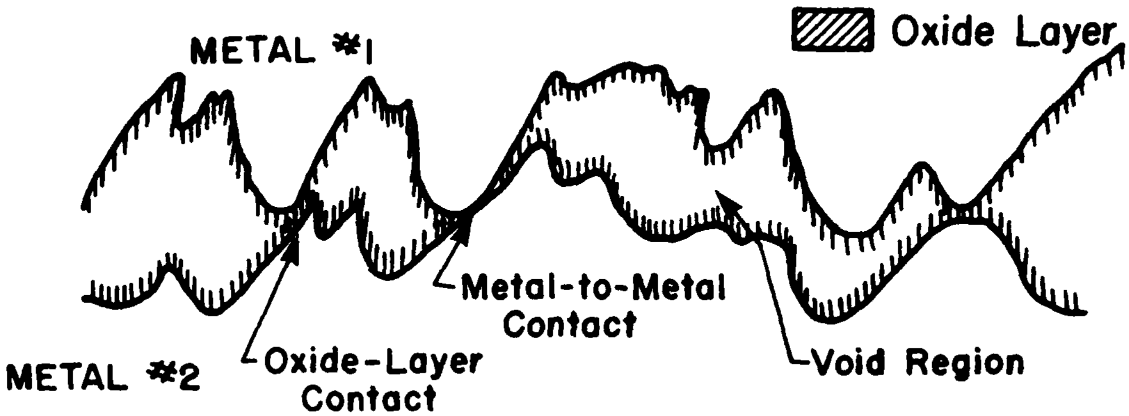

Figure 1. Model of two "smooth" metal surfaces in contact, microscopic scale

The number of actual contacting points on a pair of surfaces is given by a statistical distribution of the number and height of peaks and the probability that there will be matching peaks and valleys or matching peaks and peaks. Increasing pressure will increase the contact area and the number of individual contacting points by deforming the metal and causing plastic flow. The higher, thinner peaks will deform first with low smooth peaks and valleys deforming last, if at all. (3)

The total load bearing area is increased with the applied pressure. If all ripples on the metal surface were equal in height, the increase would be proportional to the increase of the total load bearing area. However, since the ripples are random in height, when the pressure is increased new contacts will be made so that the total area of the load bearing spots will increase at a reduced rate. Figure 2 illustrates this idea. (3)

Figure 2. Surface irregularities

The density of the contact spots and thus the density of the unit equivalent circuits will increase with pressure. This will lead to the series of I-V characteristics illustrated in Figure 3. (3)

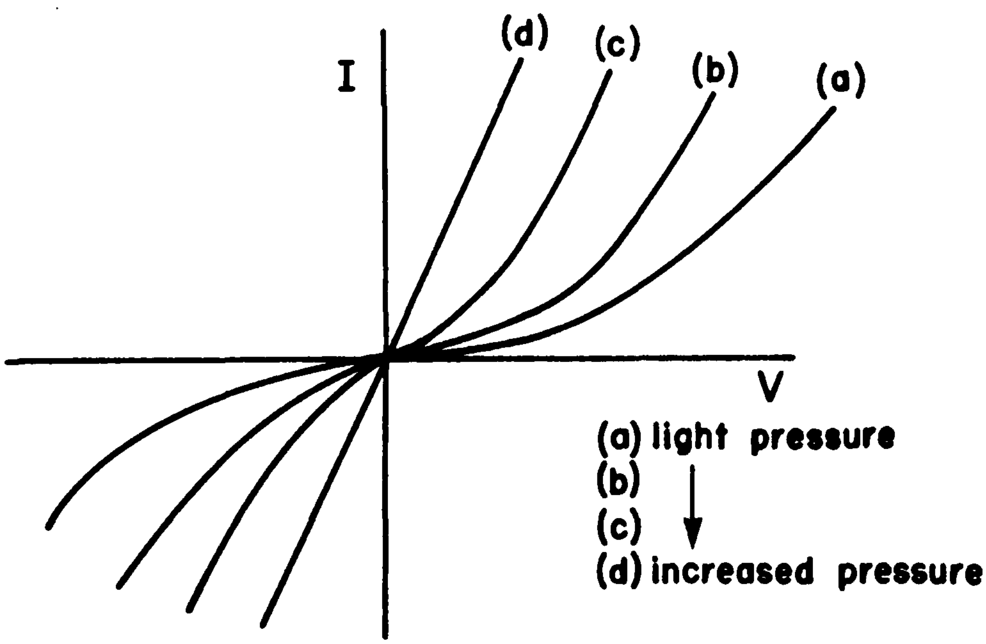

Figure 3. I-V characteristic of metal-oxide-metal junction

Assuming that the load bearing contact contains a non-linear element, a possible current for a light contact with a few contact points is given by curve (a). With increasing pressure more new contact points will be created, resulting in response curves (b) and (c). In the limit, the straight line (d) will be approached, which is the I-V curve of an ideal linear element. (3)

2.2 PHYSICS

The two predominant causes of nonlinear effects are electron tunnelling through thin oxide layers separating the metallic conductors at conductor junctions and the semiconductor action created at a metal-oxide-metal interface. Basically, the thickness of the oxide layer will determine whether tunnelling or semiconductor action takes place. Other potential sources of nonlinear operation are contingent on fabrication processing. These can include micro discharge between microcracks in metallic structures, gaseous conduction phenomena, and water vapour absorption. (3)

3. TEST PROCEDURES AND RESULTS

In order to study the properties of nonlinear junctions formed by metal-to-metal interfaces the following mechanical devices (jigs) were constructed. Junction characteristics were monitored using the experimental set up shown in Figure 4.

3.1. DYNAMIC APPARATUS

A dynamic apparatus was constructed to simulate non-linear M-O-M junctions found in equipment containing relays and contacting rotating elements. This type of apparatus is useful for statistical analysis because the non-linear generation due to make and break of contacts can be averaged over a period of time. An illustration of the dynamic apparatus is shown in Figure 5.

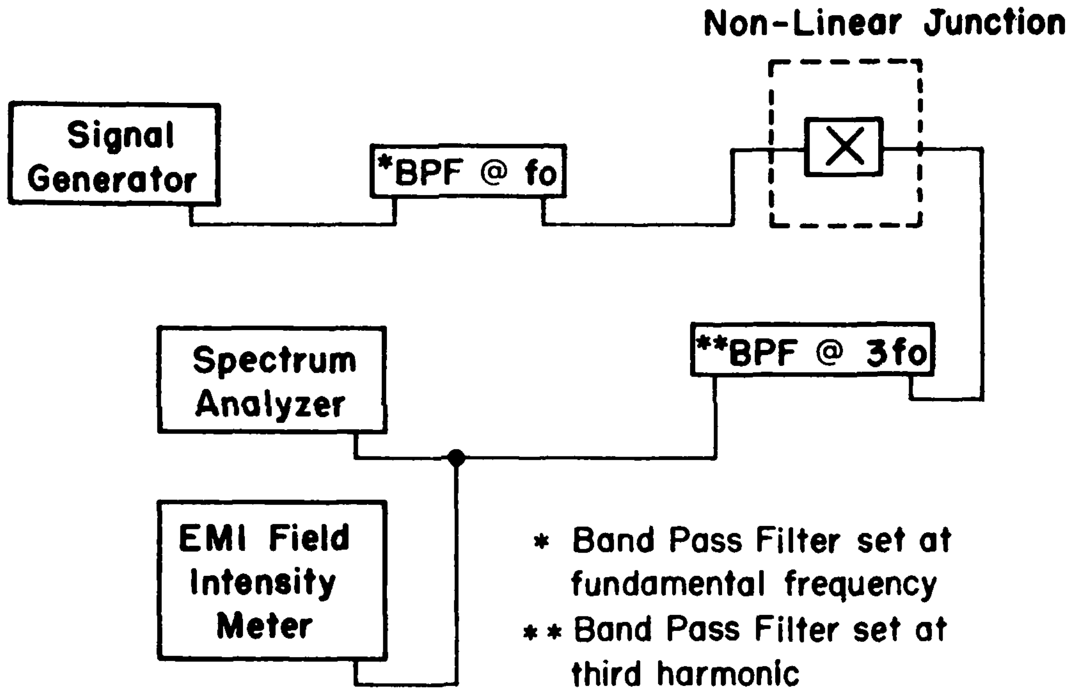

Figure 4. Basic test method

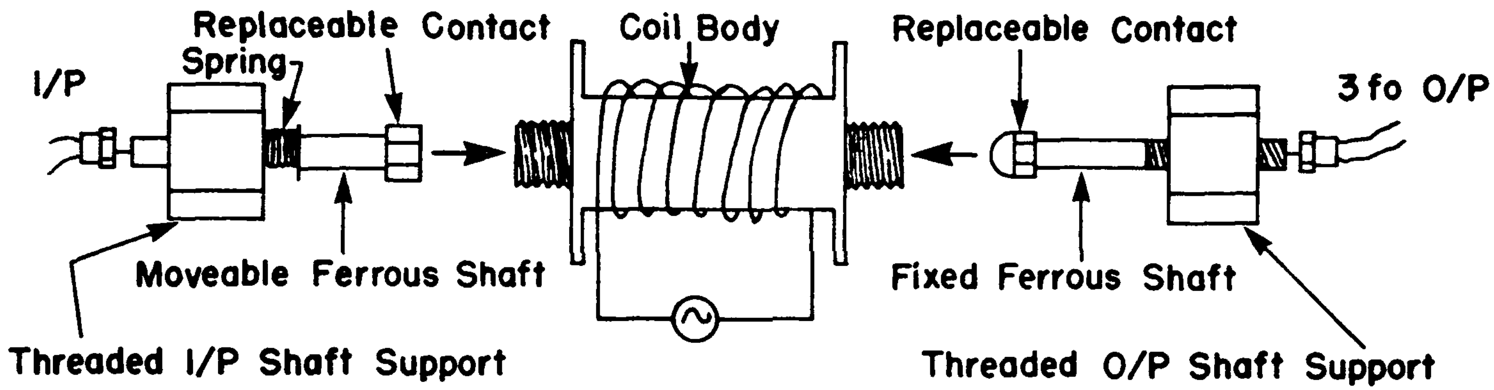

Figure 5. Dynamic apparatus

The dynamic apparatus works on the same principle as a solenoid. When a sinusoidal voltage is used to drive the coil the I/P and O/P shafts are attracted to and repelled from each other. Figure 6 shows the test set-up for the dynamic apparatus.

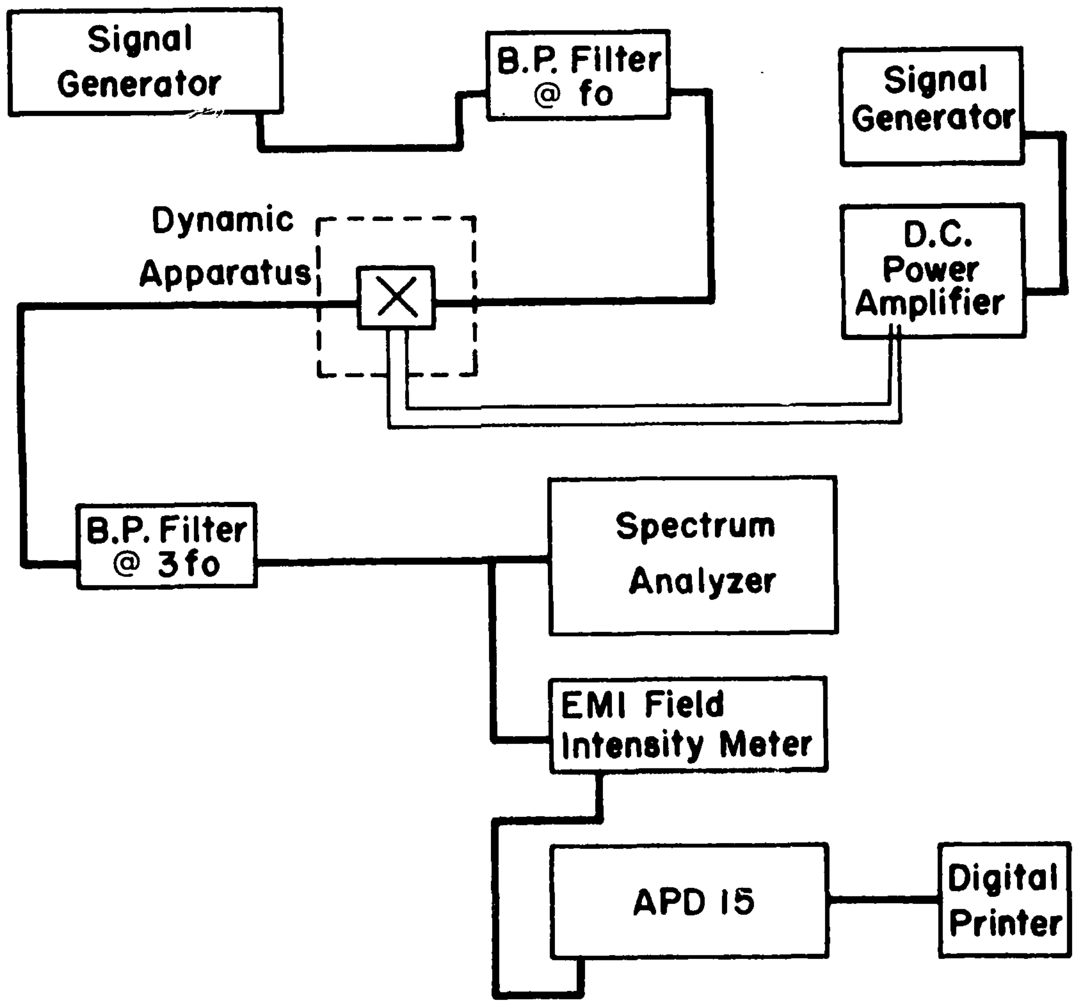

Figure 6. Block diagram of dynamic test set-up

3.1.1. Test Method

Refer to Figure 6; with the signal generator set at the fundamental frequency (fo) of interest, either 30 MHz, 100 MHz or 300 MHz, the output was fixed at 1 VRMS (one volt root mean square). Any spurious signals, present at the output of the generator, were filtered out by a bandpass filter (BPF) tuned to the fundamental. The clean fundamental was then fed to the dynamic apparatus which was adjusted to operate at a contact repetition rate of 10 Hz. Third harmonic (3fo) was bandpass-filtered from the nonlinear junction output and was detected by the Field Intensity Meter (FIM) which was tuned to the third harmonic. Third harmonic (3fo) magnitude, available at the FIM's "Linear Video" output, was analyzed over a time interval of 100s to average out any discrepancies in the 3fo signal from one contact make-break to another, by the APD-15*.

Amplitude versus percentage time curves were drawn from this information to characterize nonlinear junctions, caused by contacting metal surfaces, as metal type and fundamental frequency were varied.

3.1.2. Typical Data Output Format

Typical data output for aluminium electrodes at a contact repetition rate of 10 Hz and at a fundamental frequency of 30 MHz is shown in Figure 7.

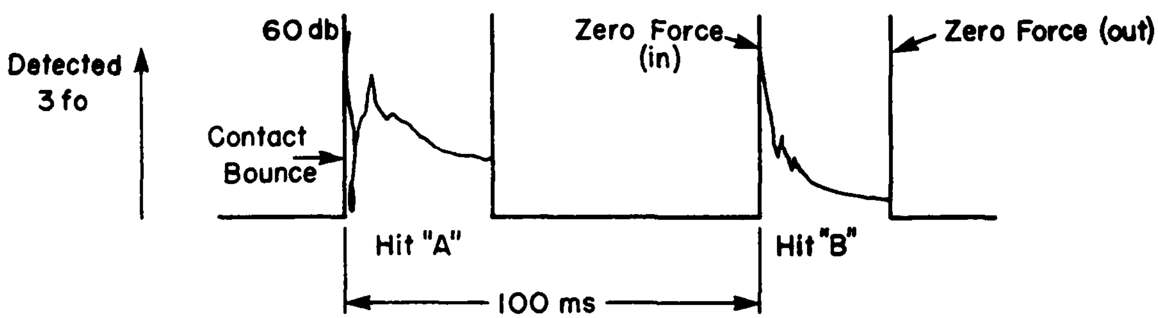

Figure 7. Typical 3fo vs time output for the dynamic set-up

* The APD-15 is a DREO-developed, 15 channel, amplitude probability distribution analyser with sampling times of 1s, 10s or 100s. A technical description of the APD-15 is in preparation.

Referring to Figure 7, note the differences in 3fo output for Hits A and B. Hit "A" contained contact bounce and the 3fo output was higher in level and was present, for a longer time. Reference 2 gives an explanation for this phenomena.

> "Since the current carrying surfaces are very small, a lateral shifting of the contact members with respect to each other by a few thousands of a millimeter result in completely different junction surfaces. A lifting and re-joining of the contact can, for equal contact force and equal signal level, change the signal-to-distortion ratio from 70 dB to 130 dB or vice versa, to mention one example. The absolute distortion level is therefore undetermined; only the change in contact force is characteristic for a given contact."

3.1.3. Test Results

The one factor affecting 3fo generation that the dynamic set-up singled out is that 3fo generation is frequency dependent. Referring to Appendix 6.1 (Dynamic Apparatus - Characterization Curves), note that the amplitude probability curves ** for Aluminium, Code Rolled Steel and Copper shift to the lower end of the probability axis as the fundamental frequency is changed from 30 MHz, to 100 MHz to 200 MHz.

3.1.4. Dynamic Apparatus Limitations

After considerable testing, it was decided to cease testing with the dynamic apparatus and construct a static apparatus for the following reasons:

1) Contact head bounce - the moving contact tended to bounce upon impact with the fixed contact because of limited mechanical damping.

2) Unknown contact force - crude force adjustment was provided by the coil drive voltage but the absolute value of force was not monitored. Contact replacement resulted in different solenoid performance. For example, when aluminium was installed in the I/P and O/P shafts, a higher coil voltage was necessary for the contacts to hit each other.

** These curves serve only as an indication of the 3fo dependence on frequency and metal type. They should not be used for comparison purposes, because contact force was not monitored.

3.2 PROTOTYPE STATIC APPARATUS

A prototype apparatus (Stat I), constructed to study static characteristics of non-linear junctions formed by contacting metal surfaces, is shown in Figure 8 below.

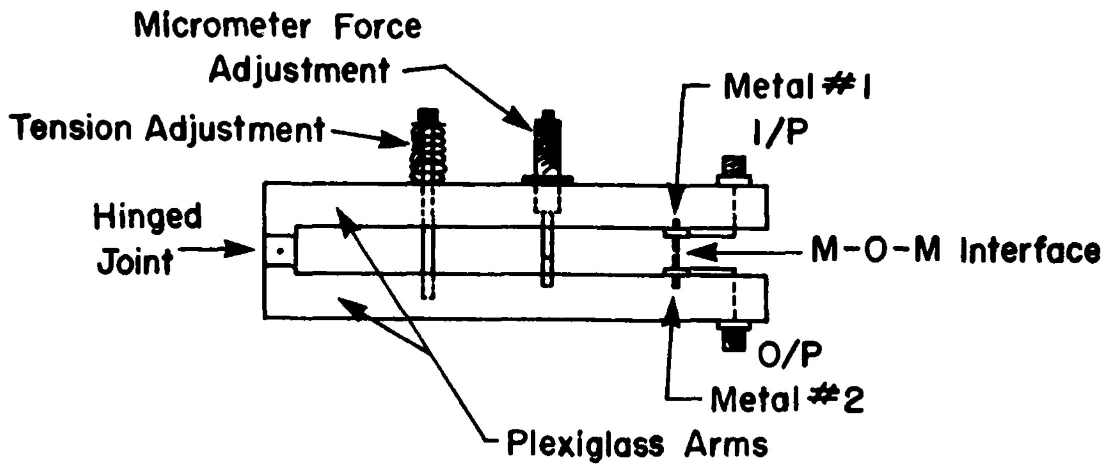

Figure 8. Stat I apparatus

Referring to Figure 8, the Stat I apparatus consisted of two hinged plexiglass arms, each having inlaid metal heads to act as contact points, and fixed type N connectors, one for signal input and one for signal output. Contact force adjustment was provided by a micrometer/spring arrangement.

Preliminary tests showed that Stat I was not suitable for testing purposes due to sensitivity and stability problems. A more rigid, precise and versatile apparatus was then constructed.

3.3 PRECISION STATIC APPARATUS

Preliminary testing showed that a static apparatus should have the following features:

1) Easily removable and replaceable contact points.

2) Precision, continuously variable force adjustment.

3) Direct reading force output.

Such an apparatus, Stat II, was constructed. A descriptive diagram is shown in Figure 9 and a photograph of the test system is shown in Figure 10.

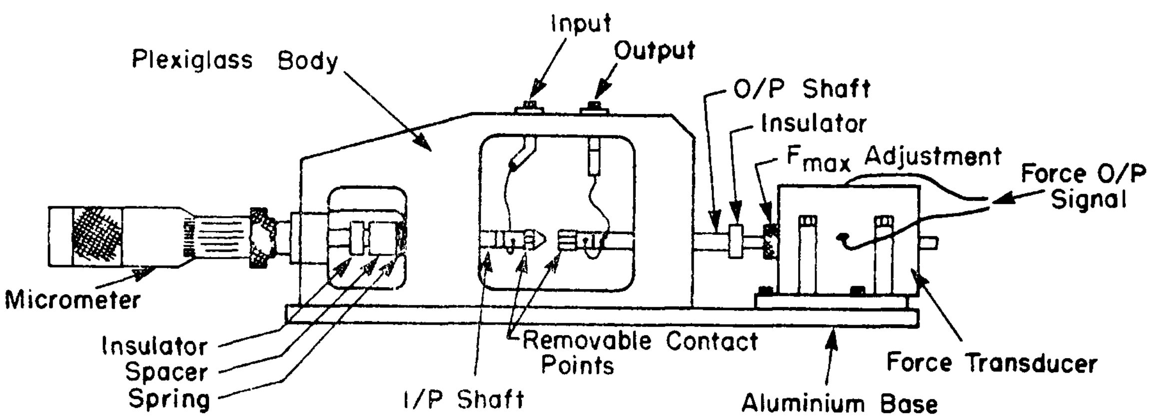

Figure 9. Stat II

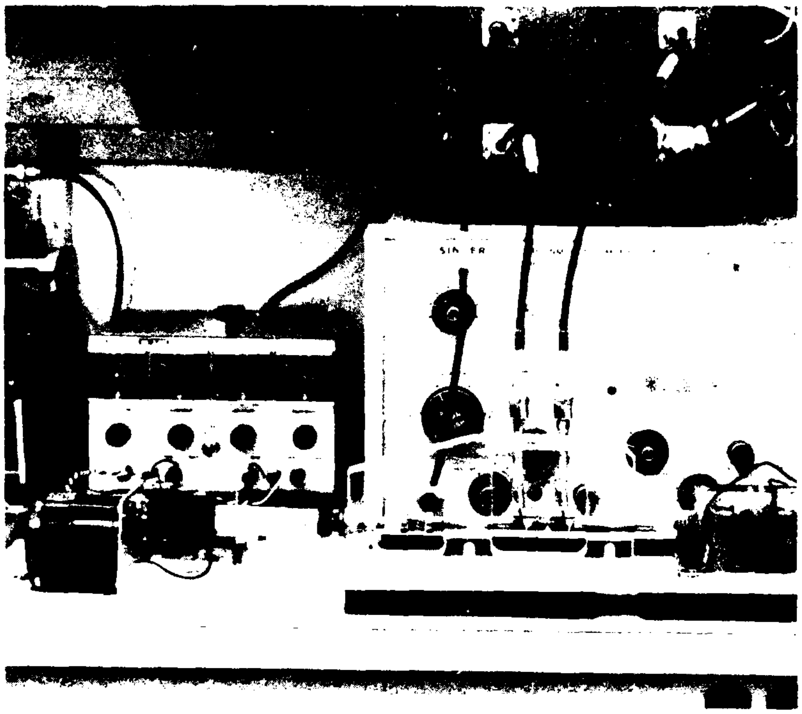

Figure 10 (a)
Stat II

(Apparatus and Drive)

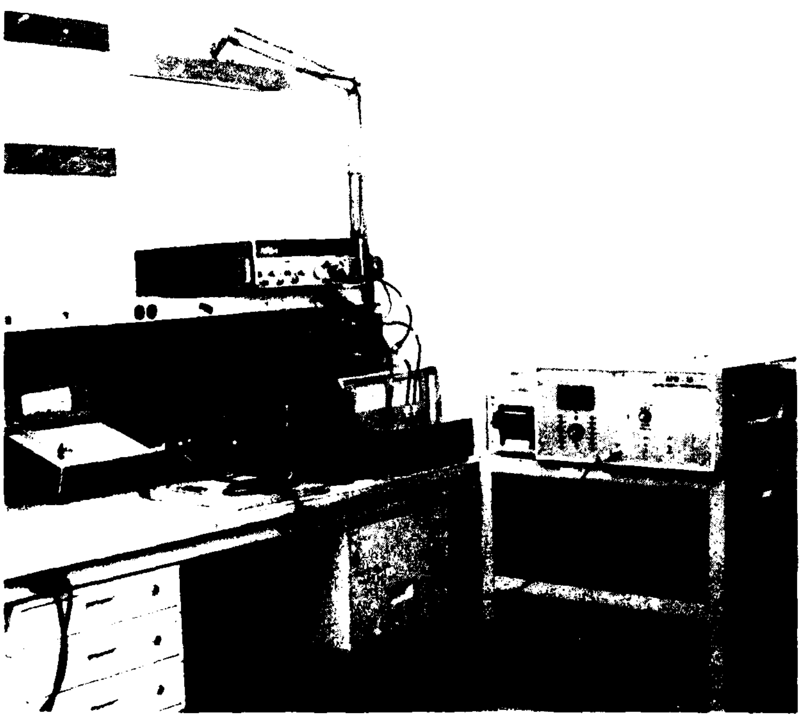

Figure 10 (b)
Stat II shown in
test set-up

Stat II was incorporated into the Basic Test Method as shown in Figure 11 below.

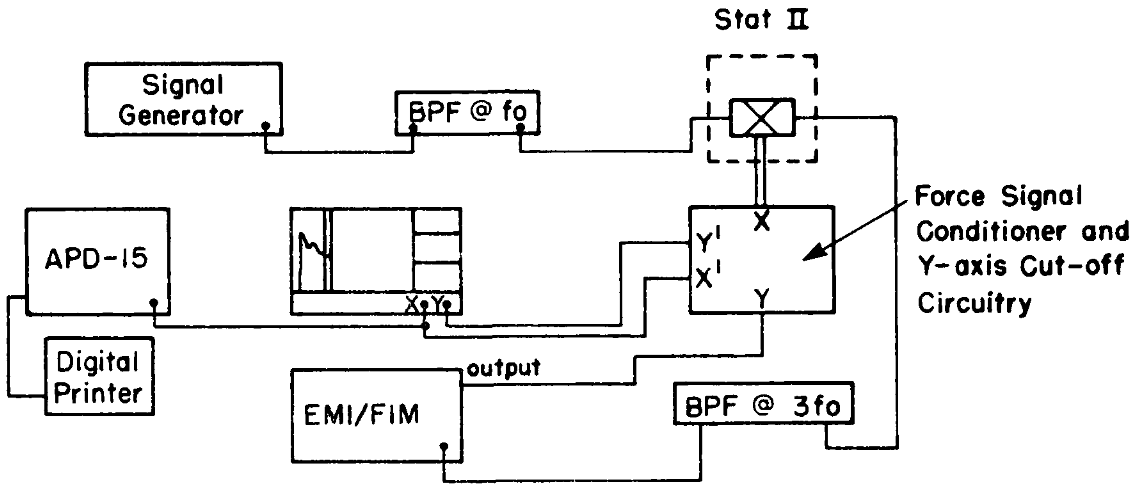

Figure 11. Block diagram of Stat II non-linear junction characterization method

3.3.1 Replaceable Contact Points

Since non-linear generation is strongly dependent on contact geometry, the following contact shapes were chosen and machined. See Figure 12.

a) Planar (3/8" diameter hexagonal cylinder with planar end).

b) Domed (3/8" diameter hexagonal cylinder with 3/16" radius hemispherical end).

c) Pointed (3/8" diameter hexagonal cylinder with 1/32" radius conical end).

Figure 12. Contact Shapes (Scale drawings ref. Figure 24 Appendix 6.2)

By using these shapes several contact forms are possible such as planar-planar, planar-dome and planar-point. Complete sets of contact heads were made up of the metals, aluminium, copper and cold rolled steel, commonly used in electronic structures.

Contribution of the threaded portion of the contact head to non-linear generation was tested by inserting a shorting section (see Appendix 6.2) between the input and output shafts of Stat II. The threaded portions of the shorting section were identical to those of the replaceable heads and served as the only * nonlinear junctions in this test. Table I lists third harmonic output due to the threaded portion of the contact head.

TABLE I

Nonlinear Generation Due to the Threaded Portion of a Contact Head

Metal Type	Fundamental Frequency			
	30 MHz	100 MHz	300 MHz	
Cold-rolled Steel	6.5 dB	0.8 dB	0.5 dB	dB (referred to 1μV)
Aluminium	4 dB	0.8 dB	0.1 dB	
Copper	4 dB	1.5 dB	0.1 dB	

3.3.2 Data Output Format

It was decided that a real-time, direct reading third harmonic versus force output would be most appropriate to characterize the effect of nonlinear generation. An X-Y plotter is well suited for this type of graphical data output format. Third harmonic magnitude was obtained from the Y-axis output of the Field Intensity Meter. Some modification to the transducer output was necessary because its output is a resistance change and a voltage was required. (See Appendix 6.3). It was also decided to terminate the 3fo signal output once the force reached 10 kg (see Appendix 6.4). The reasoning for doing this is discussed later in the section dealing with APD analysis.

*Contribution of all cable interconnections to nonlinear generation is assumed to be negligible; but, new, high quality cables must be used; if not, oxidized cable connectors could introduce extraneous nonlinear junctions that would invalidate test results.

3.3.3 Amplitude Probability Distribution (APD) Analysis

Amplitude probability distribution analysis is basically a method of signal characterization in which the percentage time that a signal is above specified levels is monitored. Typical signal sample time intervals are multiples of 1 sec. i.e. 0.1s, 1s, 10s, 100s etc.

APD analysis can be applied to Stat II if the motor's speed is adjusted so that full scale force (10 kg) is reached in a fixed time interval. By doing this a direct relationship between force (kg) and time (sec) can be established. Tests show that this relationship is linear as depicted in Figure 13.

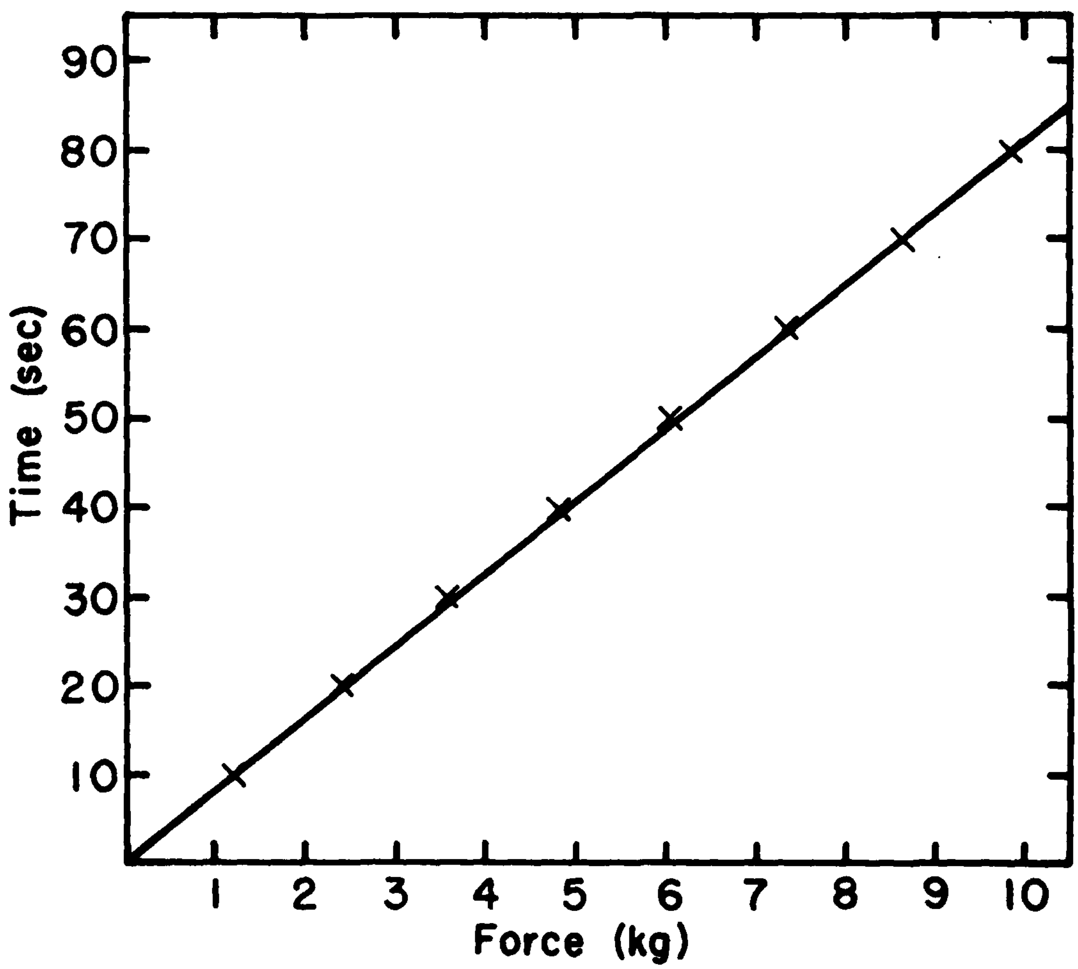

Figure 13. Force-time relationship

To use the APD-15 as a characteristic curve generator, the time interval (T_F) mentioned must be within the sampling period (T_S) of the APD-15 and should be a fixed fraction of T_F, (See Figure 14). For example with a T_F/T_S ratio of 1:2 the percentage time data obtained using the APD-15 can be simply multiplied by two (2) to give actual percentage time values.

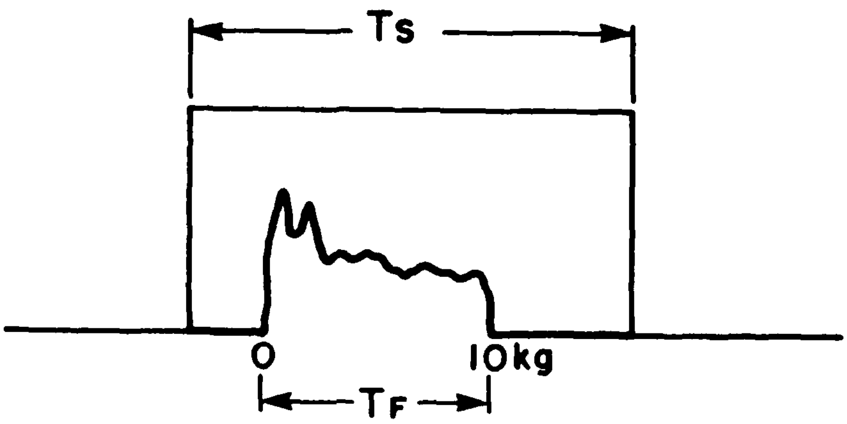

Figure 14. T_F/T_S relationship

T_S - APD-15 sampling period, T_S = 1s, 10s or 100s

T_F - Time required for Stat II to go from 0 to 10 kg (80 seconds)

3.3.4 <u>Test Method</u>

With reference to Figure 15 and Appendices 6.2, 6.3, 6.4 and 6.5, the following test method, shown in flow chart format, was adopted.

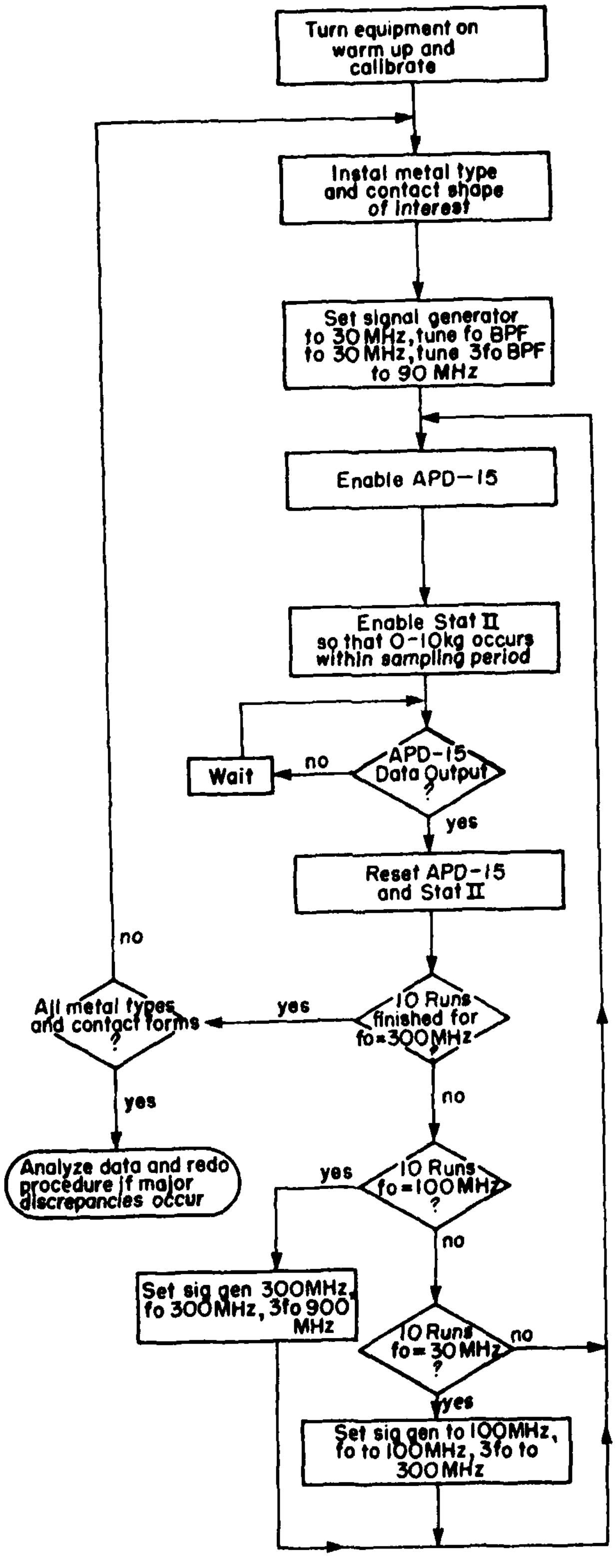

Figure 15. Flow chart of test method used with Stat II.

3.3.5 Data

Data was obtained by following the Test Method outlined in Section 3.3.4. Ten test runs were done for each metal, contact form and frequency of interest. Third harmonic versus force curves and amplitude probability distribution analysis were produced for each test run. Third harmonic versus force curves for cold rolled steel (flat-pointed contact form, fundamental frequency of 100 MHz) are shown in Figure 16. Amplitude probability distribution (APD) analysis data for these curves is shown in Appendix 6.6, and an averaged, normalized APD curve for the 10 runs is shown in Figure 17.

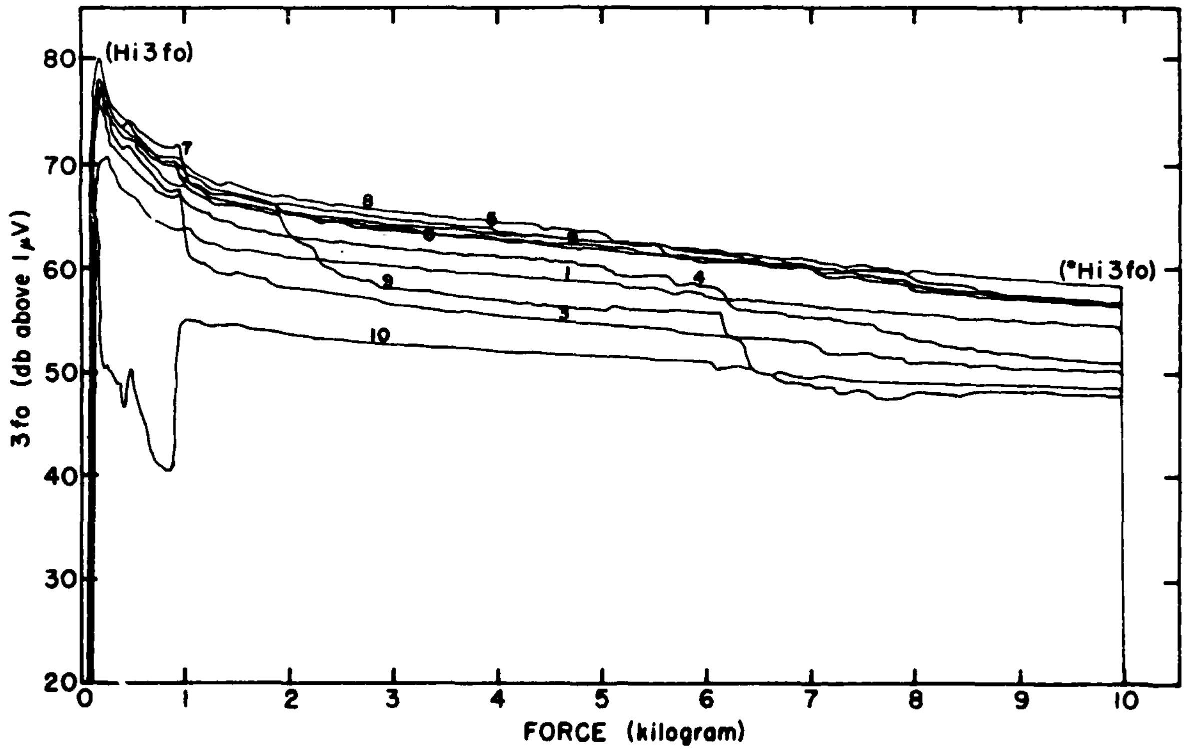

*Figure 16. Ten third harmonic versus force curves for cold rolled steel showing the points Hi3fo and * Hi3fo*

3.3.5.1 CHARACTERIZATION

Once the data was collected and analysed the following method to characterize nonlinear generation caused by contacting metal surfaces with respect to metal type, contact shape and fundamental frequency was adopted.

The points Hi3fo (0 force) and *Hi3fo (10 kg force), and Hi3fo (Lo % time) and Lo3fo (Hi % time) were arbitrarily chosen from respective third harmonic versus force and third harmonic versus % time curves (ref. Figures 16, 17). Estimated slopes were drawn on these curves to show trends in third harmonic generation.

Table II lists the characterization values for the APD characteristic curves, and Table III lists the characterization values for the third harmonic versus force curves. Figures 18, 19, and 20 illustrate the data from Table III.

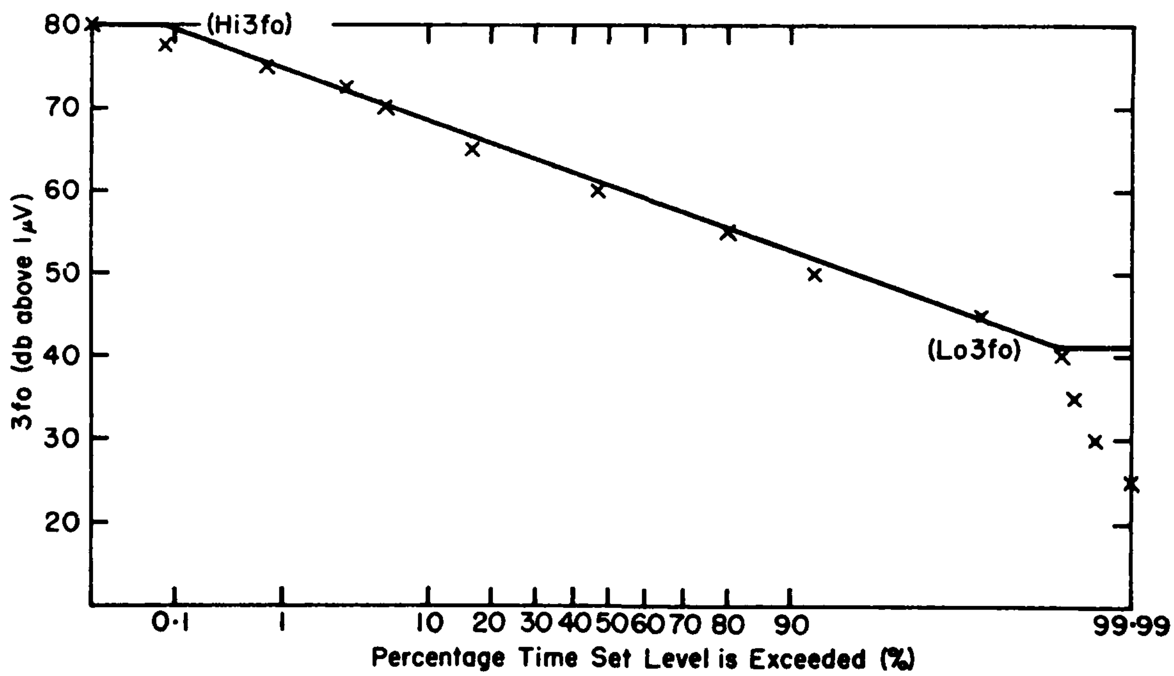

Figure 17. A normalized APD curve derived from Figure 16 showing the points Hi3fo and Lo3fo

TABLE II

Data Obtained from Averaged APD Characteristic Curves

Contact Shape	Fundamental Frequency	Cold Rolled Steel			Aluminium			Copper		
		Hi3fo	Lo3fo	Slope	Hi3fo	Lo3fo	Slope	Hi3fo	Lo3fo	Slope
Flat-Flat	30	78	21	-1.2	77	24	-0.56	14	14	0
	100	61	2.5	-1.0	74	25	-0.51	3	3	0
	300	33	5	-0.61	35	3.5	-0.37	3	3	0
Flat-Dome	30	81	20	-0.66	60	9	-2.88	14	14	0
	100	62	2	-0.67	61	5.5	-0.71	3	3	0
	300	61	3	-0.67	61	3.5	-2.31	4	4	0
Flat-Point	30	81	45	-0.44	57.5	6	-0.61	14	14	0
	100	80	41	-0.39	76	2.2	-1.1	2	2	0
	300	75	25	-0.51	54	3	-0.58	6	6	0
	in MHz	dB above 1μV		dB/%	dB above 1μV		dB/%	dB above 1μV		dB/%

TABLE III

Data Obtained from Third Harmonic Versus Force Curves

Contact Shape	Fundamental Frequency	Cold Rolled Steel			Aluminium			Copper		
		Hi3fo (0kg)	*Hi3fo (10kg)	Slope	Hi3fo (0kg)	*Hi3fo (10kg)	Slope	Hi3fo (0kg)	*Hi3fo (10kg)	Slope
Flat-Flat	30	78	23	-2	77	33	-4.5	14	14	0
	100	61	15	0	74	47	-1.9	3	3	0
	300	33	14	-1	35	7.5	-2.2	3	3	0
Flat-Dome	30	81	45	-3	60	14	-31.25	14	14	0
	100	62	41	-1	61	15	-3.35	3	3	0
	300	61	17.5	-2	61	3.5	-23.3	4	4	0
Flat-Point	30	81	63.5	-1	57.5	32	-1.5	14	14	0
	100	80	58	-1.25	76	41	-1.9	2	2	0
	300	75	44	-1	54	24	-1.5	6	6	0
	in MHz	dB above 1μV		dB/kg	dB above 1μV		dB/kg	dB above 1μV		dB/kg

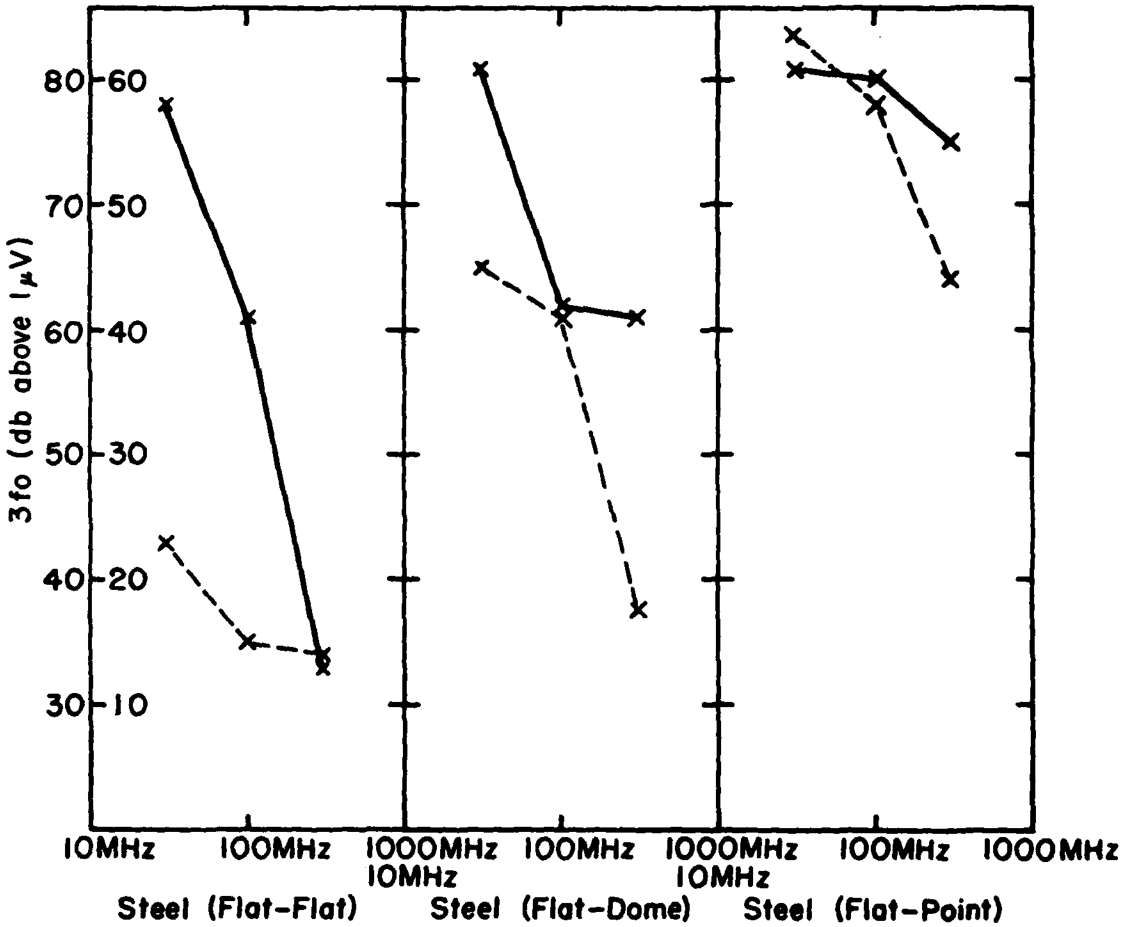

Figure 18. Third harmonic dependence on frequency and contact form/area for cold rolled steel for contact forces of 0 kg (solid lines) and 10 kg (dashed lines).

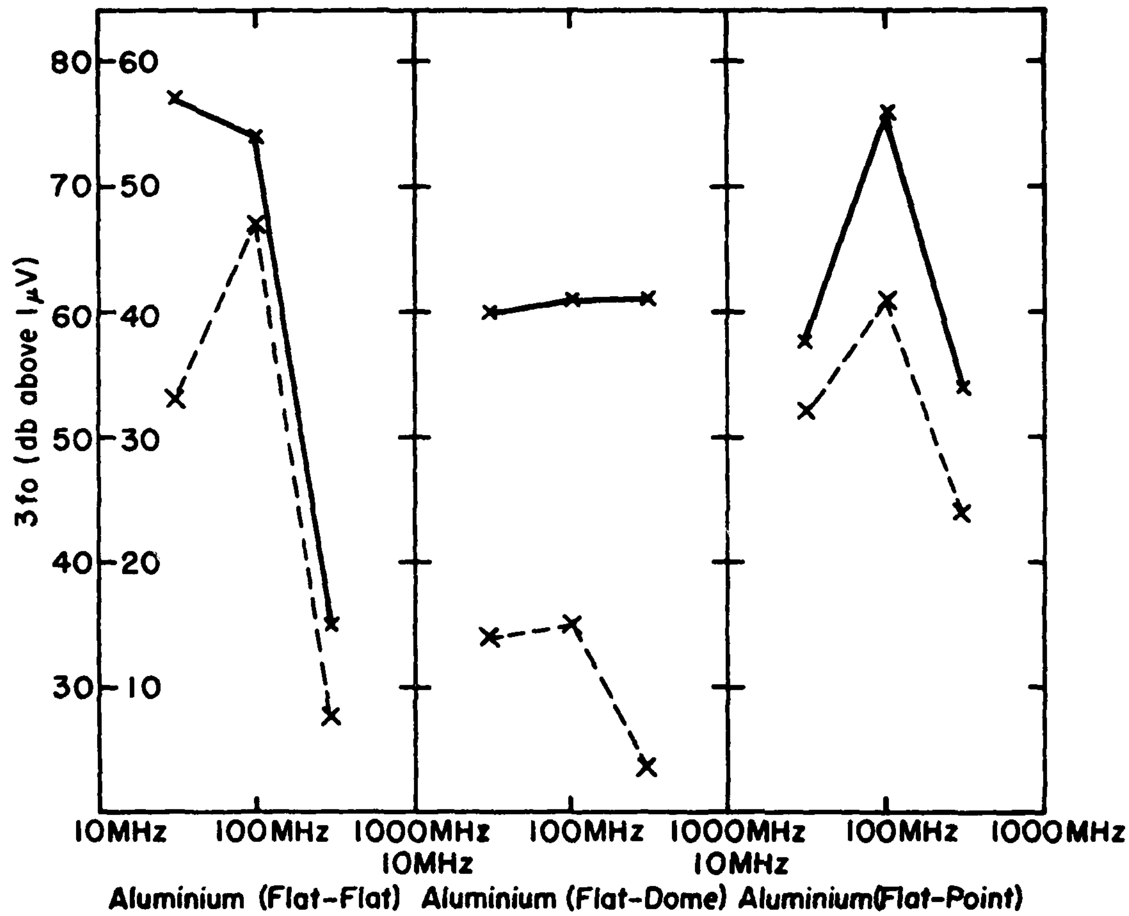

Figure 19. Third harmonic dependence on frequency and contact form/area for aluminium for contact forces of 0 kg (solid lines) and 10 kg (dashed lines).

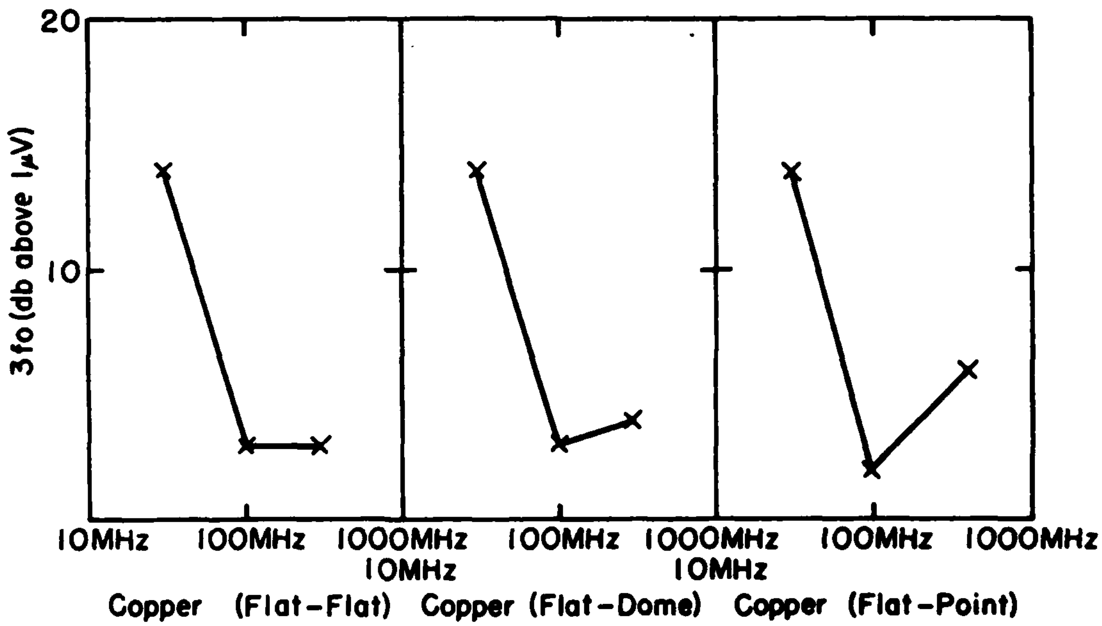

Figure 20. Third harmonic dependence of frequency and contact form/area for copper for contact forces of 0 kg (solid lines) and 10 kg (dashed lines).

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

From the measurements made the following parameters were shown to affect third harmonic generation caused by nonlinear junctions formed by contacting metal surfaces.

a) Metal Type - referring to Figures 18, 19 and 20, it can be shown that the following relationship exists:

Metal Type	Relative Third Harmonic Level
Cold Rolled Steel	Highest
Aluminium	High
Copper	Low

b) Contact Force - referring to Figure 16 and Table III, third harmonic output was shown to be dependent on contact force. Third harmonic generation versus force curves peak upon initial contact, then decrease for cold rolled steel and aluminium. The rate of decrease is greater for aluminium than cold rolled steel. Third harmonic generation curves for copper peak at zero force and remain constant, (test results for copper are most consistent).

c) Frequency - third harmonic generation dependence on frequency was found to be as follows:

For cold rolled steel, third harmonic generation decreased as the fundamental frequency was increased from 30 MHz to 100 MHz to 300 MHz (see Figure 18).

For aluminium, third harmonic generation tended to peak at a fundamental frequency of 100 MHz (see Figure 19).

For copper, third harmonic generation tended to be a minimum at a fundamental frequency of 100 MHz (see Figure 20).

d) Contact Form/Area - for cold rolled steel and copper third harmonic generation increased as the contact area was decreased; Flat-Flat, to Flat-Dome to Flat-Point. For aluminium, the hierarchy was Flat-Point, Flat-Flat and Flat-Dome (see Figures 18, 19 and 20).

The oxides that most likely contributed to nonlinear junctions due to contacting metal surfaces in the testing done are Fe_2O_3, Al_2O_3 and CuO.

4.2 RECOMMENDATIONS

Due to time and material restrictions, thorough investigation was not possible but if further testing is to be undertaken, the following criterion should be met:

(a) Full frequency coverage from 100 KHz to 10 GHz.

(b) Coverage of all metal types used in electronic structures, equipment and components.

(c) Control of environmental conditions such as temperature, humidity and atmosphere.

(d) Capability of forming specific oxides on metal types of interest and control of oxide thickness and condition (smooth, rough).

(e) Inclusion of a computer assisted data handling facility, which in our case would be an interface between the APD-15 and a mini-computer.

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6. APPENDICES

6.1 DYNAMIC APPARATUS - CHARACTERIZATION CURVES

6.2 DIMENSIONS OF CONTACT HEADS

6.3 FORCE SIGNAL CONDITIONER

6.4 Y-AXIS CUT-OFF CIRCUITRY

6.5 CONTINUOUSLY VARIABLE FORCE ADJUSTMENT

6.6 STAT II - APD-15 DATA FOR 10 RUNS OF COLD ROLLED STEEL, FLAT-POINT CONTACT FORM, FUNDAMENTAL FREQUENCY 100 MHZ

APPENDIX 6.1

DYNAMIC APPARATUS - CHARACTERIZATION CURVES

DYNAMIC APPARATUS - CHARACTERIZATION CURVES

The following results which were obtained using the dynamic apparatus (referred to in Section 3.1.3) illustrate that third harmonic generation due to contacting metal surfaces is dependent on the type of metal used and the fundamental frequency applied.

These results are shown in Figures 21, 22 and 23 for cold rolled steel, aluminium and copper respectively using fundamental frequencies of 30, 100 and 200 MHz in all cases.

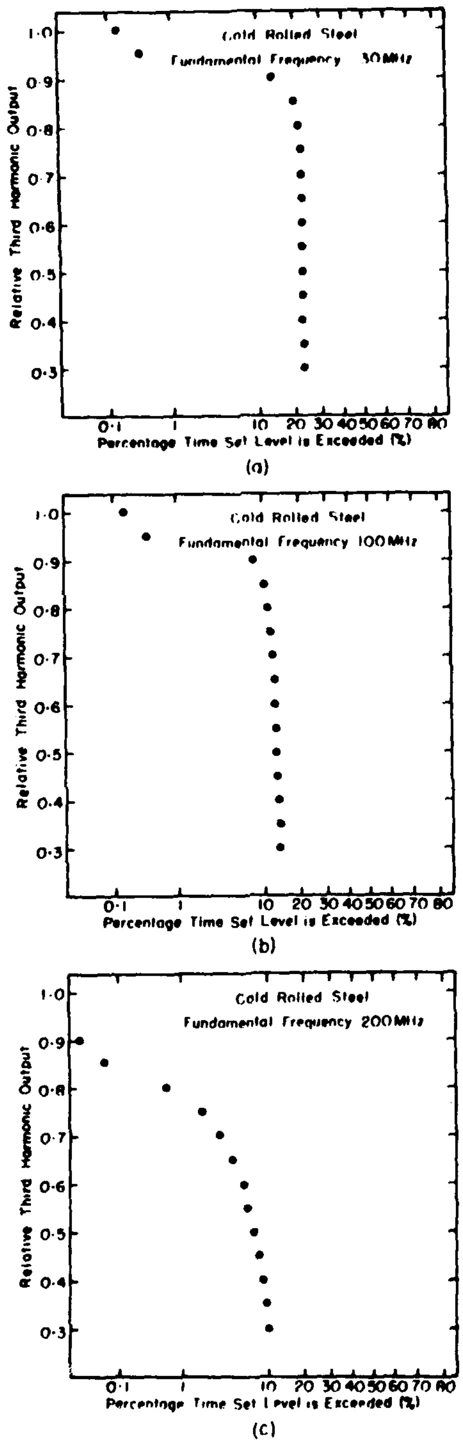

Figure 21. Relative third harmonic output versus percentage time set level is exceeded curves obtained from the dynamic apparatus for cold rolled steel at fundamental frequencies of: a) 30 MHz, b) 100 MHz and c) 200 MHz.

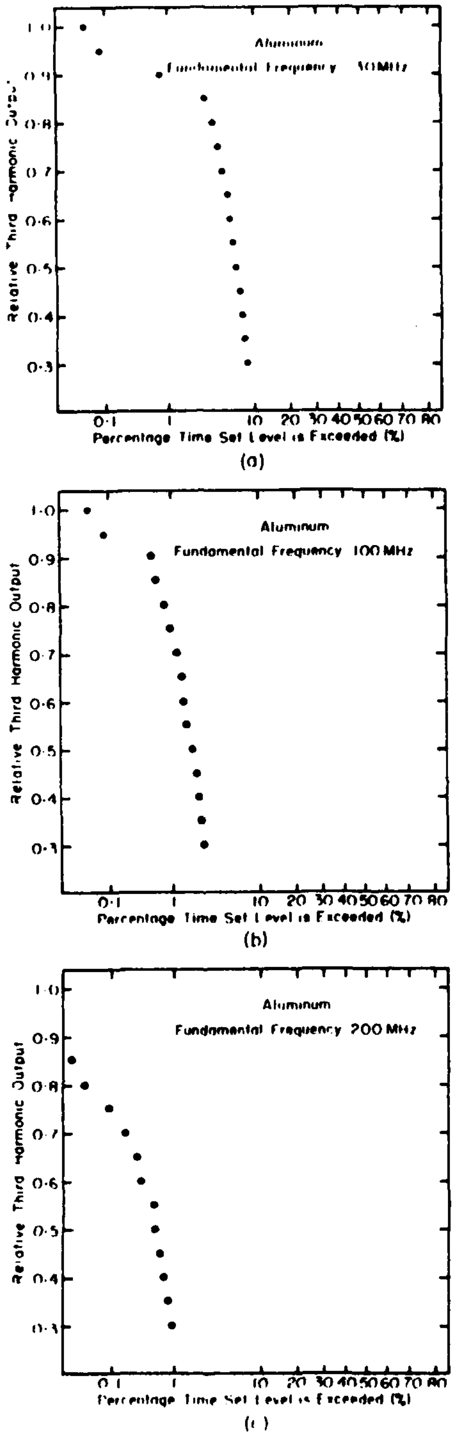

Figure 22. Relative third harmonic output versus percentage time set level is exceeded curves obtained from the dynamic apparatus for aluminium at fundamental frequencies of: a) 30 MHz, b) 100 MHz and c) 200 MHz.

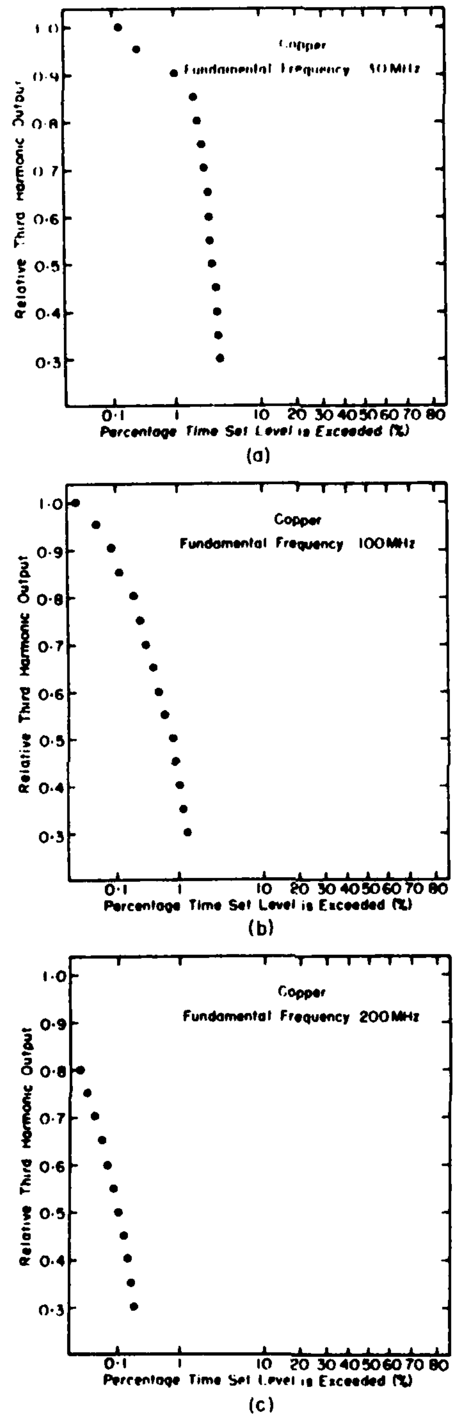

Figure 23. Relative third harmonic output versus percentage time set level is exceeded curves obtained from the dynamic apparatus for copper at fundamental frequencies of: a) 30 MHz, b) 100 MHz and c) 200 MHz.

APPENDIX 6.2

DIMENSIONS OF CONTACT HEADS

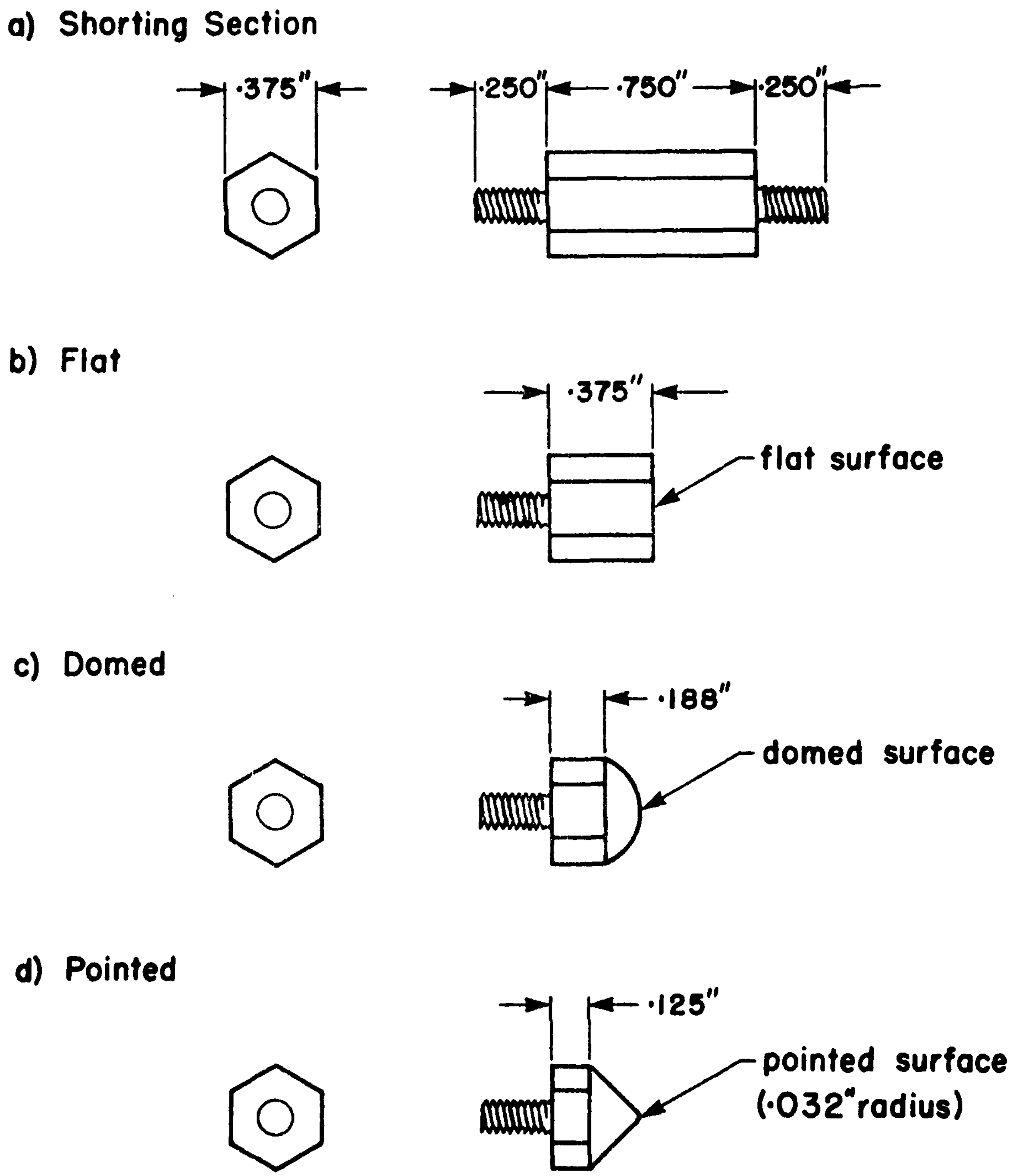

Figure 24. Dimensions of contact heads

APPENDIX 6.3

FORCE SIGNAL CONDITIONER

FORCE SIGNAL CONDITIONER

Third harmonic output was obtained from the Y-axis output of the Field Intensity Meter. The Y-axis output is 0 to 1V ± 5% across 1000 ohms, 0 to 2V open circuit, for zero to full scale meter deflection. This corresponds to a 1V/30 dB output for a high impedance load (1M Ω).

Some modification to the transducer output was necessary. Its output is a linear resistance change of 300 to 200 ohms for a corresponding input force variation of 0 to 10 kg (0 to 9.8N). The Force Signal Conditioner shown in Figure 25, transforms the transducer's output of 300 to 200 ohms to an output of 0 to 5V or .5V/kg.

The circuit comprises four operational amplifiers, two of which, IC_1 and IC_2 generate precision voltage references of + 10V and + 3V respectively. IC_3 uses the constant current source at its non-inverting input to transform the transducer's resistance change of 300 to 200 ohms to a voltage change of 0 to + 1V. IC_4, a 'X5' amplifier, generates the final output of 0.5V/kg. Full scale calibration output of 5V (10 kg) was provided by a switch-selectable 200 ohm resistor.

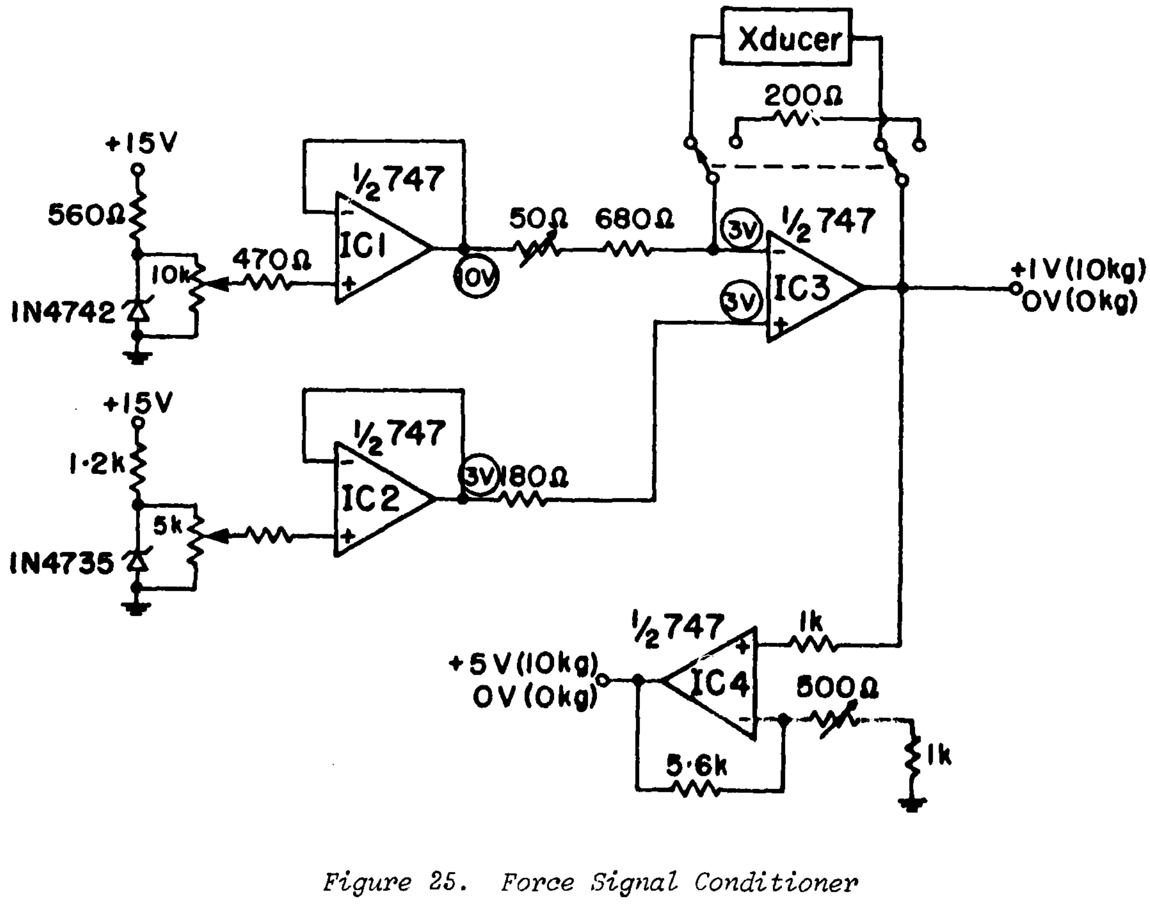

Figure 25. Force Signal Conditioner

APPENDIX 6.4

Y-AXIS CUT-OFF CIRCUITRY

Y-AXIS CUT-OFF CIRCUITRY

It was also decided to terminate the 3fo signal output once the force reached 10 kg (see Figure 26). The reasoning for doing this was discussed in Section 3.3.3 which deals with APD analysis.

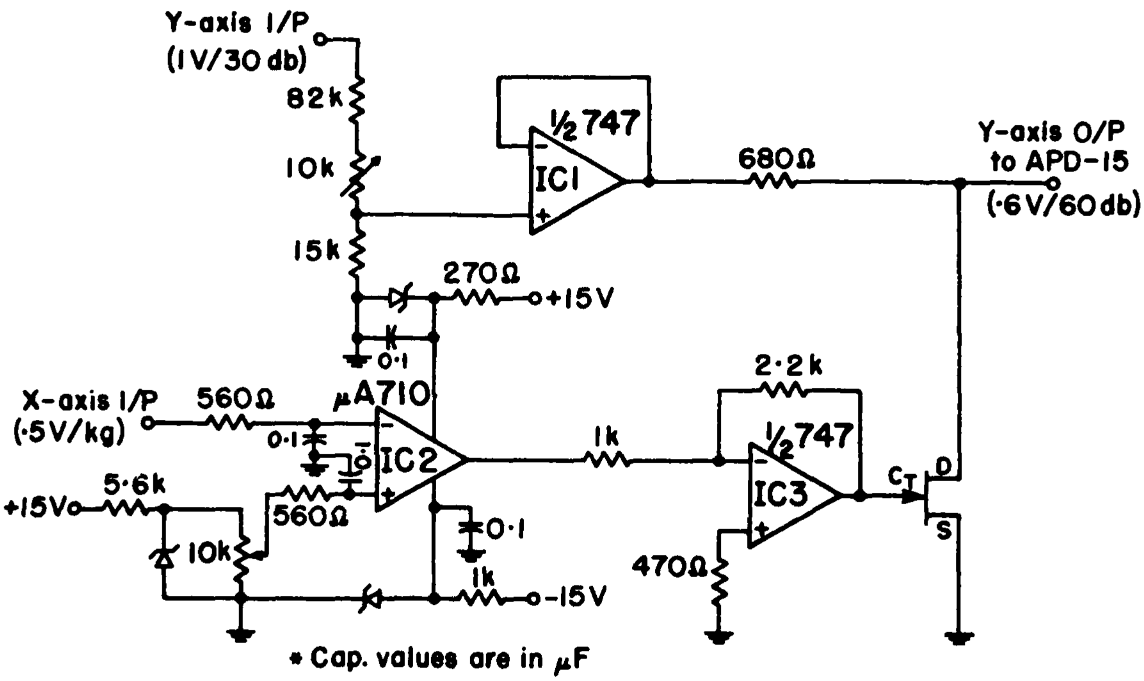

Figure 26. Y-axis cut-off circuitry

This circuit comprises a precision attenuator IC_1, a comparator IC_2, a level translator IC_3, and a field effect transistor switch Q_1. The attenuator is necessary because the maximum input to the ADP-15 is ± 1V. The comparitor, IC_2, detects when the X-axis is greater than 10 kg (+ 5V) by switching its output from + 3.5V to -0.5V. The P-channel, JFET switch (Q_1) used needs a negative voltage of (≈ - 5V) from gate to source to turn off so a level translator (IC_3) was used. When the switch turns on, (F > 10 kg) the output of the attenuator is shorted to ground via R_3 (680). This results in a voltage waveform corresponding to Figure 27.

Figure 27. Typical 3fo vs force characteristic with cut-off at 10 kg.

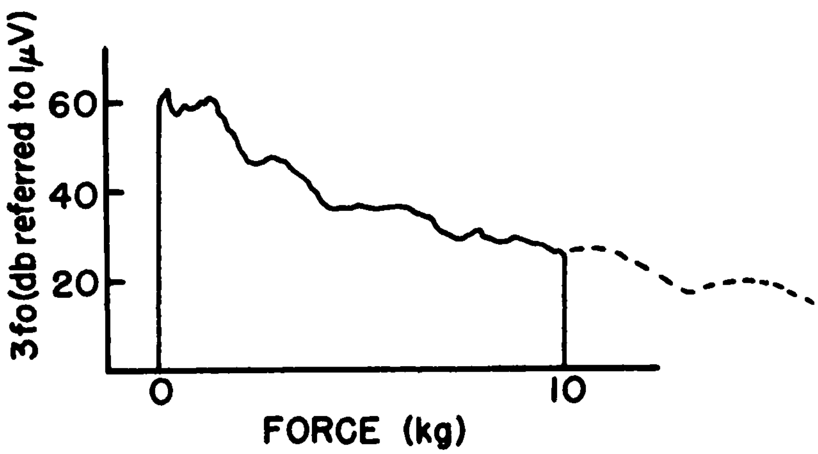

Figure 27. Typical 3fo vs force characteristic with cut-off at 10 kg.

APPENDIX 6.5

CONTINUOUSLY VARIABLE FORCE ADJUSTMENT

CONTINUOUSLY VARIABLE FORCE ADJUSTMENT

Referring to Figure 28, continuously variable force adjustment is provided by a 10 RPM (@ 60 Hz) reversible fractional horsepower, bodine motor, rubber mounted to the micrometer. The motor slides on a teflon track to compensate for micrometer head travel. Motor drive is provided by a variable frequency (30 - 80 Hz) 115 VAC power supply (signal generator and power amplifier).

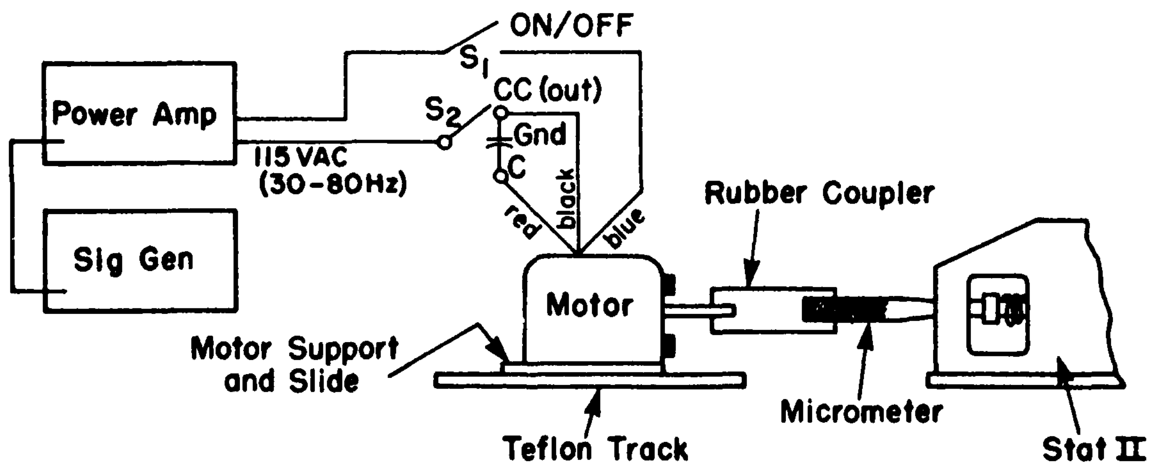

Figure 28 - Motor hook-up diagram

APPENDIX 6.6

STAT II - APD-15 DATA FOR 10 RUNS OF COLD ROLLED STEEL
FLAT-POINT CONTACT FORM,FUNDAMENTAL FREQUENCY OF 100 MHz

APPENDIX 6.6

APD Set Voltage	Run Number										Avg. of Runs 1 to 10	Norm Average
	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10		
0.600V	0	0	0	0	0	0	0	0	0	0	0	0
0.575V	0	0	0	0	0.59	0	0	0	0	0	0.059	.074
0.550V	0	0.92	0.79	0.45	1.51	0.62	0.71	0.60	0	0	0.56	.70
0.525V	0	3.31	1.75	1.27	4.13	2.49	4.59	3.50	3.18	0	2.42	3.02
0.500V	.21	4.66	3.98	2.67	5.85	5.77	7.66	7.27	5.41	0	4.35	5.42
0.450V	4.42	15.33	7.85	9.36	20.55	14.33	16.06	24.74	15.73	0.25	12.86	16.03
0.400V	23.43	54.99	9.60	39.39	56.07	53.36	59.42	56.30	19.53	0.61	37.26	46.45
0.350V	78.17	80.24	43.09	61.56	80.28	80.01	79.97	79.92	50.26	5.78	63.93	79.69
0.300V	80.37	80.27	79.75	80.00	80.32	80.05	80.00	79.95	53.16	48.96	74.28	92.60
0.250V	80.42	80.31	80.08	80.03	80.35	80.08	80.03	79.98	80.01	77.53	79.88	99.58
0.200V	80.45	80.34	80.11	80.06	80.38	80.11	80.06	80.01	80.04	80.00	80.16	99.93
0.150V	80.48	80.36	80.13	80.08	80.40	80.14	80.08	80.03	80.06	80.20	80.18	99.95
0.100V	80.51	80.38	80.16	80.11	80.42	80.16	80.11	80.06	80.08	80.05	80.20	99.98
0.050V	80.53	80.40	80.18	80.12	80.44	80.18	80.12	80.07	80.10	80.06	80.22	100

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The phenomena of non-linear junctions formed by contacting metal surfaces was investigated and a method to characterize these junctions is described.

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