A Demountable Interconnect System for a 50 x 50 Ultrasonic Imaging Transducer Array

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A novel Pad Grid Array (PGA) system allows microminiature coaxial conductors to be electrically connected to a one-half wavelength, 50 x 50 element transducer array suitable for diagnostic ultrasound at 2.5 MHz. In order to achieve the desired one-half wavelength interconnection spacing present at the backing of the transducer module, an intermediary flexible printed circuit and other custom structures provide a transitional architecture between 42 AWG coax and in line interconnect pads at a 300 micron spacing. Due to critical alignment requirements, special processes are needed for fabrication and the successful connection of the fine-pitch circuit elements. A conductive anisotropic elastomeric material acts as the medium to effect the final interconnect between the PGA and transducer module. Because the anisotropic medium provides a separable interface, the interconnect system allows repeated connection. Acoustic performance indicates suitability for diagnostic imaging.

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Abstract

A novel Pad Grid Array (PGA) system allows microminiature coaxial conductors to be electrically connected to a one-half wavelength, 50 x 50 element transducer array suitable for diagnostic ultrasound at 2.5 MHz. In order to achieve the desired one-half wavelength interconnection spacing present at the backing of the transducer module, an intermediary flexible printed circuit and other custom structures provide a transitional architecture between 42 AWG coax and in line interconnect pads at a 300 micron spacing. Due to critical alignment requirements, special processes are needed for fabrication and the successful connection of the fine-pitch circuit elements. A conductive anisotropic elastomeric material acts as the medium to effect the final interconnect between the PGA and transducer module. Because the anisotropic medium provides a separable interface, the interconnect system allows repeated connection. Acoustic performance indicates suitability for diagnostic imaging.

I. INTRODUCTION

Volumetric ultrasonic imaging may use two-dimensional fully populated or sparse arrays. Using either approach requires that many dense interconnects be made between the microminiature coaxial conductors acting as signal and power carrying lines, and the conductive electrodes attached to the back of individual array elements.

As early as 1992, a 10 x 10 PGA array was reported [1] at a 600 micron spacing. However, the technique required a spacing significantly larger than the coax diameter to allow for inter-coax structural material. This is a severe limitation, since diameters of coax used for diagnostic ultrasound are typically larger than the desired acoustic half-wavelengths.

Alternate structures have been built using overmolded lead frame architectures [2], but the reported tolerances would not allow a fifty row structure at 300 microns to be achieved.

Fully populated arrays are typically fabricated at the maximum spacing which minimizing grating lobes, one-half wavelength. Using this approach, the pitch of fully populated arrays falling in the 2-10 MHz range widely used for diagnostic ultrasound falls in the 75-375 micron range. These spacings are smaller than a 42 AWG coax typically of 340 micron diameter, so even side-by-side coaxial termination schemes may not meet interconnect density requirements.

However, this space limitation can be overcome by means of flexible printed circuits (FPC) which may be readily fabricated at alternating 0.1 mm traces and 0.1 mm spaces or finer. This approach was used by
Smith etal [3] to construct a random 42 x 42 element array for diagnostic ultrasound. Because the flex circuitry used in this embodiment is bonded to the monolithic piezoelectric material with silver epoxy prior to dicing, the resulting structure cannot be considered demountable for testing, rework, or servicing.

An interconnect system has been demonstrated for a fully populated 50 x 50 element array at a 300 micron spacing to support 2.5 MHz imaging. Through the use of an intermediary anisotropic conductive material, the interconnect system allows the cabling system and transducer module to be separated for repeated experimentation or transducer replacement.

II. PGA FABRICATION

Fifty coplanar signal lines were fabricated in a single layer 50 ohm controlled-impedance flexible printed circuit (FPC) with 51 interdigitated grounds. Flying signal interconnect leads were finished to 71 x 122 micron final size, including their 27.9 micron low stress nickel underplating and 7.6 micron gold overplating. It should be noted that the tolerance stackup for flexible circuit thicknesses does not allow stacking of FPCs to achieve the necessary array element spacing tolerances.

A 0.6 mm thick alumina substrate provides a monolithic target to allow a precise 50 x 50 interconnect hole pattern to be made (Figure 1). Using a CO2 laser (10.6 micron wavelength), 203 micron diameter through-holes are drilled at a 300 micron center-to-center spacing.

The through-holes taper due to the laser beam profile, so that entrance-hole edges are rounded and exit holes are relatively small compared with those of the entrance. These holes tend to be somewhat irregular in shape, which makes measurement of actual center-to-center spacing difficult (Figure 2).

A subsequent operation using a quadrupuled YAG laser (266 nm wavelength) "counterbores" 250 micron square pockets, 150 microns deep at every thru-hole position to allow for interconnect pad formation. Because of the difference noted between entrance and exit diameters of the through-holes, these features must be made on the opposite side from the through-hole entrance to assure that the 50 micron walls separating adjacent pockets are not compromised (Figure 3).

Each row of ceramic thru-holes is loaded with the flying lead from one FPC. Following installation of leads, the edges of the flex circuit are bonded to the ceramic substrate to stabilize the assembly. Care is required to assure that the bonding agent is prevented from wicking down any through-holes. Prior to potting, FPC leads extending through the substrate are sheared flush with the exit face.

Following the evaluation of numerous silver- and gold-based epoxies, a 99.9% gold epoxy was chosen to fill each thru-hole's pocket, thereby forming an interconnection to the lead. The choice is based on several factors, including viscosity, CTE matching, hardness following cure, and measured resistance. A three-hour 49 deg C cure completes the potting operation.

The face of the PGA is progressively lapped to remove any excess epoxy and achieve the flatness required for installation into a precise carbide alignment frame. A custom probe station keeps the alignment frame stable while positioning the array pattern to within +/- 13 microns of a corner forming X and Y datum surfaces. Z-axis perpendicularity is controlled by seating of the substrate against a backing ledge integral to the frame. Once the desired position is achieved, the ceramic substrate is bonded to the alignment frame. This stabilizes the structure to allow electrical probing of individual contact pads and subsequent lapping.

Final lapping of the face of the PGA creates a one micron rms finish which assures a planar surface essentially free of particulates. Following final lapping, the alignment is reconfirmed. It is important to mount the carbide frame, used to control the alignment to the transducer module, to the housing structure at this time so that stresses resulting from potting operations do not cause unwanted relative movements. Once potted, the integrated PGA/mounting structure is sufficiently rugged to allow coaxial termination to the unused end of each FPC (Figure 4). A final line-by-line continuity and capacitance test confirms the integrity of each interconnect.

PGA cross talk was measured using an HP 8753 network analyzer, HP83047 test set, and Precision Interconnect COMPCAL 1.0 calibration kit. Measurements were made for the first two adjacent signal traces on a single FPC and the first signal trace on two adjacent FPCs. Near field cross talk was measured on the single FPC. Far field cross talk was measured between FPCs, where the separation was approximately.150" at the test points tapering to 300 microns within the PGA structure itself. At the targeted operating frequency of 2.5 MHz, near end cross talk was measured at -62.6 dB. Far end cross talk was - 72.0 dB. Cross talk was measured at several frequencies between 1 and 10 MHz, and appear in Figure 5. Cross talk at these levels would typically not limit system performance.

III. ANISOTROPIC MATERIAL

Gold-plated brass filaments of 40 micron diameter installed in a silicone rubber material [provided by Shin-Etsu Polymer America, Inc.] act as conductive elements bridging the PGA pads to the targeted transducer array module pads (Figure 6). Center-to-center spacing of the filaments in the interconnect grid is 100 microns to provide for redundant contact to each transducer element electrode. Outside dimensions of the silicone material are 15 x 15 mm. Empirically, it was determined that 22 kg/cm2 result in individual contact resistance of less than 100 milliohms (Figure 7). In the final installation, the elastomer is situated between the precisely aligned PGA and transducer module, and compressed to 70% of its original thickness.

IV. PULSE ECHO PERFORMANCE

The effect of the elastomer on the uniformity of the interconnection was studied by examining the dependence of the pulse echo signal variation on elastomer thickness, compression and spatial pitch of the wires. An elastomer with 100 x 100 um pitch of 500 um thickness, and with 30% compression, gave the best uniformity. With this elastomer, the elements had pulse echo waveforms that were characteristic of the 2D array transducer element variations. A random pattern of 3% of the total elements was not success fully connected by the elastomer.

The PGA was evaluated as an interconnect system for the 50 x 50 element 2D array in a pulse echo mode. A 100 channel subset of the full 2500 channels of the PGA were terminated with 50 Ohm coaxial cables and terminated into a standard connector. The elements in the array were excited by a 150 V signal from a Panametrics model 5020UA pulser/receiver, the return signal was measured by an HP 54512B digital scope, and stored on a computer for further analysis.

A typical pulse echo waveform from the array reflected off of a flat stainless steel target, 1.5 cm away, is shown in Figure 8. The spectrum of this signal is shown in Figure 9, where the -6 dB center frequency of the spectrum is at 2.3 MHz, and the -6 dB fractional bandwidth is 50%. For this measurement, no additional tuning elements were used beyond the approximately 3 meters of 50 Ohm coaxial cable. Additional information can be found in the companion paper in this journal [4].

V. ACKNOWLEDGEMENTS

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VI. References

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VII. FIGURE CAPTIONS

Figure 1: 50 x 50 Thru-hole array on 300 micron centers
Figure 2: Close-up of 230 micron entrance thru-holes showing rounded edges
Figure 3: YAG laser pockets formed on the exit face
Figure 4: Completed PGA Module
Figure 5: PGA Cross talk Measurements
Figure 6: Anisotropic Material. Note tendency of material to pick up particulates.
Figure 7: Force vs. Resistance Curve
Figure 8: Waveform from 2D array through the PGA and cable
Figure 9: Frequency spectrum from 2D array through the PGA and cable

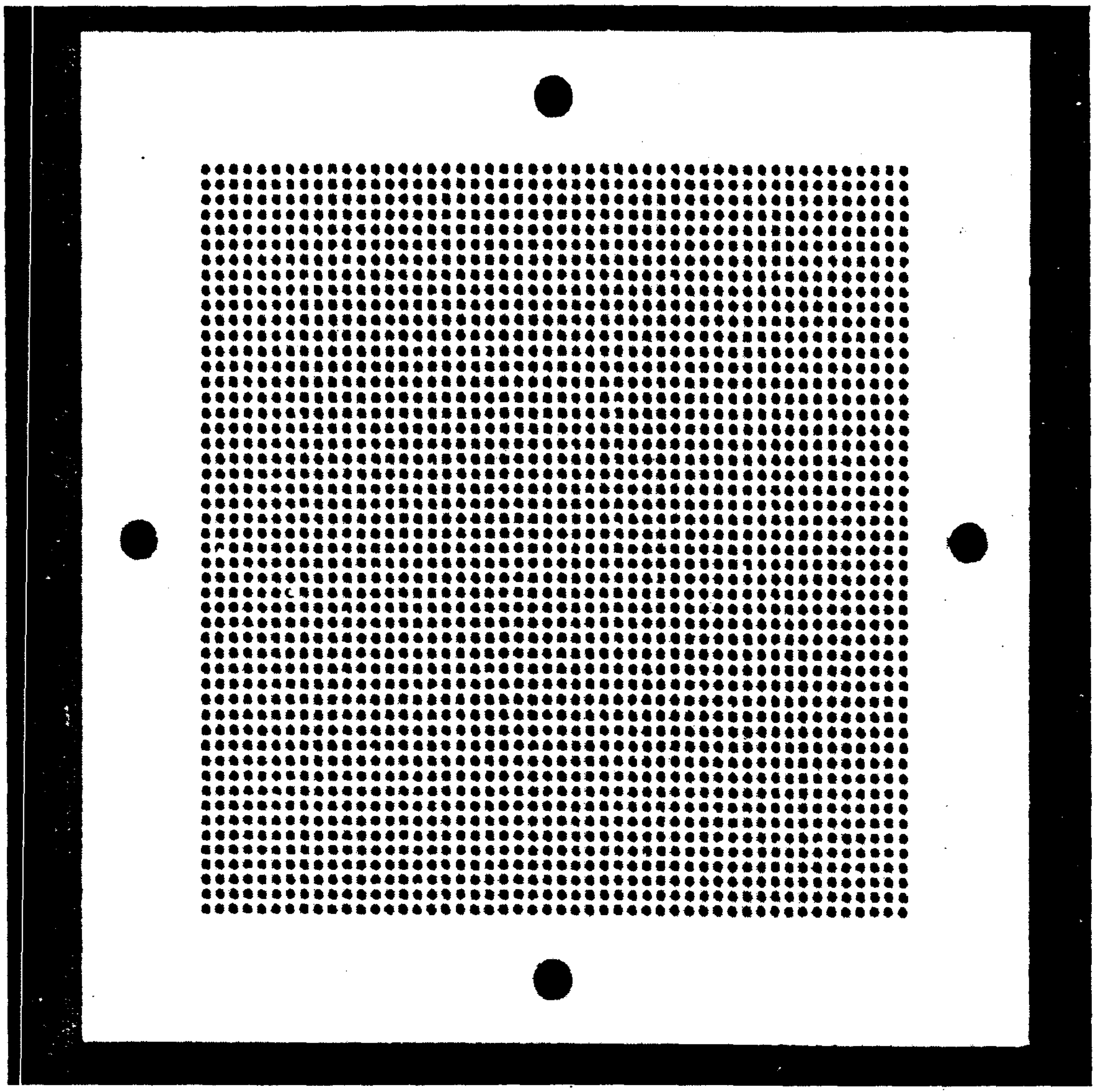


Figure 1

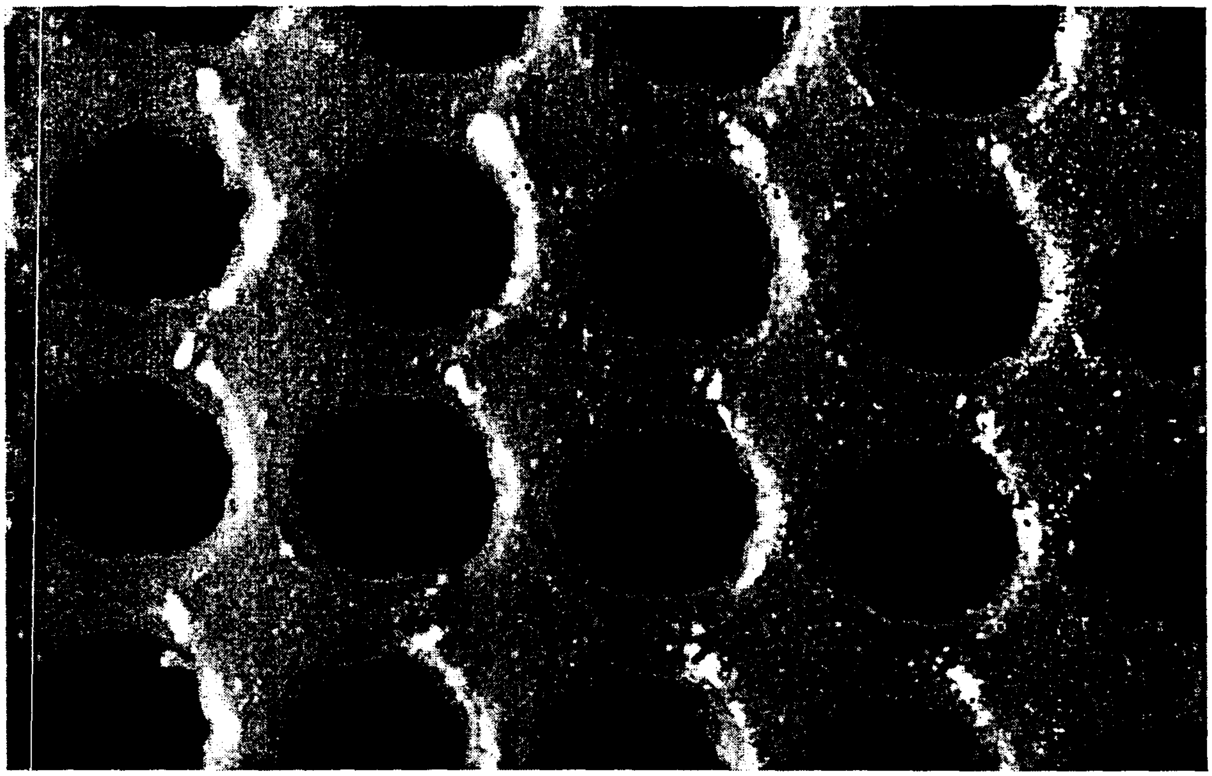


Figure 2

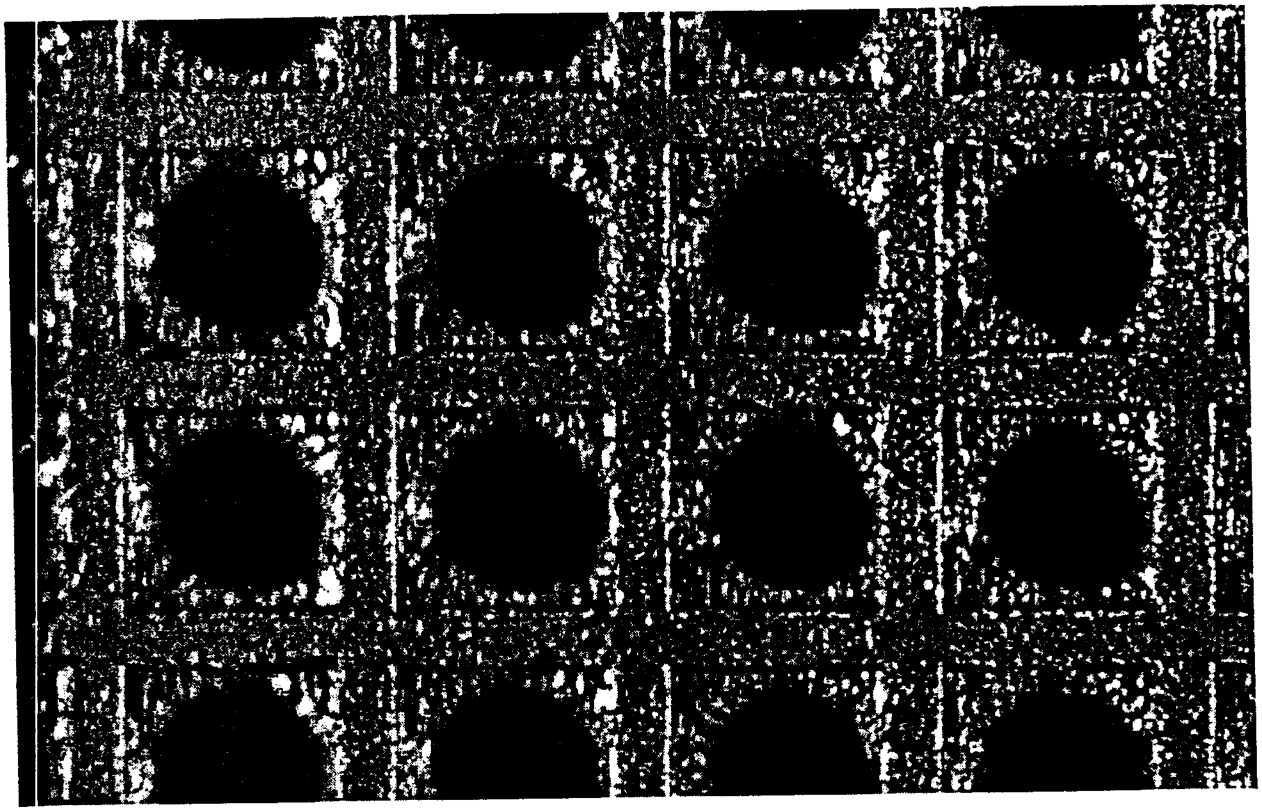
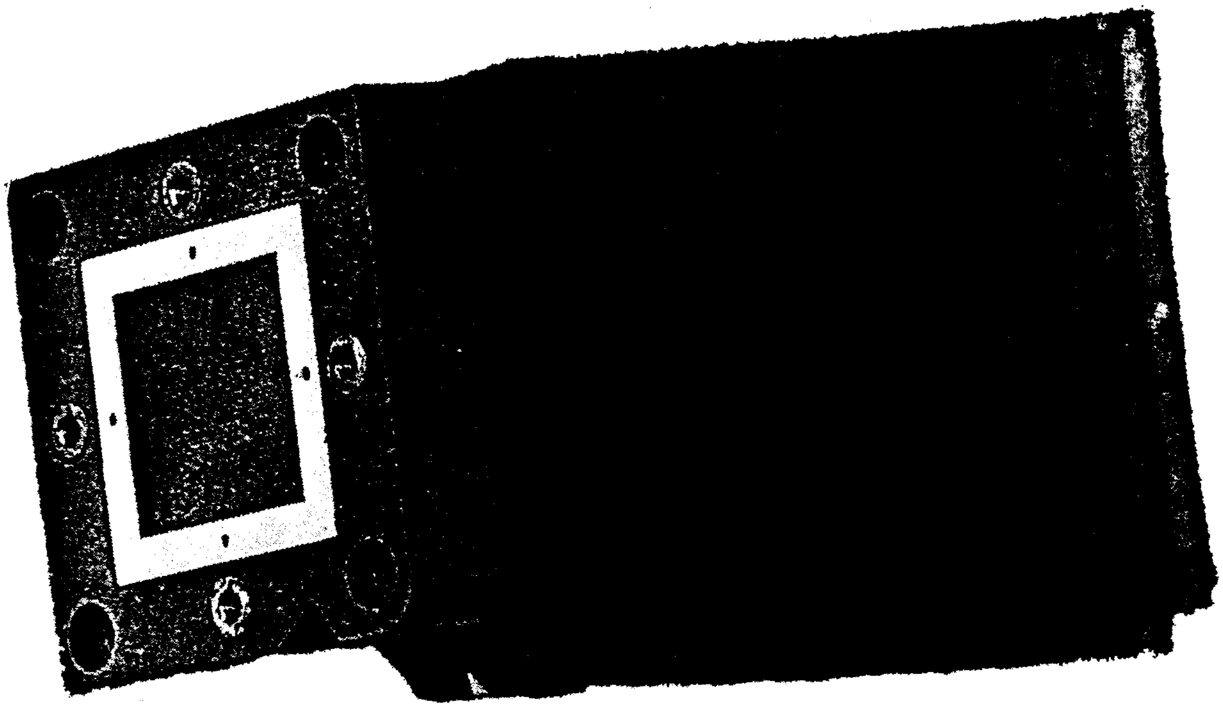


Figure 3



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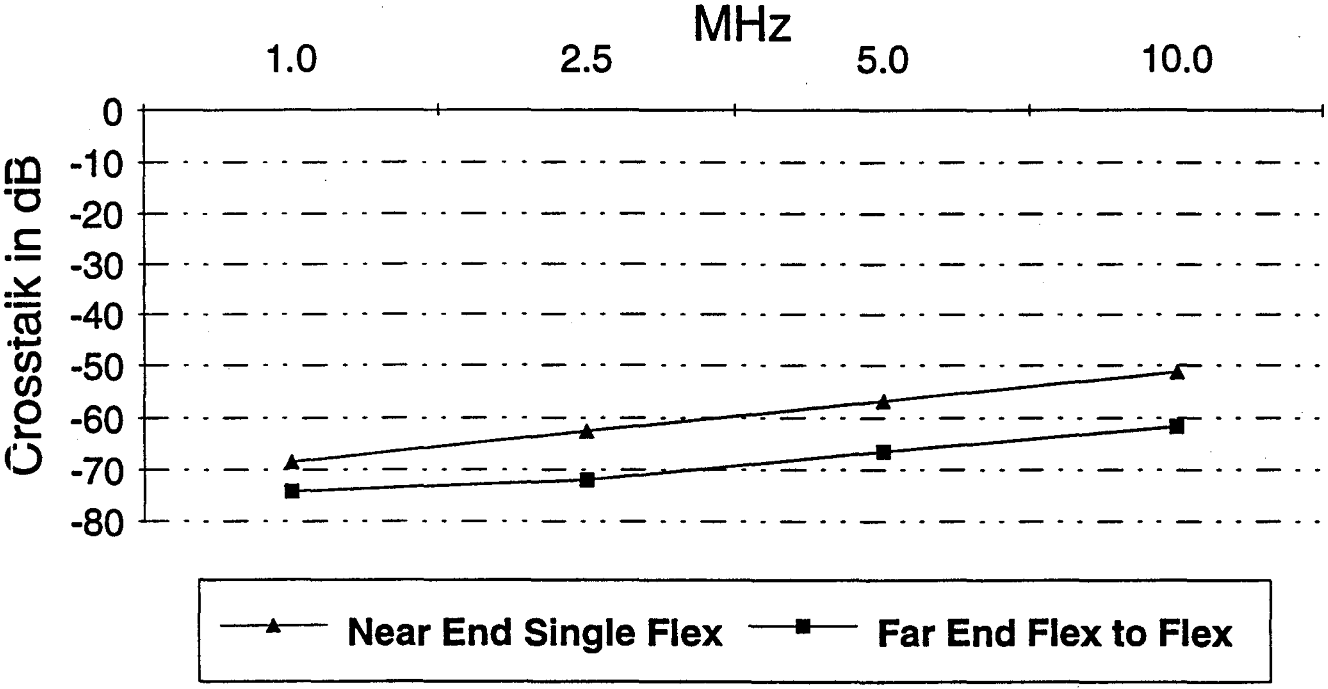
MHz
1.0
2.5
5.0
10.0
0
-10
-20
-30
-40
-50
-60
-70
-80
Crosstalk in dB
▲ Near End Single Flex
■ Far End Flex to Flex

Figure 5

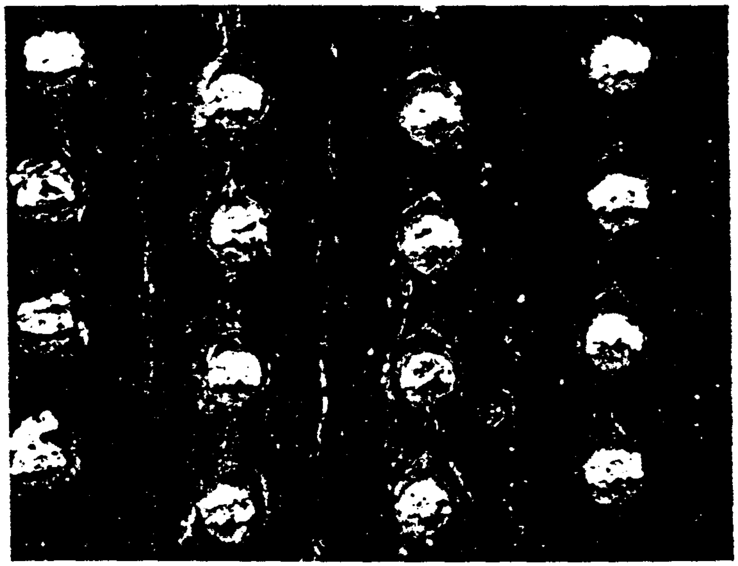

Figure 6

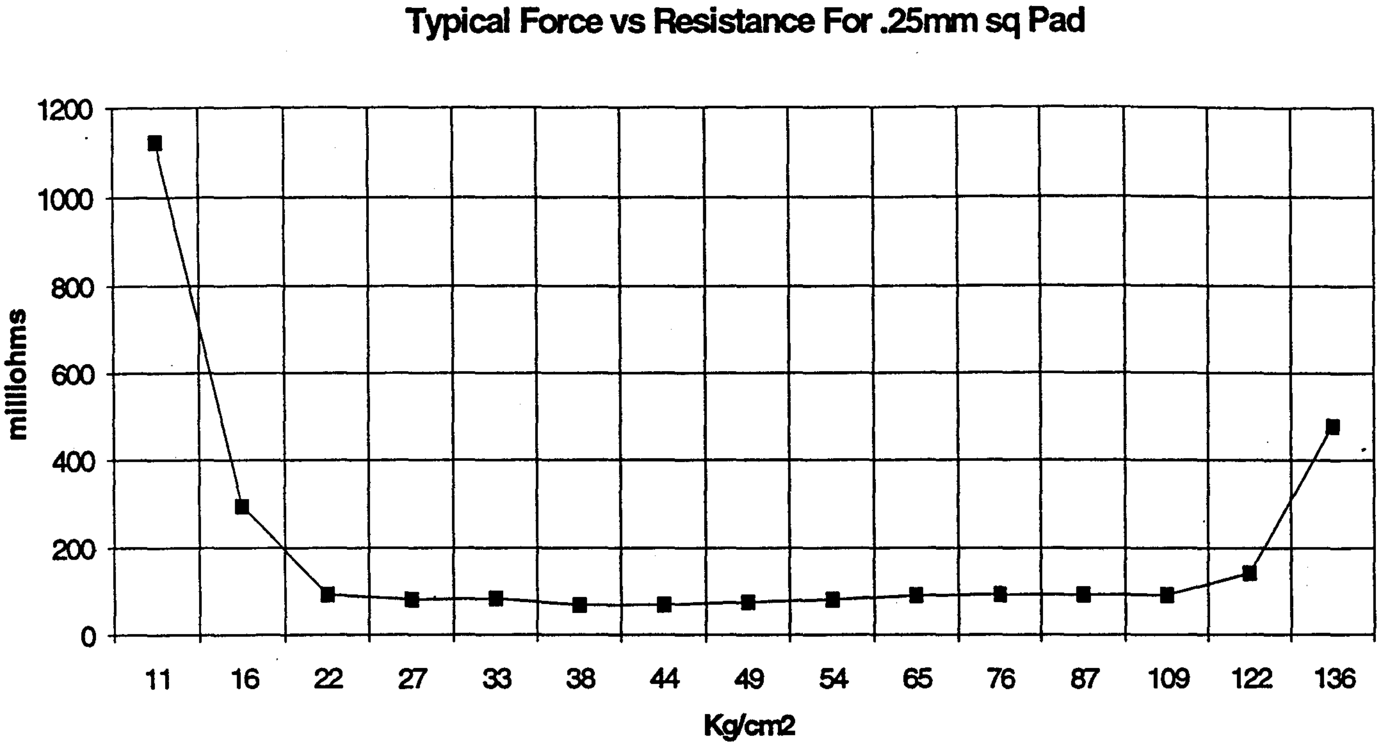
Typical Force vs Resistance For .25mm sq Pad
1200
1000
800
600
400
200
0
milliohms
11
16
22
27
33
38
44
49
54
65
76
87
109
122
136
Kg/cm2

Figure 7

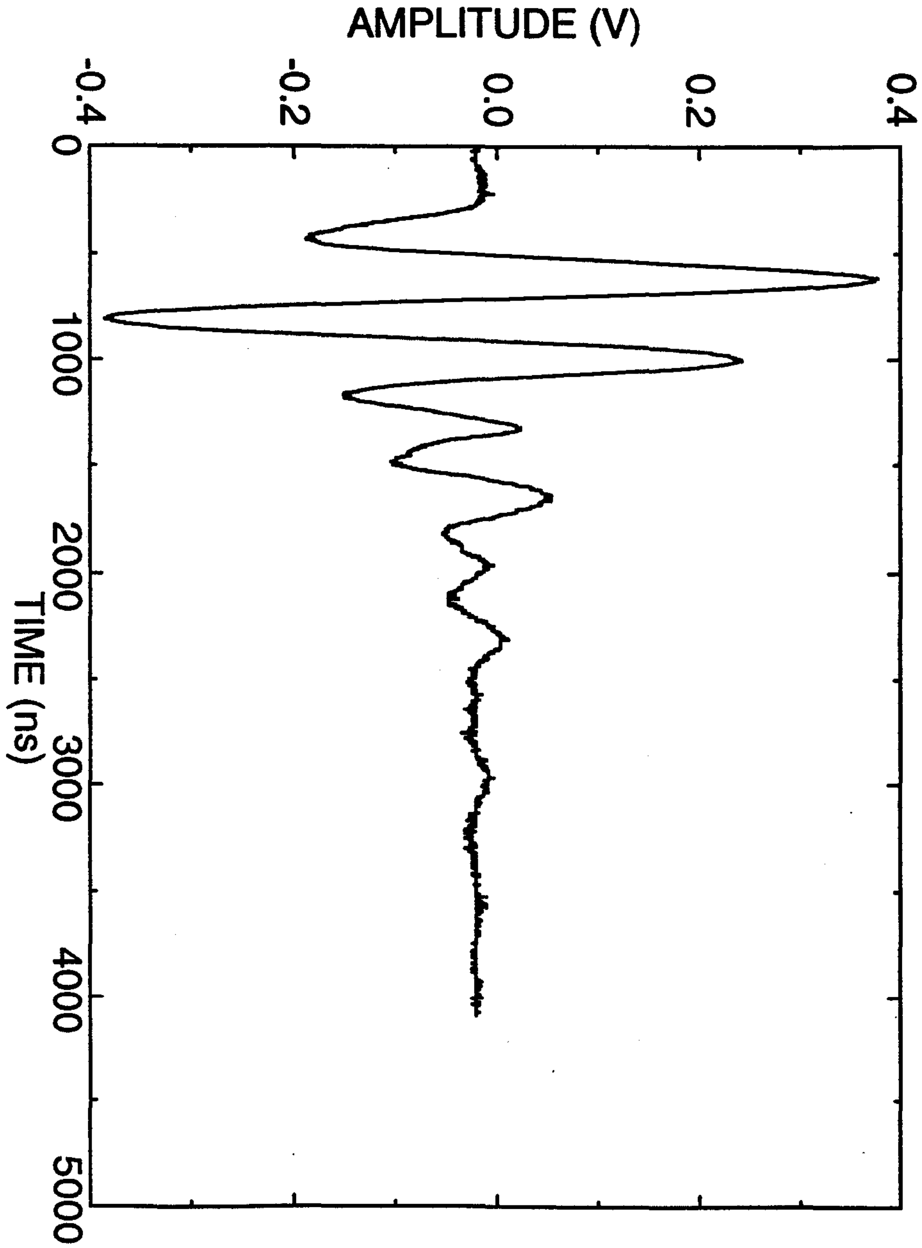

Figure 8

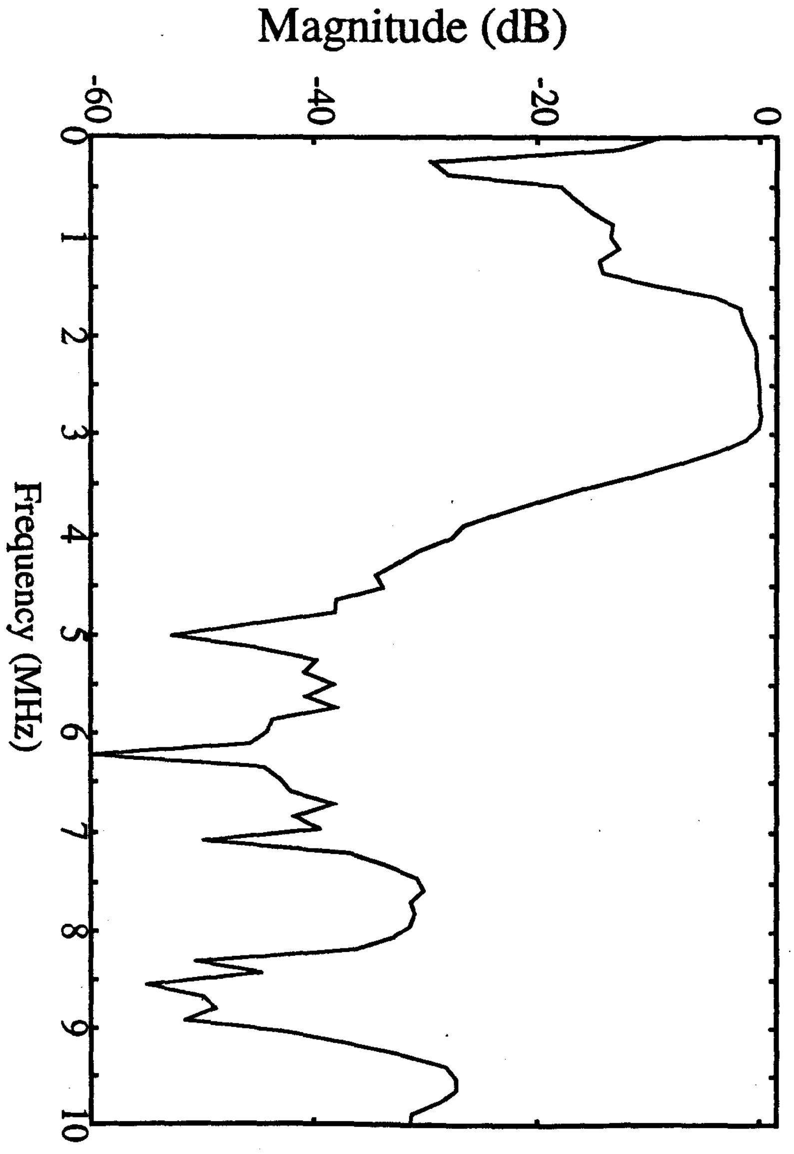

Figure 9