BUTTON CONTACTS FOR LIQUID NITROGEN APPLICATIONS

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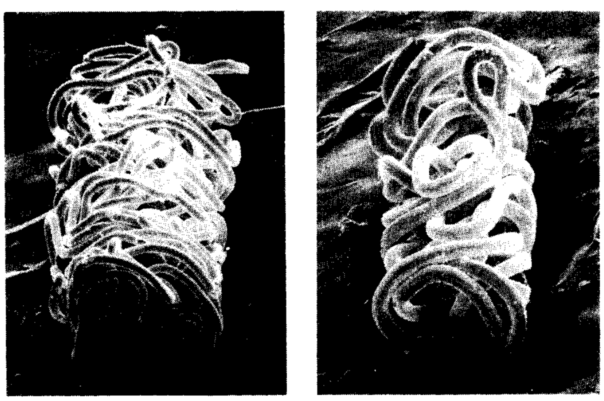
This paper covers the development of a prototype high density connector and cabling technique for use in a liquid nitrogen environment. The "Fuzz Button" and flexible printed cables were selected as the best choice of a hardware combination that remains compliant at very low temperatures.

The paper will describe test hardware used to make comparison tests at room temperature (298K) and in liquid nitrogen (77K). The development of a cable to board clamping system that functions in liquid nitrogen will be described. Test results will be discussed for both temperatures and temperature — humidity testing of the button/cable pairs.

The paper will also make general observations of this connector system applications in liquid nitrogen. Work with other interposer types will also be discussed.

I. DESIGN

The Fuzz Button is a cylinder of gold plated wire, in most cases copper/two percent silver, fifty microns in diameter, formed into sizes to fit the product application. For the liquid nitrogen work, the button is 0.5mm diameter and 1.25mm high.



The pattern selected consists of 150 buttons in three rows, 100 for signals and 50 for power. The power row is separated from the signal row by 2.54mm. Figure 2 shows the pattern and dimensions for the test vehicle and signal cables.

```
 --||--1.25mm                                          1.25mm
   ||                                                    |
oooooooooooooooooooooooooooooooooooooooooooooooooo ----    |
oooooooooooooooooooooooooooooooooooooooooooooooooo --------
                                                     |  2.5mm
ooooooooooooooooooooooooo ooooooooooooooooooooooooo --------
                                                        |
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BUTTON PATTERN
FIGURE 2

The buttons are inserted into 0.5mm holes in an .75mm epoxy glass carrier. The carrier has holes at each end to accept alignment pins. Epoxy glass was chosen as a carrier material to provide an expansion coefficient close to that of the multilayer board the connector will mate with. Contact pads on both the flexible cable and circuit board are .75mm diameter and plated with gold over nickel.

II. CLAMP

In order to provide for a high density board connector, a clamp was designed which would provide compression force to the buttons in an area not much larger than the contact area. Stainless steel was used for all parts since the expansion coefficient is similar to that of epoxy glass — the button carrier material.

Recommended button compression force was 110 grams. To provide this load, five coil springs are located between a top block and pressure bar, which compressed the buttons between the flex cable contacts and the circuit board. So that bending would stay within the button tolerance range, a 7mm thick back-up bar was used. Two shoulder screws fit through the back-up, circuit board, button carrier, flex cable, pressure bar and into the top block. These screws align the circuit board, button board, and flex cable as well as providing the compressive load. When assembled, the springs apply pressure to the buttons through the floating pressure block.

III. CHARACTERIZATION

Clamp parts made to high and low tolerance limits were assembled with randomly selected test cards, button assemblies and flex cables. Using a pressure indicating paper, the high tolerance assembly showed a load of approximately 120 grams per contact with acceptably uniform distribution. The low tolerance clamp with the same parts indicated button load in the 90 gram range, again with good load distribution. The same tests were attempted in liquid nitrogen, with no pressure indication.

The vendor stated that the indicating dyes froze near zero degrees Celcius rendering the material useless in liquid nitrogen. Many other pressure indicating materials were tried, including carbon paper, dental pressure paper, carbonless check blanks. None of them provided any pressure indication in liquid nitrogen.

To obtain a force/deflection curve for the clamp assembly while cold, a fixture was made which allowed a probe on the pressure tester to push against the pressure block, and measure spring rate. At room temperature, with the high tolerance clamp, the rate was 9.4 Kg/cm. The low tolerance clamp had a spring rate of 6.6 Kg/cm. These rates yield a per button pressure of 127 and 110 grams respectively. These numbers are approximately what was observed using the pressure paper and matching color density.

With the assembly chilled in liquid nitrogen, the high tolerance clamp had a spring rate of 9.5 Kg/cm and the low tolerance clamp 7.9 Kg/cm. These values are not exact since the liquid nitrogen container, with the clamp, had a small amount of bottom deflection, an oil-can effect. The test did show that the

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low temperature (77K) had a minimal influence on clamping pressure.

Characterization of individual buttons was done in another IBM location. Twelve buttons were tested with a constant load of 100 grams. Resistance ranged from 10.1 to 67.4 milli-ohms, with an average of 26.7 milli-ohms. Another sample of twelve buttons was deflected to the carrier thickness ten times, with force, deflection, and resistance being monitored for each trial. As can be seen from the data shown in Table 1, deflection decreased with each test, since the buttons were loaded beyond their elastic limit. Button resistance increased slightly since the reactive force from the button was reduced.

INSERTIONS		1	2	10
DEFLECTION (mm s)	HIGH	.595	.335	.321
	AVG.	.530	.258	.242
	LOW	.472	.148	.138
RESISTANCE (μ ohms)	HIGH	5.2	5.6	6.0
	AVG.	4.5	4.8	5.0
	LOW	3.8	4.1	4.3
FORCE (grams)	HIGH	1900	1720	1600
	AVG.	1520	1396	1295
	LOW	1120	940	740

INDIVIDUAL BUTTON CHARACTERIZATION
TABLE 1

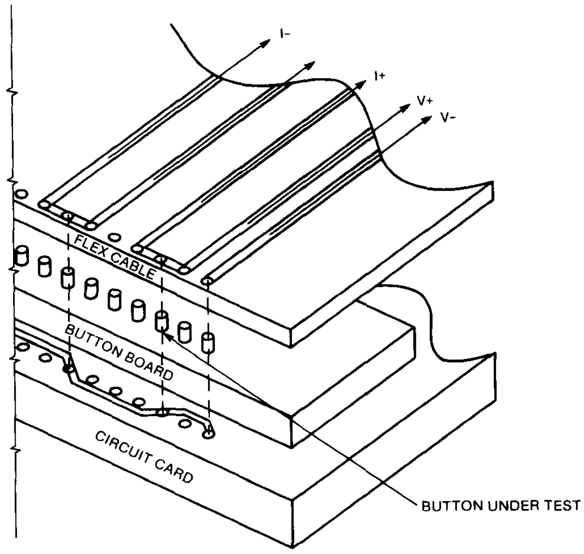
IV. VARIATIONS

Two different wire size and three wire alloy compositions were evaluated using clamps made at nominal, high and low tolerance limits. Fifty micron wire was tested in alloys of copper-silver, beryllium-copper, and Cunistan, a copper-nickle-tin alloy. Buttons made of 75 micron diameter copper-silver wire were also investigated. Due to large button resistance spread, the vendors suggested use of higher pressure springs. New springs were obtained and used in later tests.

V. TEST HARDWARE

Four point measurements were made using a unique flex cable and test card. Resistance measured includes the upper and lower contact interfaces and button body resistance, which consists of the wire, shunt paths, and many internal contacts. Throughout this paper, the two contact interfaces and button bulk resistance will be referred to as "button resistance."

Twelve buttons on each row of fifty were measured, with remaining buttons unused or used as current feed and voltage probes. Clamps used in remaining tests were "production" parts made to print by the model shop, without tight tolerances control. Figure 2 shows a schematic of the four-point connection hardware.



LNC BUTTON TEST CONFIGURATION
FIGURE 3

V. RESULTS

Measurements at room temperature and in liquid nitrogen show that the button contacts, while variable, have sufficiently low resistance to meet signal and power requirements.

Evaluating the data for both wire size copper/silver buttons, Table 2, resistance of the 75 micron wire buttons was about half of those made of 50 micron wire. This difference was observed at both room temperature and in liquid nitrogen. Original measurements on the 75 micron buttons were made with the recommended force (110 grams), however, this load was too light, resulting in erratic resistance measurements. Converting the 75 micron button clamp assemblies to heavier springs improved the stability for both room and liquid nitrogen measurements.

One would expect a much larger resistance drop from room temperature to liquid nitrogen when handbook data are reviewed. Resistivity of ideally pure copper drops from 1.7 micro-ohm centimeter at room temperature (295K) to 0.21 micro-ohm cm. at 80K. (Reference 1). The conductivity improvement of 8.1 times is for pure copper where typical copper conductors show about a seven times improvement. The two times improvement in button conduction is due to the multitude of contacts within the button and button face contact to the circuit pads. Contact resistance does not change as a sample is cooled, only the bulk material resistivity will decrease.

All measurements were taken within an hour of initial clamping. Data taken during temperature/humidity tests show significant resistance reduction with time. This effect will be discussed later.

	50µR	50µN	75µRH	75µNH
AVERAGE:	12.39	7.89	6.30	3.83
MIN:	2.40	2.50	.90	.50
MAX:	27.70	14.00	13.50	12.70
STD DEV:	4.34	2.23	3.53	2.66

VALUES IN MILLI-OHMS

R - ROOM TEMP N - LIQUID NITROGEN
H - HI PRESSURE CLAMP

BUTTON TYPE RESISTANCE VALUES
TABLE 2

In an attempt to understand why the button resistance had such variation, fifty of each wire size buttons were weighed and compared to the mass of a solid copper cylinder of the same size. The data is presented in Table 3. The fifty percent weight difference compares well with resistance difference for the two button sizes, although the variation in button resistance is much higher than the weight variation. The button resistance variation is then due to contact resistance changes caused by the button face differences and the number of internal contacts within the button.

	50µ	75µ
AVERAGE:	4.20	8.35
MIN:	3.6	6.9
MAX:	5.1	9.3
STD DEV:	0.31	0.35
% SOLID:	18.3	36.4

WEIGHT IN GRAMS x10-4

BUTTON WEIGHT COMPARISON
TABLE 3

Two different wire materials were investigated, however due to the lower conductivity, they were not considered for further use. Buttons in both cases were made with 50 micron diameter wire. Beryllium copper has twenty-two percent the conductivity of copper with Cunistan only seven percent. Button resistance data is shown in Table 4. Looking at the ideal case of the total resistances lowering by the conductivity differences, the comparison to copper would show the Be-Cu button to have average resistance of 3.9 milli-ohms and the Cunistan button 2.6 milli-ohms. If contact resistance were added back into these values, the numbers would be close to those of the copper-silver wire.

	BECUR	BECUN	CONSTR	CONSTN
AVERAGE:	17.94	19.28	37.61	49.21
MIN:	7.80	11.50	6.50	6.70
MAX:	27.20	60.80	62.80	98.00
STD DEV:	3.07	8.73	17.14	22.67

VALUES IN MILLI-OHMS

BECUR BERYLLIUM COPPER - ROOM TEMP
BECUN BERYLLIUM COPPER - LN
CUNSTR CUNISTAN BUTTONS - ROOM TEMP
CUNSTN CUNISTAN BUTTONS - LN

BUTTON MATERIAL RESISTANCE VALUES
TABLE 4

VII. TEMPERATURE — HUMIDITY TEST RESULTS

Five assemblies made using 50 micron buttons were subjected to fifty days of temperature — humidity cycling. Each daily cycle consists of four hours at 25 degrees C, 50% RH, four hours at 75C, 90-95% RH, followed by sixteen hours at 75C and 45-50 RH.

Data for each sample were averaged and shown in Table 5. The variation for each sample shows that the resistance difference between buttons are smaller as the compressed time increases.

SAMPLE / CYCLES		0	10	25	35	50
1	AVERAGE:	7.12	4.10	4.09	4.01	3.97
	MIN:	3.00	1.50	1.31	1.30	1.30
	MAX:	10.60	6.30	6.28	6.18	6.04
	STD DEV:	1.78	1.00	1.01	.99	.93
2	AVERAGE:	7.99	4.96	4.74	4.68	4.61
	MIN:	5.10	3.00	2.78	2.72	2.73
	MAX:	12.60	7.60	7.16	7.05	6.93
	STD DEV:	1.76	1.04	1.00	.99	.97
3	AVERAGE:	9.48	6.02	5.93	5.89	5.81
	MIN:	3.00	2.00	2.04	1.98	1.89
	MAX:	18.50	10.30	10.09	10.06	9.99
	STD DEV:	3.38	2.17	2.15	2.15	2.14
4	AVERAGE:	9.69	7.49	7.05	5.74	5.63
	MIN:	5.30	3.20	3.20	3.23	3.16
	MAX:	12.90	9.90	9.10	7.55	7.42
	STD DEV:	1.93	1.52	1.37	1.17	1.15
CONTROL	AVERAGE:	8.60	5.02	5.09	5.14	5.12
	MIN:	5.60	3.30	3.30	3.60	3.57
	MAX:	12.90	7.20	7.30	7.26	7.25
	STD DEV:	1.76	1.00	.95	.93	.93

VALUES IN MILLI-OHMS

TEMPERATURE / HUMIDITY TEST DATA
TABLE 5

After the first ten day reading, a resistance decrease of approximately forty percent was observed, after which, resistances remained stable. We believe this reduction is due to the multitude of contact interfaces each lowering its resistance by breaking thru surface films, reducing asparity height, and other similar factors. It is interesting to note that in the high temperature/humidity environment, button resistance did not increase, which indicates the formation of corrosion products.

One sample was removed from the cycling after ten days and held at room conditions as a control. The control sample was used to determine if cycling, and movement of the clamp due to temperature induced expansion, caused the reduction. No further reduction in resistance was noted, therefore the effect of cycling was not the reason for the decrease. Note that the four samples cycled in temperature/humidity continued to decrease their resistances, or reach stability, while the control sample held in a normal lab environment, showed a slight increase in average resistance. It may be that the temperature excursions caused the contacts to burnish, lowering button resistance, while at a stable temperature this action did not take place, allowing a slight resistance rise, probably due to stress relaxation within the button. Resistance reduction occurs within the first ten days that contact is made, although there was no attempt to measure how rapidly the reduction takes place. As can be seen from the Sample 4 data in Table 5, resistance stability was not complete until after the thirty-five day measurement.

A room temperature to liquid nitrogen cycler is being fabricated which will allow a similar set of tests to take place, where similar results are expected. The cycler will provide a dry nitrogen environment for the tests, since a chilled sample is well below the dew point when it is removed from the liquid nitrogen.

VIII. OTHER INTERPOSERS

Two elastomeric interposer connectors and one non-compliant pressure type connectors were evaluated. Both elastomer interposers were compressed with the "production" clamp used with the button boards and made contact between the flex cable and test board. As before, twelve contacts in each row of fifty were tested.

The non-compliant connector was a unique flexible cable with a .25mm gold bump plated in the center of each pad. This bump was pressed against the test circuit board using the same five spring clamp as previously used. In this case the slight bow in the back-up bar and pressure bar was enough to allow opens at the center contacts. When the assembly was chilled to 77K, the few open circuits at room temperature increased to five to six in each row of contacts. It was apparent from this evaluation that a non-compliant system was not practical for liquid nitrogen operation.

The clamp used with the button connectors was evaluated against the application guidelines defined in Reference 2 and found to be acceptable. Clamp force produced about 20% deflection where the paper recommended 5 to 25%.

One of the elastomeric interposers — a silver filled silicon rubber matrix — was evaluated at room and liquid nitrogen temperatures. With this material, the average room temperature resistance was 93.4 milli-ohms with a range of 47.7 to 143.5 milli-ohms. The wide resistance range was caused by the unique interposer construction, which allowed one, two, or three parallel paths between the contact pads. When immersed in liquid nitrogen all the contacts opened. It was observed, by looking at the chilled part under 50X magnification, that the insulating silicon rubber segments which separate the conducting portions, did not shrink as much as the silver filled material and held the conductors away from the contact pads.

A thermocouple was epoxied to the center of the pressure bar, close to the flex cable, so that the temperature where open occur could be obtained. Immersion into the liquid nitrogen caused the temperature to drop contacts to open very quickly, preventing a repeatable measurement of temperature. It was found that the warm-up temperature was slower, and the initial contact and its associated temperature could be measured reliably. High resistance, approximately 1.7 ohms, occured around -100C with the resistance dropping to 340 milli-ohms at -90C on the contact being monitered, which was located under the thermocouple. Three cycles were run, with the initial resistance being repeated when the sample warmed to room temperature.

The second elastomer also used a silicon rubber carrier, but filled with an orderly matrix of very fine curved gold wires, which extend above the elastomer surfaces by about 15 microns. Average room temperature resistance sample against the 0.75mm pads was 154 milli-ohms with a range of 107 to 206 milli-ohms. The sample had all 24 circuits open when it reached equilibrium in liquid nitrogen. As before, with the rapid chilling, it was not possible to measure the temperature where high resistance began to occur. During warm-up the monitered contact started to show continuity at approximately -110C, where the resistance was near 0.8 ohms and dropped rapidly to the 200 milli-ohm range as the temperature approached -100C. The assembly was cycled three times, with excellent repeatability of the room temperature measurements. Due to the size of the wire and the small protrusion above the elastomer carrier, it was impossible to determine the reason for the open circuits, even under 50X magnification.

From the two tests, it is apparent that elastomer interposers are not the types of materials to use at cryogenic temperatures, although they make contact at fairly low temperatures. The connector system must remain compliant throughout the entire temperature range. Conductive elastomers do not offer low temperature compliancy.

IX. CONCLUSIONS

The hardware designed for this evaluation provides a high density connector and cabling system suitable for liquid nitrogen applications. Fuzz buttons provide acceptably low resistances at room temperature and in liquid nitrogen when using clamps and springs made of materials that have similar expansion rates. The impact of clamp pressure, clamp dimensional tolerance variations, and test boards and cables thickness variations have minimal effect on button resistance. While there are differences in button resistance measurements, the variation is well below the 50 milli-ohm upper limit.

The connector assembly shows a wide range of initial resistance values which reduce as time of compression increases, at least at room temperature conditions. While some initial resistance values may be high, they drop within a short time period, with the difference between high and low becoming smaller. This phenomena is expected to occur in liquid nitrogen as well, however, tests will not be done until a room to liquid nitrogen cycler is complete.

The fuzz button connector system is relatively immune to corrosion formation caused by temperature and humidity. Results of fifty days of cycling from room conditions to high temperature/high humidity show no indication of corrosion formation measured by increased contact resistance. Hostile gas tests are used on IBM contact systems, none are planned with this system due to the benign environment provided by liquid nitrogen.

The cable was designed to have a fifty ohm characteristic impedance. Its actual value and the discontinuities caused by the connector have not been measured. Due to the size of the compressed button, its influence on crosstalk, coupling, and reflections will be minimal. Contact pads that mate with the buttons and their proximity to the grounded clamp assembly, may have an impact on characteristic impedance, but the path length of this uncontrolled segment is very short and should be of little consequence. High frequency measurements in all the areas discussed are planned.

X. REFERENCES

1) White, G.K., EXPERIMENTAL TECHNIQUES IN LOW-TEMPERATURE PHYSICS, Third Edition, Clarendon Press, Oxford.

2) Bjornsen, R.T. Jr., APPLICATION GUIDELINES FOR ELASTOMERIC CONNECTORS, Connector Technology, March 1988.

XI. ACKNOWLEDGEMENTS

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