LIGO-T880058-00-R

Electrical Vacuum Feedthrough Research

Introduction

The design of the 5 meter prototype for the LIGO team at MIT requires a large number of electrical and optical vacuum feedthroughs. The flange space available for these feedthroughs is relatively limited. This technical memo describes the results of some of the research at MIT to explore different solutions to the problem of electrical feedthroughs. The results may be useful for the engineering design of the LIGO vacuum system.

5 Meter Requirements

Table 1 presents an estimate of the optical and electrical feedthrough requirements of the 5 meter prototype for each of the two different size tanks in the system. The electrical feedthroughs are divided into three separate categories according to function. Instrumentation feedthroughs carry low voltage power supplies and grounds and noncritical high signal to noise ratio (SNR) signals. The high voltage connections are required to withstand voltages of at least 1 kV. The coaxial connections carry signals which require shielding or 50 ohm impedances.

Table 1

5 meter prototype feedthrough requirements.

Tank Type	Optical Fiber	Coaxial	Instrumentation	High Voltage
End Tank: max	16	18	68	15
min	8	2	31	15
Central Tank: max	72	84	346	44
min	36	12	232	44

The total surface area of the wires used inside the vacuum system may be as much as 10% of the total surface area of the vacuum tanks. Some care must be taken to use wire and cable that will not present an excessive gas load to the system.

The Traditional Solution

The traditional solution to the electrical vacuum feedthrough problem is the glass or ceramic-to-metal hermetic seal. This technology is well developed, vacuum clean, and the feedthroughs can be baked. It is also relatively expensive and requires long lead times for even fairly standard multipin connectors. A standard 55-pin connector which is capable of withstanding 1 kV has been purchased to fulfill both the instrumentation and the high voltage requirements for the 5 meter system.

Coaxial ceramic-to-metal seal connectors are wasteful of flange space, especially for connectors with isolated grounds.[1] The best alternative discovered so far seems to be an

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[1] Electrically isolating the shield on sensitive coaxial signals from the vacuum system tanks reduces noise pickup.

isolated ground SMB series connector which is 0.495 inches in diameter – the same as a standard common-ground BNC hermetic connector. There is apparently no demand in industry for SMB series connectors at present, so lead times are long and prices are high.[2]

An Alternative Solution

Another method of making hermetic seals is to "pot" the connections in epoxy. Two firms which specialize in this process have been contacted. Both firms claim to be able to seal practically anything into one of their standard housings, and in particular it is possible to seal miniature coaxial cables with a much higher surface density than is practicable with the traditional ceramic-to-metal seals. Coaxial passthroughs manufactured by PAVE Technology Company were selected for tests because of lower price,[3] faster delivery and broader temperature specifications. At issue in the tests is the leak rate through the connectors and the gas load presented by the epoxy and cable.

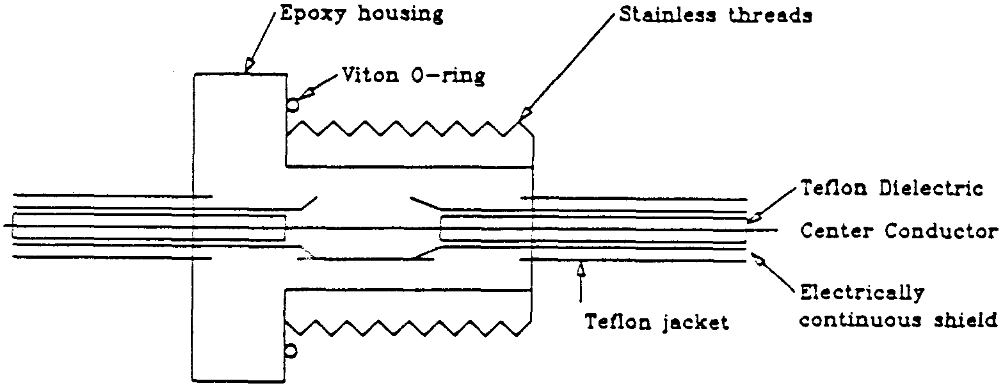

Figure 1
Cross section of an epoxy seal (enlarged).

Figure 1 shows a cross section of the seal. The coaxial cable is standard 50 ohm impedance RG-178. The size of a single cable has been enlarged for clarity. The center conductor is continuous. The dielectric material is removed for some length along the cable. The shield is partially dismantled and electrically reconnected inside the feedthrough. The outer jacket stops just inside the epoxy surface and is not part of the hermetic shield.

Vacuum Test Results

The passthroughs were evaluated by installing them in a 1.75 liter stainless steel vacuum chamber through a 6 inch knife edge flange. The chamber was pumped by a liquid Nitrogen trapped diffusion pump with an estimated pumping speed for air of 12.7 liters/sec. An Inficon Quadrex 100 residual gas analyzer was connected to the chamber and used to conduct the tests.

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[2] $160 per connector

[3] $25 per cable connection

The test chamber was baked under vacuum without a passthrough installed to establish a baseline total pressure and residual gas spectrum for comparison. The baseline total pressure was 8×10^{-8} Torr. Table 2 shows the composition of the spectrum.

Table 2

Composition of the residual atmosphere in the empty vacuum test chamber.

Mass (amu)	Gas	Composition
2	Hydrogen	12.7%
18	Water	59.7%
28	CO	17.7%
44	CO_2	9.8%

Table 3 contains a summary of the test results. In addition to the coaxial passthrough, several samples of epoxy were evaluated. None of the passthroughs leaked helium as received from the factory. Figure 2 shows the spectra of the residual gas from the passthrough and the epoxy. Water is the dominant constituent.

Table 3

Test results of PAVE passthrough.

Material	j_O (Torr-Liter/cm^2/sec)	Pumping Time (hours)
Empty Chamber	1.1×10^{-9}	–
Coax Passthrough	4.1×10^{-8}	12
Epoxy Sample	4.8×10^{-8}	30

A sample of the RG-178 cable was separately evaluated and was quite dirty "off-the-shelf". Baking at 150° C for 48 hours brought the outgassing rate down to $6 \pm 2 \times 10^{-9}$ T·L/cm^2/sec. Since this is slightly less than published pure teflon outgassing rates,[4] it is assumed that the major contribution to the outgassing of the cable is just the teflon jacket. The implication is the RG-178 cable does not trap gas along the center conductor or the braid for lengths of up to 24 meters, making it suitable for high vacuum use. Furthermore, the cable does not appear to rehydrate quickly when exposed to air, retaining its low outgassing properties for at least two weeks.

Initial tests of the passthroughs encountered thermal problems. The passthroughs are available in two versions: a stainless steel shell with an epoxy plug, or an all epoxy version with stainless threads (as pictured in Figure 1). Both versions have the same epoxy area

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[4] O'Hanlon, J. F. in *A User's Guide to Vacuum Technology*, Wiley & Sons, 1980, p. 369 quotes a value of 2.5×10^{-8} T·L/cm^2/sec for Teflon after 10 hours under vacuum.

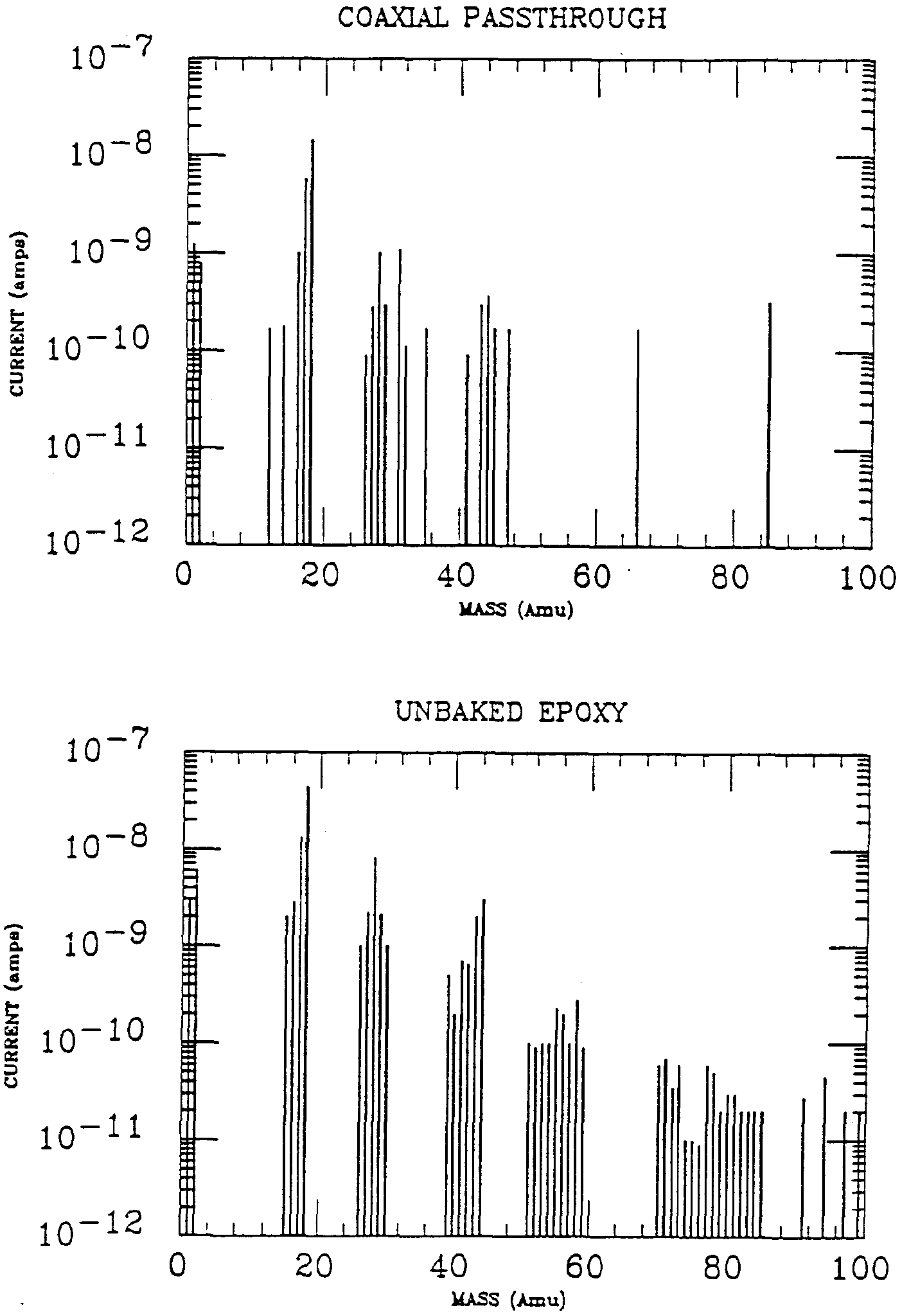

Figure 2
Residual gas spectra

exposed to the vacuum and hence the same outgassing properties, but the version with the stainless steel shell relies on the stainless and epoxy interface to form the vacuum seal. The stainless steel version developed a leak after a very mild bakeout (100 °C) which was well within specifications. The nature of the leak was unusual in that every metal-epoxy interface leaked, including the wires along their length. The all-epoxy passthrough is supposed to be more thermally rugged than the stainless version because there is less interface surface area, but since the passthroughs will not be subjected to temperature cycling in the 5 meter system, the manufacturer was asked to bake the RG-178 for 48 hours before assembling the passthrough and the finished units were not subjected to a bake test.

An estimated gas load budget for the 5 meter prototype is listed in Table 4. The gas load from the teflon cable dominates over the load from the epoxy in the passthrough and suggests that if good vacuum practices are followed with the other equipment installed in the 5 meter system, the teflon cable may limit the ultimate pressure attainable.

Table 4

5 meter prototype gas loads.

Surface	jo (T-L/cm^2/sec)	Area (cm^2)	Q (Torr-Liter/sec)	P_∞ (Torr)
Stainless (tanks)	1.0×10^{-10}	7.5×10^{5}	7.5×10^{-5}	7.8×10^{-8}
Teflon cable	8.4×10^{-9}	8.1×10^{4}	6.8×10^{-4}	7.1×10^{-7}
Epoxy	4.8×10^{-8}	1.3×10^{2}	6.1×10^{-6}	6.4×10^{-9}

Electrical Test Results

One of the passthroughs, selected at random, was subjected to an electrical test. An RF oscillator was used to inject a signal into one of the coaxial lines. The other end of that line, terminated with 50 ohms, was fed into an oscilloscope and compared with the drive. Coaxial lines in the passthrough other than the one being driven were also examined for evidence of crosstalk with an RF spectrum analyzer.

The transmission of the coaxial line being driven was comparable to that of a test piece of standard RG-58/U of the same length (3 feet) for frequencies from DC to 80 MHz. Crosstalk was observed between lines with a pickup level of -85 to -90 db relative to the driving signal at 50 MHz. For comparison, a twisted pair of RG-58/U showed no crosstalk greater than -120 dB at 100 MHz and -90 dB at 70 MHz with the measurement at 100 MHz limited by the noise floor of the spectrum analyzer.

A major fraction of the crosstalk appears to be capacitive. A quick calculation with a lumped circuit model indicates that the amount of crosstalk should increase linearly with frequency for a capacitive coupling, and a rough transmission line calculation predicts that the coupling should decrease with the natural logarithm of the separation between the wires. The amount of crosstalk does appear to increase linearly with frequency between 5-100 MHz. (At 5 MHz the crosstalk is ~ -95 dB relative to the drive and the slope is

$\sim 5.3 \times 10^{-12}$ /Hz. The crosstalk number at 50 MHz, quoted in the preceding paragraph, is actually smaller than what is predicted by a simple straight line fit.) A comparison of nearest neighbor crosstalk with that between lines on opposite sides of the passthrough indicates that the crosstalk does decrease with distance, but not as rapidly as expected from a simple lumped circuit model.

The manufacturer of the passthrough which was tested (PAVE) does not reconstruct the coaxial braid during fabrication. The crosstalk could presumably be reduced by paying more attention to preserving the shielding properties of the cable or by deliberately inserting additional shielding. PAVE would probably be willing to modify their process to achieve better electrical isolation.

Conclusion

The epoxy seal technology provides a low cost solution to the isolated ground coaxial feedthrough problem without adding an outgassing problem which could compromise the vacuum. Other types of wires such as ribbon cable and connectors can also be fabricated with the same techniques. Epoxy passthroughs are available for extended temperature ranges and could be useful for the LIGO, but it is recommended that the thermal properties be reexamined and tested carefully. The electrical characteristics of the miniature coaxial passthrough could probably be improved by more attention to the shielding when the braid is electrically reconnected inside the connector.

Standard commercially available RG-178 cable is adequate for vacuum use if baked for 48 hours in air.

Acknowledgment

Nelson Christensen set up the vacuum testing chamber and performed some of the outgassing tests.

Appendix

Names and addresses of the two companies currently making epoxy feedthroughs.

PAVE Technology Co.
2751 Thunderhawk Court
Dayton, Ohio 45414
Tel. 513-890-1592
Contact: Walter Wood

Douglas Engineering Co.
14 Beach Street
P.O. Box 645
Rockaway, NJ 07866
Tel. 201-627-8230

Jeff Livas
July 25,1988