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CRYOGENIC PERFORMANCE OF MICROWAVE TERMINATIONS, ATTENUATORS, ABSORBERS, AND COAXIAL CABLE

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I. Introduction

Microwave components are finding increasing use at cryogenic temperatures in the areas of radio astronomy, low-temperature physics research, and other applications requiring cooled detectors. Some examples are [1] and [2] where coaxial attenuators, isolators, terminations, and cables are used for testing or are incorporated in gallium-arsenide field-effect-transistor amplifiers used for radio astronomy. However, most microwave components are only rated for a -55C to +125C temperature range and manufacturers do not have the facilities for cryogenic testing. These facilities, including cryogenic refrigerators and well-matched coaxial and waveguide transitions to room temperature, are available at National Radio Astronomy Observatory and were used for the measurements reported here.

The temperature dependence of loss in a component is a function of the physical mechanism causing the loss. If the loss is due to impurity scattering as in an alloy, the resistivity is independent of temperature to a high degree. This is helpful in the case of nichrome resistors in terminations and attenuators but prevents loss reduction at low temperatures for stainless steel or beryllium copper used in low thermal-conductivity coaxial cables. On the other hand, in pure metals the electrical loss is due to lattice vibrations and the resistivity decreases substantially at cryogenic temperatures to reach a limiting value dependent upon minute impurities within the metal. For this reason the loss of copper or silver-plated coaxial-cables decreases at low temperatures but the final value depends upon purity and may vary from batch to batch.

Another physical process which is relevent is the decrease in the number of carriers in an undoped semiconductor such as carbon at low temperatures. Thus carbon in terminations, attenuators, and absorber material becomes an insulator at low temperatures and a large change in performance is observed.

II. Terminations and Attenuators

The temperature variation of the microwave behavior of 50 ohm terminations and attenuators can be evaluated by measuring the variation of DC characteristics with temperature. The DC resistance and attenuation can, of course, be measured with extreme accuracy and temperature effects upon the reactive components and resistive variation with frequency will be very small.

Several manufacturers of 50 ohm coaxial SMA terminations and 20 dB attenuators were measured at DC and at temperatures of 300K, 77K, 15K and 4K. The results are given in Tables I and II with the best cryogenic performers at the top of the table. DC resistances were measured with a DVM and the attenuation was determined by measuring the output voltage into a 50 ohm load with 1.000 volts applied at the input.

The reader is reminded that terminations are built into isolators and most directional couplers; the cryogenic performance of the termination should be checked with a DC resistance measurement.

III. Microwave Absorber Material

Six types of bulk absorber material were tested in a stripline test fixture described in Figure 1. The materials and results are summarized in Table III.

TABLE I - DC Resistance of 50 Ohm Terminations

MFG.		MODEL	DC Resistance			
			300K	77K	13K	4K
EMC	[3]	4112P	51.1	50.2	NM	NM
			51.4	49.9	NM	NM
			51.2	50.1	NM	NM
			51.2	50.0	49.9	50.0
EMC	[3]	4170J	50.9	50.2	50.2	50.3
SOLITRON	[4]	SF8018-6005	50.1	51.0	NM	NM
			50.3	50.6	51.1	51.4
			50.1	50.9	NM	NM
			49.8	50.2	NM	M
OMNI SPECTRA	[5]	20020P	51.6	47.8	NM	NM
			51.0	54.2	NM	NM
MIDWEST	[6]	2055	50.8	56.9	NM	NM
NARDA	[7]	-	50.2	53.5	NM	NM
WEINSCHEL	[8]	1408	52.3	273.0	597	NM

NM = not measured.

TABLE II - DC Resistance and Attenuation of 20 dB SMA Pads

MFG.	MODEL	INPUT R*			ATTENUATION, dB		
		300K	77K	13K	300K	77K	13K
EMC [3]	4420 #1	55.6	53.7	53.5 (1)	20.88	20.70	20.68
	#2	52.7	51.8	-	20.09	19.98	-
	#3	48.0	49.6	-	20.19	20.17	-
HP† [9]	8692 #1	50.5	51.1	51.6 (2)	20.47	20.47	20.49
	#2	49.7	51.5	-	19.92	19.99	-
	#3	48.3	49.1	49.7	20.58	20.59	20.66
NARDA [7]	4772	50.2	50.3		19.73	19.57	-
MIDWEST [6]	263	53.1	58.0	-	19.79	20.18	-
WEINSCHEL [8]	3-20	50.3	63.0	-	19.68	20.23	-
TEXSCAN [14]	F87P	45.4	44.8	-	20.01	19.82	-

*Input resistance with pad terminated in 50 ohms.

†Modified by replacing conductive rubber contacts with bellows contacts [13].

(1) Also 53.5 ohms at 4.2K.

(2) 51.7 ohms at 4.2K.

TABLE III - Attenuation of Microwave Absorber Materials

Absorber Type	Mfg.	Thickness T	8 GHz Attenuation dB/cm 300K	15K
EMA7175	[10]	.1 cm	2.36	1.60
MF114	[11]	.1 cm	2.10	1.84
MF117	[11]	.1 cm	2.20	1.85
MF124	[11]	.1 cm	2.55	2.46
AN72	[11]	.3 cm	1.21	1.11
GDS	[11]	.15 cm	1.84	1.80

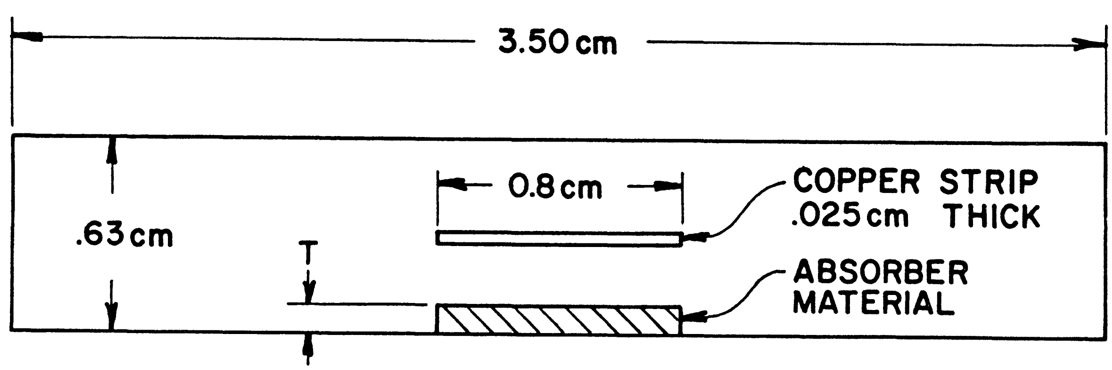

Fig. 1. Cross-section of stripline transmission line used for evaluation of absorber materials. View is in direction of propagation. Length of absorber material was 3.05 cm and test fixture length was 5.27 cm between N connector flanges. The thickness, T, is given in Table III along with attenuations at 300K and 15K for various materials.

The attenuation values (dB/cm) are configuration and frequency dependent but the temperature dependence should not be configuration dependent and is most likely independent of frequency in the microwave range. For example, the attenuation of EMA7175 at 15K should be 68% of its 300K value independent of configuration or frequency.

The materials tested were selected to not contain carbon and are fairly stable with temperature. The EMA and MF types are mechanically hard materials used for waveguide terminations and attenuation of unwanted transmission in microwave components. The AN material is a foam structure used to absorb free-space radiation while the GDS material is a flexible rubber sheet used for RFI gasket material.

Waveguide attenuator vanes are usually constructed of a thin dielectric coated with a resistive film. DC resistance tests were conducted on nichrome films deposited by two manufacturers [4,12] on crystalline quartz substrates. In both bases the DC resistivity of 160 ohms per square changed by less than 3% after cooling from 300K to 77K.

IV. Semi-Rigid Coaxial-Cable

Microwave cryogenic systems often have requirements for coaxial lines with one end at a low temperature and the other end at a higher temperature. The requirement that there be low electrical attenuation is incompatible to a requirement for low heat flow due to the Wiedemann-Franz law [15] which states that thermal conductivity is proportional to electrical conductivity in a metal. The law applies to alloys and pure metals except at very low temperatures (< 10K). However, at microwave frequencies the high conductivity region need only be a few skin depths thick (skin-depth, proportional to $1/\sqrt{f}$ is 2 μm for copper at 1 GHz);

the high conductivity region is often thicker than this for mechanical reasons or to allow the cable to have very low loss at low frequencies. A good thermal transistion cable can be made with silver- or copper-plated stainless-steel inner and outer conductors, but this is not commercially available.

Measurements of the attenuation of five types of commercially available [16,17] semi-rigid cables at 300K, 77K and 15K are reported in Table IV along with the calculated heat flow for a 10 cm length of the cable between various temperatures. The attenuations are measured at 15 GHz on 30 cm or 60 cm of either type .141 or .085 (nominal outside diameter in inches) cable and the results are expressed in attenuation relative to type .141 at 300K which is taken to be $.0034\sqrt{f_{GHz}}$ dB/cm where f_{GHz} is the frequency in GHz. Since the attenuation is inversely proportional to cable inner diameter, it is assumed that type .085 cable has 1.78 times the attenuation of type .141 and only one size need be measured. The calculated heat flows are based upon material thermal conductivities averaged over temperature as given in Table V.

TABLE IV - Relative Attenuation and Heat Flow (mW for 10 cm length) for Various Coaxial Cables

OUTER COND	INNER COND	TYPE	Relative Attenuation*			Heat Flow, mW x 10 cm		
			300K	77K	15K	300K -77K	77K -20K	20K -4K
CU	AG/CU/SS	.141	1	.44	.25	2902	1748	506
		.085	1.78	.78	.44	1529	923	268
BeCu	BeCu Tube	.141	2.41	2.2	2.06	383	39	2.8
		.085	4.29	4	3.67	192	20	1.4
SS	AG/BeCu	.141	2.16	1.8	1.59	161	21	2
		.085	3.85	3.3	2.82	67	9	0.7
SS	AG/CU/SS	.141	2.16	1.8	1.59	241	99	26
		.085	3.85	3.3	2.82	128	54	15
SS	SS	.141	7.1	6.4	5.8	100	11	.5
		.085	12.6	11.4	10.3	49	5.6	.25

*Attenuations are relative to $.0034\sqrt{f_{GHz}}$ dB/cm or $.0086\sqrt{f_{GHz}}$ dB/inch where f_{GHz} is frequency in GHz.

Type .141 - Outer conductor diameter 3.58 mm, dielectric diameter 2.98 mm, and inner conductor diameter 0.91 mm.

Type .085 - Outer conductor diameter 2.20 mm, dielectric diameter 1.68 mm, and inner conductor diameter 0.51 mm.

AG/CU/SS - Silver-plated, copper-clad stainless steel. Plating thickness is ∿ 1 μm for type .085 and ∿ 2 μm for type .141. Cladding is ∿ 65 μm thick.

AG/BeCu - Silver-plated beryllium-copper; thickness as above.

BeCu Tube - Inner conductor is a hollow tube with hole diameter .25 mm for type .085 and .5 mm for type .141.

TABLE V - Average Material Heat Conductivities in mW/°K cm Used in Table IV

Material	Temperature Range		
	300K -77K	77K -20K	20K -4K
Copper	4100	9,700	10,000
Silver	4200	15,000	10,000
Stainless Steel	123	55	9
Beryllium Copper	500	200	50

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[3] EMC Technology, 1971 Old Cuthbert Road, Cherry Hill, NJ 08034.

[4] Solitron Microwave, P. O. Box 278, Port Salerno, FL 33492.

[5] Omni-Spectra, 21 Continental Boulevard, Merrimack, NH 03054.

[6] Midwest Microwave, 3800 Packard Road, Ann Arbor, MI 48104.

[7] Narda Microwave, 435 Moreland Road, Hauppauge, NY 11788.

[8] Weinschel Engineering, 1 Weinschel Lane, Gaithersburg, MD 20760.

[9] Hewlett-Packard Co., Palo Alto, CA.

[10] Dielectric Communications, Newtown Road, Littleton, MA 01460.

[11] Emerson-Cumming, 59 Walpole Street, Canton, MA 02021.

[12] Norsal Industries, 85-D Hoffman Lane South, Central Islip, NY 11722.

[13] Type 2146 bellows, Servometer Corp., 501 Little Falls Road, Cedar Grove, NJ 07009.

[14] Texscan Corp., 2446 North Shadeland Avenue, Indianapolis, IN 46219.

[15] H. M. Rosenberg, "The Behavior of Materials at Low Temperatures," Advanced Cryogenics, ed. C. A. Bailey, New York: Plenum Press, 1971, pp. 77-101.

[16] Uniform Tubes, 200 W. Seventh Avenue, Collegeville, PA 19426.

[17] Precision Tube Co., Church Road and Wissahickon Avenue, N. Wales, PA 19454.