PRACTICAL DIELECTRIC FILLED WAVEGUIDE

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Abstract

This paper describes the development of a laminated teflon-filled dielectric waveguide using techniques similar to what has been done in the flexible coaxial line. It describes the development of dielectric waveguide giving the theoretical design of the teflon-filled dielectric waveguide from both a mechanical and electrical point of view.

The emphasis on this dielectric waveguide development has been to arrive at a practical waveguide construction which would be suitable for a radar systems application. This dielectric waveguide is intended to provide a miniaturized waveguide circuit which will have essentially the same peak power handling capabilities as standard waveguide which would be suitable for use up to 200°C.

The fabrication technique is described along with a description of the measurement procedure for determining the characteristics of this dielectric waveguide including match, attenuation, and high power breakdown.

The design of special transitions from air-filled waveguide to dielectric-filled waveguide are described also.

This work was performed under contract number AF33 (600) 26763 for Wright Air Development Center and is intended to eventually yield a series of dielectric-filled waveguides, both rigid and flexible.

Waveguide Techniques

The object of this dielectric waveguide development is to come up with a practical dielectric-filled waveguide, both rigid and flexible, for the following performance:

a. This waveguide is to operate over the temperature range from -55°C. to +200°C. and to have a peak power handling capability at 130,000 feet altitude equivalent to that of standard guide at atmospheric pressure. Waveguide assemblies in this dielectric-filled waveguide are to show less than 0.5 db attenuation per foot and components such as bends, twists, and adapters are to have a maximum VSWR over the entire usable waveguide range of less than 1.10.

b. The development is to cover three waveguide sizes, RG-91/U (WR-62), RG-52/U (WR-90) and RG-49/U (WR-187) so as to cover a large range of frequencies and guide sizes so that the technique can be fully evaluated

Table 1 shows the size reduction that can be achieved using teflon dielectric and the theoretical attenuation to be expected from this material for both air and dielectric waveguides. From this table, it is obvious that approximately 60% reduction in size can still, from a theoretical basis, meet the attenuation requirements of this contract.

The problem of dielectric waveguide materials is of paramount significance in this development which will meet a 200°C. operating temperature range. The choice of suitable low loss dielectric materials is limited to teflon and fused quartz. Table 2 shows some of the characteristics of these two materials for possible application as a dielectric waveguide.

The use of fused quartz as a waveguide medium is virtually impossible since the manufacturing problems in fused quartz make the use of it out of the question from a practical waveguide point of view. The possibility of firing silver-coated quartz for this dielectric waveguide application is very attractive for short sections, and fused quartz has actually been used for such elements as cavities and structures of the type where dimensional stability is extremely important. As a practical dielectric waveguide material, however, it is very difficult to handle. Teflon, although an ideal electrical material, suffers from an extremely high thermal coefficient of expansion.

Table 3 shows the comparison of thermal coefficient of expansion for teflon versus aluminum. From this table, it is apparent that over a 200°C. change in temperature expansion of teflon will result in almost .020 increase/inch of length for the dielectric waveguide as against the outer conductor. This would set up internal stresses which would be far beyond the yield points of the aluminum and make construction and handling of such a dielectric guide virtually impossible. The present day techniques for handling teflon and the molding of modified teflons such as asbestos loaded, graphite loaded, zirconium loaded, have made it possible to create modified teflons with reduced thermal coefficients of expansions. It is hoped that by loading teflon with such materials as powdered fused quartz, a modified teflon will be obtained which will have a thermal coefficient of expansion very closely matching that of aluminum as an outer conductor. Samples of modified teflon are being obtained and because of the refractory and powder metallurgy type of handling which the basic teflon material requires, the production of these modified teflons should yield satisfactory dielectrics. Because of the hardness of such load materials, there will be some increased difficulty in the machinability of these materials. But, if the loss factors can be held to as low as might be expected, the over-all electrical performance of such a dielectric guide would warrant this expense.

Construction of Techniques

There are various methods for making a dielectric-filled guide. One of the oldest techniques is shown in Fig. 1 where components are made in two identical mating halves. The dielectric is filled or shaped to fit between them and they are assembled as shown in the hybrid ring of Fig. 1 which is using air dielectric guide. This technique is, unfortunately, rather expensive unless hobbing techniques or precision casting techniques can be used to simplify the construction of the outer conductors.

If the quantity is sufficiently large so that the dielectric-fill can be molded to shape, it should be possible to make dielectric-filled waveguide assemblies rather easily by this method.Unfortunately, the quantities involved would generally require 1000 to 5000 quantities before such tooling becomes economical. With these modified teflons as a dielectric material, electrodeposition by electroplating alloys or by metal spraying using flame spray or vacuum metallized coatings are possible solutions to the construction of a practical dielectric waveguide.

In any practical dielectric waveguide construction, the problem of excluding air voids between the dielectric and outer conductor is a severe one, to avoid corona, localized heating and distortion of dielectric. This localized heating might automatically soften the teflon binder and failure of the waveguide under high power conditions occurs. Two solutions are immediately apparent for this air exclusion problem. One is to obtain an extremely tight-fitting outer conductor. This could be done by deliberately shrinking the outer conductor waveguide over the dielectric and the other solution is to provide a thin film of silicon grease with a matching dielectric constant between the dielectric and the outer conductor. Likewise, it might be possible to construct this dielectric waveguide using a laminated sheet of teflon with a silicon grease between the layers for the exclusion of air.

Bolt-on type flanges are planned for these dielectric waveguides using rectangular RF and air pressure seals which have been developed for air dielectric waveguides in lieu of choke and cover combinations to avoid the air dielectric inter-face problem. These flanges will be bolted together with a thin wiping of silicon grease to exclude air, and bolting together with the dielectric waveguide assemblies. It is planned to develop bolt-on type TR and ATR seats to mate with this dielectric waveguide along with crystal holder details, secondary waveguides, directional couplers, etc., to avoid soldering of these components to the dielectric-filled waveguide. The use of epoxy resins for joining components to the dielectric waveguide has been investigated and metallic loaded epoxies have yielded good RF contact and excellent bond, and offer an alternate solution to the bolt-on component technique.

Testing of These Components

Testing of dielectric waveguides is a rather severe problem in that determination of breakdown will be very difficult. It is planned at the moment to run as high a peak power and average power as are commercially available, and measure attenuation at low level and under high level conditions as a criterion for high level breakdown. Any increase of attenuation at high level conditions would be a result of corona formation. The heating of the dielectric with 200°C. ambient will determine the power rating for peak operation with corona and for C.W. by dissipating losses.

Fig. 2 shows a typical high power test set to be used for this evaluation — a 4J50 magnetron operating at 250 KW at X-band providing 250 watts average power will be used for these evaluations.

Existing Waveguide Techniques

It would be inopportune at a meeting of this type not to take a look at the existing waveguide techniques for miniaturization. One of the most attractive of these is the use of ridge waveguide as shown in Fig. 3 where considerable miniaturization can be accomplished without too much penalty for peak power handling capabilities and attenuation. Fig. 3 shows a precision standard section of double ridge guide made up for test evaluation of a waveguide which was designed for commercial weather penetration radar systems and is designed to propagate 5400 and 9300 Mcs/sec. This double ridge waveguide, about 60% of the size of its equivalent C-band waveguide, has measured peak power handling capabilities of 1.50 megawatts at 5400 Mcs. and 1.28 megawatts at 9300 Mcs. with measured attenuations for drawing tubing aluminum of .045 db/ft. at 5400 Mcs. and .043 db/ft. at 9300 Mcs/sec. These numbers compare favorably with standard rectangular waveguide at a considerable saving in size for a C-band installation. Both rigid waveguide and flexible waveguide are available for this particular double ridge guide.

The use of double ridge guide over single ridge makes for a much simpler manufacturing and provides for the possibility of making flexible waveguide using Airtron type S tubing techniques where two identical halves are mated along the narrow seam.

The use of coax-to-waveguide hybrids has provided a very compact dual balanced mixer as shown in Fig. 4. This dual balanced mixer uses a waveguide type local oscillator and provides for a balanced receiver and balanced AFC mixer operation. A three-arm coaxial, one-arm waveguide hybrid is used in three locations. One hybrid for local oscillator power splitting and two hybrids for actual mixer applications using coaxial crystal mounts with direct and reverse polarity crystals. This has resulted in extremely compact waveguide mixers and has been subsequently applied from 10.000 MCs. down to 3,000 Mcs. for a very compact miniaturized mixer. The size of this unit compares very favorably with microstrip receiver techniques from a size point of view with no penalty for dielectric losses.

The first application at Airtron for dielectric waveguides has been as miniaturized secondary guides for directional couplers. Fig. 5 shows such a unit—here a slab of teflon fills both the secondary waveguide and the coupling holes to provide a broadband (12%) 20 db coupler with 15 db minimum directivity.

TABLE 1

Designation	Air Dielectric Dimensions, ID	Dielectric Wg. Dimensions, ID	Frequency KMC/sec.	Attenuation, Theoretical Db/ft. Alum., Outer Conductor	
				Air	Dielectric
RG-91/U	.622 x .311	.432 x .216	12.4	.061	0.46
RG-52/U	.900 x .400	.625 x .278	8.2	.055	0.28
RG-49/U	1.872 x .872	1.300 x .606	3.95	.018	0.13

Dielectric Teflon K = 2.1

$\tan\delta = .00015$

TABLE 2

POSSIBLE DIELECTRIC MATERIALS FOR DIELECTRIC RECTANGULAR WAVEGUIDE AT 200°C.

Material	Dielectric Constant	Loss Tangent	Thermal Coefficient of Expansion
Teflon	2.1	0.00015	12.3×10^{-5}
Fused Quartz	3.78	0.00006	5.7×10^{-6}

TABLE 3

Material	Thermal Coefficients parts/inch/inch/°C.
Teflon	12.3×10^{-5}
2S Aluminum	2.3×10^{-5}

Difference is closely 10^{-4} inch/inch/°C.; thus for 200°C. temperature rise, Teflon will have expanded 0.020" for a one-inch length.

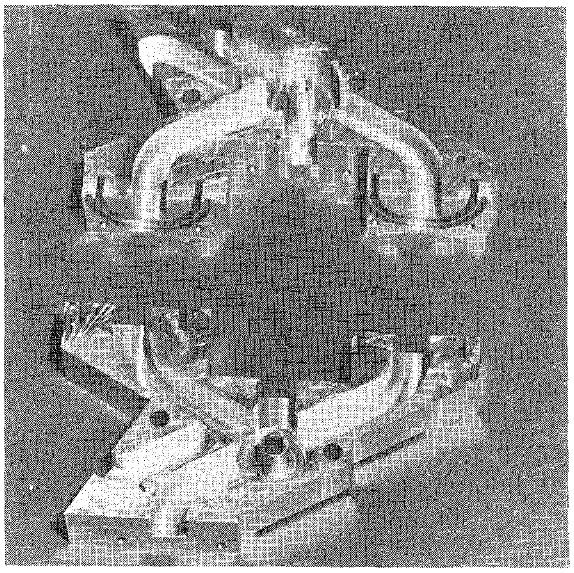

Fig. 1 - Split block construction technique. Hybrid ring.

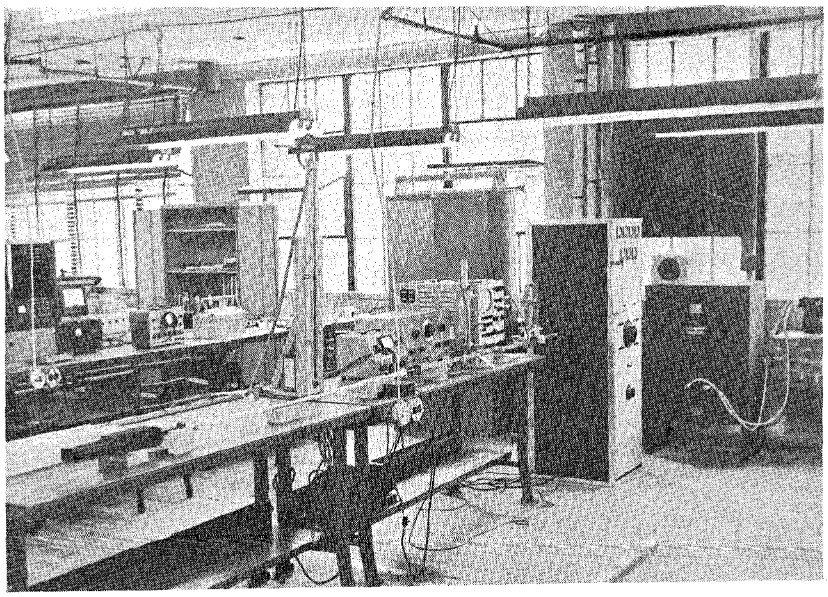

Fig. 2 - High power breakdown test set-up 1 x 1/2 waveguide (250 KW).

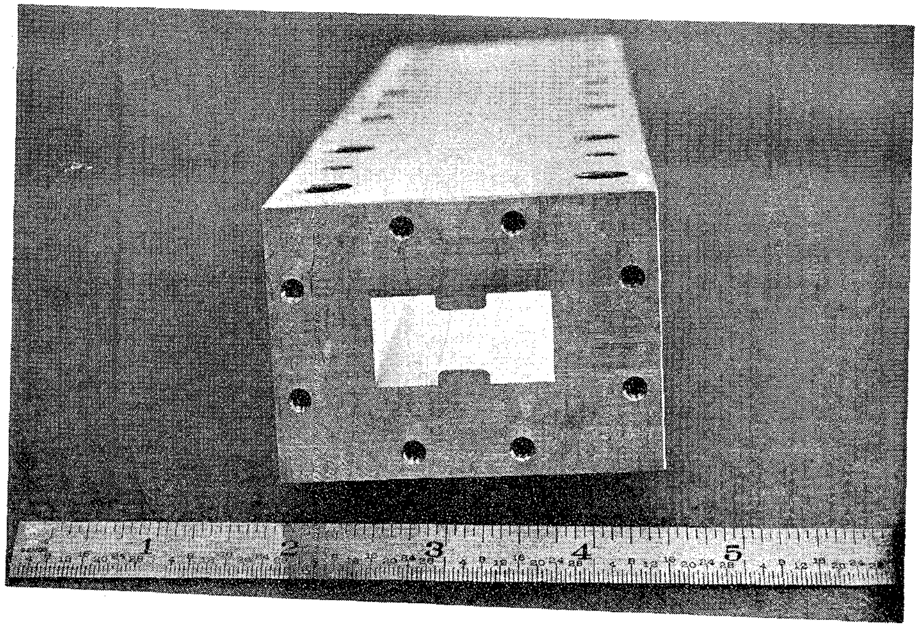

Fig. 3 - Double ridge waveguide for commercial airlines application.

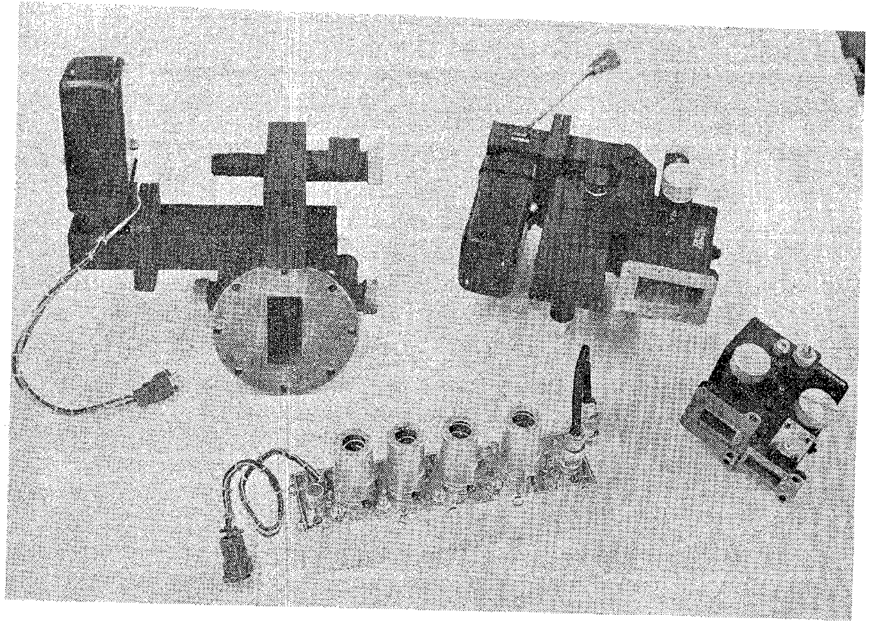

Fig. 4

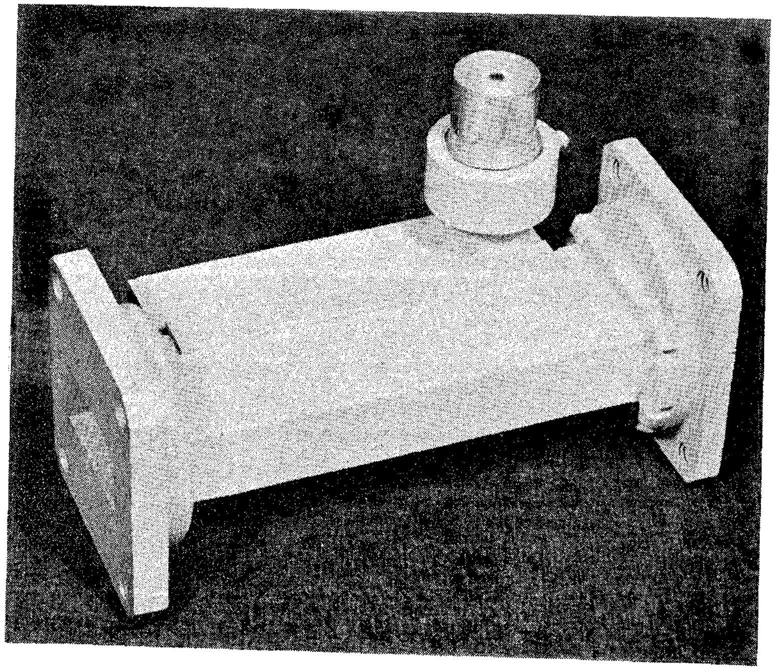

Fig. 5 - Directional coupler dielectric secondary waveguide.