MEASUREMENTS OF ATTENUATION AND PHASE VELOCITY OF VARIOUS LAMINATE MATERIALS AT L-BAND

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Abstract

Measured data are plotted for the characteristic impedance, velocity of propagation, and attenuation of dielectric sheet supported strip transmission lines for four dielectric materials: teflon bonded glass cloth, epoxy bonded glass cloth, polyester bonded glass mat, and XXXP paper base phenolic. At 1000 megacycles the teflon material is excellent and the epoxy and polyester materials satisfactory for low Q applications, such as microwave transmission lines.

The equivalent physical length of a dielectric sheet supported strip transmission line right angle is reported.

Introduction

A high Q strip transmission line supported by a thin dielectric sheet such as that described by Fubini, Fromm and Keen[1,2] (Fig.1) is well suited to the production of the complex antenna feeder systems required by Tchebyscheff arrays. However, because of fringing fields, the velocity of propagation (v_p) and the characteristic impedance (Z_o) are less in the dielectric sheet supported strip transmission line than they are in the corresponding compensated dielectric bead supported transmission line. Furthermore, the velocity of propagation is a function of the width of the strip conductor and of the thickness and dielectric constant of the dielectric sheet for a given spacing between ground planes. The velocity of propagation, characteristic impedance, and attenuation have been measured as a function of the parameters strip width and dielectric sheet thickness in order to provide data for the design of antenna arrays, and to choose a copper clad laminate that is satisfactory from the standpoint of both loss and cost. All the measurements reported herein were made at a frequency of about 1000 megacycles.

Four different materials were considered as base materials for the foil cladding - XXXP paper base phenolic, polyester bonded fiberglass mat, epoxy bonded fiberglas cloth, and teflon bonded fiberglas cloth. The manufacturers' published characteristics of these materials are tabulated in Fig. 2, together with the characteristics of a new styrene co-polymer bonded fiberglas (Rexolite 2200) on which no measurements have yet been made.

Velocity of propagation, characteristic impedance and attenuation measurements were made for the transmission line strips printed on one side and on both sides of the dielectric, for spacing (b) between ground planes of 0.375 and 0.750 inch, and for the dielectric sheet thickness (t) 0.064, 0.032, and 0.020 inch.

Characteristic Impedance

The measured characteristic impedance of four different laminate materials is shown in Fig. 3 for a ground plane spacing of 0.375 inch and a dielectric sheet thickness of 0.064 inch. For teflon bonded fiberglas clad on both sides with 0.00135 inch copper foil, the measured characteristic impedance as a function of the strip width divided by the cavity height ($\frac{w}{b}$) is identified in form but about 1 per cent lower than a curve plotted from the relation given by Cohn[3] for a solid metal strip of the same ratio of thickness to cavity height ($\frac{t}{b} = 0.17$). The fact that the Z_o for the other materials is considerably lower than that for the teflon tends to indicate that the effective dielectric constants for the materials are higher than published.

Velocity of Propagation

Fig. 4 shows the velocity of propagation for a dielectric sheet supported strip transmission line clad two sides for the four different materials and for two thicknesses of the epoxy bonded laminate.

The measured velocities of propagation of the singly clad sheet were lower than those of a doubly clad sheet of the same material by a percentage constant within about plus or minus 0.1 per cent for each of the four or five measured points that were taken for each material. This percentage is tabulated in Fig. 5 as a correction factor to apply to Fig. 4.

The variation of velocity of propagation with relative thickness ($\frac{t}{b}$) of the dielectric is plotted in Fig. 6 for epoxy bonded fiberglas. These data were measured for strip width to ground plane spacing ($\frac{w}{b}$) constant at 1.33.

Attenuation

Fig. 7 shows the attenuation in db per wavelength measured for the different materials and for a copper strip with

$\frac{t}{b} = 0.0267$. The attenuation of the copper strip was measured by a resonant cavity method and provided an approximate calibration of the experimental setup. The measured attenuation was 0.012 $\frac{db}{\lambda}$ (unloaded Q = 2250) compared with about 0.0085 db per wavelength computed for a strip transmission line assuming a uniform current distribution and neglecting fringing effects. For these measurements the half wavelength resonant strip was supported by strips of polyfoam located approximately one-third the distance from the ends of the strip.

In order to provide a check of the attenuation and velocity of propagation, an expression was derived, considering only the TEM made, for the attenuation as a function of velocity of propagation in terms of the dielectric constant and loss tangent of the laminate material. The velocity of propagation in a composite TEM line such as shown in Fig. 9 was derived as a function of $\frac{t}{D}$ where t is the thickness of the material of relative dielectric constant ϵ, and D is spacing between ground planes. All attenuation was considered due to the material of dielectric constant ϵ and net power transfer was solved for in terms of the dielectric constant and $\frac{t}{D}$. The parameter $\frac{t}{D}$ was eliminated between the two equations resulting in

$$\frac{P_{out}}{P_{in}} = 1 - \left(\frac{1 - V}{V}\right)\left(\frac{1}{\sqrt{\epsilon} - 1}\right)(1 - e^{-2\alpha l})$$

where V is the velocity of propagation of the composite line
ϵ is the dielectric constant relative to air
α is the attenuation constant of the dielectric = $\frac{\pi}{\lambda}\tan\delta$
l is the length of transmission line
e is the base of Naperian Logarithms

The loss is computed as a function of V from the equation and is converted to db per wavelength. Attenuations computed for the loss tangents tabulated in Fig. 2 are plotted in Fig. 8. Measured points taken from data plotted in Figs. 4, 5, 6 and 7 show attenuations considerably greater than the computed curves of Fig. 8. For example, the attenuation for teflon bonded fiberglas laminate is greater by a factor of four than indicated by values computed from $\epsilon = 3.75$ and $\tan\delta = 0.005$. Some of the increased loss may be due to the adhesive used to bond the copper foil to the laminate, but it is unlikely that this could account for the entire deviation. The deviations for other materials are even greater - up to a factor of eight for the polyester mat and the XXXP paper base phenolic. Moisture absorption - about 0.4 per cent in 24 hours for both XXXP and polyester mat in 1/8 inch thicknesses - probably accounts for the great increase in attenuation. For example, the following measurements are cited.

SINGLY CLAD DIELECTRIC SHEET SUPPORTED STRIP TRANSMISSION LINE*

Material	Freshly Stripped Material**	Same Material After Six Months Exposure to Normal Indoor Conditions***
XXXP Phenolic	.138 db/λ	.3 db/λ
Polyester Glass Mat	.078 db/λ	.08 db/λ
Epoxy Bonded Glass Cloth	.176 db/λ	.084 db/λ
Teflon Bonded Glass Cloth	.078 db/λ	.04 db/λ

*Strip width, one inch; dielectric sheet thickness, 0.064 inch
**Ground plane spacing, 0.375 inch
***Ground plane spacing, 0.750 inch

These data may not be compared directly because of the difference in ground plane spacing. Doubling the spacing of the ground planes, however, should halve the attenuation, and on this basis the attenuation of the teflon bonded and epoxy bonded materials has remained the same. The attenuation of the polyester has increased by a factor of two and that of XXXP has increased by about four and one-half. However, even with the increased attenuation due to moisture, the polyester mat is as good as the epoxy bonded glass cloth material.

The effect of ferric chloride etching on attenuation was checked by measuring the attenuation on two samples cut from the same sheet of epoxy bonded laminate. It was found that the piece that had been etched with ferric chloride had an attenuation of 0.12 db/λ compared with 0.13 db/λ for the piece that was prepared by hand stripping the copper. It may be concluded that the effect of the etchant on epoxy bonded material and teflon bonded material is nil. Although no measurements have been made to check the effect of the etchant on the polyester and XXXP material they are suspect because of their moisture absorption characteristic.

The temperature dependence of the dissipation factor is plotted in the article by Place[4], and it should be noted that as temperature is increased from 20 degrees C. to 120 degrees C. the dissipation factor of XXXP increases by about

200 per cent, of polyester glass mat by about 250 per cent and of teflon by less than 20 per cent.

Right Angle Bends

Published data available on right angle bends in strip transmission line indicate that for Z_o approximately 50 ohms, a low SWR right angle bend may be constructed merely by drawing the diagonal of the square formed by the intersection of the transmission lines and removing the metal between the diagonal and the exterior corner. These data were checked and additional data were taken by resonant cavity methods for dielectric sheet supported strip transmission lines of 75 and 33 ohms Z_o. In the procedure used, a right angle was cut to a length providing full wave resonance in a transmission type cavity at the design frequency. A second right angle was cut for $\frac{3}{2}$ wavelength resonance, using previously measured propagation velocity information. For full wave resonance a voltage maximum appears at the plane of symmetry and the resonant condition is affected only by the shunt susceptive component. Similarly, when the strip is resonant at $\frac{3}{2}$ wavelength, a current maximum occurs at the plane of symmetry and the series term only affects the resonant condition. Matching the right angle was performed by varying the dimensions (f) in Fig. 10 until the resonant frequency for both the full wavelength and $\frac{3}{2}$ wavelength cases were identical. The variation of f with strip width is plotted in Fig. 10 - for the best match at 50 ohms $\frac{f}{w}$ should be about 0.032.

The length of the right angle, in terms of equivalent straight transmission line was determined by subtracting the lengths of the arms of the right angle from the length of a straight strip resonant under the same conditions and frequency. It is seen that the length of the right angle, normalized in terms of strip width, increases slightly with increasing strip width due to the presence of the compensation.

The matching configuration was chosen for simplicity. Single frequency measurements only have been made, but the right angle should be fairly broadband.

Measurement Procedures

Velocity of Propagation and Attenuation

The standing wave ratio (SWR) method was used to measure the velocity of propagation of laminate materials with relatively high dissipation factors.

The velocity of propagation of the energy in the dielectric sheet supported transmission line is determined by short circuiting a length of the transmission line and varying the frequency until a minimum reading is observed at a reference probe four wavelengths from the short circuit.

To measure attenuation, the SWR existing in the transmission line is determined by probing a one inch slot centered on a voltage minimum and recording the data necessary to determine the SWR by the three point method. Attenuations measured in this manner include the loss due to currents in the bars used to short circuit the strip to the ground planes. Therefore, the attenuations are rechecked in the same setup by additional measurements with the transmission line open circuited approximately $\frac{\lambda}{4}$ from the original short circuit plane. In making attenuation measurements, bars parallel to the transmission line are used to short circuit the two ground planes together and thus avoid radiation loss due to tilt or displacement of the center conductor in the E-plane.

A second method used to measure attenuation and velocity of propagation utilizes the section of transmission line under test as part of a resonant circuit in the manner described in the paper presented by Fubini, Fromm and Keen[1,2] at the 1954 IRE Convention. The attenuation is computed from

$$\frac{27}{Q_u}$$

where Q_u is the unloaded cavity Q determined from the relationship

$$Q_u = \frac{Q_L \sqrt{T}}{1 - \sqrt{T}}$$

where T is the power transmission coefficient

Q_L is the measured or loaded Q

The phase constant is derived from this method experimentally by adjusting a length of strip for full wave resonance at a desired frequency and then reducing the length until halfwave resonance at the same frequency is achieved. The fringing fields at the input and output are the same in both cases for a constant spacing between the resonant circuit and input and output couplings, provided the coupling is small. Thus the difference in length is one-half wavelength. The attenuation may be determined in a similar fashion for one-half wavelength resonance and for full wave resonance. The difference is the attenuation for a one-half wavelength with end effects eliminated.

Characteristic Impedance

The strip-to-ground plane capacitance was measured at 25 megacycles with a Q meter, and the characteristic impedance calculated from

$$Z_O = \frac{1}{VC}$$

where V is velocity of propagation
Z_O is characteristic impedance
C is capacitance per unit length

Acknowledgment

The technical data presented resulted from work done for the U.S. Air Force under the technical cognizance of the Antenna Section at the Rome Air Development Center. The support of that group has encouraged our work in the application of strip line techniques to antenna problems.

References

1. Fubini, E., Fromm, W., and Keen, H., "New techniques for high-Q strip microwave components," Convention Record of the IRE Communications and Microwave Part 8, pp 91-97; 1954.

2. Fubini, E. G., Fromm, W. E., and Keen, H. S., "Microwave applications of high-Q strip components," Convention Record of the IRE Communications and Microwave Part 8, pp 98-103; 1954.

3. Cohn, Seymour B., "Characteristic impedance of the shielded-strip transmission line," Transactions of the IRE, Professional Group on Microwave Theory and Techniques, Vol. MTT-2, No. 2, pp 52-55; July 1954.

4. Place, S. W., "Evaluating dielectric properties of plastics laminates," Electrical Manufacturing, Vol. 54, No. 4, pp 95-102; October 1954.

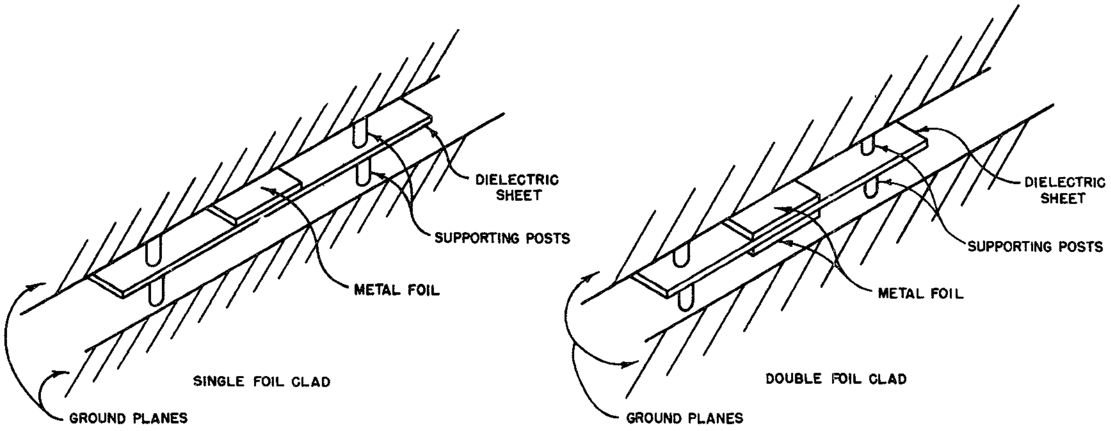

Fig. 1 - Dielectric sheet supported strip transmission line.

MATERIAL	GRADE	AT 1 MC		AT 100 MC		AT 1000 MC		WATER ABSORPTION % IN 24 HRS.
		ϵ	Dissipation Factor	ϵ	Dissipation Factor	ϵ	Dissipation Factor	
Paper Base Phenolic	XXXP-26	3.8	.022	3.6	.035	3.5	.038	.038
Polyester Bonded Fiberglas	Estoglas GM-PE	3.88 4.3	.0127 .008	4.25	.008	4.25	.01	.4
Epoxy Bonded Fiberglas	Epoglas FF-91	5.26 4.75	.018 .018		.039			.016
Teflon Bonded Fiberglas	GB-112T	2.8	.0006	2.8	.0011	2.8	.003	.02
Styrene Co-Polymer Bonded Fiberglas	Rexolite 2200	2.77	.0004	2.77	.0009	2.77	.0012	<.05

Manufacturers:

Epoglas, Estoglas	Plastilite, Inc.
FF-91	Formica, Inc.
XXXP-26, GM-PE, GB-112T	Continental Diamond Fibre
Rexolite 2200	Rex Corporation

Data Tabulated from:

a) Manufacturers' Literature
b) Place, S.W., "Evaluating Dielectric Properties of Plastics Laminates," Electrical Manufacturing, Vol 54 pp 95-102, October 1954

Fig. 2 - Characteristics of dielectric laminates.

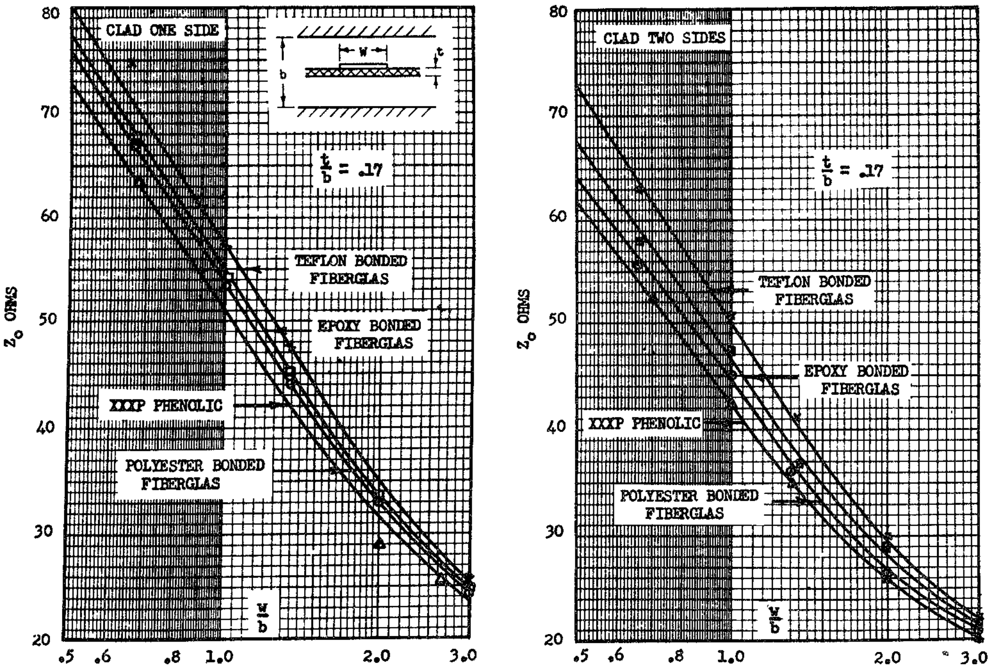

Fig. 3 - Characteristic impedance of dielectric sheet supported strip transmission line.

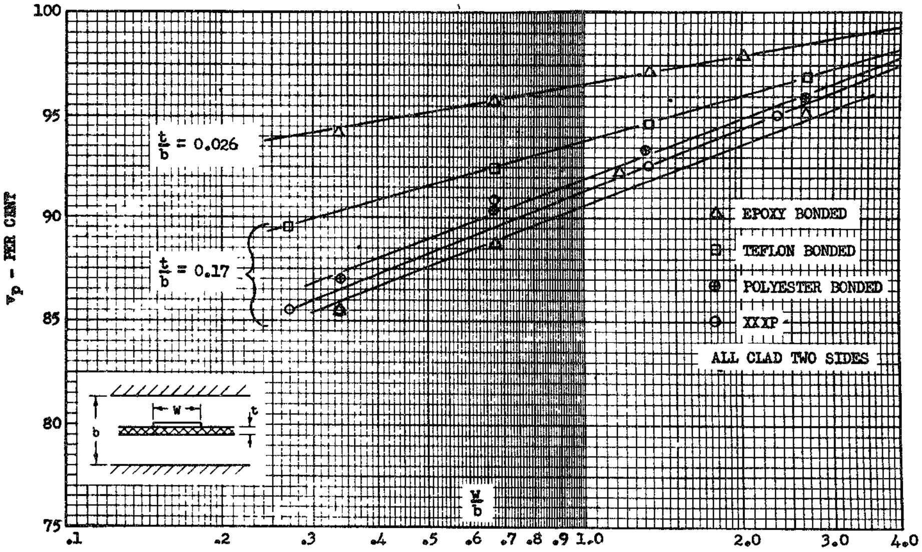

Fig. 4 - Velocity of propagation for dielectric sheet supported strip transmission line.

SINGLY CLAD MATERIAL	$\frac{t}{b}$	VELOCITY OF PROPAGATION REFERRED TO DOUBLE CLAD MATERIAL
Teflon Bonded Fiberglas	0.17	-4.5%
Epoxy Bonded Fiberglas	0.026 0.17	-1.8% -5.6%
Polyester Bonded Fiberglas	0.17	-5.5%
XXXP - Phenolic	0.17	-5.0%

Valid for $.25 < \frac{w}{b} < 4.33$

Fig. 5 - Velocity of propagation for singly clad dielectric.

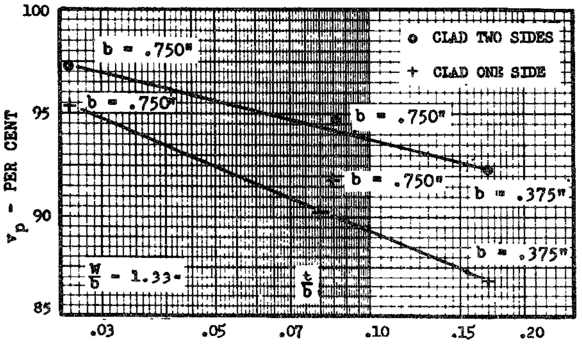

Fig. 6 - Velocity of propagation for epoxy bonded fiberglas.

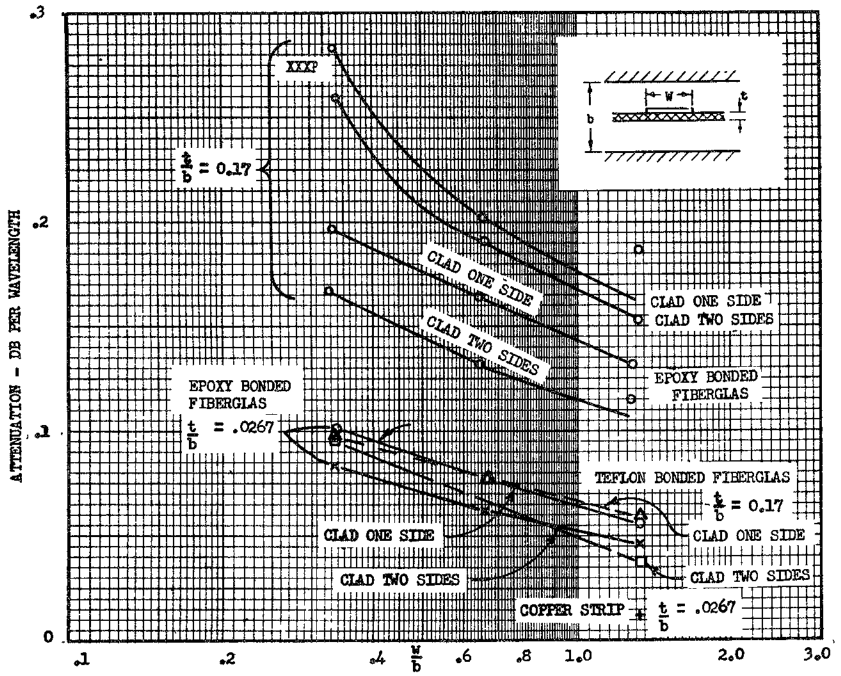

Fig. 7 - Attenuation of dielectric sheet supported strip transmission line.

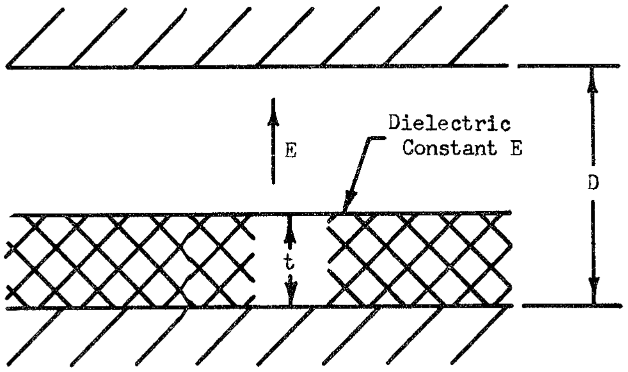

Fig. 9 - Composite TEM transmission line.

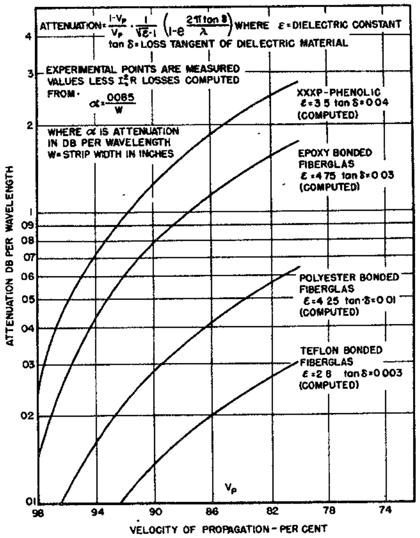

Fig. 8 - Attenuation vs velocity of propagation for composite TEM transmission lines.

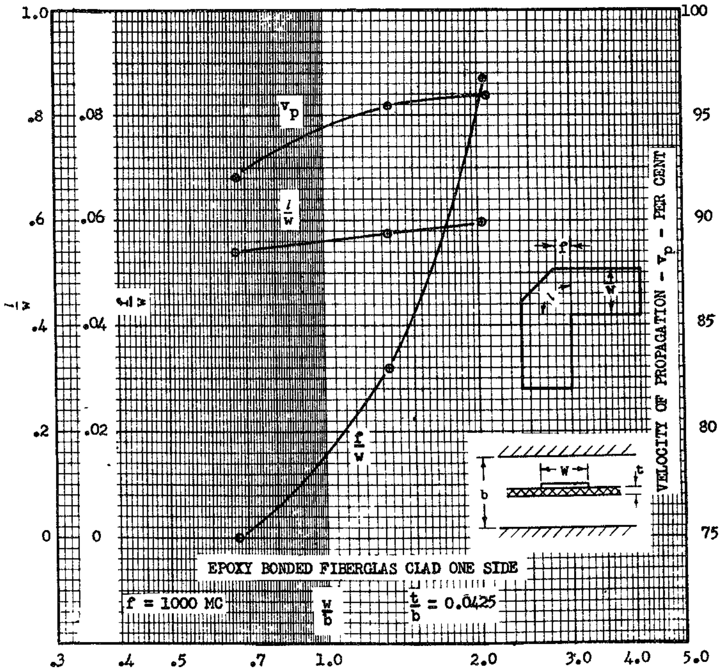

Fig. 10 - Characteristics of matched strip right angle.