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Foam technology for integration of millimetre-wave 3D functions

J.P. Harel, Ch. Person and J.Ph. Coupez

It is demonstrated that shielded foams can be efficiently used as millimetre-wave waveguides. Experimental examples are provided and discussed with respect to standard planar or waveguide techniques in the 26–40GHz frequency range. A 2% bandpass foam-waveguide filter is designed, with an insertion loss of ~ -3.2 dB at 28.7 GHz.

Introduction: Polymethacrylimide foam (PMI, simply called here ‘foam’), is a closed-cell rigid plastic, presenting outstanding mechanical and electrical properties (especially in terms of density, weight, dielectric values and losses). Furthermore, this material can easily be machined or pre-formed by press-moulding or milling techniques, and therefore offers the possibility of creating any geometrical configurations with very simple and cheap procedures.

Even if the usual fields of application for foam are patch antennas and radomes, the use of such a material, with such a low density, low dielectric constant and low loss values ($\epsilon_r = 1.08$ and $\tan\delta = 0.001$ measured at 60GHz), may be successfully used in a waveguide approach, as a substitute for air. Under this assumption, foam could consequently be used as a propagation media, and also as a mechanical support itself. In the following, we demonstrate that such electrical and mechanical advantages can be exploited to realise very low cost devices, such as waveguides and filters, for operation in the millimetre-wave domain.

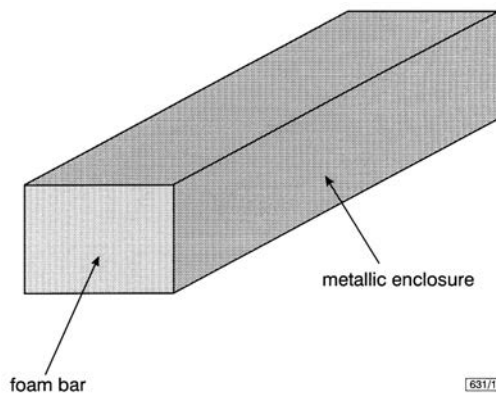


Fig. 1 Shielded foam bar as waveguide structure

Realisation and characterisation of foam waveguides: Waveguides are popular because of their low insertion loss, high power handling capabilities and high Q, compared to those of other electromagnetic propagation media such as planar structures (i.e. microstrip and coplanar lines). Unfortunately, this is not a low cost solution, mainly for millimetre-wave applications, due to size constraints.

One major problem in building a waveguide using a simple foam bar is the difficulty of realising the metallic enclosure of the guide. This metallic shielding should have a good electrical performance and should be easily manufactured, for cost reasons. To this end, several tests have been carried out in order to define a simple metallic shielding procedure, and a comparison made with the performance obtained using a standard WR 28 brass guide. All pieces were 100mm long.

Table 1: Measured insertion loss depending on shielding method

Shielding method	Averaged IL
	dB
Standard brass waveguide, air filled	0.25
Standard brass waveguide, foam filled	1.3
Foam bar shielded with thin sticked copper film	1.75
Foam bar painted with silver solution	1.9
Foam bar shielded by press-moulding techniques (copper film and foam sticked together by means of adhesive polypropylene dielectric film)	1.5

The corresponding insertion loss measurements are compared in Table 1. It can be seen that the use of foam implies the addition of a

1.05dB minimum loss per 100mm with respect to a conventional air-filled brass guide. In comparison, a 50Ω 100mm microstrip line realised on an $\epsilon_r = 2.2$ substrate ($\tan\delta = 10^{-3}$) gives approximately a 2dB insertion loss.

The various waveguide structures presented here are somewhat better than a microstrip transmission line, even if the employed metallic shielding methods are still not optimised. Indeed, the insertion loss should significantly decrease through, for example, an electrochemical metallisation procedure which is an industrially mature technology. Consequently, we conclude that PMI foam can be considered to be a good substitute for standard millimetre-wave brass guides.

Application of foam-waveguide filters: Many applications in future millimetre-wave systems (WLL, LMDS,...) will require filters with very narrow frequency bandwidths ($< 5\%$). Of course, those filters will have to have the lowest insertion loss possible and good return loss, which implies high quality factors Q_o . Consequently, only waveguide filters could be used to obtain the better performances required in terms of the available Q_o values in comparison with those possible using planar technology.

We have investigated the possibility of developing 3D bandpass filters with the proposed foam waveguide solution. The objectives were to design an easily reproducible and non-tunable filter to enable mass production, by means of standard press-moulding and etching techniques.

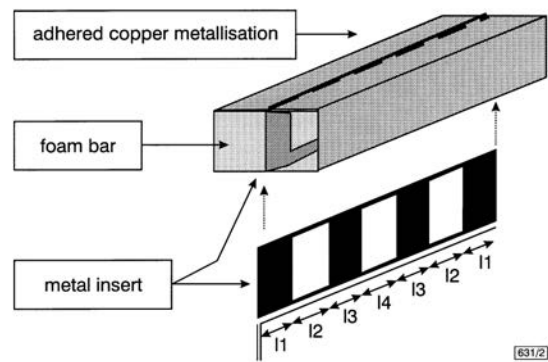


Fig. 2 E-plane filter using shielded foam guide

$$l_1 = 1.009\text{mm}, l_2 = 4.778\text{mm}, l_3 = 3.87\text{mm} \text{ and } l_4 = 4.796\text{mm}$$

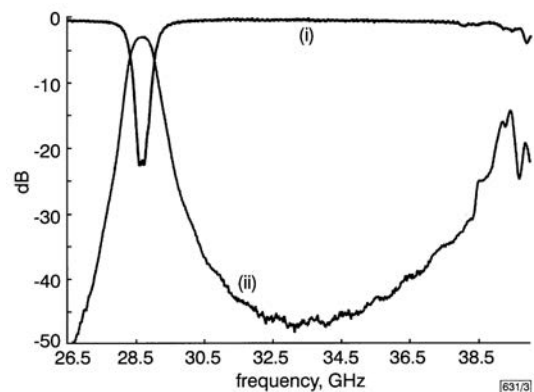


Fig. 3 Measurements of foam-guide metal insert filter

- (i) Return loss
- (ii) Insertion loss

We have chosen the ‘E-plane metal insert bandpass filter’ topology, shown in Fig. 2.

Such a topology is quite easy to synthesise and quite insensitive to technological spread [1]. A third-order E-plane metal insert filter is presented in Fig. 2 which is designed to operate in the Ka band. The metal insert thickness was chosen to be $t = 0.254$ mm; the device was patterned by photoetching techniques. A WR 28 waveguide housing ($7.112 \times 5.556\text{mm}^2$) was used. We have realised such a filter with a foam bar (40mm long), shielded with a thin copper sheet. The metal insert network was simply centred into the bar, and then welded to the external copper sheet. The experimental results (Fig. 3) are quite good, with a centre frequency of 28.73GHz, a -3 dB band of 575MHz (2%) and an IL of ~ 3.2 dB only.

This result once again has to be compared with the results obtained from common planar filtering techniques, which may have an IL \sim 10dB for such small bandwidth filters.

Conclusion: We have realised millimetre-wave waveguides and filters by using shielded low-loss foams. Encouraging performances have been obtained, especially concerning losses and technological constraints (reproducible solutions, with very simple and cheap tools and materials). Those realisations show that passive functions can be obtained in a rather simple manner, at extremely low cost. Therefore, compared to other technical possibilities for millimetre-wave applications, we believe that the use of foam in waveguides may be a good candidate for mass production and very low-cost applications in such frequency bands.

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References

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