AN IMPROVED LOW-PASS HARMONIC ABSORBER

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Abstract

A new technique is proposed for the design of non-reflective high power microwave lowpass filters. This technique is shown to be much less expensive to produce in the frequency range up to S-band.

Introduction

The microwave non-reflective lowpass filter has been previously reported.[1] These filters are used extensively for harmonic suppression in high power radar systems. The non-reflective design provides a low-loss, low VSWR path for the fundamental energy while providing an absorptive path for harmonic frequencies and energy contained in higher-order modes. Thus, the spurious signals are not emitted, and are not reflected back into the high power transmitting tube. This latter result is important for the prevention of frequency pulling, hot-spotting, oscillation, and other effects when certain classes of megawatt-level broadband amplifing tubes are utilized.

The classical design approach suffers from an economic shortcoming in that long dielectric-loaded shunt cylindrical waveguides operating below-cut-off to the fundamental energy are used to conduct the spurious signals into a load area. At lower microwave frequencies (L-band) the physical length of dielectric might be 5" - 7", with diameter of 1 1/2" - 1 3/4". Each tube acts as a transducer element to a portion of the spurious energy while simultaneously providing a reflective interface for fundamental energy at the waveguide surface. The tube length is chosen (using EQ. 1) to provide at least 30-40db reflection of the fundamental frequency band.

(1) $$\text{Loss (db)} = 54.5\left(\frac{\text{length}}{\lambda_c}\right)\left[1-\left(\frac{\lambda_c}{\lambda_o}\right)^2\right]^{1/2}$$

Where λ_c = dominant mode cut-off wavelength of shunt tube

λ_o = operating frequency free space wavelength, mainguide

Tube diameter is chosen to realize a cut-off sufficiently removed from the fundamental frequency to enable low VSWR launching of harmonics while minimizing required tube length. Experience has shown that for 40db second harmonic stopband, approximately 200 dielectric tubes are required. Therefore, each group of 5 tubes (Fig. 1) is capturing about 20% of the harmonic energy. Considering both faces,

$10 \log (1-0.4)^{20} = 44\text{db}$, or 20 rows of 5 tubes face = 100 tubes/face
= 40db at the second harmonic

Transducer efficiency is somewhat lower for the higher harmonics, causing a lesser stopband value to be achieved if a uniform tube positional distribution is desired. This latter restriction is usually forced by the required mechanical spacings for successful assembly. Maximum transduction of energy requires the dielectrically - loaded tubes to be placed at E-field maxima for the particular model distribution being suppressed. Also, as dielectric cross-section increases, it can be shown that axial current distribution within the main guide becomes of greater significance, increasing the difficulty of maintaining a reflective interface.

Thus, it is necessary to use a relatively high dielectric constant to load the shunt waveguides. Further, a close fit must be maintained between the dielectric and the conductive wall of the shunt guide to prevent air-gaps which could lead to high-power breakdown.

In the region extending downward from S-band, the costs associated with high-precision machining of expensive low-loss high-ϵ_r material predominate.

An additional shortcoming of the cylindrical approach is the VSWR degradation experienced at the higher harmonics associated with the limited "matched" bandwidth available. This bandwidth, or ratio of the cut-off wavelengths of the first two modes in the shunt guide, places a limitation upon the terminating load VSWR, and hence upon filter harmonic VSWR.

The new design considerably reduces the amount of dielectric required, resulting in intrinsically lower cost of manufacture, as well as offering improved VSWR and greater attenuation per unit length.

Principle of Operation

The basic approach is depicted in Figure 2. It can be seen that a section of ridged waveguide is used to replace a portion of each dielectrically loaded shunt guide. The ridge configuration is adjusted to match the cut-off characteristics of the rectangular, dielectrically loaded waveguide utilized as an interface with the main waveguide. (EQ. 2)

$$\lambda_{c_{10}}\Big|_{\substack{\text{DIELECTRIC}\\\text{LOADED}\\\text{RECT. GUIDE}}} = \lambda_{c_{10}}\Big|_{\substack{\text{RIDGED}\\\text{GUIDE}}}$$

(2)

There exists an intrinsic difficulty in matching the real and imaginary parts of the propagation constant of rectangular guide with those of ridged guide (it is impossible to realize the equivalences of EQ's (2) and (3) simultaneously). The concomitant impedance mismatch raises the question as to why a dielectrically loaded section is used to interface with the main waveguide. The answer lies in two considerations - (1) Power handling capability of the dielectric section, which is greater in the small cross-section necessitated by the requirements of the section I than that of an unloaded section; and (2), the empirical necessity for a slight protrusion of the shunt section into the main waveguide for purposes of optimizing the passband VSWR.

While it might be argued that the former consideration is relevant only for high harmonic power content (double ridge waveguide can achieve sufficiently low fc_{10} in small cross-section, for most applications), VSWR reduction with high incident fundamental power is solved more practically with dielectric protrusion than with ridge protrusion.

For lowest stopband VSWR, the shunt sections must be designed for minimum harmonic reflection. Thus, it is desirable to provide a wide shunt section passband, starting at least 10% above the highest fundamental frequency, with the section matched to its terminating load. This requirement for wide passband conflicts with EQ. (2) (the rectangular section has

$$\frac{\lambda_{c_{10}}}{\lambda_{c_{20}}} = 2$$

For no intrinsic mismatch within the shunt waveguides, EQ. 3 must be satisfied, thus matching propagation constants of the two cascaded shunt cross-sections.

$$(3) \quad \left.\frac{\lambda_{c_{10}}}{\lambda_{c_{20}}}\right|_{\text{RECT. GUIDE}}^{\text{DIELECTRIC}} = \frac{\lambda_{c_{10}}}{\lambda_{c_{20}}}$$

The difficulty is resolved through the use of Figure 3, wherein a short dielectrically loaded single ridge section is joined to the main guide, and is terminated by an unloaded double ridge section and matched load. EQ's (2) and (3) can be exactly satisfied. Using ref. (2), shunt bandwidths of 2.7 are readily achievable, with exact match of propagation constants. A computer program has been developed in which dielectric constant, minimum $\frac{\lambda_{c_{10}}}{\lambda_{c_{20}}}$, a and b are related for an arbitrary ridged section. Ridge dimensions for dielectrically loaded and unloaded guides are then computed using Rosen's gradient - projection method for constrained optimization. The program equates $\lambda_{c_{10}}$ and $\lambda_{c_{20}}$ for the loaded guide to $\lambda_{c_{10}}$ and $\lambda_{c_{20}}$ for unloaded guide, while constraining bandwidth. This program was used to design S-band test sections with performance given in Table I.

Design & Performance

Desired passband: 2.6 - 3.5 GHz
40db stopband: 4.20 GHz - 14.0 GHz
Waveguide - WR-284

Design 1 - (Ref. Figure 2)

Using WR-75 cross-section for shunt guides, f_c = 7869 MHz

Let $\epsilon_r = 4$

Then fc_{10} = 3934 MHz

fc_{20} = 7868 MHz

Picking a single ridge configuration in WR-75 with

$$BW = \frac{f_{c_{20}}}{f_{c_{10}}} \cong 2.0, \text{ and } f_{c_{10}} = 3934 \text{ MHz}$$

From Ref. 2,

$$\frac{s}{a} = 0.85$$

$$\frac{d}{b} = 0.14$$

$$BW = 2.1$$

$$\text{Intrinsic Mismatch} = \frac{(2.1)}{(2.0)}$$

A test section was constructed using 15 shunt tubes on each broad face and 6 tubes on each narrow face, with a total tube length (for 30db reflection per EQ. 1) of 4.1 inches. Dielectric length is 1", providing 8db attenuation in the dielectric section. Performance is shown in Table I. Active loss/inch of main guide is therefore found to be 2db/inch, necessitating a total filter length of 20 inches for 40db stopband.

Design 2 (Ref. Figure 3)

Again using WR-75 cross-section, but with ϵ_r = 2.1 (Teflon), iterative computer design results in the following dimensions:

Single Ridge
Teflon Loaded Section

$$\frac{d}{b} = 0.37$$

$$\frac{s}{a} = 0.22$$

$$\frac{\lambda_{c_{10}}}{\lambda_{c_{20}}} = 2.7$$

Cutoff = 3934 MHz

Double Ridge Unloaded Section	$\frac{d}{b} = 0.125$
	$\frac{s}{a} = 0.8$
	$\frac{\lambda_{c_{10}}}{\lambda_{c_{20}}} = 2.7$
	Cutoff = 3934 MHz

With no intrinsic mismatch, performance of a similar test section is shown in Table 1. Active loss/inch is found to be 2.2db/in, necessitating a total filter length of 18 inches. For comparison, results of a cylindrical shunt guide test section are also shown in Table I. (Design 3)

Conclusion

We have presented a new approach to the design of high power harmonic absorbing filters providing cost reduction and improved stopband VSWR. Additional improvement can be expected with more understanding of the junction between evanescent dielectric-loaded ridge guide and propagating guide. The literature indicates that use of guide configurations derivable from non-separable Helmholtz equation solutions might further improve bandwidth and power handling but at some additional fabrication cost. (Ref. 5)

TABLE I

Design	Dielectric Length & Cross-Section Used	Freq.	Passband Max. Loss	Max. VSWR	Attenutation At 4.2 GHz	Harmonic VSWR 2nd	3rd	4th	Test Section Active Length	Figure of Merit (db/inch)
1	$\epsilon_r = 4$ 1.1" .75 x .375	2.6-3.5	.05db	1.08	6.3db	1.3	1.42	1.6	3.15 in.	2.0
2	$\epsilon_r = 2.1$ 1.1" .75 x .375	2.6-3.5	.05db	1.04	6.9db	1.11	1.2	1.3	3.15 in.	2.2
3	$\epsilon_r = 9$ 0.6" Diam.	2.6-3.5	.05db	1.05	6.0db	1.2 - 1.3	1.35	1.5	4.05 in.	1.5

References

1. Wantuch and Maines, "A Novel High Power Harmonic Suppressor", Trans. G-MTT, Nov. 1962.

2. Hopfer, "Design of Ridged Waveguides", Trans. G-MTT, Oct. 1955.

3. Pyle, "Cut-off Wavelength of the TE_{10} mode in ridged rectangular waveguide of any aspect ration", Trans. G-MTT, April 1966.

4. Goodwin, "Broad-Band Impedance Matching into Dielectric - Filled Waveguides", Trans. G-MTT, January 1963

5. Luypgert & Schoonaert, "On the Field Energy & Power of Waveguide and Cavities synthesized with non-separable solutions of Helmholtz wave equation", 1975 MTT-S Symposium Proceedings, pp. 57-59.

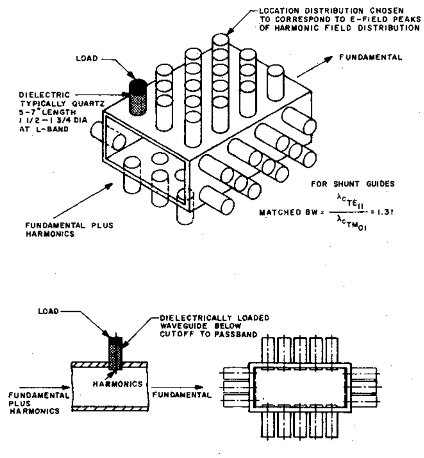
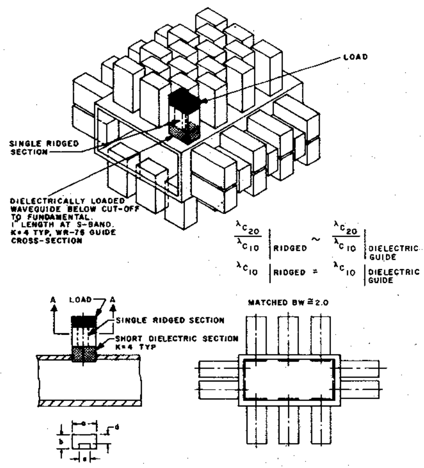


FIG. 1



SECTION A-A FIG. 2

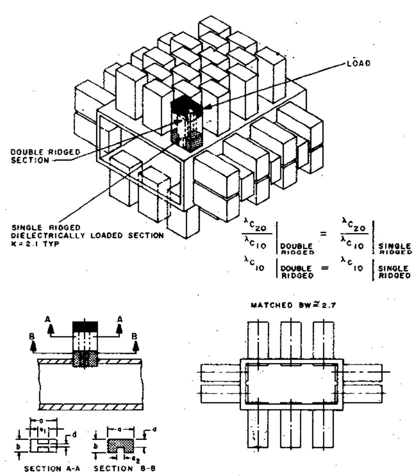


FIG. 3