SYNTHESIS OF HIGH-POWER HARMONIC REJECTION WAVEGUIDE FILTERS

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Introduction. Waveguide filters for rejection of harmonic power content of high-power transmitters are widely used, and corrugated waveguide or waffle-iron filters are most commonly employed for this application(1). The method of design described in the literature is based on the use of image parameters, and may be considered a rather complicated non-optimum procedure which may be difficult to control, particularly in regard to pass band VSWR, since empirical adjustments are usually required. The new methods described here are based on synthesis techniques, and give practical results close to the initial specifications. Only filters of the reflective type will be discussed, but occasionally conversion to the absorptive class is feasible.

Capacitive-iris waveguide filters. Harmonic rejection filters are often required in low or medium power systems, and frequently the stop-band region specified is not too wide,e.g. mainly second harmonic. The waffle-iron filter appears to be a rather complicated, possibly expensive, and (because of the impedance transformers required) certainly a rather lengthy filter for such applications. Originally the capacitive iris filter was conceived as a better solution to the problem, and subsequently it was found to handle as much power as a waffle-iron filter, making it suitable also for high-power applications where space is at a premium, although the harmonic rejection capability does not extend as high in frequency as the corrugated structures.

Capacitive-iris filters are known, having been described by Mumford[2] and Smullin[3], but mainly as variants of the more commonly used inductive-iris filters, i.e. with cavities of approximately $\lambda g/2$ in length, (180° electrical length). The cavities of inductive iris filters are somewhat shorter than 180°, while those of capacitive iris filters are longer. The latter possess an advantage in that the bandwidth remains fairly constant when the filter is tuned over a wide frequency range(3), and the rate of cutoff is more rapid above the high frequency band edge com-

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pared with the low frequency band edge, the reverse situation holding for inductive-iris filters. The disadvantages of half-wavelength capacitive iris filters are that it is difficult to produce large capacitive susceptances in waveguide, so that narrow-band direct-coupled filters are not feasible, and the harmonic rejection capability is little better than that of the inductive-iris version since the cavities are long, and so possess harmonic pass bands at comparatively low frequencies above the main pass-band.

The existence of a pass band at low frequencies, or where the cavity lengths are between 0° and 90° in electrical length is also known, e.g.[2], but no applications nor design techniques appear to have been described. This pass band is of truly low-pass character in the reciprocal guide-wavelength or electrical length frequency variables. The spacing between successive irises is of the order $\lambda go/4$ - $\lambda go/8$ (λgo being the guide wavelength at cut-off), so that theoretically the second harmonic pass band for the fundamental mode is at a very high frequency.

The general n-cavity filter is depicted in Fig. 1(a). The theory presented previously for half-wavelength direct-coupled filters[4] is not completely applicable in this case since the cavities are very short, and the filter is low pass, not band pass. The susceptances are determined in a similar manner by equating the VSWR of each to the corresponding junction VSWR V_i of a distributed low-pass prototype filter[5], shown in the impedance-inverted form[4] in Fig. 1(b), leading to the equations

$$b_i = \sqrt{V_i} - 1/\sqrt{V_i} \qquad (i = 1, 2, \ldots\ldots n+1) \qquad \ldots\ldots (1)$$

The theory gives an exact realization of the cut-off frequency of the filter if the susceptance values are chosen to satisfy Equ. (1) at that particular frequency, and also if the spacings between irises are chosen to be

$$\Theta_i = \Theta_o + \frac{1}{2}\left(\tan^{-1}\frac{2}{b_i} + \tan^{-1}\frac{2}{b_{i+1}}\right) \qquad \ldots\ldots (2)$$

where Θ_o is the commensurate electrical length of the prototype low pass filter, shown in Fig. 1. An extension of the theory to the case of thick capacitive irises is straightforward.

Comparison between theory and experiment for a C-band WR 137 six-cavity filter having a length of 2.45 in. is shown in Fig. 2. Rather closer agreement has been obtained for several later designs, and the cut-off frequency is usually reproduced quite accurately. An X-band version of the filter was tested at high power, and broke down at 55 KW.

The order of magnitude of the interaction effects between adjacent irises may be estimated by calculating the proximity factor P by which adjacent capacities must be multiplied to give a more correct result, as described by Green(6). In the filter of Fig. 2, P>0.9, and the interaction effects are small. If necessary, the factor may be taken into account within the design program.

Synthesis of corrugated waveguide filters. The new design is almost a direct realization in waveguide of the distributed low-pass prototype filter(5). The fringing capacities are taken into account using a technique presented in a previous paper on coaxial low-pass filters(7), and similarly gives an exact realization of the cut-off frequency. Unlike conventional corrugated waveguide filters, the resulting structure is not periodic, but the filter is inherently matched over a broad-band. A 15-element filter was constructed in WR 90 to give a cut-off frequency at 18 GHz, and was designed to attenuate Ka-band by at least 40 dB. In order to keep the high impedance sections of the lines to reasonable dimensions it was necessary to normalize the structure to a reduced height waveguide, in this instance 0.1 in. Two-section transformers to the standard 0.4 in. guide are used, and within the specified pass band the VSWR is better than 1.07, and the insertion loss <0.1dB. The attenuation at Ka band is generally >50 dB, and the 18 GHz cut-off frequency is realized almost exactly. The smallest gap in the corrugated structure is 0.053", i.e. considerably greater than that of conventional waffle-iron filters, and the breakdown power of 65 KW at normal pressure is in agreement with theoretical calculations. Theoretically, the only higher-order mode having low attenuation in Ka band for this filter is the TE_{05}, and unless this mode is present there appears to be no need to suppress TE_{0n} modes by means of longitudinal slots (conversion to a waffle-iron filter).

Tapered corrugated filters. A technique developed more recently gives a design which combines the desirable features of both filters described above, i.e. the latest method results in a corrugated filter matched to standard waveguide.

The guide impedance is stepped within the filter at each end to give the same effective result as the quarter-wave transformers, but without waste of length or deterioration of VSWR, so that an extremely efficient and compact structure results.

References

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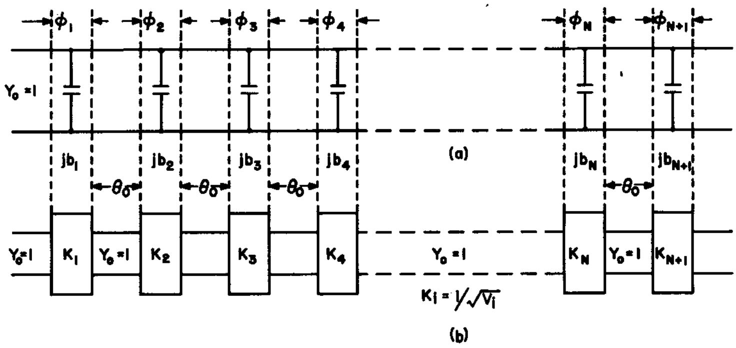

Fig. 1 (a) n-cavity capacitive iris waveguide filter.

(b) Distributed low-pass prototype filter in impedance-inverter form[4].

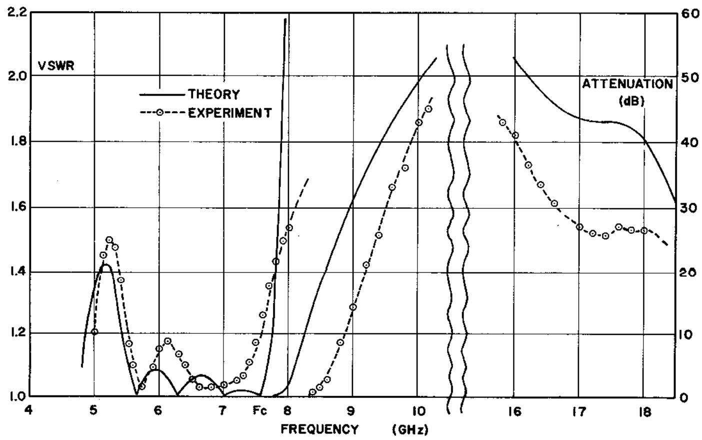

Fig. 2 Comparison between theory and experiment for a 6-cavity filter in WR 137.