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PREDISTORTION TECHNIQUES FOR MULTICOUPLED RESONATOR FILTERS*

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ABSTRACT

This paper presents predistortion, lossy design techniques as applied to general, multicoupled resonator networks. The analytical procedure predistorts the poles of the transfer function to recover the lossless passband flatness at the expense of insertion loss. Experimental results on a dielectric-loaded, 6-pole, elliptic-function filter confirm the validity of the theory.

INTRODUCTION

A multicoupled-cavity filter employs synchronously tuned resonators coupled by apertures and irises to produce the desired transfer function. The standard synthesis procedure assumes that the resonator Q's are sufficient to realize transfer functions that are only marginally different from the lossless theoretical functions. However, when the bandwidths are small compared to the center frequency, this assumption is not always true, and significant band edge rounding of the response can occur.

In 1939, Darlington (1) showed that the lossless insertion loss response of a network could be essentially recovered by realizing a transfer function whose poles were shifted to compensate for the network loss. In 1975, Chen and Mahle (2) applied this technique to the successful realization of all pass functions in coupled microwave resonators. This paper extends this work to optimum filter transfer functions. Results on two experimental, elliptic-function filters correlate well with the theory.

Theory of Pole Predistortion

A general low-pass insertion loss function, t(s), that can be synthesized by coupled cavities is given by

$$t(s) = \frac{1}{\varepsilon} \frac{\Pi\left(s^2 + p^2\right)}{\Pi(s - v)} \tag{1}$$

where v represents the poles of the transfer function and $\Pi(s - v)$ is a Hurwitz polynomial. Note that the order of the numerator must be at least 2 less than the order of the denominator. Since $|\rho(s)|^2 = 1 - |t(s)|^2$ and $|\rho(s)|^2 = \rho(s) \cdot \rho(-s)$,

$$\rho(s) = (-1)^n s^n \frac{\Pi\left(s^2 + z^2\right)}{\Pi(s - v)} \tag{2}$$

The actual response of a real filter will differ from t(s) and ρ(s) because losses are present in the structure. Assuming uniform dissipation, the circuit model is modified to include a loss resistance, r, in each resonator. The resulting low-pass functions are then obtained by replacing s with s + r, which causes the frequency axis to shift to the right in the s-plane, where r is given by

$$r = \frac{1}{Q_u \cdot F_{BW}} \tag{3}$$

Q_u is the unloaded resonator Q, and F_{BW} represents the fractional bandwidth.

The most straightforward way to counter uniform dissipation is to displace all the poles and zeros of t(s) by r in the z-plane. However, since coupled-cavity resonator networks require zeros on the imaginary axis, only the poles can be predistorted. Fortunately, this has only a small effect on the in-band behavior of the filter, because the effect of the zeros contributes mainly to out-of-band behavior. Therefore, pole predistortion of t(s) results in

$$t_p(s) = K \cdot \frac{1}{\varepsilon} \frac{\Pi\left(s^2 + p^2\right)}{\Pi[s - (v + r)]} \tag{4}$$

where K is introduced to ensure that $t_p(s)$ has a maximum magnitude of unity.

The response of a predistorted 6-pole, elliptic-function filter is illustrated in Figure 1. Note that pole predistortion increases both the amount of power reflected and the insertion loss of the network. Thus, pole predistortion is limited to those applications where minimum insertion and maximum return loss are not required.

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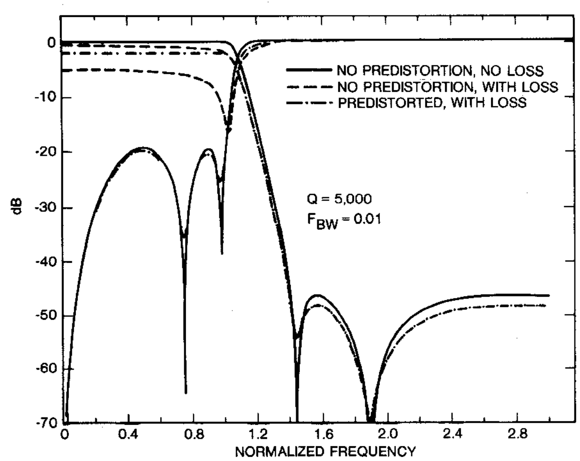

Figure 1. Theoretical Transmission and Return Losses of a 6-Pole Elliptic-Function Filter

Synthesis

The synthesis of the predistorted transfer function, equation (5), follows almost identically to that described by Atia, Williams, and Newcomb (3).

For the symmetrical, even-order, lossless transfer function, the reflection zeros lie on the imaginary axis, and only one choice of zeros and one solution of couplings result. However, for the predistorted transfer function, synchronous and nonsynchronous coupled-cavity solutions will result, depending on the choice of reflection zeros. Total left or right half reflection zeros lead to asymmetrical solutions, while a mixed choice of zeros leads to symmetrical asynchronous solutions.

EXPERIMENTAL FILTER

To illustrate the effects of predistortion, two 6-pole, elliptic-function filters were designed using the $HE_{11\delta}$ dual dielectric loaded cavity mode. The first filter used the conventional lossy technique (3), while the second was designed with the present theory. Both designs had a center frequency of 3.986 GHz, a bandwidth of 29 MHz, and an unloaded Q of 8,000. The measured responses for both units are compared in Figure 2, and the effects of predistortion are clearly evident. The photograph in Figure 3 compares the dielectric loaded filter to a typical 6-pole, air-filled, cylindrical, dual-mode structure. Because of the inherent poor return loss of predistorted filters, high-quality circulators (VSWR <1.04 and return loss ~35 dB) must be used at the filter input.

CONCLUSIONS

Predistortion pole techniques (as applied to optimum filter transfer functions) are successfully realized in general microwave-coupled resonator structures. Symmetrical asynchronous and asymmetrical synchronous solutions are derived. Techniques such as these lead to significant improvements in system efficiencies for applications such as satellite transponder input multiplexers, where insertion loss can be traded for in-band flatness.

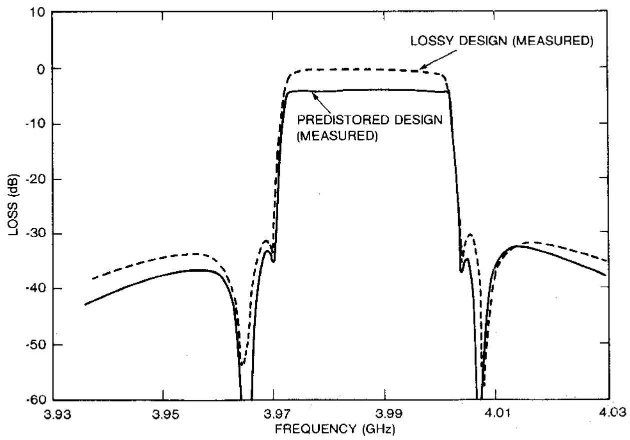

Figure 2. Measured Transmission Response of a Dielectric Loaded Filter, With and Without Predistortion

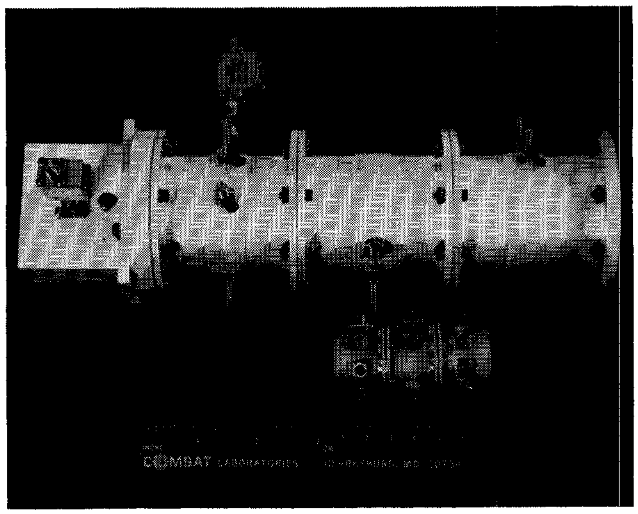

Figure 3. Comparison of 6-Pole, C-Band, Dielectric Loaded and Air Cavity Filters

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