DUAL-PLANE COUPLED-LINE MICROWAVE FILTER*

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ABSTRACT

Realization of a bandpass elliptic filter which employs quasi TEM resonators at different planes coupled through small apertures is described herein. Bethe's small-hole diffraction theory is used to predict the aperture couplings. An experimental filter illustrates the concept and shows that the configuration is suitable for high-temperature superconducting thin film implementation.

INTRODUCTION

Recent advances in high-temperature superconducting film have stimulated a renewed interest in planar microstrip filters [1],[2]. The improved unloaded Qs of superconducting resonators allow the realization of high-performance microstrip filters which are comparable to waveguide cavity filters, thus achieving significant size and mass reduction. Even though design techniques of microstrip Chebychev filters using parallel coupled lines are well-established, those of elliptic filters are usually complicated and require a large number of microstrip elements.

This paper presents a novel realization of a four-pole bandpass elliptic filter realized by two sets of resonators each located at different planes, henceforth described as a dual-plane filter. The synthesis of a dual-plane filter, which is illustrated in Figure 1, draws its analogy from the narrow-bandpass waveguide filter developed by Atia and Williams [3]. Unlike the dual-mode microstrip resonators described in Reference 2, all resonators operate at single dominant quasi TEM mode. The couplings between resonators can be realized in terms of parallel coupling and inter-planar coupling. The former is adjusted by the distance between parallel coupled lines, while the latter is controlled by position and size of an iris at the shared common ground plane. The folded structure of the dual-plane filter can be easily fabricated on most microwave thin film substrates, including high-temperature superconducting films.

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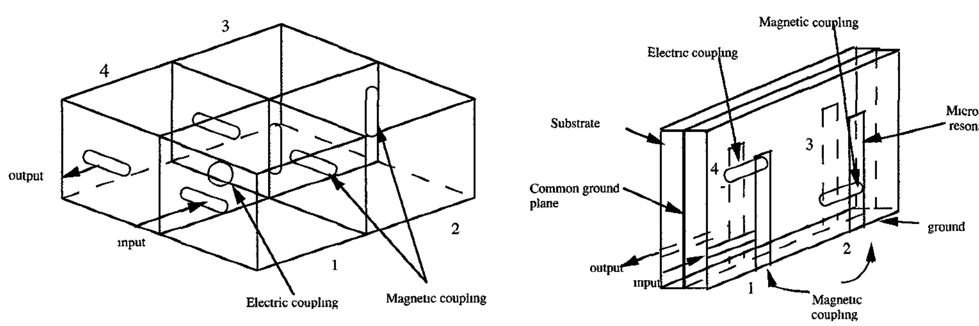
DUAL-PLANE FILTER DESIGN

The equivalent circuit for both waveguide and dual-plane filters is given in Figure 2. An elliptic response filter function is characterized by the input/output transformers (R_{in}, R_{out}) and the coupling coefficients between resonators (M_{12}, M_{23} and M_{14}). Expressions for calculating these values are given in Ref. 3. For a four-pole elliptic function, M_{14} is negative to provide the zero of transmission at stopband. The geometric design parameters for the



(a) Waveguide Filter *(b) Dual-Plane Filter*

Figure 1. Analogy Between Waveguide Cavity Filter and Dual-Plane Filter

* This work was sponsored by Communications Satellite Corporation.

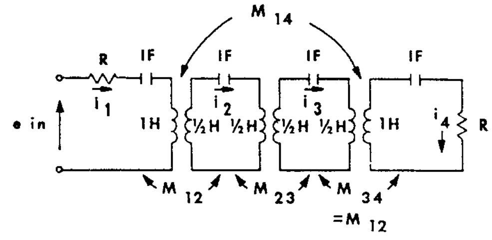


Figure 2. Equivalent Circuit

dual-plane filter are derived from these coefficients and from the required center frequency and bandwidth.

<u>Resonators</u>

The dual-plane filter uses direct-coupled uniform quasi TEM resonators with comb-line arrangement at each plane. The exact length of the resonators can be determined either experimentally or by numerical electromagnetic simulation and is approximately one quarter-wavelength. Deviation from the exact quarter-wavelength is due to the effects of open ends, interaction between adjacent resonators, and interactions between resonators and test fixture.

The equivalent waveguide model of a microstrip resonator of width W is shown in Figure 3. The effective width W' of the equivalent resonator is [4]

$$W' = \frac{h}{Z_o} \frac{120\pi}{\sqrt{\varepsilon_{reff}}} \tag{1}$$

where Z_o is the impedance of the microstripline.

Although in general W'>W, it does not account for all of the microstrip side fringing fields. As a result, the perfect magnetic wall of the parallel plate is replaced by an empirical exponential field decay. The quasi TEM fields are then expressed as

$$H_x \approx \begin{cases} -H_o \cos\dfrac{2\pi z}{\lambda_g} & x < |W'/2| \\ -H_o \cos\dfrac{2\pi z}{\lambda_g} \exp\left[-\dfrac{|x|-W'/2}{W'}\right] & x > |W'/2| \end{cases}$$

$$E_y \approx \begin{cases} \dfrac{\eta_o}{\sqrt{\varepsilon_{reff}}} H_o \sin\dfrac{2\pi z}{\lambda_g} & x < |W'/2| \\ \dfrac{\eta_o}{\sqrt{\varepsilon_{reff}}} H_o \sin\dfrac{2\pi z}{\lambda_g} \exp\left[-\dfrac{|x|-W'/2}{W'}\right] & x > |W'/2| \end{cases} \tag{2}$$

where ε_{reff} relative effective dielectric constant of substrate

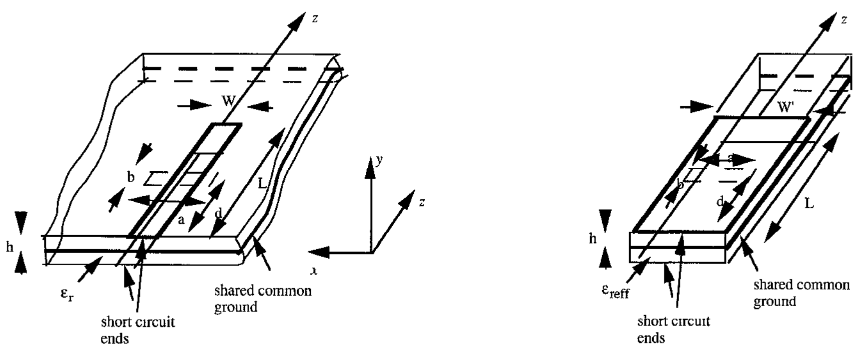
$\eta_o = 377\Omega$ impedance of free space

$\lambda_g = \lambda_o / \sqrt{\varepsilon_{reff}}$ resonator wavelength.

These field expressions will be used in the analysis of inter-planar coupling.

<u>Input/Output Transformers</u>

The input/ouput transformers of the filter are related to the external loading ($Q_e = \frac{1}{R}$) of the first and last resonators. The dual-plane filter uses direct tapping of the resonator described by Dishal [5]. The design formula is given by



(a) Cross Section of Microstrip Resonator *(b) Equivalent Waveguide Model*

Figure 3. Equivalent Waveguide Model of Microstrip Resonator

$$Q_e = \frac{\pi}{4} \frac{Z_R}{Z_o} \frac{1}{\sin^2(\frac{\pi}{2}\frac{l}{L})} \quad (3)$$

where
- Z_R characteristic impedance of the tap line
- Z_o characteristic impedance of resonator
- L resonator length
- l tapping point from short-circuit end.

Inter-Planar Coupling Through Rectangular Aperture

To calculate the coupling coefficient (k) between resonators through rectangular slots, Bethe's small-hole diffraction theory is applied [6]. An expression given by Matthaei et al. [7] is extended to

$$k = \frac{P_{mx}\mu H_{xo}^2 + P_{mz}\mu H_{zo}^2 + P_{ey}\varepsilon_r\varepsilon_o E_{yo}^2}{\varepsilon_r\varepsilon_o \int\int_v\int |E_y|^2 \, dv} \quad (4)$$

where P_{mx}, P_{mz} and P_{ey} are the magnetic and electric polarizabilities of the aperture given by Refs. 8 and 9. E_y is the dominant field of the the resonator as given in equation (2) and the volume integral is related to the stored energy. H_{xo} and H_{zo} are the tangential H-fields located at the aperture, and E_{yo} is the corresponding normal E-field. For small apertures, uniform fields given by the values at the aperture center are assumed.

Measurements using the method described in Ref. 10 and the calculated coupling coefficients are shown in Figure 4. It is obvious that by choosing the position of the slot, we are able to achieve couplings of different signs due to the change between magnetic and electric coupling.

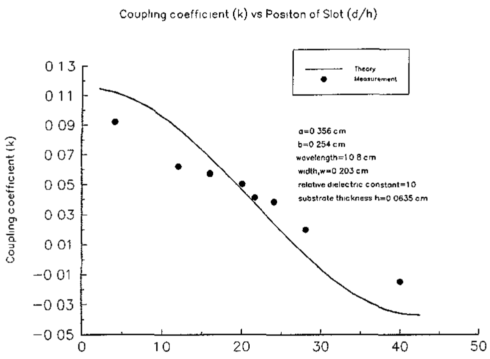


Figure 4. Theoretical and Measured Inter-Planar Coupling Coefficient

Parallel Coupling

It was reported that exact TEM quarter-wave-coupled lines with comb-line arrangement could result in a stop-band network, as equal and opposite magnetic and electric couplings cancelled each other [11]. But when the lines are not pure TEM and not exactly the same length, adjacent resonators can be tuned to couple. This is shown in Figure 5, where measured couplings are compared with the values obtained from

$$k = \frac{4}{\pi} \frac{Z_{oe} - Z_{oo}}{Z_{oe} + Z_{oo}} \quad (5)$$

Equation (5) is similar to that given in Ref. 5, but expressed in terms of the even and odd mode impedances. Notice that the impedance ratio is the familiar coupling factor.

EXPERIMENTAL DUAL-PLANE FILTER

An 80-MHz bandwidth elliptic filter centered at 1.1 GHz is designed according to the above procedure. The construction of the filter involved normal patterning of a planar circuit with additional patterning of coupling slots at the ground plane. Two such planar circuits are stacked back to back with proper grounding. Figure 6 is a photograph of an experimental filter and the coupling apertures. The measured transmission and return loss curves, given in Figure 7, show that they match the theoretical curves within experimental errors.

CONCLUSION

This paper has introduced a design technique for realizing a class of elliptic filters in a dual-plane configuration. Both electric and magnetic couplings required for

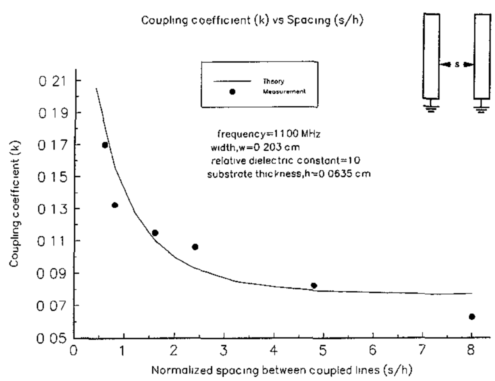


Figure 5. Measured Parallel Coupling

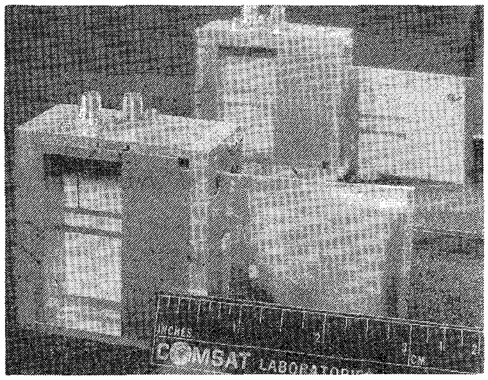


Figure 6. Photograph of Experimental Dual-Plane Filter

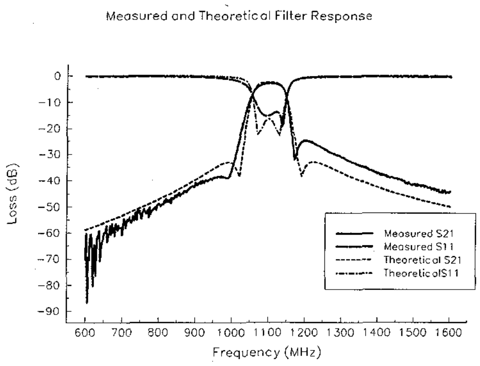


Figure 7. Measured and Theoretical Filter Response

the elliptic filter can be realized by aperture inter-planar couplings. The experimental filter illustrates the concept and shows that the simple configuration is suitable for superconducting thin film implementation.

ACKNOWLEDGMENTS

The authors acknowledge the support and assistance provided by Dr. A. E. Williams through valuable discussions and the help provided by Jeffrey Sanders in the measurements and fabrication masks.

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