GENERALIZED CROSS-COUPLED FILTERS USING EVANESCENT MODE COUPLING ELEMENTS

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ABSTRACT

Generalized cross-coupled filters require implementation of both positive and negative cross coupled elements. A positive element frequently uses inductive coupling, while a negative coupling element uses capacitive coupling. While the required negative couplings are readily achieved in most cases using inductive irises, the synthesized values for capacitive coupling frequently require larger coupling values than can be achieved with a simple iris. Traditional methods for realizing capacitive couplings have included the use of capacitive probes, which are difficult to adjust in practice. Further, the negative couplings can be large enough to again cause problems with simple inductive irises. In this paper, we present the use of resonated evanescent mode sections to realize both positive and negative couplings by employing the phase shift and impedance characteristics of the bandpass element represented by a short resonated section of evanescent mode waveguide. The structure is quite practical and flexible in packaging. Examples will include use of up to four cross couplings, two negative and two positive.

INTRODUCTION

Implementation of generalized cross-coupled filters requires the use of both positive impedance (inductive) and negative impedance (capacitive) couplings. The former are used for placing real-axis transmission zeros for delay equalization while the latter are used for placing real-frequency zeros, used for additional selectivity. Inductive and capacitive irises are common in the literature and, in many cases, can be used for the aforementioned positive and negative couplings. The iris couplings usually take the form of a simple opening between two segments of the filter. One example is a direct opening between the input portion of the filter and the output. This opening in essence provides a shorter path between the **2** terminating ports than is represented by the full traverse of all the filter elements. Some energy “leaks” from the input directly to the output. If the “leaking” energy is coupled in an inductive manner, the coupling is such as to reduce the net effect on attenuation of the remaining filter elements and simultaneously to reduce the total group delay variation due to the interference generated at the output termination between the leaking energy and the remainder which fully traverses the filter. In other cases, the “leaky” (or cross) couplings will be placed well within the filter, between any pair of resonant sections. In some cases, however, the values of computed coupling are such as to make impractical a simple opening between two parallel portions of the filter. The use of resonated evanescent mode sections allows implementation of both positive and negative couplings by employing the phase shift and impedance characteristics of the bandpass element represented by a short resonated section of evanescent mode waveguide.

METHOD

In **Fig. 1**, we illustrate a generalized lowpass cross-coupled filter prototype using an impedance inverter formulation. The cross couplings may be inductive or capacitive, depending on the synthesis and design requirements. Inductive-pi and tee equivalent circuit representations of a section of evanescent guide are well known [5], [6], [7], [8]. Conversion of the evanesecent section into a single or multiple pole bandpass filter has again been well documented (Ref.[9] and U.S. Patent 5,220,300) and consists of placing resonating capacitive section transverse to the direction of propagation within the evanescent waveguide. Inductive (and some capacitive) coupling irises can be thought of as very short sections of below cutoff waveguide. Indeed, when the iris becomes large and thus approaches dominant mode propagation rather than decay, the parasitic effects become dominant and it no longer acts as a selective coupling. Some capacitive coupling designs have used a probe which provides an electric field coupling between the two parallel portions of the filter. Such probes perturb the field within the sections to which they are coupled, with the perturbations acting to modify the electromagnetic characteristics of the particular filter sections, which are normally computed in an idealized electromagnetic environment, in isolation. The mode and concomitant dimensions are chosen, with couplings assumed right at the boundaries...clearly not the case when a probe actually enters the resonant area. Of course, electromagnetic simulation can be used to correct for this perturbation effect, but no simulation will enable easy adjustment of

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physically isolated and mechanically unstable capacitive probes.

We propose the use of resonated sections of evanescent guide to provide the couplings between the two cross-coupled portions of the filter. The coupling inverters shown in **Fig. 1** can be represented either as a tee or a pi. The inverter must provide a coupling magnitude and phase shift as required by the synthesis. In most instances, we will use a single capacitive element to resonate a shunt element, although in some cases the required inverter bandwidth is such as to require the use of two capacitive elements making the coupling essentially a two pole bandpass filter. **Fig. 2** presents the even and odd mode decompositions of the pi model. The only difference between the even and odd halves are the signs of constant reactances remaining. Thus, knowledge of either even or odd half circuit element values is sufficient for determining the response of the entire filter. **Fig. 3** portrays the even and odd half equivalent circuits for a cross-coupled filter. A software package called **FILPRO** has been developed which includes the necessary transformations and response calculations; a pair of presentations describing the capabilities of **FILPRO** will be presented during a workshop at this Symposium.

The principle proposed herein: Energy couples into a bandpass section based upon the match of that section to its source and load, and then passes through the bandpass section undergoing some phase shift, with both the coupling into and phase shift through depending on the resonant frequency of the bandpass section. Proper choice of the match and resonant frequency enable achievement of a very large range of positive and negative couplings which also offer the benefit of being quite selective and thus providing the desired coupling only over a desired band of frequencies. **Fig. 4** is a schematic representation of a single section of resonated evanescent mode guide used to provide coupling between the two adjacent paths in the bandpass filter. The range of achievable couplings depends upon the lengths of evanescent waveguide and the value of the capacitor used to resonate the center element of the tee representation. In essence, the cross coupling is a single-pole evanescent mode bandpass filter, whose transfer function provides coupling between the two adjacent sections of the main bandpass filter. The transformers shown in **Fig. 4** represent the effect of the junction between the small evanescent waveguide cross coupling "iris" and the cross-section of the main line of the filter. **Fig. 5** provides physical detail on the implementation of the schematic of **Fig. 4**. Additional phase shift and range of coupling are achievable if a two section evanescent bandpass section is used for cross-coupling. This is illustrated in **Fig. 6**. When real-frequency zeros are located very close to the passband, the **Fig. 6** configuration frequently is required. **FILPRO** enables calculation of both implementations illustrated in **Figs. 5 and 6**. Simple ABCD or scattering calculations provide the coupling to the main line.

EXAMPLES

1200 MHz center frequency, 2 positive and 2 negative couplings. Photos are shown in **Fig. 7 and 8**. **Table 1** presents the requirements, **Figs 9 and 10** the preliminary results of the prototype. Final results and other examples will be shown during the talk.

CONCLUSIONS

Use of resonant sections of evanescent waveguide have been shown to provide both negative and positive couplings suitable for imbedment within cross coupled filters. The required construction technique has been well-developed during the maturation of the evanescent filter design methodology over the years, and can yield sturdy, temperature-compensated and highly reliable filters. A sophisticated software package [11] has been developed which allows the design of many cross coupled filters without much effort. It is planned to incorporate optimization and E-M analysis capability into this package, which should further enhance the application of the method described in this paper.

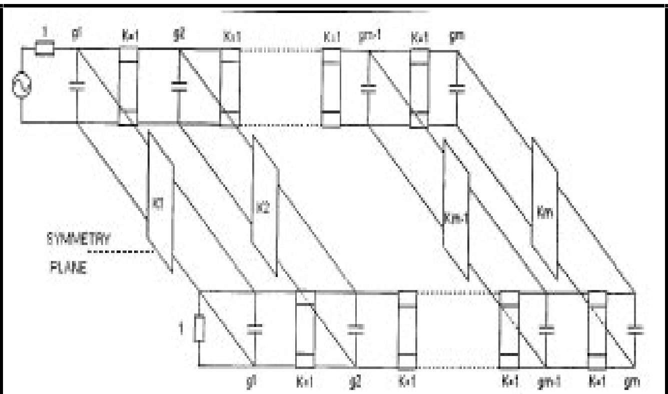

FIGURE 1
A symmetric cross-coupled lowpass prototype filter circuit with inverters

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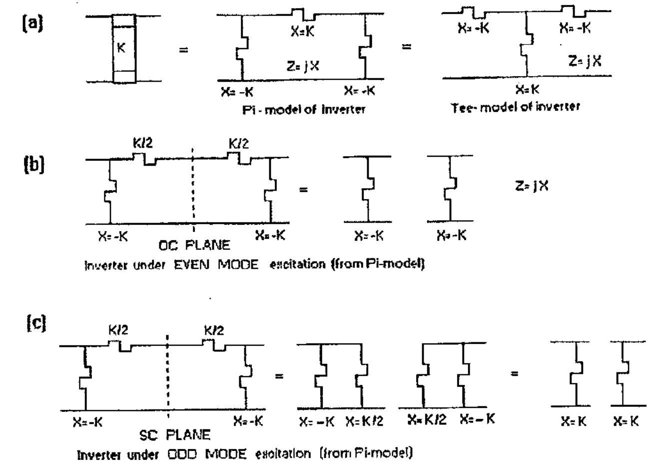
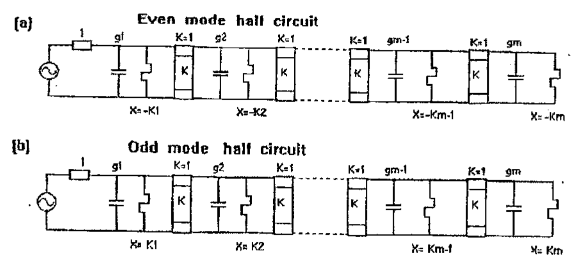
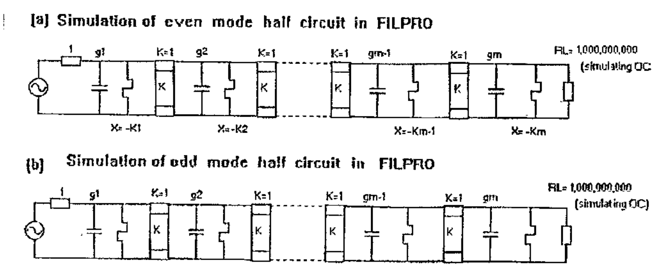


a) Pi-model & Tee-model of an ideal inverter in terms of constant reactances
b) Decomposition of the Pi-model into even halves
c) Decomposition of the Pi-model into odd halves

FIGURE 2



a) Even and odd mode half circuits for symmetric cross-coupled filters



b) Convention for displaying even and odd mode half circuits in FILPRO.

FIGURE 3

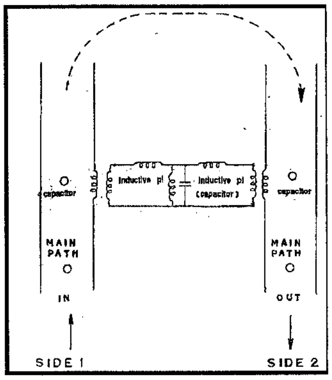


FIGURE 4 Resonated inductive pi representation of two lengths of evanescent waveguide with capacitor centered between the two sections. The end inductors are coupled to the main lines of the filter. The single pole of resonance can provide a wide range of phase shifts, while the end inductive sections provide the requisite coupling magnitudes.

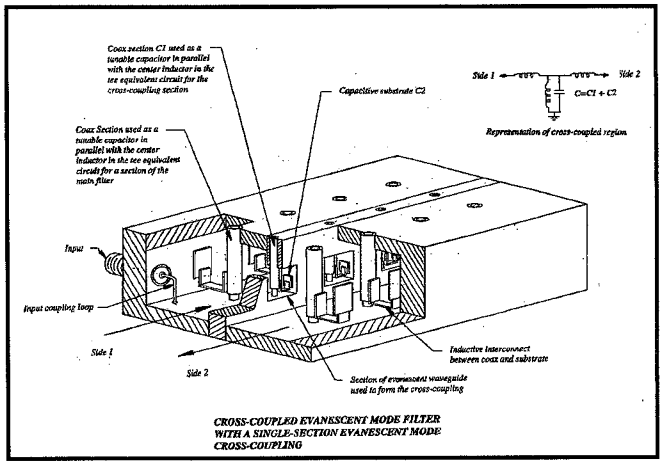


FIGURE 5

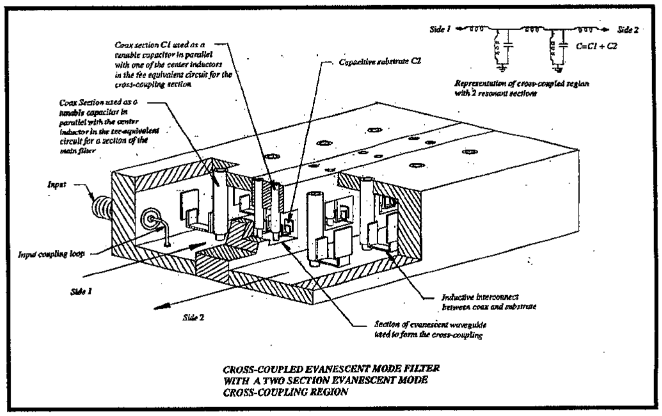


FIGURE 6

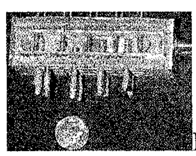


FIGURE 7

Open Filter

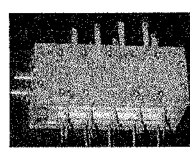
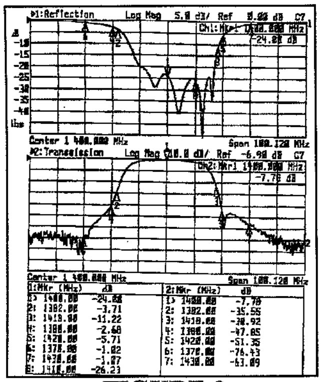


FIGURE 8

Closed Filter



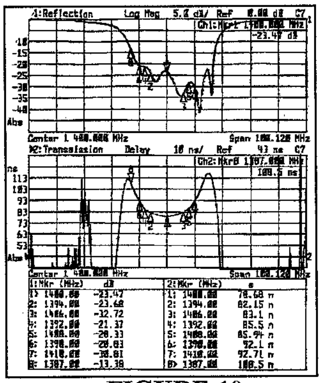


FIGURE 9 **FIGURE 10**

Prototype Preliminary Results

CROSS COUPLE FILTER				
PARAMETER	**UNIT**	**MIN**	**NOM**	**MAX**
FREQUENCY	**MHz**		**1200**	
BANDWIDTH	**MHz**		**26**	
INSERTION LOSS	**dB**			**6**
OUT OF BAND REJECTION				
CF+/- 15MHz	**dBc**	**-1.5**		
CF+/- 18MHz	**dBc**	**-20**		
CF+/- 20MHz	**dBc**	**-40**		
CF+/- 30MHz	**dBc**	**-50**		
GAIN VARIATION				
CF+/- 6MHz	**dBc p-p**			**0.3**
CF+/- 8MHz	**dBc p-p**			**0.5**
CF+/- 10MHz	**dBc p-p**			**0.9**
CF+/- 12MHz	**dBc p-p**			**1.8**
CF+/- 13MHz	**dBc p-p**			**3**
GAIN SLOPE				
CF+/- 6MHz	**dB/MHz**			**0.05**
CF+/- 8MHz	**dB/MHz**			**0.1**
CF+/- 10MHz	**dB/MHz**			**0.27**
CF+/- 12MHz	**dB/MHz**			**0.55**
CF+/- 13MHz	**dB/MHz**			**1.2**
GROUP DELAY				
CF+/- 6MHz	**ns**			**2**
CF+/- 8MHz	**ns**			**4**
CF+/- 10MHz	**ns**			**12**
CF+/- 12MHz	**ns**			**36**
CF+/- 13MHz	**ns**			**60**
GROUP DELAY RIPPLE	**ns p-p**			**2.5**
Over and 10 MHz within Passband				

TABLE 1
Filter Requirements
Positive Couplings = 2 Negative Couplings = 2

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