# Broadbanding Microstrip Filters Using Capacitive Compensation

*Microstrip filters in alumina and gallium arsenide have faster propagation for the odd than the even field modes of parallel line filters. The resulting performance loss can be compensated using capacitors between the lines.*

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High performance filters are an integral part of microwave systems. Parallel coupled microstrip filters are extensively used as bandpass filters because they are compact in size and easy to fabricate. These filters can be designed with reasonable accuracy using the design information given in the literature [1-4] and by using commercial CAD tools.

Since microstrip is a non-homogeneous medium, the even- and odd-mode phase velocities for a coupled pair of microstrip lines are unequal. The difference in the phase velocities results in the filter having an asymmetric passband response, deteriorates the upper stopband performance and moves the second passband (which is at about twice the center frequency) toward the center frequency [5,6].

Often this poor stopband rejection forces the microwave designer to employ a low-pass filter preceding the bandpass filter in subsystems. The second passband of a bandpass filter, at twice the center frequency, also results in poor second harmonic suppression when used as output filters in oscillators and amplifiers. To overcome this problem bandpass filters using parallel coupled stepped impedance resonators have been implemented [7].

This paper describes a capacitively compensated parallel coupled microstrip filter design with symmetric passband and second passband well above twice the filter's center frequency. The compensated structure does not require any extra CAD tools for design and is compatible with hybrid and monolithic microwave integrated circuit technology.

*Design Application*

The stopband performance of a parallel coupled microstrip bandpass filter is improved if the phase velocities of the even and odd modes are equalized. There are several ways to equalize the phase velocities in parallel coupled microstrip resonators:

1) Using a suitably placed shielding cover [8],
2) Using a suspended microstrip configuration,
3) Using dielectric overlay [9],
4) Overcoupling the resonators [6], and
5) Using capacitors at the ends of the coupled section [10,11].

*The difference in the phase velocities results in . . . an asymmetric passband response . . . deteriorates the upper stopband performance and moves the second passband*

Several of these techniques are illustrated in Figure 1. Of all of these equalization techniques, it is the author's feeling that the simplest method to employ is capacitive compensation. This approach has previously been reported to improve the directivity of directional couplers [10,11], and its use to compensate microstrip filters is the subject of this paper.

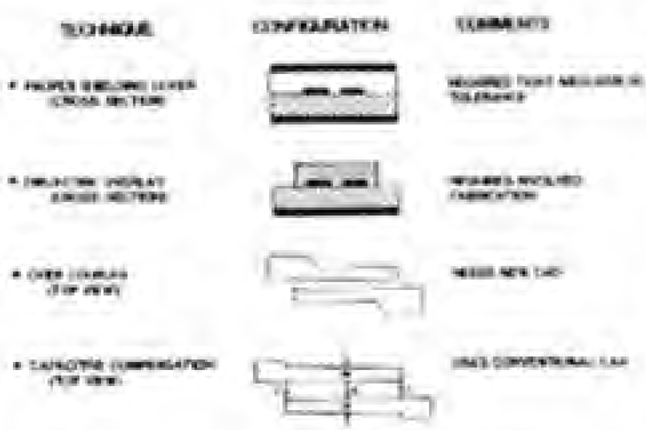


**Figure 1. Various methods for equalizing the even and odd mode propagation on microstrip coupled lines.**

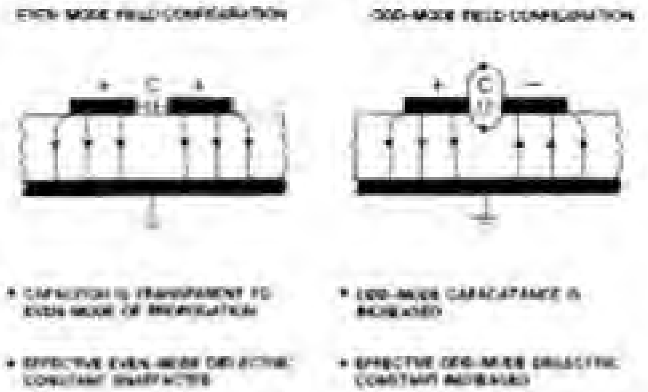


**Figure 2. The compensating capacitors, C, affect mainly the odd mode.**

Capacitive compensation of phase velocity difference in parallel coupled microstrip lines is illustrated in Figure 2. Microstrip even mode phase velocity is lower than odd mode, because the even mode is more dielectrically loaded than is the odd mode, which propagates largely in air. Therefore the odd mode electrical length must be extended. This can be accomplished by installing capacitors, C, between the lines.

In the even mode, the capacitors are nearly invisible because they do not go to ground. However, they directly load the odd mode, reducing its phase

*the simplest method to employ is capacitive compensation*

velocity, and thereby provide the needed increase in the odd mode electrical path length. The physical length of the filter sections are desirably a quarter of the even mode wavelength at the design center frequency, fo. The capacitor values may be calculated from [10]:

$$C = \Delta\theta_o/(\pi f_0 Z_{0o})$$

The step by step design procedure for a capacitively compensated parallel coupled microstrip filter is outlined below:

- Design a prototype low-pass filter with the desired passband characteristics.
- Determine K-inverters, and even and odd mode impedances of required quarter wave resonators.

- Calculate physical dimensions and capacitors values
- Optimize complete filter using CAD tools

To illustrate the design procedure for a capacitively compensated high performance parallel coupled microstrip filter, two design examples have been chosen.

Example 1:

Center frequency fo = 4 GHz
Response = Chebyshev with 0.2 dB ripple
Bandwidth = 0.4 GHz
Attenuation = 40 dB, +/- 0.6 GHz
GaAs substrate, dielectric constant = 12.9
h = 0.2 mm
Conductor thickness = 5 micrometers

The number of half wave resonators required is 4. Alternatively, 5 coupled quarter wave sections may be employed. The various parameters for the filter (Figure 3) are listed in Table I, which lists the effective characteristic impedances and dielectric constants for the respective even and odd modes.

*Microstrip even mode phase velocity is lower than odd mode. ... the even mode is ... dielectrically loaded ... the odd mode, ... propagates largely in air.*

The insertion loss and return loss of a 4-section filter (with and without the capacitive compensation) are shown in Figures 4 and 5, respectively. The filter structure has been assumed lossless. It may be noted from Figure 4 that for the compensated case the second passband level is 40 dB below the fundamental passband response level for at least 2.5 times the center frequency.

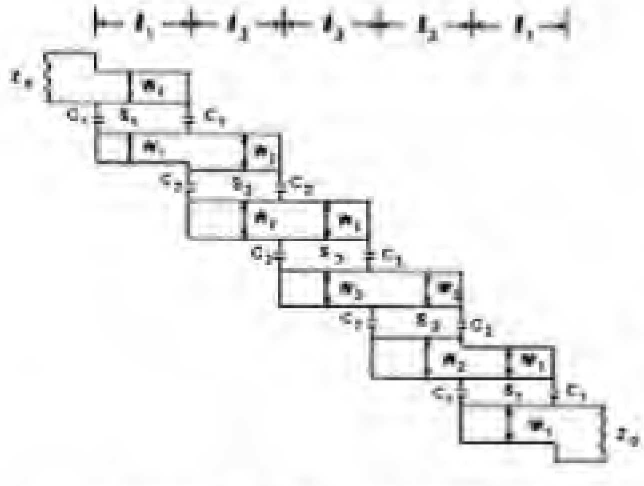

Figure 3. Schematic diagram of the Example 1 filter.

| n | $Z_{0e}$ (Ω) | $Z_{0o}$ (Ω) | $\epsilon_e^{eff}$ | $\epsilon_o^{eff}$ | $W_n$ (mm) | $S_n$ (mm) | $\ell_n$ (mm) | $C_n$ (pF) |
|---|---|---|---|---|---|---|---|---|
| 1,5 | 73.4 | 38.7 | 8.712 | 7.189 | 0.098 | 0.072 | 6.67 | 0.055 |
| 2,4 | 56.8 | 44.7 | 8.963 | 7.442 | 0.132 | 0.232 | 6.56 | 0.033 |
| 3 | 55.4 | 45.6 | 9.008 | 7.538 | 0.134 | 0.274 | 6.54 | 0.032 |

Table I. Parameters for the 4 section (Example 1) filter on a GaAs substrate.

*for the compensated case the second passband level is 40 dB below the fundamental passband response ... for at least 2.5 times the center frequency.*

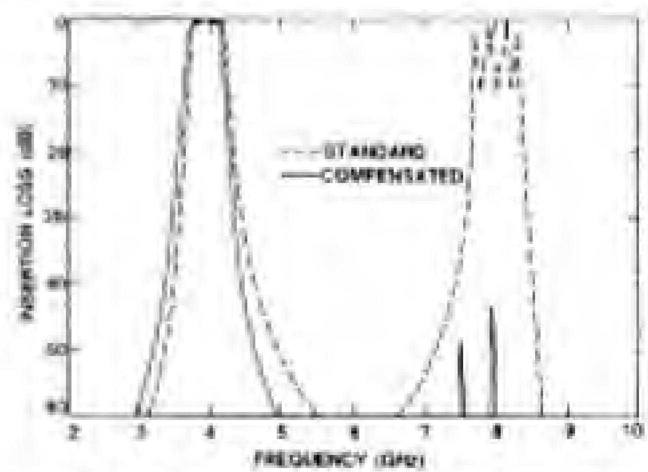


Figure 4. Calculated insertion loss of the Example 1 filter.

The slight shift in the passband towards the lower frequency in the capacitive compensated case is due to the fact that the resonator length is approximately a quarter wavelength when computed from the even mode velocity of the compensated design, rather than the average of the even and odd mode velocities for an uncompensated design. Here no attempt was made to fully optimize the circuit.

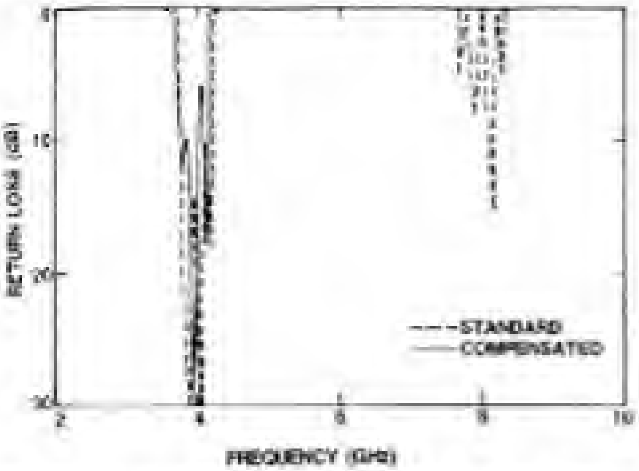

Figure 5. Calculated return loss of the Example 1 filter.

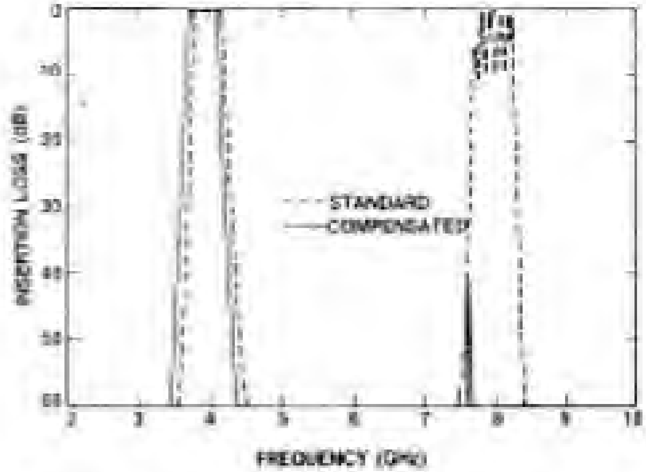

Figure 6. Insertion loss of the standard and compensated (Example 2) filter designs.

Example 2:
Center frequency fo = 4 GHz
Response = Chebyshev with 0.2 dB ripple
Bandwidth = 0.4 GHz
Number of Sections = 6
Quartz substrate,
dielectric constant = 3.8
h = 0.5 mm
Conductor thickness = 5 micrometers

The various parameters for the filter are listed in Table II.

| n | $Z_{0e}$ (Ω) | $Z_{0o}$ (Ω) | $\epsilon_e$ | $\epsilon_o$ | $W_i$ (mm) | $S_i$ (mm) | $l_i$ (mm) | $C_p$ (pF) |
|---|---|---|---|---|---|---|---|---|
| 1,7 | 72.8 | 38.6 | 3.057 | 2.536 | 0.665 | 0.116 | 11.22 | 0.028 |
| 2,6 | 56.4 | 44.0 | 3.128 | 2.808 | 1.020 | 0.545 | 10.89 | 0.031 |
| 3,5 | 54.6 | 45.6 | 3.123 | 2.722 | 1.035 | 0.626 | 10.87 | 0.029 |
| 4 | 54.7 | 46.0 | 3.122 | 2.725 | 1.037 | 0.775 | 10.87 | 0.018 |

Table II. Parameters of the Example 2 filter, a 6 section compensated design on a quartz substrate.

The insertion loss and return loss of a 6 section Chebyshev filter (with and without the capacitive compensation) are shown in Figures 6 and 7, respectively.

It is seen that the compensated design has a second passband level that is 40 dB below the fundamental passband response level, at least up to 2.5 times the center frequency. Here, also, no attempt was made to optimize the circuit more fully.

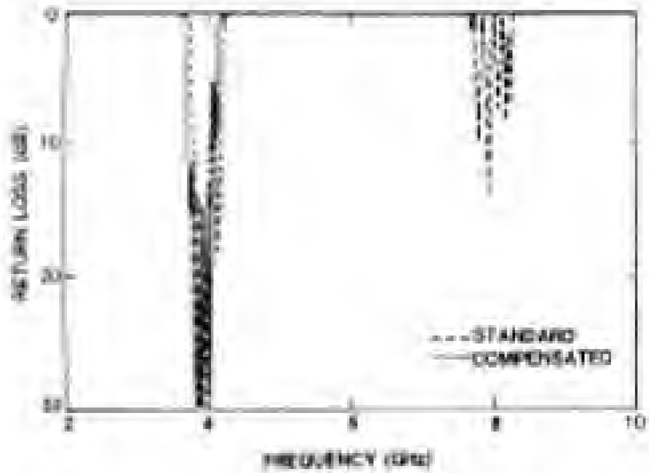

Figure 7. Return loss of the standard and compensated (Example 2) filter designs.

## Appendix

For four λ/2 resonators, the prototype values are

$g_0 = 1$, $g_1 = 1.0029$, $g_2 = 1.2844$, $g_3 = 1.9761$, $g_4 = 0.8640$, $g_5 = 1.5386$, and $\omega_1 = 1$

$BW = 0.4$ GHz $f_0 = 4$ GHz
$\Delta f = BW/f_0 = 0.1$

The K inverters for various sections are given below.

$$\frac{Z_0}{K_{01}} = \frac{Z_0}{K_{56}} = \sqrt{\frac{\pi \Delta f}{2\omega_1 g_0 g_1}} = \frac{0.3963}{\sqrt{g_0 g_1}} = 0.3477$$

$$\frac{Z_0}{K_{12}} = \frac{Z_0}{K_{34}} = \frac{\pi \Delta f}{2\omega_1 \sqrt{g_1 g_2}} = \frac{0.3571}{\sqrt{g_1 g_2}} = 0.1214$$

$$\frac{Z_0}{K_{23}} = \frac{Z_0}{K_{45}} = \frac{\pi \Delta f}{2\omega_1 \sqrt{g_2 g_3}} = 0.0986$$

After calculating the K's, the even and odd mode impedances of the coupled lines which are λ/4 at the center frequency are calculated from the following relations:

$$\frac{(Z_{0e})_{j,j+1}}{Z_0} = 1 + \frac{Z_0}{K_{j,j+1}} + \left(\frac{Z_0}{K_{j,j+1}}\right)^2, \quad j = 0 \text{ to } n$$

$$\frac{(Z_{0o})_{j,j+1}}{Z_0} = 1 - \frac{Z_0}{K_{j,j+1}} + \left(\frac{Z_0}{K_{j,j+1}}\right)^2, \quad j = 0 \text{ to } n$$

The physical dimensions of the filter sections are then calculated from desired $Z_{0e}$ and $Z_{0o}$. An approximate value for the physical length is obtained from the average value of the even and odd mode velocities, i.e.

$$\theta = \frac{2\pi}{\lambda} l = \frac{2\pi}{\lambda_0} \frac{\sqrt{\epsilon_e^e} + \sqrt{\epsilon_e^o}}{2} l = 90°$$

$$\text{or } l = \frac{\lambda_0}{2} \frac{1}{\sqrt{\epsilon_e^e} + \sqrt{\epsilon_e^o}} = \frac{3.75}{\sqrt{\epsilon_e^e} + \sqrt{\epsilon_e^o}} \text{ cm}$$

$$C = \Delta\theta_o / (\omega Z_{0o})$$

where Zoo is the odd mode characteristic impedance and delta theta is the effective increase required in the odd mode electrical length.

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