

## BANDPASS FILTER

### BACKGROUND

[1] Most microwave filters built using microstrip transmission lines have a tendency of not suppressing 2<sup>nd</sup>, 3<sup>rd</sup> and 4<sup>th</sup> harmonic signals. Traditionally, the way to solve this problem is to add a lowpass filter at the two ends of a bandpass filter. Physically, this makes the filter structure bigger. Electrically, using lowpass filters increase signal loss, and the suppression of the harmonics for the most part is not as good as desired.

### SUMMARY OF THE DISCLOSURE

[2] An edge-coupled filter includes a phase velocity compensation transmission line section comprising a series of alternating T-shaped conductor portions.

### BRIEF DESCRIPTION OF THE DRAWINGS

[3] Features and advantages of the disclosure will readily be appreciated by persons skilled in the art from the following detailed description when read in conjunction with the drawing wherein:

[4] FIG. 1 is a layout of an exemplary embodiment of a bandpass filter.

[5] FIG. 2 is a cross-sectional diagrammatic view of the filter of FIG. 1, taken along line 2-2 of FIG. 1

[6] FIG. 3 is a graph of attenuation as a function of frequency for an exemplary filter implementation, where the response shows attenuation of the 2<sup>nd</sup> and 3<sup>rd</sup> harmonics.

[7] FIG. 4A is a top view of an enlarged portion of a filter layout, showing overlapped, edge-coupled conductor strips. FIG. 4B is a diagrammatic end view of the bandpass filter of FIG. 3A. FIG. 4C is a graph depicting velocities of even and odd modes of propagation as a function of filter parameters.

[8] FIG. 5 is a layout of an alternate embodiment of a bandpass filter.

#### DETAILED DESCRIPTION

[9] In the following detailed description and in the several figures of the drawing, like elements are identified with like reference numerals.

[10] In an edge coupled filter fabricated in a planar transmission line medium, such as microstrip or stripline, energy is propagated through the filter through edge-coupled resonator elements or conductor strips. Harmonics in the filter response appear due to the mismatch in phase velocities of the even and odd modes. In microstrip coupled lines, the odd mode travels faster than the even mode. Also, the odd mode tends to travel along the outer edges of the microstrip coupled lines or conductor strips, while the even mode tends to travel near the center. In an exemplary embodiment, to suppress the harmonics of the filter, a means for equalizing the even and odd mode electrical lengths is provided.

[11] In an exemplary embodiment illustrated in FIGS. 1 and, a microstrip filter 20 comprises spatially separated input/output (I/O) ports 22 and 24, which are connected by a phase velocity compensation transmission line section 30. The transmission line section 30 comprises edge-coupled resonator elements 32-40 in this exemplary embodiment. The ports 22, 24 are positioned along a filter axis 26 in this embodiment. The transmission line

section 30 comprises a series of alternating conductor sections or lines 32-40, arranged in a staggered offset manner relative to the filter axis 26. The conductor sections are edge-coupled at an RF operating frequency band. The spatial separation of the conductor sections provides DC isolation. The lines 32-40 include coupled line portions which are adjacent a corresponding coupled line portion of an adjacent conductor line. For example, line 32 includes a line segment 32C which overlaps a line segment 34C of line 34. These overlapping line segments are approximately  $\frac{1}{4}$  wavelength in length in an exemplary embodiment, at an operating frequency.

[12] Each conductor section includes a respective T-shaped portion 32A-40A. The T-shaped portions have a parallel leg portion oriented in parallel to the filter axis, and a transverse stub oriented perpendicularly to and bisecting the parallel leg portion in this exemplary embodiment. For example, T-shaped portion 32A has a parallel leg portion (comprising a portion of the conductor section 32) and a transverse stub 32B. The directions of the transverse stubs 32B-40B alternate, as do the stub lengths. The filter response is symmetric about its center frequency (as shown in FIG. 4); depending on the length of the  $\frac{1}{4}$  wave length coupled line, the transverse stub lengths may be optimized, which may result in different stub lengths. Because the odd mode tends to travel along the outer edges of the coupled lines or conductor strips, while the even mode tends to travel near the center, the T-shaped sections add transmission line length which is traveled by the odd mode, but not the even mode. As a result, the odd and even mode components propagating along the transmission line 30 arrive at the output port in phase.

[13] The exemplary filter embodiment of FIGS. 1 and 2 may be constructed in microstrip. The filter comprises a substantially planar dielectric substrate 23, e.g. a substrate such as alumina or duroid having a substrate height  $h$ . A conductive ground plane layer 25 is formed on one surface of the dielectric substrate, here the bottom surface of the substrate 23. A conductive microstrip trace pattern is formed on the opposite substrate surface, in this example the top surface. The trace pattern forms the conductor

sections 32-40 and the I/O ports 22, 24. In an exemplary embodiment, the trace pattern may be fabricated using photo lithographic techniques.

[14] The phase velocity mismatches of the even and odd modes may be compensated by extending the odd mode traveling path. In an exemplary filter structure, the alternating T-shaped portions of the filter provide the compensation. In a microstrip coupled line, the odd mode is faster and tends to travel on the edges of the line, while the even mode is slower and travels along the center of the coupled lines. The exemplary filter architecture illustrated in FIG. 1 compensates for the mismatch of phase velocities of the even and odd modes in the filter structure by periodically introducing stubs, and by adjusting the electrical length of the quarter wave coupled line sections in the filter. In an exemplary embodiment, most of the phase compensation is provided by the T-shaped portions. Some phase compensation may be provided by varying the lengths of the coupled lines away from the nominal  $\frac{1}{4}$  wavelength, e.g. by optimization.

[15] FIGS. 4A-4C depict how variation in design parameters for a microstrip transmission line embodiment affect the phase velocities of the even and odd modes propagating in an edge coupled filter. FIG. 4A is a diagrammatic illustration of edge-coupled conductor strips C1 and C2 formed as microstrip conductors on a surface of a dielectric substrate 23. The conductor strips C1 and C2 are arranged in parallel, and are spaced apart by a distance  $s$ . As depicted in the end view, FIG. C, the substrate 23 has a height  $h$ . FIG. 4C is a graph showing calculated phase velocities for the even mode ( $v_e$ ) and odd mode ( $v_o$ ) as a function of the ratio  $s/h$ , and for different ratios  $w/h$ .

[16] In an exemplary simulation embodiment, the filter 20 attenuates the 2<sup>nd</sup> and 3<sup>rd</sup> harmonics as shown in FIG. 3 with very good out-of-band rejection. FIG. 3 is a graph of attenuation as a function of frequency for an exemplary filter implementation, over a passband centered at 10 GHz, with a nominal bandwidth which is about 2.5 GHz. FIG. 3 illustrates an exemplary simulation plot of the return loss ( $S(1,1)$ ) and insertion loss ( $S(2,1)$ ) as a function of frequency. The exemplary simulation embodiment whose performance is

depicted in FIG. 3 was done using Agilent's ADS linear simulator tool. This exemplary embodiment of a microstrip filter also exhibits very low loss filter with very high out-of-band rejection characteristics. This exemplary filter embodiment exhibits a good linear phase for over 80% of the filter bandwidth. Harmonics in the insertion loss characteristic have been suppressed.

[17] An embodiment of the filter is very compact, resulting in significant reduction of size and weight of most microwave integrated circuits which utilize multiple filters.

[18] This filter architecture can be implemented in a transmission line type other than microstrip, e.g. in stripline or coplanar waveguide.

[19] Another exemplary embodiment is illustrated in FIG. 5, which depicts a layout of a hairpin filter 100. The hairpin configuration comprises I/O ports 102, 104, and a phase velocity compensation transmission line section 110. The transmission line section 110 is arranged in a serpentine or series of U-shaped bends, each comprising edge-coupled resonator sections and a T-shaped portion disposed in the U-bend. For example, conductor sections 112, 114 are around  $\frac{1}{4}$  wavelength in electrical length at an operating frequency, and are disposed in parallel with a spacing between them. Similarly conductor sections 118, 120 are edge-coupled. T-shaped portion 116 connects ends of conductor sections 114, 118, and provides phase velocity phase compensation. The lengths of the  $\frac{1}{4}$  wavelength sections may also adjusted to provide phase velocity compensation. The filter 100 can be constructed in microstrip or stripline, for example. An exemplary passband is 200 MHz centered at 1.85 GHz.

[20] Although the foregoing has been a description and illustration of specific embodiments of the invention, various modifications and changes thereto can be made by persons skilled in the art without departing from the scope and spirit of the invention as defined by the following claims.

## CLAIMS

What is claimed is:

1. An RF bandpass filter circuit, comprising:
  - a first input/output (I/O) port (22);
  - a second I/O port (24);
  - a phase velocity compensation transmission line section (30) coupled between said first I/O port and the second I/O port, said transmission line section comprising a plurality of parallel-coupled conductor portions (32-40) arranged for signal coupling between alternate conductors;
  - the phase velocity compensation transmission line section comprising a plurality of shaped conductor portions for phase velocity compensation of respective odd mode and even mode propagation signal components.
2. A filter according to Claim 1, wherein said shaped conductor portions are T-shaped portions and have a first conductor leg, and a transverse stub (32B-40B) oriented transversely to the first leg.
3. A filter according to Claim 2, wherein the transverse stub of said T-shaped portion bisects said first leg.
4. A filter according to any of Claims 1-3, wherein the phase velocity compensation transmission line section is a microstrip transmission line section.
5. A filter according to any of Claims 1-3, wherein the phase velocity compensation transmission line section is a stripline section.

6. A filter according to any of Claims 1-5, wherein the phase velocity compensation transmission line section comprises:

- a dielectric substrate (23) having first and second opposed planar surfaces;
- a ground plane (25) formed on the first substrate surface;
- said parallel-coupled conductors formed on the second dielectric surface in a staggered arrangement about a linear filter axis (26) with gaps between ends of alternate conductors to provide edge coupling.

7. A filter according to any preceding claim, wherein said phase velocity compensation line section provides compensation for an odd mode propagation velocity which is greater than an even mode propagation velocity.

8. A filter according to any preceding claim, wherein harmonics of a response of the filter are suppressed by said phase velocity compensation transmission line section.

9. A filter according to any preceding claim, wherein said filter is free of low pass filters at said first and second I/O ports.

10. A filter according to any of Claims 1-5, wherein the transmission line section is arranged in a hairpin configuration (110).

11. A filter according to Claim 10, wherein the shaped conductor portions (116) are arranged in U-bends of the hairpin configuration.

12. A filter according to any of Claims 1-5, wherein said conductor portions (32-40) are arranged in a staggered arrangement about a linear filter axis (26).