Miniature Microwave Bandpass Filter Based on EBG Structures

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Abstract—A new design of a planar microwave filter, based on
rejection band properties of an electrically small electromagnetic
bandgap (EBG) structure, is proposed. The proposed EBG
structure demonstrates effective impedance manipulation,
exhibits a simple analysis, and is about three times smaller as
compared to stepped-impedance hairpin (SIH) resonators with
similar response. The new bandpass filter has a reduced footprint
and can be fabricated in standard thick-film manufacturing
technology. Measured and simulated results exhibit good
agreement. The measured results show improvement in the filter
characteristics in comparison to existing SIH filter design.

Index Terms—Electromagnetic bandgap, microstrip, microwave filter, slow-wave effect.

I. INTRODUCTION

Compact, high-performance microwave filters are essential
for high-efficiency miniaturized microwave systems. The
filter circuit size is large in traditionally designed planar
bandpass filters due to a high number of large area resonators.
The rejection level in the upper stopband of the filters is
usually degraded by the spurious response at twice the
passband frequency. Several types of resonators have been
designed to overcome these problems, and miniaturized
hairpin resonators, stepped-impedance hairpin resonators, and
slow-wave open-loop resonators. Coupled transmission line
sections are frequently used today for the realization of
compact matching circuits to various devices [1, 2].

Miniaturized resonators lead to a reduced filter size, but not
always improve the spurious response. Another method relies
on various resonator realizations within one filter structure to
reduce the circuit size, such as the coupled line filter with SIH
resonator proposed by Wang et al. [3]. Two coupled line
resonators loaded by the stepped-impedance hairpin resonator
are employed in this filter. The performance of the filter can
be significantly enhanced by carefully adjusting the load
impedances of the coupled line sections.

The load impedance adjustment can also be achieved by
implementing slow-wave EBG structures, which reduces the
length of the microwave resonator and contributes to the filter
miniaturization [4, 5].

This paper proposes an EBG structure exhibiting a low-
pass, slow-wave characteristic for impedance manipulation of
reduced size bandpass filters. A combination of slow-wave
EBG structures and coupled line resonators leads to compact
bandpass filters, exhibiting improved stopband characteristics.
As an example this paper presents measured and simulated
results for a high performance reduced dimension bandpass
filter in comparison to existing filter types.

II. MICROSTRIP EBG STRUCTURE

It is generally assumed that EBG structures give rise to
large area filters, as has been shown by various groups [6, 7].
However, compact slow-wave EBG structures can be realized
in a form of a periodically loaded transmission line. The
proposed pattern for a microstrip line is shown in Fig. 1.

![Fig. 1. Periodically loaded microstrip transmission line section used as a
slow-wave EBG structure.](image)

The concept of the structure behavior can be explained by
considering relations for the transmission line. As can be seen
in Fig. 1, the EBG structure consists on a high impedance
microstrip line with characteristic impedance $Z_{TRL}$ given by

$$Z_{TRL} = \frac{L_{TRL}}{C_{TRL}},$$

where $C_{TRL}$ is the capacitance per unit length and $L_{TRL}$ is the
inductance per unit length of the line. The high impedance
transmission line is loaded by a patch with width $W_p$ and
length $l_p$ using short transversal stubs. In this configuration
the most significant contribution to the equivalent capacitance of
the EBG structure comes from the parallel plate capacitance of
the patch, which can be obtained by

$$C_p = \frac{\varepsilon_r \varepsilon_0 W_p}{h},$$

where $\varepsilon_0 = 8.85 \cdot 10^{-12}$ F/m, $\varepsilon_r$ is the relative permittivity, and $h$
is the thickness of the substrate in Fig. 1.

The characteristic impedance of the resulting structure can
be estimated by:
\[ Z_{\text{EBG}} = \sqrt{\frac{L_{\text{TRL}}}{C_{\text{TRL}} + C_p}} = Z_{\text{TRL}} \sqrt{\frac{C_{\text{TRL}}}{C_{\text{TRL}} + C_p}}. \quad (3) \]

The quantities \( C_{\text{TRL}} \) and \( Z_{\text{TRL}} \) are calculated using the well-known relations for microstrip lines. Obviously, \( C_p \) and \( L_{\text{TRL}} \) have the most significant influence on the characteristics of the EBG section. The inductance \( L_{\text{TRL}} \) is adjusted by varying the transmission line width \( W_{\text{TRL}} \), whereas the capacitance \( C_p \) can be adjusted by varying the parameter \( W_p \). By tuning these parameters and the microstrip section length \( \lambda_p \), different slow-wave effects can be attained at different frequencies. The operating frequency bandwidth depends on the number of transversal stubs. The feeding lines, which connect the structure to the 50 Ohm load, should be also taken into account because they have an influence on parameters of the structure.

An advantage of this EBG structure is that no etching nor via holes are required in the ground metallization or in the substrate, respectively. Therefore, this technique is compatible with planar fabrication techniques and simplifies the filter design process.

Using such a structure the self-capacitance and the self-inductance per unit length of the transmission line are increased, giving rise to a slow-wave effect. Due to this effect the microstrip device dimension can be significantly reduced. At the same time, it is possible to manipulate the line impedance. The effectiveness regarding the occupied area for a given impedance transformation is illustrated in Table 1.

**TABLE 1**

<table>
<thead>
<tr>
<th>Transformation ratio</th>
<th>1:2</th>
<th>1:3</th>
<th>1:4</th>
<th>1:5</th>
<th>1:6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length/( \lambda )</td>
<td>0.13</td>
<td>0.13</td>
<td>0.13</td>
<td>0.13</td>
<td>0.13</td>
</tr>
<tr>
<td>Width/( \lambda )</td>
<td>0.101</td>
<td>0.110</td>
<td>0.118</td>
<td>0.120</td>
<td>0.150</td>
</tr>
</tbody>
</table>

\( \lambda \) is the wavelength in the substrate material; number of shunt stubs is 4

The impedance transformer employing the EBG section is less than quarter wavelength in length and width and can be used for a wide range of impedance ratios. Indeed, it can be seen from Table 1 that different impedance transformation ratios are achieved with different widths \( W_p \) in the range of \( 0.1 \leq \lambda \leq 0.25 \), while keeping the length and the number of shunt stubs constant.

The analysis of the proposed structure has been successfully accomplished using well-known transmission line models. The microstrip transmission-line models provide sufficient accuracy for the construction of the EBG structure in the frequency range considered here.

### III. Bandpass Filter Based on Coupled Line Sections and EBG Structure

The new EBG structure is employed in the design of the bandpass filter shown in Fig. 2. This filter has the same center frequency and bandwidth as that presented in [3]. The filter of [3], however, based on SIH resonator instead of an EBG structure. The SIH resonator implemented in [3] improves the selectivity and eliminates the 2nd-harmonic response of coupled-line sections simultaneously. Filter circuits were implemented on a FR-4 substrate with \( \varepsilon_r = 4.4 \) and thickness \( h = 0.745 \) mm. Fig. 3(a) illustrates measured results for the transmission and return loss characteristics of this filter.

The return loss characteristics can be significantly improved by reducing the impedance of the coupled lines and increasing the coupling level. This means that the coupled lines width \( W_c = 0.2 \) mm or the separation between the lines \( S = 0.2 \) mm have to be reduced even further, which makes the fabrication process more difficult decreases reproducibility.

![Fig. 2. Schematic of the coupled line bandpass filter with EBG structure (dimensions in mm).](image-url)

![Fig. 3. Measured transmission and return loss characteristics. (a) Filters comparison. The dotted line: existing (SIH based filter) design; the solid line: proposed (EBG based filter) design. (b) Spurious response.](image-url)
An alternative way is to change the load of coupled lines by
replacing the SIH resonator with the proposed EBG structure,
as shown in Fig. 2. In this configuration the load impedance
of the coupled lines can easily be adjusted for improved filter
matching.

As mentioned above the EBG structure exhibits low-pass
characteristics. Due to this fact, the 2nd-harmonic response is
effectively suppressed. This is because the EBG as well as the
SIH structure give rise to the same parasitic effect to increase
the shunt capacitance. The selectivity of the filter at high
frequencies is controlled by the EBG sections, whereas the
coupled line sections control the low frequency response.

The proposed filter in Fig. 2 is designed using empirical
models for single and coupled microstrip lines. Empirical
models for coupled microstrip lines are not as accurate as
those for single lines [8], since the mutual inductance and the
mutual capacitance are not easily predictable.

An accurate prediction of the coupled lines response is
carried out using method of moments simulations. The device
was fabricated on the same substrate as the traditional filter
mentioned above [3].

The EBG structure employed in the filter is three times
smaller as compared to the SIH resonator. The new filter has
therefore a footprint area reduced by about 30% as compared
to the filter proposed in [3]. The overall dimensions of the
filter are approximately 0.15λ × 0.27λ, where λ is the guided
wavelength in the substrate at center frequency.

Measurement results for the proposed filter and the one
discussed in [3] are shown in Fig. 3 and Fig. 4. It can be seen
from Fig. 3a that the implementation of the EBG structure in
Fig. 1 improves the matching of the device. Also, the
2nd-harmonic response is effectively suppressed. The passband
insertion loss is about 1.5 dB, including the connector and the
tapped feed line loss. The selectivity of the filter can be defined as

$$\xi = \frac{\alpha_{\text{min}} - \alpha_{\text{max}}}{f_s - f_p} \left( \frac{\text{dB}}{\text{GHz}} \right), \quad (4)$$

where $f_s$ is the stopband frequency at $\alpha_{\text{min}}$ with a 20-dB
attenuation point, and $f_p$ is the 3-dB cutoff frequency at $\alpha_{\text{max}}$
with a 3-dB attenuation point. The lower- and upper-band
selectivity of the new bandpass filter is improved to better than
43 dB/GHz and 38 dB/GHz, respectively. The 2nd-harmonic response of the proposed structure is improved from
-53 dB to -55.6 dB. The filter has center frequency $f_0 = 2.3$ GHz and a first spurious response at about $2.7f_0 = 6.2$
GHz. At this spurious frequency, the minimum insertion loss is
found to be 10.5 dB, as shown in Fig. 3b.

The group delay is an important performance aspect for a
wide-band filter, especially for filters used for processing of
signals with complex frequency content. Fig. 4 shows a plot of
the group delay within the filter passband region.

The designed structure achieves a smooth delay pattern in
the operating frequency band with a variation of the order of
600 ps. Taking advantage of this property, the device can be
effectively used as a component in a variety of systems
requiring linear phase characteristics.

The developed filter is intended to be used in a microwave
camera for medical applications.

IV. CONCLUSION

The development of microstrip circuits using EBG
structures and coupled lines is promising for the development
of compact high performance microwave components. A filter
has been designed and fabricated for the demonstration of the
compactness and improved performance of this method
 technique. The new filter exhibits improved matching
characteristics and suppression of the harmonic response in the
stopband. It also reduces the overall geometrical
dimensions of the circuit. The fabrication technology is
simple, inexpensive, and does not require via-holes or etching
in a ground plane. An improvement in the 2nd harmonic
suppression has been achieved reaching a measured value of
-55.6 dB. The filter exhibits a 3 dB bandwidth of 45% and an
insertion loss of 1.5 dB, a return loss in the passband of better
than 25 dB, with good phase linearity, leading to a group delay
of ± 300 ps.

REFERENCES

line impedance transformers,” IEEE MITT-S Digest, pp. 1951–1954,
2004.
polarization, stacked, probe-fed microstrip patch antenna array,”
Microwaves, Radar and Wireless Communications, vol. 2, pp. 473-476,
May 2004.
[3] Yu-Zhen Wang, Mao-Long Her, Yi-Chyun Chiuo, and Ying-De Wu,
“New coupled-line bandpass filter with stepped impedance hairpin (SIH)
resonator,” Microwave And Optical Technology Letters, vol.44, no.1,
structure band-pass filter,” International Journal Of Electronics, vol. 92,
no. 9, pp. 467-472, 2005.
Microwave And Optical Technology Letters, vol. 44, no, 4. pp. 363-365,
February 2005.
Used as Filters in Microstrip Circuits,” IEEE Microwave and Guided
planar printed microwave and PBG filters using an FDTD method,”