Multimode Ultra-Wideband filters by using a Grounded Open Ring Resonator

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***Abstract*—This paper reports a novel multimode resonator (MMR) ultra-wide band-pass (UWB) filter design using a grounded open ring resonator. The utilization of 30 μm gaps between input ports and the central resonator achieve high coupling level. Five resonant modes are used to perform a 128% fractional bandwidth at 4.3 GHz. The fabricated prototype exhibits a band-pass with insertion losses around 0.5 dB. A theoretical model based on transmission lines matrices is proposed and used to explore the limits of the design through different parametric analysis. Excellent agreement between theoretical predictions, electromagnetic simulations and measurement are found.**

***Index Terms*: Multi-mode resonator, parallel-coupled microstrip line, ultra-wideband band-pass filters.**

I. INTRODUCTION

Many efforts have been devoted to the development of the ultra-wide band pass (UWB) filter using multi-mode resonator (MMR) [1]. From the conceptual point of view, MMR is one of the simplest approaches to the design of UWB. The technique was originally proposed by Zhu and Menzel in 2005 [2], and further developed with diverse approaches can be found in literature [3-7]. In [2] a five-pole filter was built using a single triple-mode stepped-impedance resonator (SIR) for UWB application. In [3] two short-circuited stubs where attached to the initial MMR to form a quadruple-mode UWB band pass filter. In [4], a packaged UWB filter based on stub-loaded resonators is proposed. In [5], the triple open stubs in shunt to a SIR are used to build UWB filter. A compact UWB using the dual-mode ring resonator is presented in [6]. In [7] a superconducting UWB band-pass filter with sharp rejection skirts by using MMR is reported. The utilization of ring resonator in the UWB design was introduced in [8].

A compact UWB band-pass filter using grounded open ring resonator as a MMR is proposed in this paper. The approach allows using 5 resonances to produce a 128% fractional bandwidth into the ultra-wide band bandwidth standard frequencies. A general theoretic framework has been established using transmission matrix description of the filter constituent components.

As illustrative example, a 128% FBW filter between 1.2 GHz and 5.5 GHz has been designed and fabricated. The prototype has been fabricated in a 1.27 mm thick Rogers 3010 substrate with a relative dielectric constant of 10.2. The dimensions of the filter are 21.5mm×10mm ($\cong 0.66\lambda_g \times 0.30\lambda_g$), where λ_g is the central frequency wavelength.

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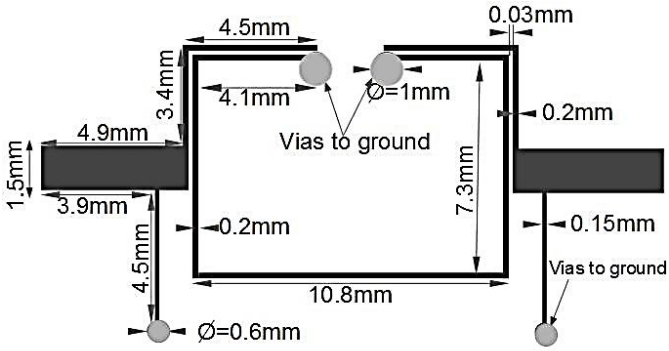
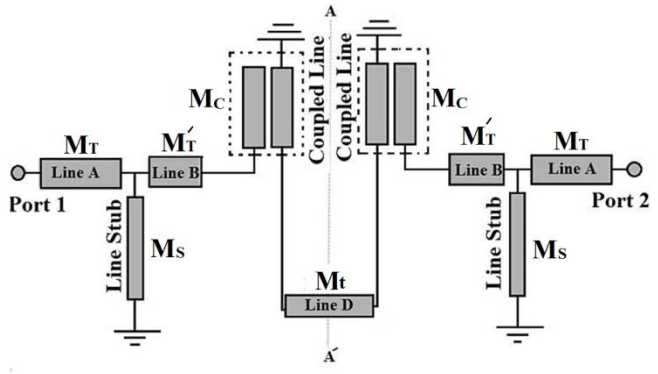
II. PROPOSED DESIGN DESCRIPTION

Fig. 1(a) shows the physical layout of the proposed MMR-UWB. The distance between the I/O ports and the MMR is fixed to 0.03 mm. The width of the open ring resonator grounded and the extension of the I/O port have been fixed to 0.2 mm.



(a)



(b)

Fig. 1. a) Layout of the designed MMR-UWB filter. (b) Schematic of proposed MMR-UWB equivalent circuit model.

The layout and corresponding equivalent circuit model for the proposed filter are shown in Figs. 1(a) and 1(b), respectively. The two 0.15 mm width, 4.5 mm long grounded stubs have been designed to match the impedance of the I/O ports. The length of these I/O ports extensions coincides with the first resonant frequency of the grounded open ring resonator. The basic idea of the design is that the length of the grounded square ring determines the position of the resonant modes, and the extension of the coupled line in the ring perimeter

determines the number of modes into the band pass. On the other hand, the structure of the layout let the identification of the constituent elements of the design in terms of sections which can be theoretically described using transmission matrices representation.

III. CIRCUIT ANALYSIS

Fig. 1(a) shows the proposed MMR-UWB filter layout and Fig. 1(b) the proposed equivalent circuit model based on coupled microstrip transmission lines. The coupled transmission lines are characterized trough the even and odd characteristic impedance and electric length (Z_{oe}, θ_e, and Z_{oo}, θ_o respectively). This implies the coexistence of two different modes with different phase velocity and propagating constant corresponding to the different effective relative permittivity.

The even and odd-mode characteristic impedances Z_{oe} and Z_{oo} can be obtained from the expressions:

$$Z_{oe} = \frac{1}{c\sqrt{C_e^a C_e}} \quad (1)$$

$$Z_{oo} = \frac{1}{c\sqrt{C_o^a C_o}} \quad (2)$$

where C_e^a and C_o^a are the even and odd mode capacitances that can be derived directly from the geometrical parameters of the design [9].

The distributed equivalent circuit model showed in Fig.1 (b) can be described by a single ABCD matrix between the input and output ports. Due to the A-A' plane symmetry, the internal structure of this matrix can be described by the Eq.(3)

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = M_T M_S M_{T'} M_C M_t M_C M_{T'} M_S M_T \quad (3)$$

Where

$$M_T = \begin{bmatrix} cos\theta_T & jZ_T sin\theta_T \\ j\frac{1}{Z_T} sin\theta_T & cos\theta_T \end{bmatrix} \text{ and } M_{T'} = \begin{bmatrix} cos\theta_{T'} & jZ_T sin\theta_{T'} \\ j\frac{1}{Z_T} sin\theta_{T'} & cos\theta_{T'} \end{bmatrix} \quad (4)$$

are the ABCD matrices of the line A and B,

$$M_t = \begin{bmatrix} cos\theta_t & jZ_t sin\theta_t \\ j\frac{1}{Z_t} sin\theta_t & cos\theta_t \end{bmatrix} \quad (5)$$

is the ABCD matrix associated to the center transmission line D,

$$M_S = \begin{bmatrix} 1 & 0 \\ \frac{1}{jZ_s tan\theta_s} & 1 \end{bmatrix} \quad (6)$$

is the ABCD matrix associated to the grounded stub S,

$$M_C = \begin{bmatrix} \frac{-Z_{11}}{Z_{12}} & \frac{-(Z_{11}^2 - Z_{12}^2)}{Z_{12}} \\ \frac{-1}{Z_{12}} & \frac{-Z_{11}}{Z_{12}} \end{bmatrix} \quad (7)$$

is the ABCD matrix associated to the coupled lines.

Being the elements of the coupled line:

$$Z_{11} = Z_{22} = \frac{-j}{2} Z_{oe} \cdot cot(\theta_e) - \frac{j}{2} Z_{oo} \cdot cot(\theta_o) \quad (8)$$

$$Z_{12} = Z_{21} = \frac{-j}{2} Z_{oe} \cdot csc(\theta_e) + \frac{j}{2} Z_{oo} \cdot csc(\theta_o) \quad (9)$$

The physical dimensions showed in Fig.1 (a) correspond to the electrical parameters are Z_T=44.5 Ω, Z_t=66.6 Ω, Z_s=101.6 Ω, Z_{oe}=145.5 Ω, Z_{oo}=30.5 Ω and 6.5 and 5.8 effective relative dielectric constants for even and odd mode respectively.

Although expressions are complicated [9], the Z_{oe} and Z_{oo} impedances can be analytically evaluated from the substrate thickness (h), the strip width (W) and the separation between coupled lines (S). Fig.2 shows the mapping of these expressions illustrating the fact that for higher S/h relation there is a clear increment of Z_{oo} and a diminution of Z_{oe}. On the other hand, an increment in the W/h ratio implies a reduction of both Z_{oe} and Z_{oo} parameters. According to this map, the extreme values achievable with our fabrication facilities are fixed to Z_{oe}=145.5 Ω and Z_{oo} =30.5 Ω, corresponding to W= 0.2 mm and S= 0.03 mm for a fixed h=1.27 mm.

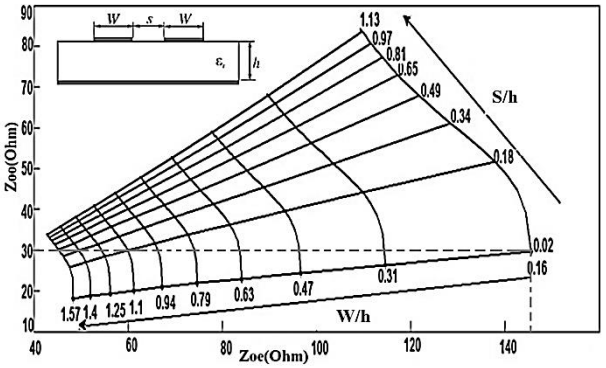


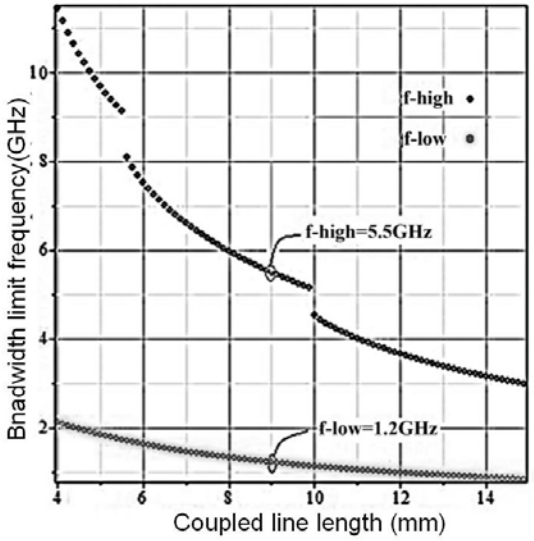
Fig. 2. Even and odd mode (Z_{oe}, Z_{oo} respectively) impedance mapping as function of the S/h and W/h ratios. In all the cases substrate has a fixed valued of h=1.27mm and ε_r=10.2.

The resulting ABCD matrix can be used to evaluate the limits of the filter fractional bandwidth (FBW) following the expression.

$$\text{FBW} = \frac{(f_h - f_l)}{f_c} \quad (10)$$

$$f_c = \frac{f_h + f_l}{2} \quad (11)$$

Where f_c denotes the center frequency and higher and lower frequency limits of the bandwidth are represented by f_h and f_l, respectively. It is observed that the center frequency is inversely proportional to the length of coupling line, when the center frequency decreases, the length of coupling line increases. The length of the coupled line of proposed filter is 9 mm long and 0.2 mm wide, the measured high and low frequency are 5.5 GHz, 1.2GHz respectively.



(a)

(b)

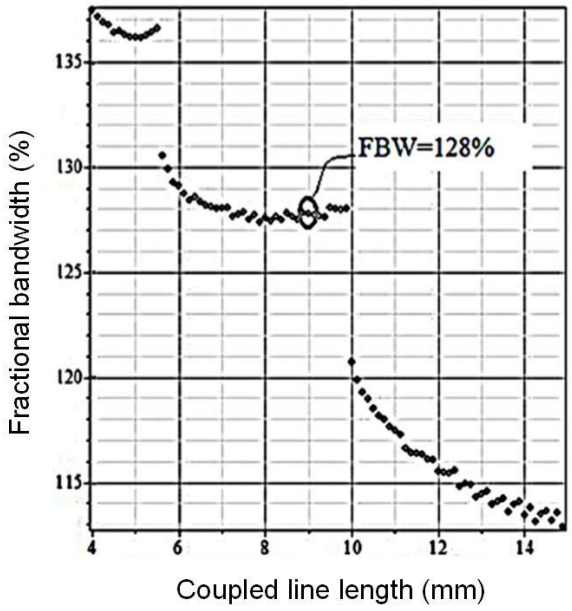


Fig. 3. Show the upper and lower limits of the FBW as a function of the length of the coupled line (D).

Fig.3 shows the upper and lower limits of the MMR-filtering structure (in Fig. 3.a) and the corresponding FBW (in Fig. 3.b) as a function of the length of the coupled line section (see Fig. 1.a). The different number of resonant modes included in the band-pass produces the plateau like behavior observed in Fig. 3.b. For coupled line length below 5 mm there are six resonant modes into the band. In the case of coupled line length between 5 and 10 mm five resonances are included into the MMR design, and four for coupled line length between 10 and 15 mm. As the number of modes into the transmission band increases so does the FBW. However a higher number of resonant modes in the band compromise the rejection band level and the losses in the transmission band frequencies. The proposed design maintains a rejection level below -20 dB with a 128 % FBW at the UWB standard frequencies. The design process can be complex, but due to the equivalent circuit model based on the transmission matrices of the filter sections, relations between physical parameters and filter performance can be established.

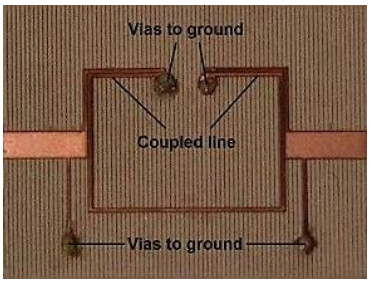
Comparison of fractional bandwidth of this work with other references is given in Table I.

TABLE I
Comparison with other proposed UWB Filters.

Ref.	FBW
[2]	113٪@2dB
[3]	119٪@3dB
[5]	114٪@3dB
[7]	110.6٪@3dB
This Filter	128٪@3dB

IV. MEASURED RESULT AND DISCUSSION

As shown in Fig 5, there are five resonant modes generated in the pass band of the MMR filter. Comparing with Fig 3b; it can be seen that, by decreasing lengths of coupled lines, resonant modes are changed. The theory predicts that decreasing coupled line (from 5.5 mm to 5.4 mm), increase band pass filter correlation. The theory was developed and compares well with the measurements parameter of bandwidth. To verify these simulated results, proposed MMR-UWB filter is fabricated and measured by network analyzer. A photograph of the fabricated prototype is shown in Fig. 4.



A. **Fig. 4**. Photograph of the new compact designed MMR-UWB filter.

The comparison of theoretical, simulation and measurement result shows in Fig .5.

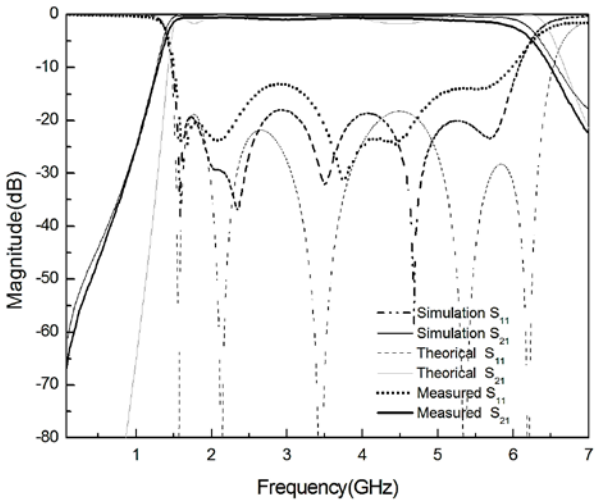


Fig. 5. S-parameter responses of the EM simulation, theoretical and measurement of MMR-UWB filter.

There is good agreement between the theoretical prediction, simulated and the measured results.

In the measurement, the lower and higher cutoff frequencies of the UWB filter are equal to 1.2 GHz and 5.5 GHz, respectively as can be observed in Fig. 3(a). This indicates that the relevant fractional bandwidth achieves about 128%.at the central frequency 2.56 GHz.

V. Conclusion

The paper presents a MMR-UWB filter approach with controllable characteristics. Relations between physical parameters and filter performance characteristics such as the central frequency, FBW, or the number of resonant modes into the band-pass have been studied using a distributed transmission matrices model.

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