Coplanar Waveguide Resonator Design for Array Antenna Applications

Mihai ŞOVA[1], Ion BOGDAN[2]

Abstract - **In this paper we are concerned on coplanar waveguide (CPW) resonator design for X band antenna applications. The CPW technology can be considered as a good alternative to microstrip due to uniplanar presence of both signal and ground planes, thus offering high possibility of integrating active components.**

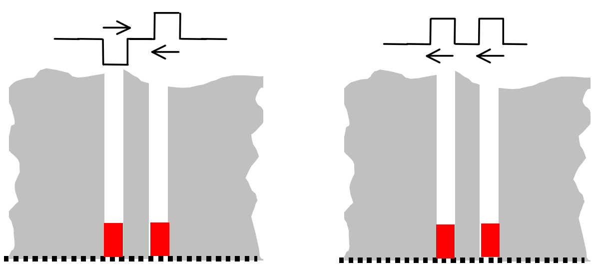
Keywords – **coplanar waveguide, bandpass filter, coplanar resonator, odd mode, even mode, array antenna**

I. INTRODUCTION

The CPW technology can be considered as a good alternative to microstrip due to unplanned presence of both signal and ground planes, thus offering high possibility of integrating active components [5].

The major disadvantage of CPW is unintentional excitation of the parasitic slot-line mode, known also as odd mode, in asymmetric circuits. Generally speaking, the fundamental modes in coplanar transmission line are even and odd mode, represented in Fig. 1 [3].

Depending on application, it is necessary to eliminate one of them, that is to say the odd mode.



(a) (b)

Fig. 1 CPW slot excitation: a) even mode b) odd mode

To control the odd mode air-bridges can be used, that insure the same potential on each side of the ground plane. The suppression of the parallel plate mode, which can lead to unwanted box-type resonance in the parallel plate mode and cause power leakage from the desired CPW mode, is extremely important to the proper operation of CPW and its variants [4].

[1] *Eng*. Mihai ŞOVA, *Ph.D.*, is with the Military Technical Academy, Bucharest, 81-83, George Coşbuc AV., 75275, ROMANIA, E-mail: sova@mta.ro
[2] *Prof. Eng*. Ion BOGDAN, *Ph.D.*, is with the Telecommunications Department, Technical University "Gh. Asachi", Blvd. Carol I, no.11, 6600, Iaşi, ROMANIA, E-mail: bogdani@etc.tuiasi.ro

The objective of this paper is to realize the coupling between even and odd mode, for a structure with two even resonators, thus obtaining a dual-mode four poles resonator.

Some notches inserted along coplanar transmission line give the asymmetry needed for odd mode. These are located at the quarter of the even resonator's length.

II. MODELLING OF CPW RESONATORS

Microwave resonators are lumped elements networks or distributed circuit structures that exhibit minimum or maximum real impedance at a single frequency or at multiple frequencies. The resonant frequency f_0 is the frequency at which the input impedance or admittance is real.

Further, the resonant frequency may be defined in terms of a series or shunt mode resonance: the series mode is associated with small values of input resistance at the resonant frequency, while the shunt mode is associated with large values of resistance at resonant frequency.

Resonators may be characterized by their unloaded quality factor Q_u, which is the ratio of the energy stored to the energy dissipated per cycle of the resonant frequency. Resonators are also characterized with respect to their reactance α and their susceptance β slope parameters, which are defined as [1]:

$$\alpha = \frac{\omega_0}{2}\frac{dX(\omega)}{d\omega}\bigg|_{\omega=\omega_0} \quad \text{and} \quad \beta = \frac{\omega_0}{2}\frac{dB(\omega)}{d\omega}\bigg|_{\omega=\omega_0} \qquad (1)$$

These parameters are very important because they influence Q_u and the coupling between resonators in multiple resonators filters.

In terms of reactance and susceptance slope, Q_u may be defined as:

$$Q_u = \frac{\alpha}{R_{series}} = \beta R_{shunt} \qquad (2)$$

where R_{series} and R_{shunt} are the resonator series/shunt resistance.

Taken together these resistances represent the resonator loss [2]. The unloaded quality factor can be determined from measuring of the resonant frequency and the –3 dB bandwidth from the following equation:

$$Q_l = \frac{f_0}{\Delta f}\bigg|_{\Delta f\ =\ -\ 3\ \text{dB bandwidth}} \qquad (3)$$

In Fig. 2 is presented the dispersion characteristics of attenuation constant for different metal layer. As we can see, for a given impedance the constant decrease with increasing of frequency. These analyses can be useful for choosing CPW for specific applications.

Another important perspective on CPW with finite ground planes behaviour is given by the variation of characteristic impedance and effective permittivity as function of w/d and h/d ratio.

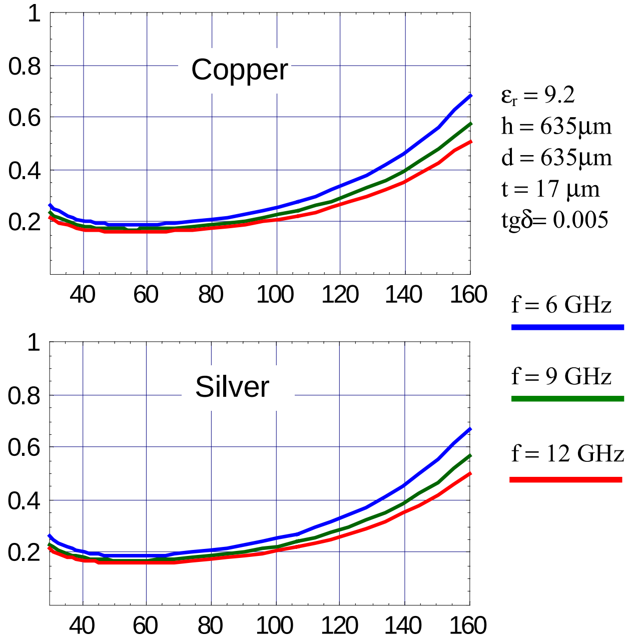


Fig. 2 Dispersion characteristics of attenuation constant as function of characteristic impedance for different metal layer

The simulated results, for dispersion parameters, are shown in Fig. 3, using fomulas from below [4].

$$\varepsilon_{ef} = 1 + \frac{C_2}{2C_1} = 1 + \frac{\varepsilon_r - 1}{2} \frac{K(k_3)}{K'(k_3)} \frac{K'(k_2)}{K(k_2)} \quad (4)$$

$$Z_0 = \frac{30\pi}{\sqrt{\varepsilon_{ef}}} \frac{K'(k_2)}{K(k_2)} \quad (5)$$

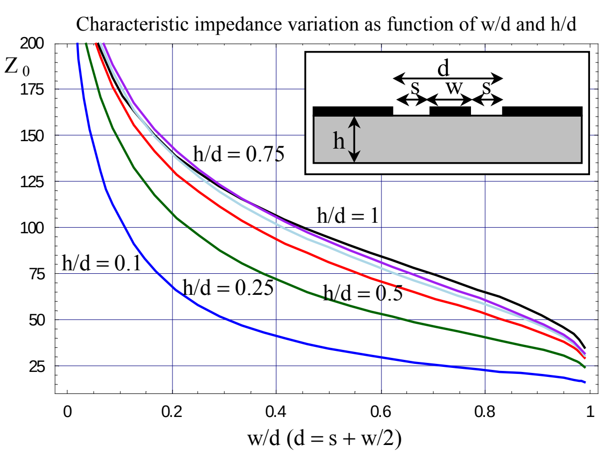


Fig. 3 Dispersion and variation of effective permitivity and characteristic impedance for CPW for ε_r = 2.323, h = 635μm s = 200 μm w =1600 μm

As we can expect, in this CPW effective permitivity decrease and characteristic impedance increase with increasing of h/d for a given w/d. This show that the impedance of CPW increase due to limiting of ground planes, fact that can be useful in obtaining coplanar transmission lines without reducing central conductor.

The factor that affects most the filter performance is the resonator coupling. For easier manufacturing and tuning is preferred a common resonator coupling type. Matthaei, Young and Jones proposed a configuration with J (admittance) and K (impedance) inverters both to allow a common type of resonator and to serve as coupling elements for resonators [1].

The J inverters may be represented as the admittance of the element or the value of the characteristic admittance of a quarter-wavelength line in the equivalent circuit that couples the resonators.

The K inverters may be represented as the impedance of the element or the value of the characteristic impedance of a quarter-wavelength line that couples the resonators.

This allow the general expression of the coupling between resonators to be written as:

$$k_{i,i+1} = \frac{J_{i,i+1}}{\beta} \quad \text{and} \quad k_{i,i+1} = \frac{K_{i,i+1}}{\alpha} \quad (6)$$

for shunt type and series type resonators, respectively, where the coupling between the i^{th} and the i^{th+1} resonator is represented by $k_{i,i+1}$.

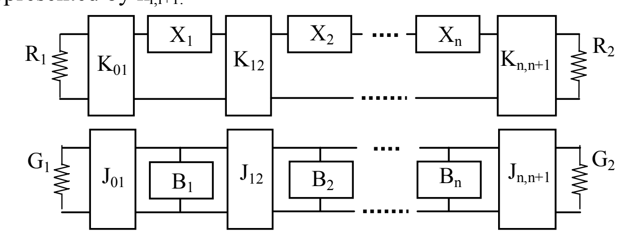


Fig. 4 Filter prototypes using impedance/admittance inverters

III. PRACTICAL DESIGN EQUATIONS

First it should be noted the theoretical background of capacitive gap coupled transmission line filters. Taking into account the approach given by Matthaei, Young and Jones for this kind of filters we have following design equations:

$$\frac{J_{01}}{Y_0} = \frac{J_{n,n+1}}{Y_0} = \sqrt{\frac{\pi}{2} \frac{w}{g_0 g_1 \omega'_1}}$$
$$\frac{J_{i,i+1}}{Y_0} = \frac{\pi w}{2\omega'_1} \frac{1}{\sqrt{g_i g_{i+1}}}, \quad i \neq 0, n \quad (7)$$

where w is the fractional (or normalized) bandwidth, ω'_1 = 1 is the prototype filter cutoff frequency and g_i are the normalized impedances. These equations acts for the configurations realized by resonators connected with J inverters, as in Fig. 4.

To obtain the J inverter using CPW, we employ the gap in the signal line of CPW with the electrical length φ and J value:

$$\varphi = -\tan^{-1}\left(\frac{2B_b}{Y_0} + \frac{B_a}{Y_0}\right) - \tan^{-1}\left(\frac{B_a}{Y_0}\right) \quad (8)$$

$$\frac{J}{Y_0} = \left| \tan\left\{\frac{\varphi}{2} + \tan^{-1}\left(\frac{B_a}{Y_0}\right)\right\} \right| \quad (9)$$

where $B_a = \omega C_a$ and $B_b = \omega C_b$, C_a and C_b are the parallel and series capacitances of the gap.

Thus the total electrical length of the ith resonator is:

$$\theta_i = \pi + \left(\frac{\varphi_{i-1,i}}{2} + \frac{\varphi_{i,i+1}}{2} \right) \qquad (10)$$

IV. EXPERIMENTS AND RESULTS

In this section, we present some results from our work, related to coplanar waveguide bandpass filter using CPW resonator. The goal of this work was the characterizing of coplanar waveguide behavior in X band, as a first step in designing applications for array antennas.

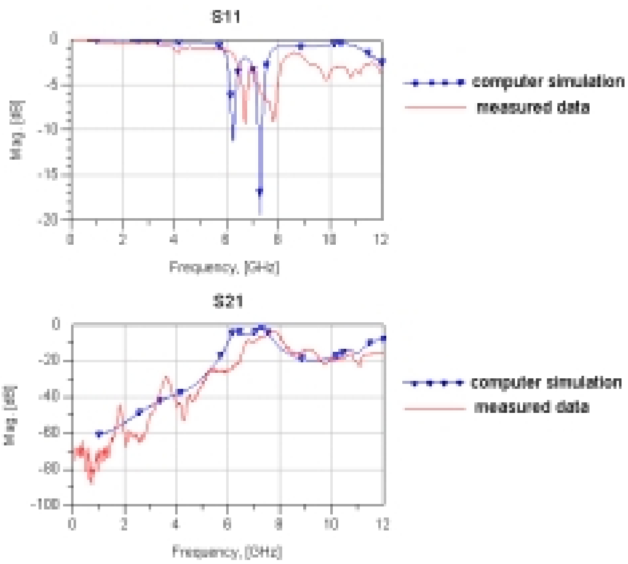


Fig. 5 Comparative design of an single and an double CPW resonator: computer simulation and measured data

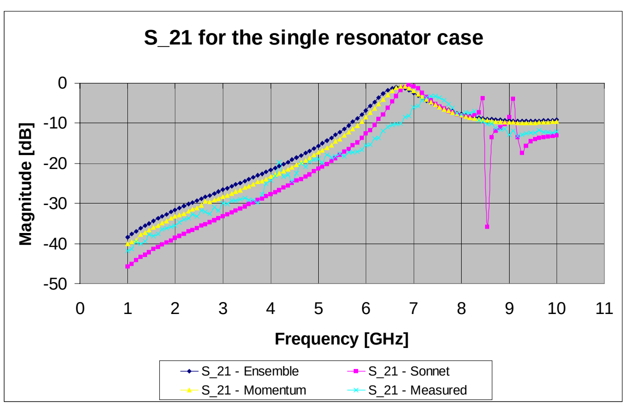


Fig. 6 Comparative data for an single CPW resonator case, using most known microwave CAD software

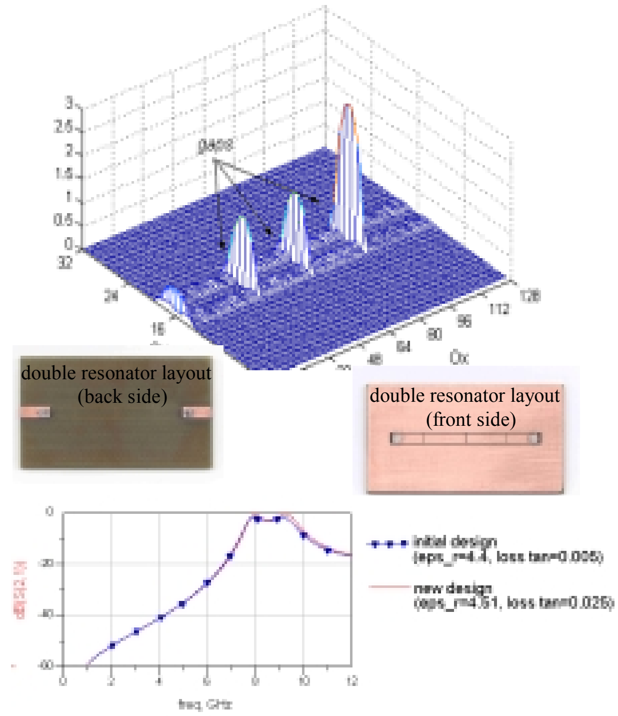


Fig. 7 CPW resonator analysis using different substrates

V. CONCLUSION

Through this paper, we have designed, manufactured, measured and analyzed the CPW resonator for bandpass filters used for antenna applications in X band. The results obtained have proved the advantage of coplanar technology over the microstrip in MMIC. The practical design and measurements have been made in S.E.P.T./ M.O.S.E. - E.N.S.A.E. Microwave Laboratory, Toulouse, France.

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