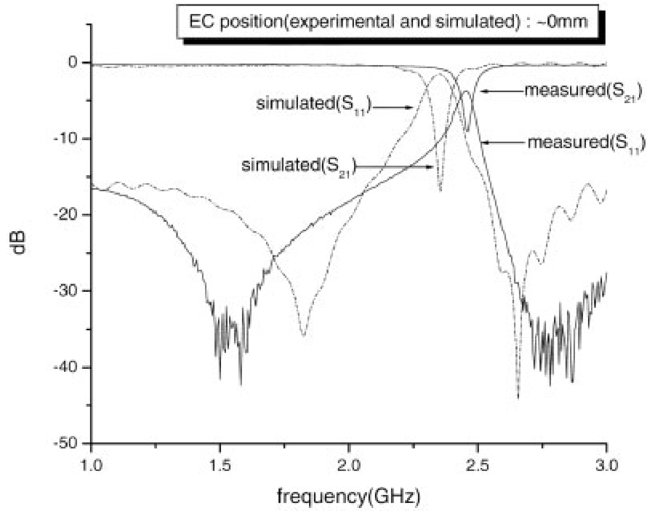

Figure 8 Measured and simulated results of EM-coupled CRR-notch filter

in most of the pass band is less than −0.4 dB. This can be further improved by using substrate (like Al_2O_3) with lower loss tangent.

Reflection measurements (S_{11}) show that most of the energy at the center notch frequency is reflected back to the source and not radiated. (see Figs. 5–8)

Is ring better than the patch resonator (the one which is extensively used as antennas) was also a question. We have, therefore, tried simulation of an equilateral triangular patch notch filters as well, with flexible EC (unlike reported isosceles patch [1] which was designed to eliminate higher harmonics). This is not found to be good in pass band, as it has one more rejection mode frequency at 2.8 GHz nearby the dominant mode at frequency of 2.2 GHz (unlike ring). The other reported notch filters [1–3] with in-plane coupling, are also seen to give lesser rejection then SRR if only single resonator is used (with higher order filter one can obviously get more rejection). Overall it may be said that to the best of our knowledge EC with SRR is one of the best single resonator notch filter compared with any other geometry reported till now.

4. CONCLUDING REMARKS

The present Planar notch filters using EM-coupled resonators offer sufficiently high attenuation (with TMM4 substrate) at desired f_0 with very low loss in pass band (≤ 0.4 dB) and narrow bandwidth. Added advantage of this type of flexible EM coupling is that resonating circuits can be easily replaced or additional notch resonators can be added, easily without affecting the underlying feed line and port connections, thus giving multifrequency operation. Multiple resonators on same top substrate can be used.

ACKNOWLEDGMENT

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MICROSTRIP-CPW BANDPASS FILTER FOR ANTENNA APPLICATION

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ABSTRACT: *This article presents a quasi-lumped bandpass filter with CPW-microstrip ports. The structure serves as CPW-microstrip transmission in addition to its filtering function. The filter was integrated with a microstrip patch antenna. To enable the filter design, the characteristic impedance of the slotted microstrip line and the coupling strength of microstrip to microstrip, CPW to CPW and microstrip to CPW transitions were calculated.* © 2007 Wiley Periodicals, Inc. Microwave Opt Technol Lett 50: 51–55, 2008; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.23001

Key words: *antenna; bandpass filter; filter; transition circuit*

1. INTRODUCTION

Multilayer coplanar line [1, 2] is a suitable technology for integrated microwave circuits and MMIC circuits, as it offers designers a wider degree of freedom than the standard CPW. The multilayer coplanar line was introduced as a good candidate for filter applications in [2, 3], since it offers a wider characteristic impedance range and provides a tighter effective capacitive coupling between the resonators by locating them on the two sides of the substrate [3]. Some multilayer coplanar line coupling structures for filters have been proposed in [4].

Recently [5], a modified multilayer coplanar line of modified cross sections were introduced by opening a slot in the ground plane of the microstrip line under the guided wave line. By this way the slotted microstrip line was achieved, Figure 1(a). CPW can be achieved by building the ground plane on the top side of the substrate instead of the rear side, Figure 1(b). Making the use of a metallization on the rear side we get a multilayer line, Figure 1(c), which can be used were high capacitive coupling is required. These structures can be easily integrated with both CPW- and microstrip-based circuits, depending on the side of the substrate that these feed lines are built on. This is not the case in standard microstrip and CPW lines, as these technologies need the transition networks to be integrated together [6, 7]. Various components can be designed with such a configuration of doubly metallized copla-

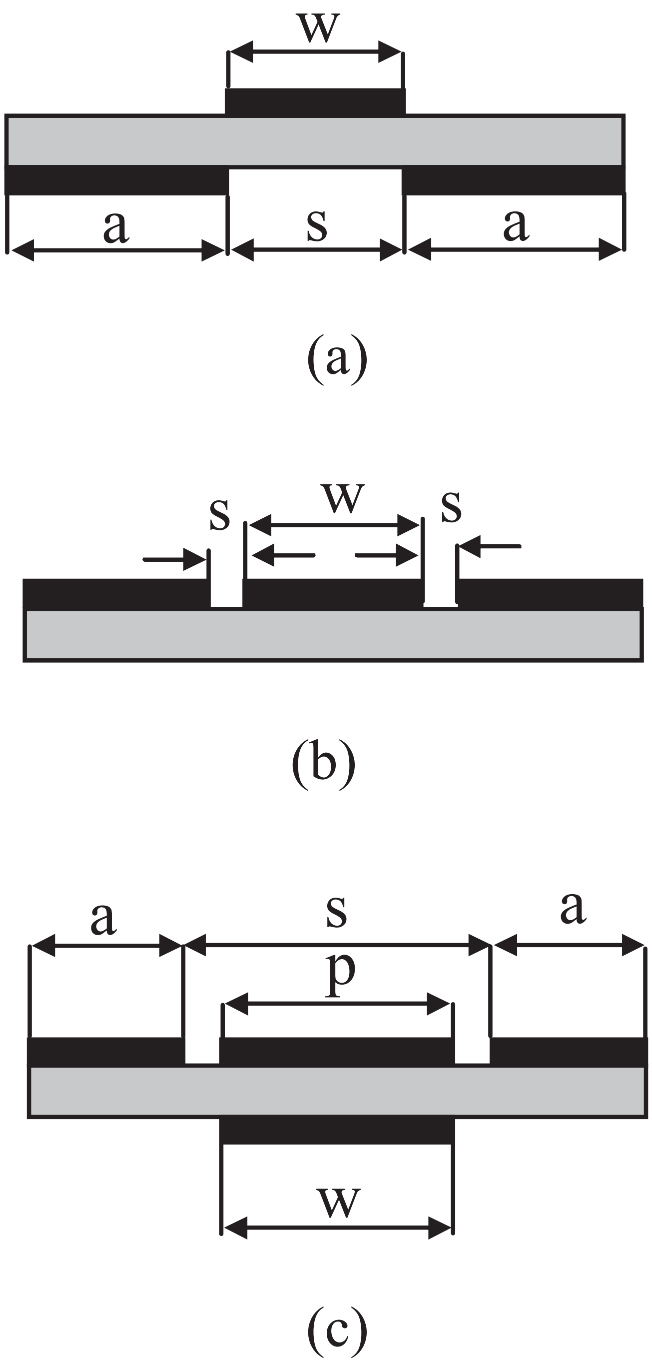

Figure 1 Cross-section (a) a slotted microstrip line, (b) CPW, (c) multilayer coplanar line

nar line and slotted microstrip line. Very compact quasi-lumped element filters were introduced with slotted microstrip line ports as well as with CPW ports [5] based quasi-lumped elements [8].

In this article, a bandpass filter that has been investigated in [5], is modified to serve as a microstrip-CPW transmission in addition to its own filtering function. In addition, the parametric study of these lines is presented together with the analysis of their mutual coupling. Very compact bandpass filter compatible with both CPW and microstrip is presented. It is applied as a transition the standard patch antenna to the CPW, and at the same time cutting the higher order patch resonances.

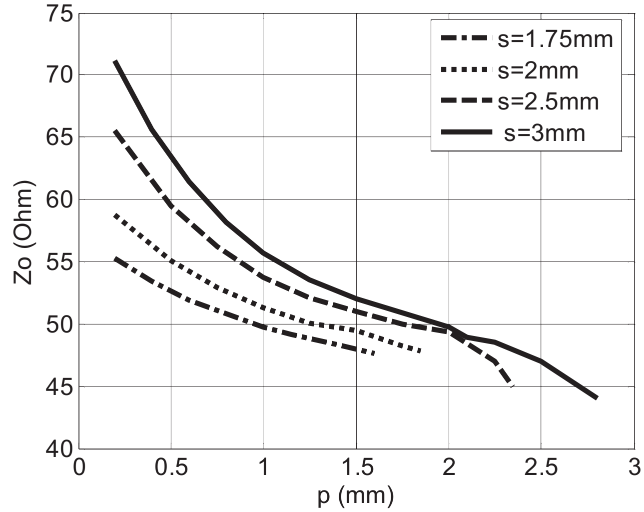

Figure 2 Characteristic impedance of the multilayer coplanar line defined in the text calculated by Microwave Studio as a function of strip width *p* for different channel width *s*

2. FILES REQUIRED

Modified coplanar lines offer the higher degree of freedom in the design of microwave circuits than the standard planar lines. The cross sections of the lines under discussion are shown in Figure 1 [5]. This technology achieves a very wide range of characteristic impedances. The rear side of the substrate is ready for assembling the circuit elements. Consequently, we can obtain very compact circuit structures. Figure 2 shows the characteristic impedance of the multilayer coplanar line, Figure 1(c), calculated by Microwave Studio (MwS) as a function of multilayer coplanar line channel width *s* and central strip width *p.* Other parameters are substrate permittivity 6 and thickness 0.787 mm, $a = 4.65$ mm and $w = 1.4$ mm. The calculated characteristic impedance of the slotted microstrip line, Figure 1(a), is plotted in Figure 3 as a function of strip width *w* for different values of *s.* The width of the ground conductors is $a = 4.65$ mm. The same substrate as in Figure 2 is used.

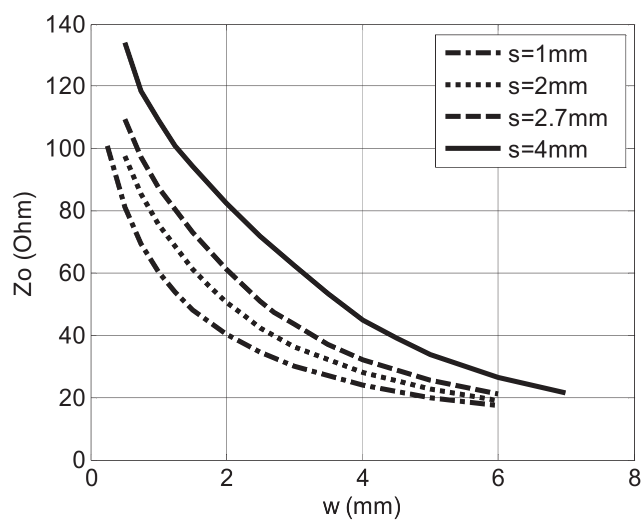

Figure 3 Characteristic impedance of the slotted microstrip defined in the text calculated by Microwave Studio as a function of strip width *w* for different slot width *s*

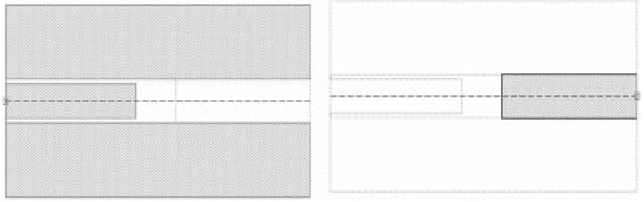

Figure 4 Top and bottom layout of the broadside coupled structure

The analysis of both lines was performed with the perfect magnetic wall inserted to the line longitudinal plane of symmetry. Consequently, the basic modes with the even symmetry of the electric field component perpendicular to the substrate were assumed. There are of course the modes with odd symmetry corresponding to the perfect electric wall. There is no need to involve these modes in the design of presented filters as they are shortened at their structure.

The analysis performed by SONNET [9] shows the great advantage of the tight coupling in a broadside coupled combined structure doubly metallized coplanar line-a slotted microstrip line compared to CPW and microstrip line structures. The enhanced coupling is due to the overlapping of the strips in the doubly metallized coplanar line-a slotted microstrip line structure located on the two sides of the substrate, see Figure 4. Figure 5 shows the coupling capacitance calculated as a function of the distance *D* between the ends of the line strips. The negative value of *D* in Figure 5 means overlapping of the strips located on the opposite sides of the substrate.

3. FILTER WITH MICROSTRIP AND CPW FEED LINES

The filter presented in [5], layout of which is shown in Figure 6, has been reconstructed to achieve a bandpass filter compatible with both CPW and microstrip feed lines. That original filter consists of two wide patches capacitively coupled to input/output 50 Ω slotted microstrip feed lines. The patches are interconnected by a narrow inductive strip, which is grounded at its centre by a shunt inductive strip. The equivalent circuit of the structure, Figure 7, was already investigated earlier in [5]. This filter was reconstructed to obtain the microstrip-CPW feeding lines. So the ground planes under the original 50 Ω

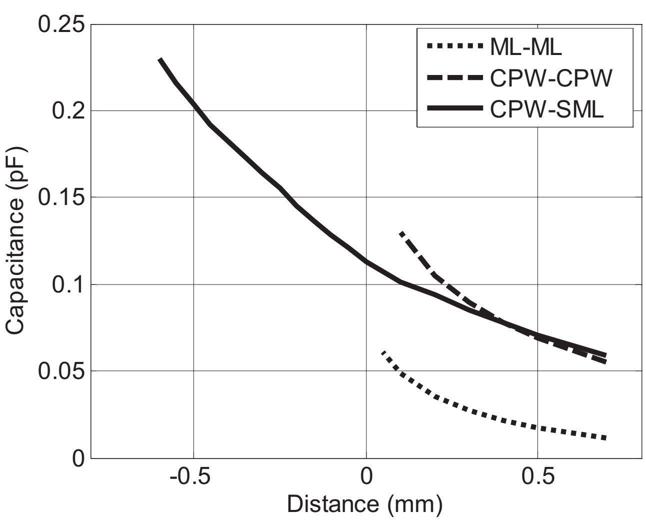

Figure 5 Calculated coupling capacitance between the two ends of the 50 Ω strips of particular lines: CPW-CPW, microstrip-microstrip (ML-ML) and doubly metallized coplanar line-slotted microstrip line (SML)

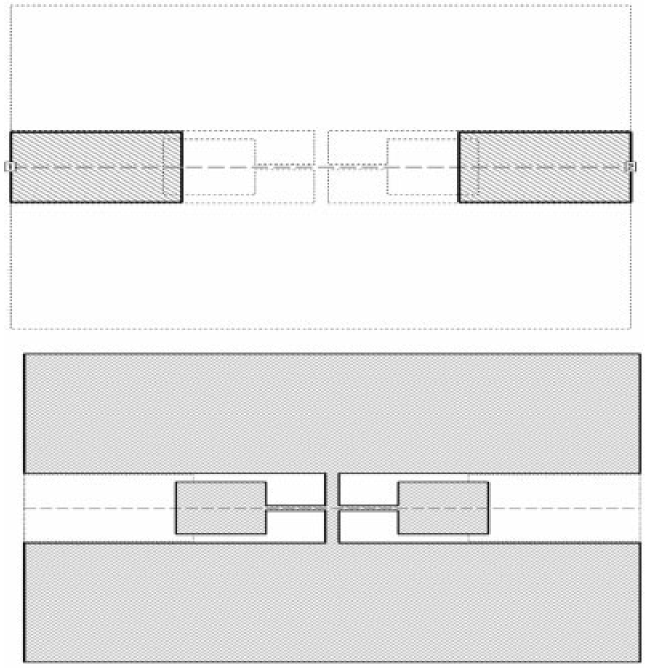

Figure 6 Top and rear side layouts of a band-pass filter designed in [4] for the frequency band 1 GHz in width with the central frequency 6 GHz

slotted microstrip line feeding line were closed, and the slotted microstrip line was thus replaced by a 50 Ω microstrip line coupled via a patch. The slotted microstrip line from the other side of the filter was replaced by a 50 Ω CPW line, and a small patch was added on the top side of the substrate to increase the capacitive coupling between the CPW line and the filter itself. The layout of the modified filter is shown in Figure 8. The filter has been designed using the AR600 substrate 0.787 mm in thickness with a relative permittivity of 6, the filter has a length of about 16 mm.

The bandwidth of this filter can easily be widened by either narrowing the shunt inductive strips, or by increasing the coupling between the patches and the input/output lines. The central frequency of the filter pass-band can be controlled namely by inductive strip length *l*, see Figure 8. This is documented by the results of a parametric study in Figure 9, where the return loss of the filter for different *l* is plotted. Increasing *l* shifts the central frequency of the filter to a lower frequency band. The filter was designed with the help of results presented in the previous paragraph. The particular patches and strips were designed using the simple transmission line theory. The whole filter structure was finally optimized by SONNET software.

The simulated frequency response of the filter from Figure 8 prepared for the integration with the patch antenna is plotted in Figure 10.

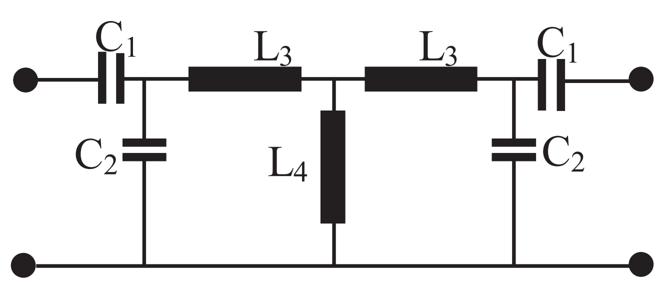

Figure 7 Equivalent circuit model of the filter

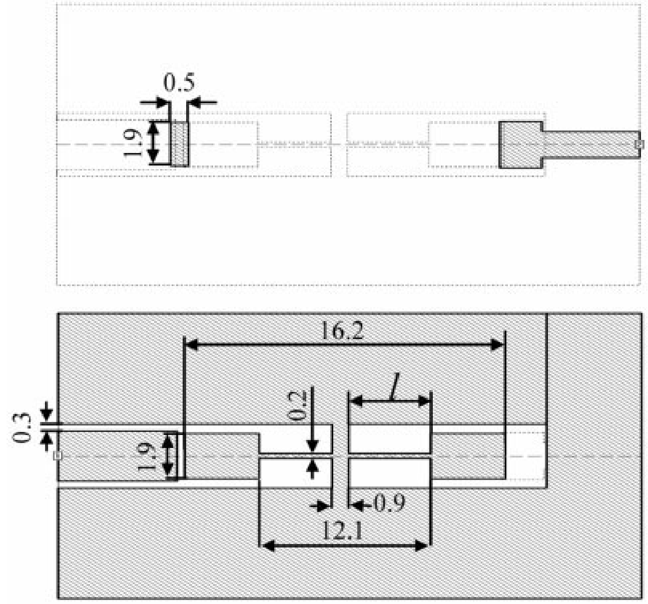

Figure 8 Top and rear side layouts of a band-pass filter with microstrip line-CPW feeding lines. The dimensions shown in mm correspond to the filter integrated with a patch antenna where $l = 4.7$ mm for the central frequency 3.5 GHz

This filter was designed as a transition between the CPW and the microstrip line in the case of a required filtering behavior. The top layout for such an application designed for the central frequency of 3.5 GHz is shown in Figure 11. The filter is inserted into a patch antenna feeding circuit. Thus, the antenna is ready to be integrated directly to the CPW based circuit located on the rear substrate side. The filter cuts out the higher order resonant responses of the patch antenna. This is documented in Figure 12, where the calculated and measured S_{11} scattering parameter is plotted versus frequency. Figure 12 shows at the same time the response of the patch antenna itself calculated by Microwave Studio. The tolerances of the fabrication process, however, caused a slight shift of the antenna frequency band.

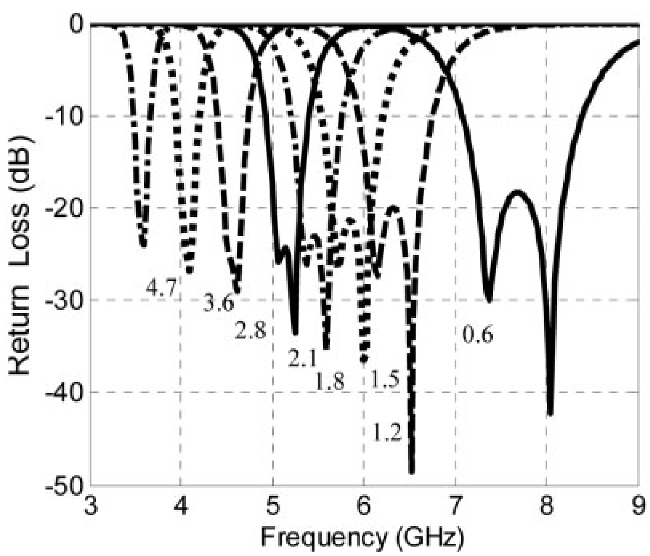

Figure 9 Returns losses of the filter from Figure 7 calculated by SONNET for inductive strip length l varying from 4.7 to 0.6 mm

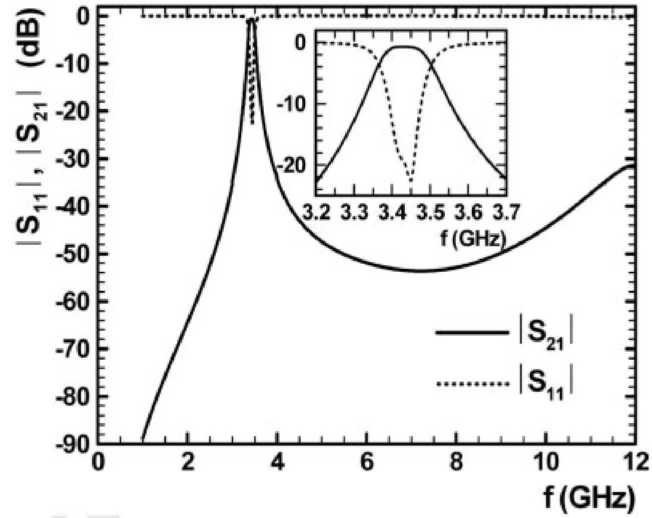

Figure 10 Simulated insertion and return losses of the filter from Figure 8

The presence of the filter had a slight influence on the antenna radiation pattern, as shown in Figure 13. The maximum radiation intensity is directed at 105°, Figure 13. The radiation pattern was measured at 3.65 GHz, representing the best match of the fabricated antenna, whereas the simulation by Microwave Studio was done at 3.5 GHz, which corresponds to the best match obtained by Microwave Studio. The radiation pattern in the plane perpendicular to the plane defined in Figure 13 is symmetrical and has a standard shape, as expected for the patch antenna.

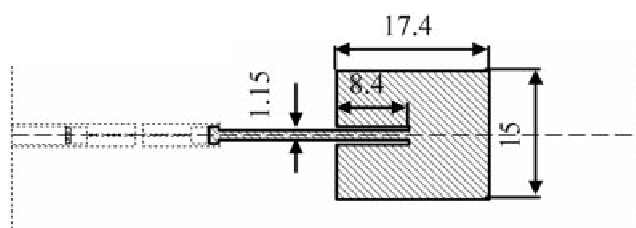

Figure 11 Top layout of the filter from Figure 6 integrated with the patch antenna

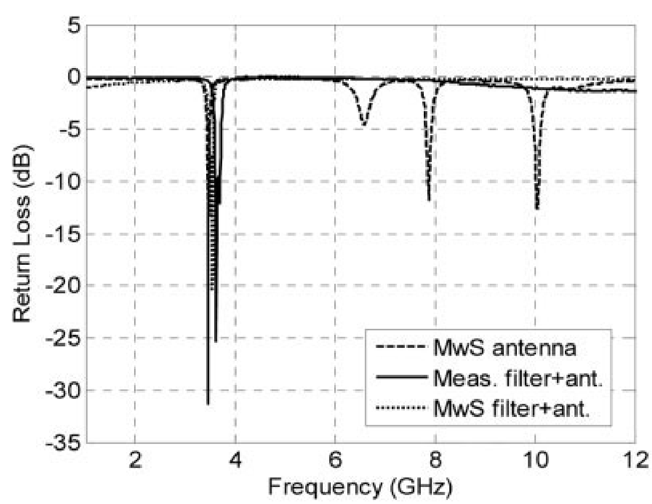

Figure 12 Return loss of the patch antenna itself and the patch antenna integrated with the filter from Figure 7

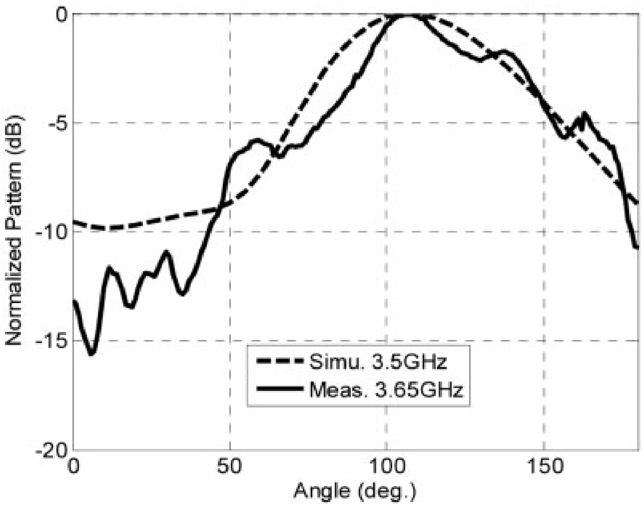

Figure 13 Radiation pattern of the patch antenna integrated with the filter measured in the longitudinal plane of symmetry, Figure 9. The angle of 180° corresponds to the direction of the feeding line, while 90° represents the direction perpendicular above the patch

4. CONCLUSION

This article briefly reviews the modified multilayer coplanar lines, their characteristic impedance, and mutual coupling. These transmission lines were used as building blocks for the design of the quasi-lumped filter assembled on the two sides of the substrate. This bandpass filter is compatible with CPW on one port and with the microstrip line on the other port. It is applied as a transition between the CPW feed and a microstrip patch antenna, and at the same time cuts the higher order patch resonances. The electromagnetic simulation shows acceptable agreement with the experimental results.

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RADIATION PROPERTIES OF AN OMNIDIRECTIONAL PLANAR MICROSTRIP ANTENNA

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ABSTRACT: *The pattern and directivity of an ideal omnidirectional antenna, collinear coaxial, and omnidirectiontal microstrip antenna (OMA) are compared. The radiation of an OMA originates from the arraying of two radiating edges along each element. The width of the (OMA) elements determines omni-plane pattern variation.* © 2007 Wiley Periodicals, Inc. Microwave Opt Technol Lett 50: 55–58, 2008; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.22995

Key words: *omnidirectional; microstrip antenna; pattern variation*

1. OMNIDIRECTIONAL ANTENNA THEORY

The design of a linear omnidirectional antenna generally consists of a geometry, which creates an equivalent of a set of colinear stacked half-wavelength dipoles. To analyze this type of antenna theoretically, we will assume a set of uniform amplitude inphase stacked half-wavelength sinusoidal currents. Each half-wavelength radiator will be called a segment. This assumption is justified in section 1.1 from the inspection of currents produced by a method of moments solution of a coaxial colinear (COCO) antenna.

We may use magnetic vector potential to compute the electric field (E_z) of the far-field radiation patterns from this assumed current distribution (Figure 1). The assumed sine function represents the current on each radiating segment. We sum the contributions to the z directed vector potential from each segment to obtain the total field contribution at a given angle θ:

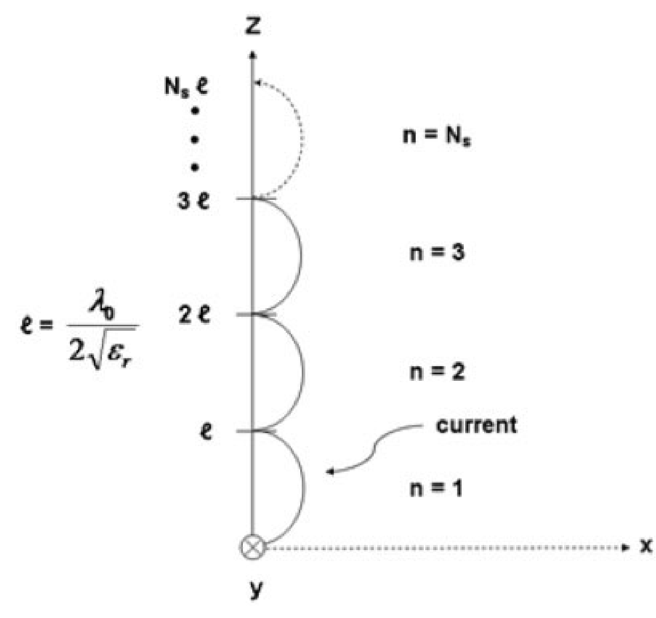

Figure 1 Currents on a perfectly driven set of ideal stacked half sinusoidal currents which produce an omnidirectional pattern