

Wide-Band Slot Antennas With CPW Feed Lines: Hybrid and Log-Periodic Designs

Alpesh U. Bhoobe, Christopher L. Holloway, *Senior Member, IEEE*, Melinda Piket-May, *Senior Member, IEEE*, and Richard Hall

Abstract—In microwave and millimeter wave applications, slot antennas fed by coplanar waveguide (CPW) lines are receiving increasing attention. These antennas have several useful properties, such as a wider impedance bandwidth compared to microstrip patch antennas, and easier integration of solid-state active devices. In this paper novel CPW-fed wideband slot antennas are presented. The design procedure of CPW-fed hybrid slot antennas (HSA) having impedance bandwidths ($VSWR < 2$) up to 57% is described. Theoretical and measured results are shown. We also describe the design procedure of a CPW-fed log-periodic slot antenna (LPSA). The impedance matching and the radiation characteristics of these structures were studied using a method of moment technique. Simulated and measured results for different dielectrics are presented.

Index Terms—Coplanar waveguide (CPW)-fed, slot antennas, wide-band antennas.

I. INTRODUCTION

NUMEROUS advantages have been obtained by feeding a radiating element with coplanar waveguide (CPW) feeds; such as lower radiation leakage and less dispersion than microstrip lines. CPW-feed lines also facilitate parallel as well as series connection of both active and passive components on one side of the planar substrate thereby eliminating via hole connections. Many slot antenna elements suitable for a CPW-fed configuration have been reported in literature. Open-end CPW-fed microstrip antennas have been studied experimentally [1], [2]. Similar geometries of microstrip antennas inductively and capacitively coupled to CPW have also been investigated [3]. The conventional CPW-fed slot antenna is a one-wavelength center-fed slot antenna (Fig. 1). Antennas of this type have been reported in literature for various applications and have impedance bandwidth between 15 to 20% [4]–[8]. An alternative to this design is an open-end CPW structure [Fig. 2(a)], which can be modified to a so-called half-wave capacitively coupled slot antenna [Fig. 2(b)] giving an impedance bandwidth of 10% to 15%. Note that this type of structure has been modeled as a radiating element and is referred to as a CPW-fed slotline dipole antenna in [9]. Unfortunately, no rigorous study of these structures has been formally documented.

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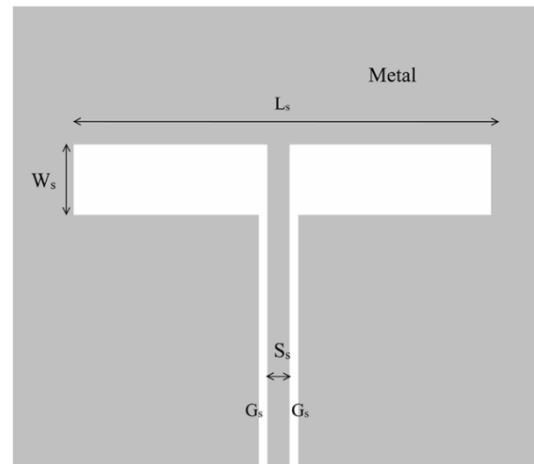


Fig. 1. CPW-fed standard one-wavelength slot antenna.

We present the characteristics of such antennas when compared to the standard one-wave CPW-fed slot antenna. This structure plays an important role in the design of the novel CPW-fed hybrid slot antenna (HSA), discussed in Section III, in which a wider impedance bandwidth is achieved. In this paper we also present a novel design of a CPW-fed log-periodic slot antenna (LPSA).

The paper is structured as follows. In Section II we discuss the half-wavelength CPW-fed slot antenna. Section III introduces a hybrid wide-band CPW-fed antenna and shows results of the prototype that have been realized. In Section IV we introduce the log-periodic design. All the investigated designs were simulated using the method of moments.

II. HALF-WAVE CPW-FED SLOT ANTENNA

The CPW open-end structure is shown in Fig. 2(a). A modification to this open-end structure is presented in Fig. 2(b). This generalized CPW open-end structure [Fig. 2(b)] is a half-wavelength capacitively-coupled slot antenna, in contrast to the standard one-wavelength CPW-fed slot antenna (Fig. 1). The generalized CPW open-end structure can be considered as a slotline resonator shorted at two ends and fed symmetrically on its length by the two slots of the CPW feed line. This rectangular slot has width W and length $L = 2l_e + 2G + S$ [Fig. 2(b)]. The short-end inductance increases the effective electric length of the slot; hence, the physical length is slightly less than one half-wavelength at the center frequency.

A generalized CPW open-end antenna was designed for a center frequency of 4.8 GHz on a substrate of dielectric constant $\epsilon_r = 4.3$ and a thickness of 1.58 mm. A CPW line of 50Ω

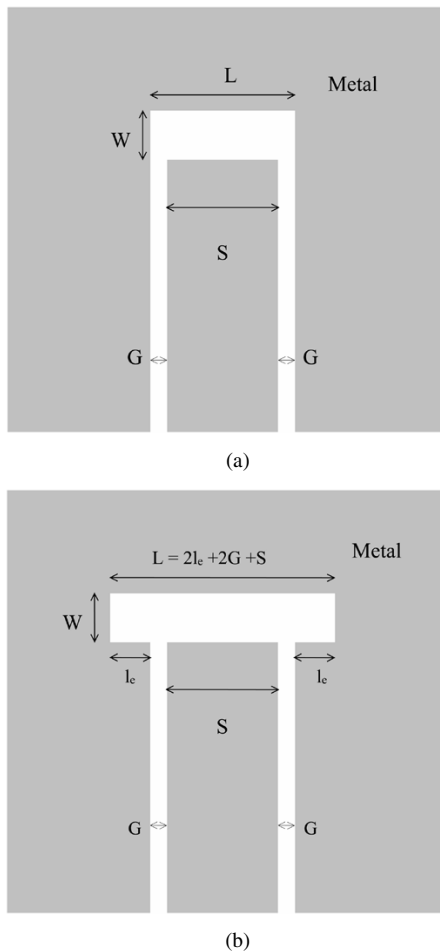


Fig. 2(a) CPW open-end structure. (b) CPW generalized open-end structure (dual of the CPW-fed half-wavelength dipole antenna).

TABLE I
GEOMETRY OF THE GENERALIZED OPEN-END CPW FED SLOT ANTENNA

Substrate (FR4)	$\epsilon_r = 4.3$	$h = 1.58$ mm
CPW feedline	$G = 0.7$ mm	$S = 11$ mm
Slot dipole	$L = 41.4$ mm	$W = 4.5$ mm

feeds the antenna. The parameters of the antenna are shown in Table I.

The antenna resonates at 4.8 GHz with a return loss of -38 dB, which agrees well with the measured values, as shown in Fig. 3. Both the measured and calculated impedance bandwidth of the antenna for a $VSWR < 2$ is 13%. The electric field inside the slot has a sinusoidal distribution with a maximum at the center, and a null at the end of the slot. The computed and measured H and E-plane normalized radiation patterns are plotted in Fig. 4. This slot antenna radiates symmetrically in both upper and lower hemisphere; hence, we show only the upper hemispherical portion of each far-field radiation pattern. The results are in good agreement with one other. The H-plane pattern is broad and smooth, having a half-power beamwidth (HPBW) of the order of 80° . The E-plane pattern is similar, except that the E-field magnitude approaches zero at the horizon because of the infinite conducting ground plane

used in the simulation. The HPBW in this plane is around 170° . The cross-polarization in both planes is 30 dB below co-polarization. The directivity of the antenna is computed by [8]

$$\text{Directivity(dB)} = 10 \log \left(\frac{32400}{\Theta_E \Theta_H} \right) \quad (1)$$

where Θ_E is the half power beamwidth in the E-plane, and Θ_H is the half-power beamwidth in the H-plane. Both the calculated and measured gain in the broadside direction is 2.38 dB.

These characteristics of the generalized half-wavelength open-end CPW-fed slot antenna are similar to the characteristics of the standard one-wavelength CPW antenna, except that the latter exhibits a wider impedance bandwidth. The bandwidth of the generalized CPW open-end antenna increases as the center conductor width S of the CPW feed line increases, as shown in Fig. 5. These results are for antennas designed for a center frequency of 4.5 GHz on substrates of relative dielectric constant ϵ_r of 10.2, 6.2, and 4.3. For all cases the bandwidth increases from 2% for S of 1 mm to around 14% for S equal to 13 mm. Fig. 6 shows a similar trend for antennas designed to resonate at a frequency of 6 GHz on the same substrates.

As the CPW center conductor strip width S increases, the width W of the slot antenna also has to be increased to obtain an optimum match. We would expect this behavior, since this structure is the dual of a fat dipole. These characteristics for generalized open-end CPW slot dipoles resonating at 4.8 and 6 GHz are depicted in Fig. 7 and 8, respectively. For all designs, cross-polarization remains 30 dB below the co-polarization, even for the antenna with the widest width.

III. CPW-FED HSA

The impedance bandwidth of the generalized CPW open-end slot antenna can be increased by combining it with the standard CPW slot antenna as shown in Fig. 9. This structure is referred to as the HSA. The center frequencies of the two structures were kept slightly apart to increase the bandwidth of the overall structure. The following procedure is used to design such a hybrid CPW fed slot antenna.

- Design a standard CPW antenna at a frequency slightly below the center frequency of the desired band (roughly between 8% to 10% below the center frequency for higher dielectric constants [$\epsilon_r > 6$], and between 11% to 15% for lower dielectric constants ($2 < \epsilon_r < 6$]).
- An output port from the standard CPW antenna is used to feed the generalized CPW open-end antenna with equal excitation amplitude and phase at the center frequency with the standard CPW antenna. The separation distance between the two antennas is given by $\lambda/2$ at the center frequency.
- Design a generalized CPW open-end antenna with a CPW feedline with dimensions the same as those of the output CPW line of the standard CPW antenna. The frequency of this antenna should correspond to the center frequency of the desired band.
- Optimize the widths of both structures so that an optimum match is obtained over the entire bandwidth.

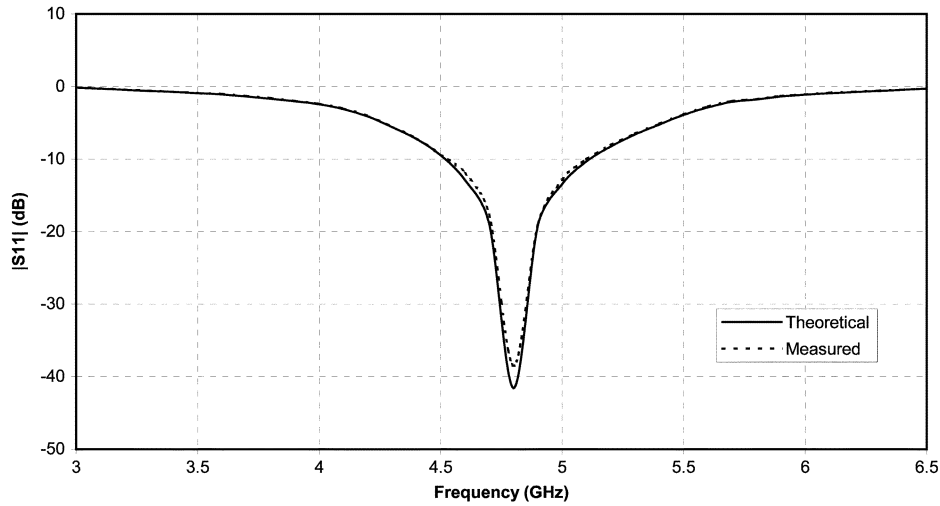


Fig. 3. Return loss of the CPW-fed half-wavelength slot antenna. $\epsilon_r = 4.3$, $h = 1.58$ mm, $S = 11$ mm, $G = 0.7$ mm, $W = 4.5$ mm, $L = 41.4$ mm.

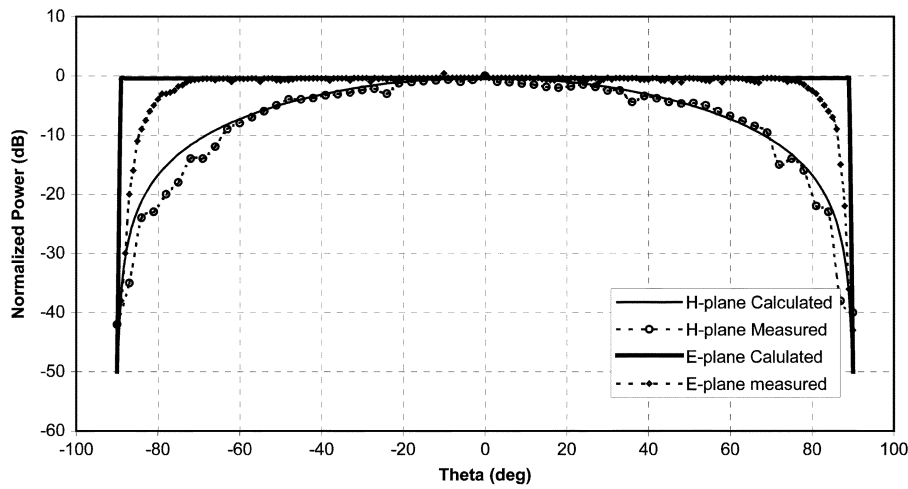


Fig. 4. E and H-plane radiation pattern of the CPW-fed half-wavelength slot antenna for $\epsilon_r = 4.3$, $h = 1.58$ mm, $S = 11$ mm, $G = 0.7$ mm, $W = 4.5$ mm, $L = 41.4$ mm.

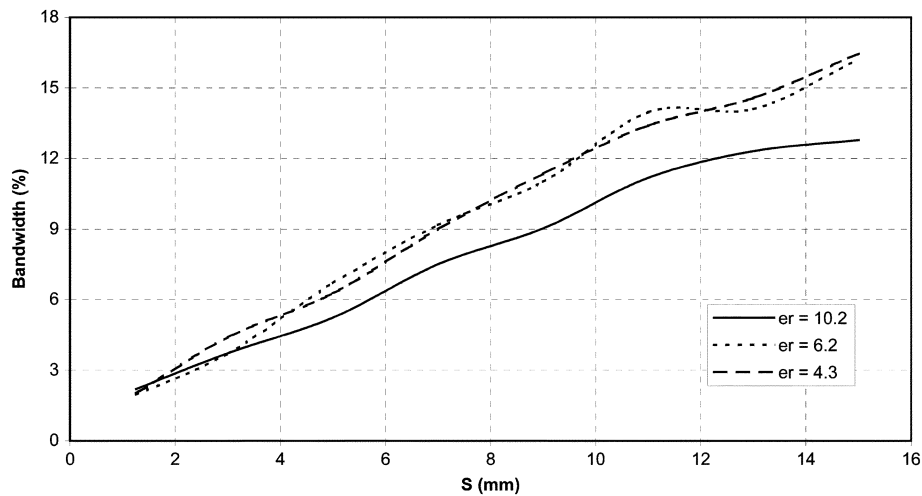


Fig. 5. Variation of the bandwidth with respect to S of the CPW-fed open-end slot antenna at 4.8 GHz for $\epsilon_r = 4.3, 6.2,$ and 10.2 .

A. Design Examples

Several prototype wide-band antennas were designed using the above procedure. The theoretical and measured return loss

for an antenna designed and built on 1.58 mm thick substrate of dielectric constant 4.3 is plotted in Fig. 10. The dimensions of the structure are shown in Table II. The standard CPW antenna was designed to resonate 4.4 GHz, and the generalized CPW

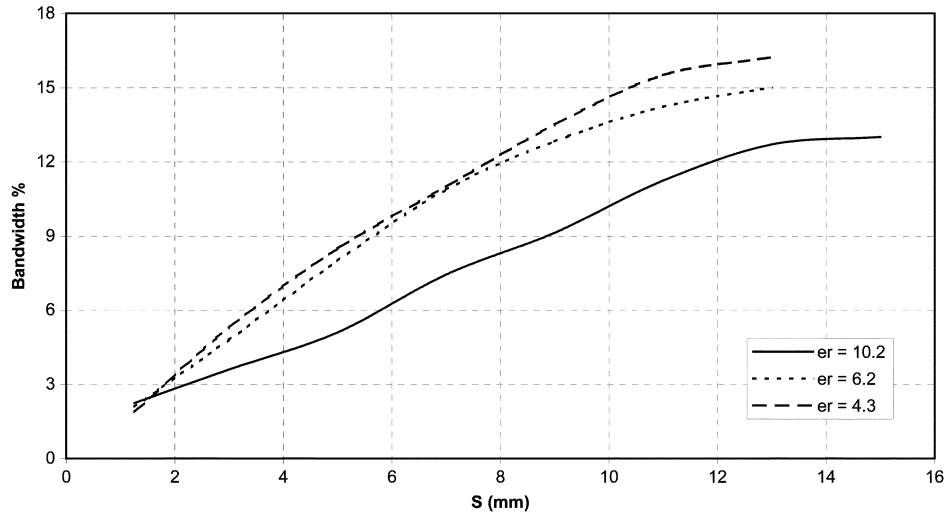


Fig. 6. Variation of the impedance bandwidth with respect to S of the CPW-fed open-end slot antenna at 6 GHz for $\epsilon_r = 4.3, 6.2,$ and 10.2 .

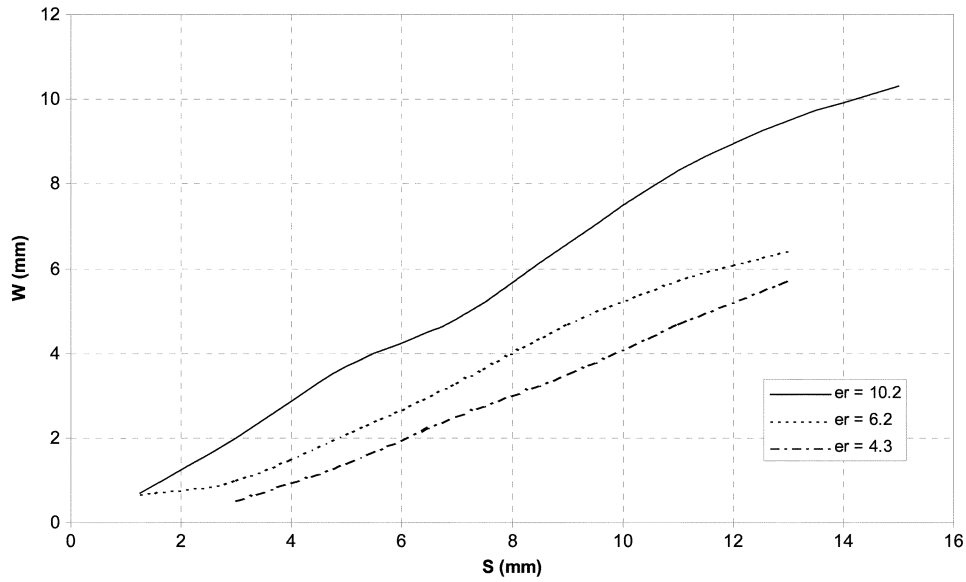


Fig. 7. Variation in slot width W for increasing S of the CPW open-end slot antenna at 4.8 GHz for $\epsilon_r = 4.3, 6.2,$ and 10.2 .

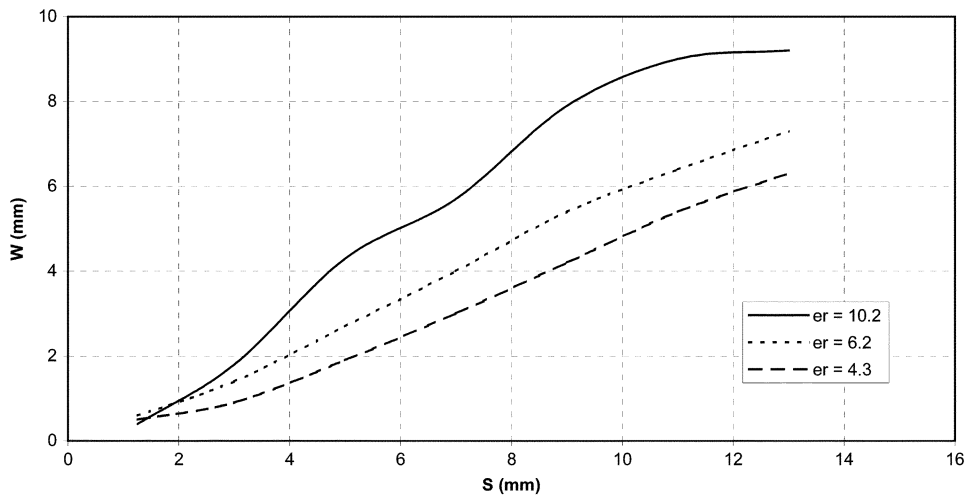


Fig. 8. Variation in slot width W for increasing S of the CPW-fed open-end slot antenna at 6 GHz for $\epsilon_r = 4.3, 6.2,$ and 10.2 .

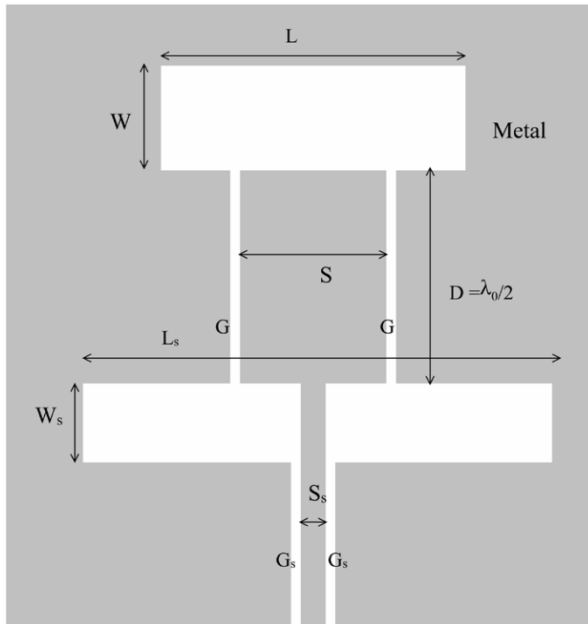


Fig. 9. Layout of a CPW-fed HSA.

open-end antenna at 4.8 GHz. The two antennas were then combined to be fed in phase at frequency of 4.8 GHz. The overall impedance bandwidth of the structure obtained from both simulation and measurement is 49%. Radiation patterns at the center frequency of 4.8 GHz in both E and H-plane (Fig. 11) show beamwidths similar to a single-element standard CPW slot antenna and a generalized open-end CPW antenna with a gain of 4 dB in the broadside direction. Good agreement between the measured and calculated patterns is noted. At the adjacent frequencies, the pattern degrades in the E-plane, due to the fact that the two resonators are not fed in phase at these frequencies. The normalized gain of the structure in the broadside direction, both measured and calculated is shown in Fig. 12. The cross-polarization in both the planes is always at least 30 dB below the co-polarization level throughout the bandwidth. The radiation bandwidth for the wide-band antenna is 43%.

Using the same procedure, another wide-band hybrid structure was designed on a substrate with dielectric constant of 12.5. The dimensions are shown in Table III. The center frequency of the structure is 4.7 GHz. Fig. 13 shows measured and computed VSWRs between 3 and 6 GHz. The bandwidth for a VSWR < 2 is 1.4 GHz, yielding an impedance bandwidth of 33%. The center frequency, theoretical and measured, radiation patterns for both principal planes are shown in Fig. 14. At this frequency, the patterns are quite symmetrical, with very low cross-polarization levels. Again, the radiation patterns at adjacent frequencies show degradation when compared to the patterns at 4.7 GHz. The gain in the broadside varies from 2 to 4 dB across the band. The normalized gain, as a function of frequency, is plotted in Fig. 15.

IV. LPSA

A well-known approach for increasing the impedance bandwidth of an antenna is to utilize a log-periodic design. A wide bandwidth can be obtained by arraying different narrow bandwidth resonators, each having its own frequency of operation.

TABLE II
DIMENSIONS OF THE WIDE BAND ANTENNA ON $\epsilon_r = 4.3$, $h = 1.58$ mm

$\epsilon_r = 4.3$	$h = 1.58$ mm
$S = 11$ mm	$S_s = 1.26$ mm
$G = 0.5$ mm	$G_s = 0.25$ mm
$L = 21.8$ mm	$L_s = 40.3$ mm
$W = 6.7$ mm	$W_s = 4.3$ mm

TABLE III
DIMENSIONS OF THE WIDE BAND ANTENNA ON $\epsilon_r = 12.5$, $h = 1.27$ mm

$\epsilon_r = 12.5$	$h = 1.27$ mm
$S = 11$ mm	$S_s = 0.88$ mm
$G = 0.5$ mm	$G_s = 0.5$ mm
$L = 17.5$ mm	$L_s = 32.26$ mm
$W = 6.5$ mm	$W_s = 4.5$ mm

Various configurations of low profile, conformal antennas have been developed [10]–[13]. Log-periodic antennas are characterized by two geometric quantities. The first is the geometric ratio τ or scaling factor, given as

$$\tau = \frac{L_{n+1}}{L_n} = \frac{R_{n+1}}{R_n} \quad (2)$$

where L_n and L_{n+1} are the lengths of the n th and the $n + 1$ th element, respectively. The second is the angle of divergence α , given as

$$\alpha = \tan^{-1} \left[\frac{L_n}{R_n} \right]. \quad (3)$$

By applying the scaling factor to the first element's dimension, we obtain the dimensions of the other elements. In order to realize wideband performance, the scaling procedure has to be applied to the substrate thickness. However, substrate thickness cannot be periodically scaled in practice [11].

A 5-element prototype array, shown in Fig. 16, was designed on a substrate of dielectric constant 12.5 and thickness 1.27 mm. First the element corresponding to the highest frequency of the desired bandwidth was designed. Different scaling factors from 0.75 to 0.95 were chosen to design the remaining elements. The wideband nature of such a structure is achieved using a scaling factor of 0.95; α for the design is 5° . Fig. 17 illustrates the theoretical impedance bandwidth for VSWR < 2 of 33% and the measured one as 38%. The theoretical and measured normalized gains of this log-periodic structure are shown in Fig. 18. LPSA with 7, 9, and 11 elements were designed on a substrate of dielectric constant of 2.2 and thickness of 1.57 mm. The theoretical return losses for these antennas are shown in Fig. 19. An impedance bandwidth of 32% is obtained for the 7-element design. As the number of elements is increased to

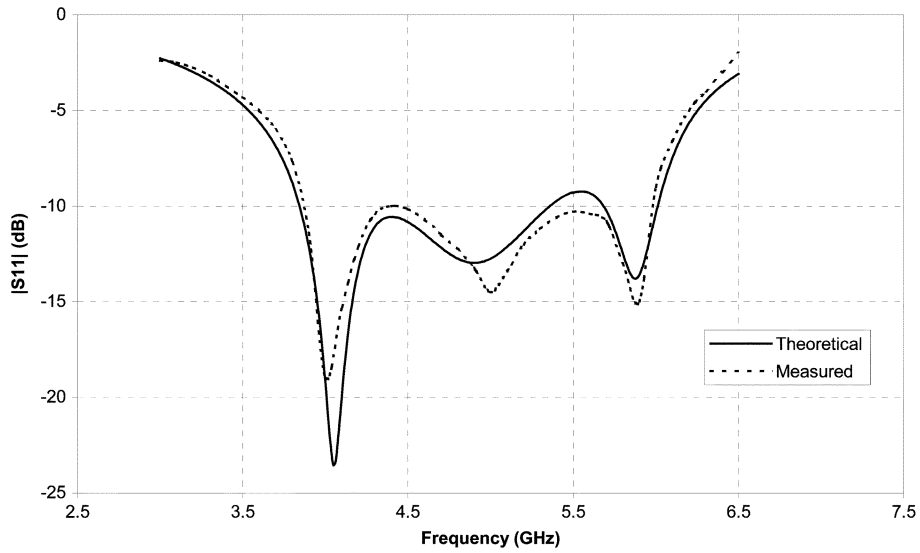


Fig. 10. Theoretical and measured return loss of the CPW-fed HSA for $\epsilon_r = 4.3$, $h = 1.58$ mm, $f = 4.8$ GHz.

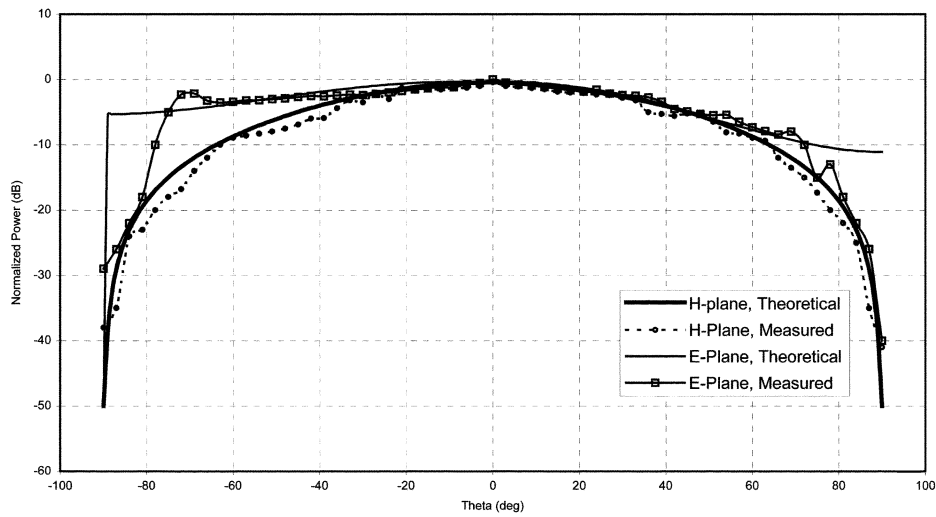


Fig. 11. Theoretical and measured radiation patterns of the CPW-fed HSA at the center frequency of 4.8 GHz for $\epsilon_r = 4.3$, $h = 1.58$ mm.

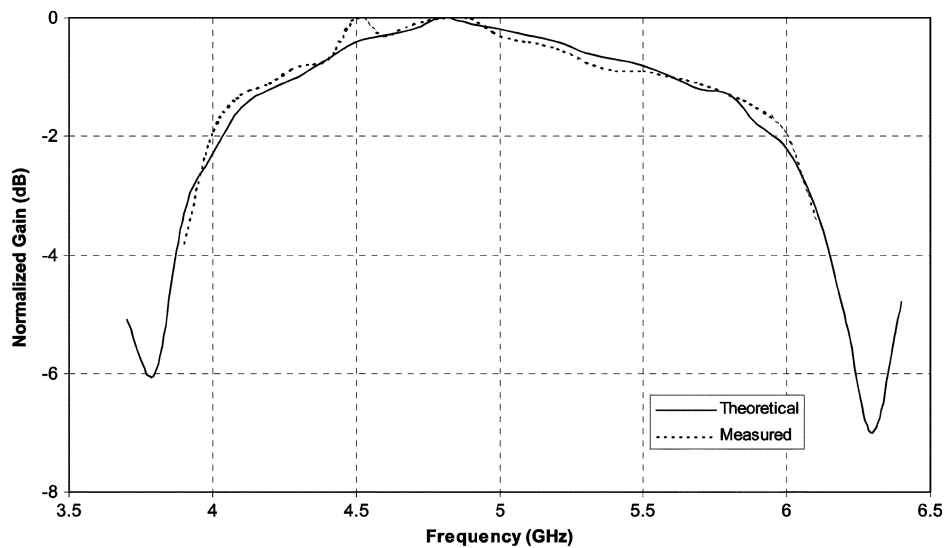


Fig. 12. Normalized gain in the broadside direction of the CPW-fed HSA as a function of frequency for $\epsilon_r = 4.3$, $h = 1.58$ mm, $f = 4.8$ GHz.

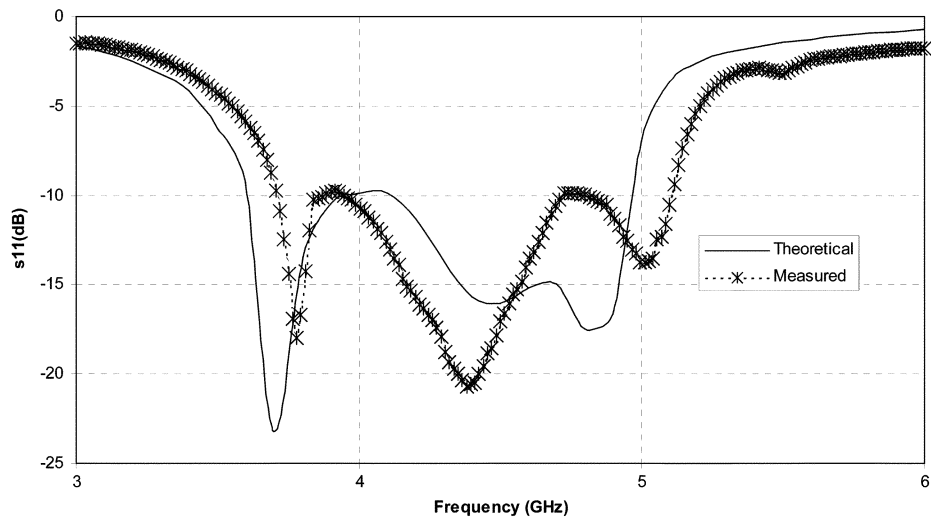


Fig. 13. Theoretical and measured return loss for CPW-fed HSA for $\epsilon_r = 12.5$, $h = 1.27$ mm, $f = 4.7$ GHz.

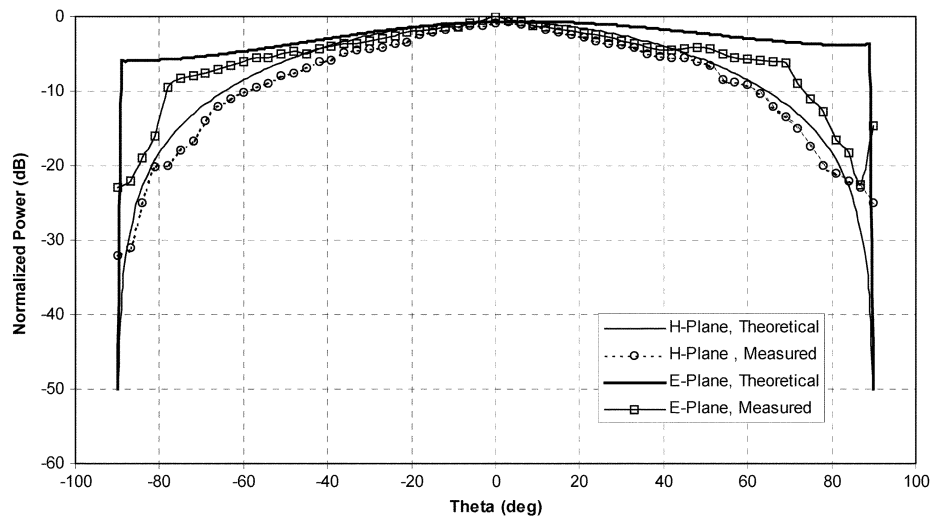


Fig. 14. Theoretical and measured radiation patterns in E and H-planes of the CPW-fed HSA for $\epsilon_r = 12.5$, $h = 1.27$ mm, $f = 4.7$ GHz.

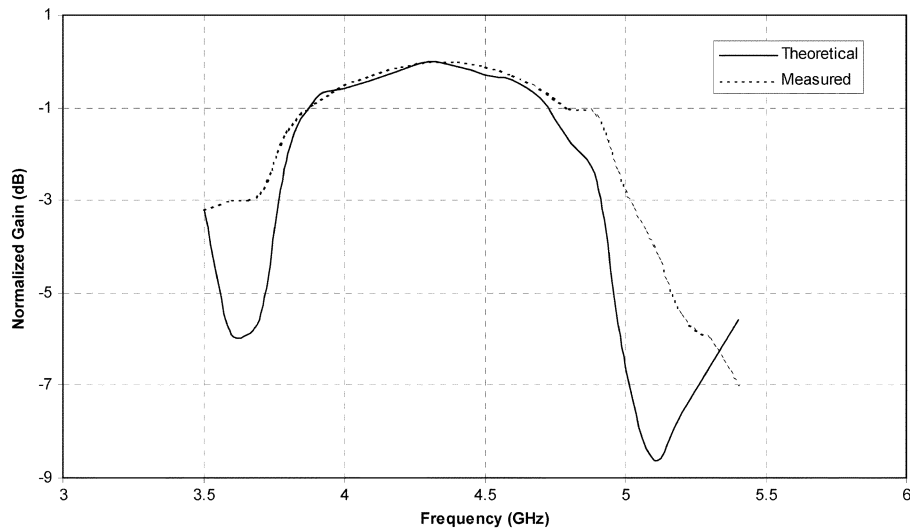


Fig. 15. Theoretical and measured normalized gains of the CPW-fed HSA for $\epsilon_r = 12.5$, $h = 1.27$ mm, $f = 4.7$ GHz.

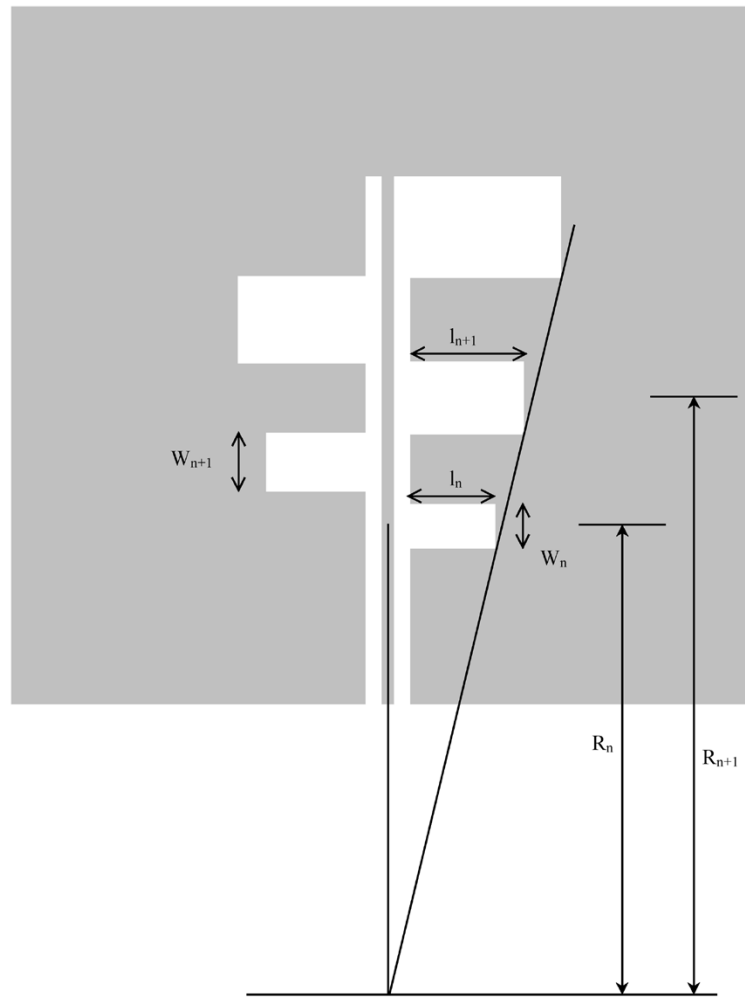


Fig. 16. Layout of a CPW-fed five-element LPSA.

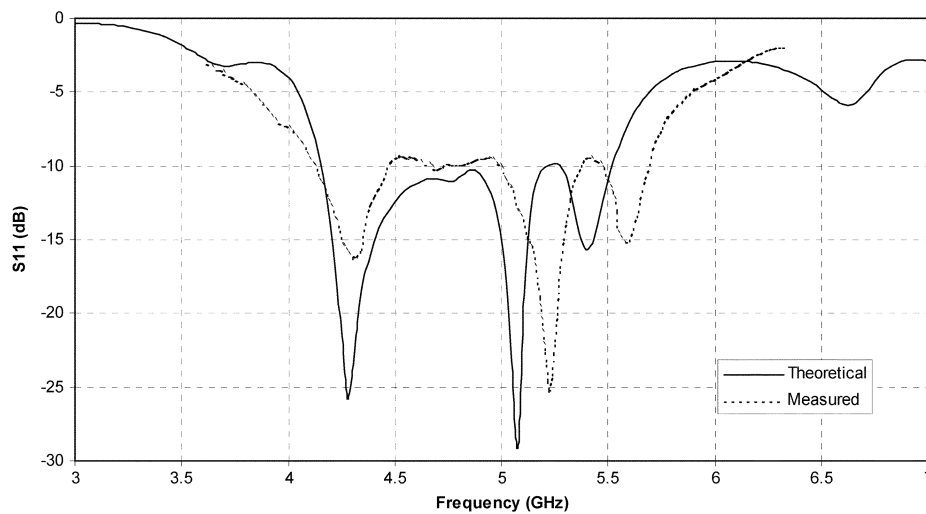


Fig. 17. Theoretical and measured return loss of a CPW-fed 5-element LPSA for $\epsilon_r = 10.2$, $h = 1.27$ mm, $f = 4.8$ GHz.

9, the bandwidth increased to 41%. The bandwidth for the 11-element log-periodic structure is 48%. This structure suffers from a high level of cross-polarization, typically 12 to 15 dB below the co-polarization level.

V. CONCLUSION

In this paper, we have presented novel designs of CPW-fed wideband slot antennas using the moment method technique.

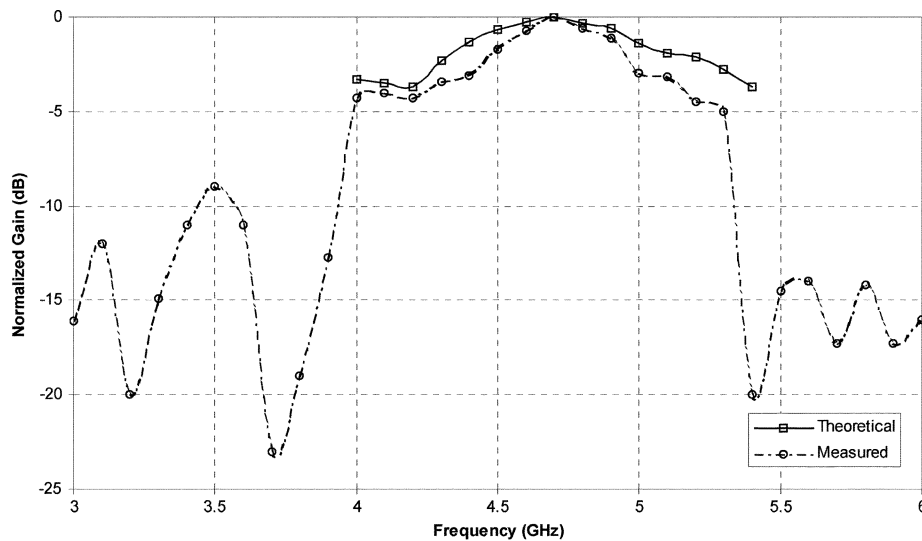


Fig. 18. Normalized gain of the CPW-fed LPSA for $\epsilon_r = 10.2$, $h = 1.27$ mm, $f = 4.8$ GHz.

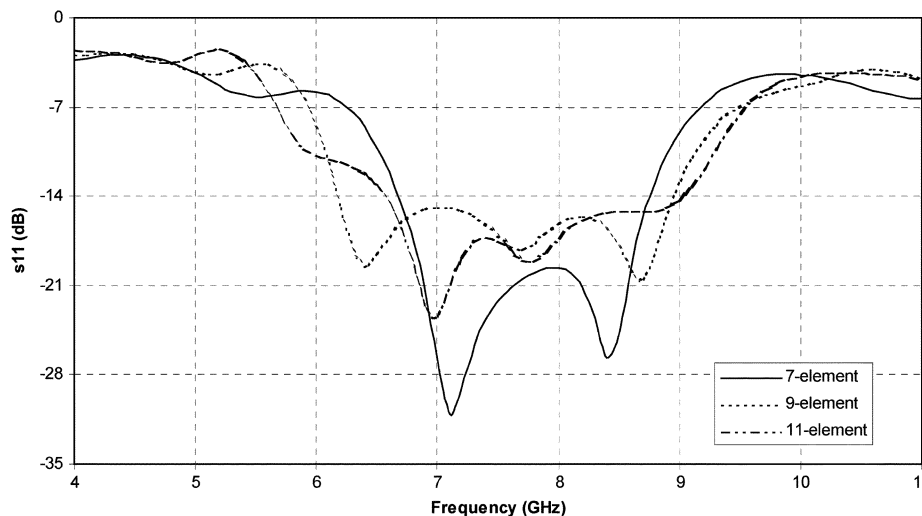


Fig. 19. Theoretical return loss for CPW-fed 7, 9, and 11-element LPSA for $\epsilon_r = 2.2$, $h = 1.6$ mm.

The validity of the design procedure has been illustrated by two design examples of the HSA structure, obtaining impedance bandwidths up to 57%. In both examples good agreement between theory and experiment is obtained. A procedure for designing a CPW-fed LPSA has also been presented. Though the bandwidth obtained from log-periodic structures is comparable to the bandwidths obtained from the HSA structure, it suffers from high cross-polarization levels, typically between 12 to 15 dB below the co-polarization.

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