NOVEL MICROSTRIP ANTENNA ELEMENT AND 2-BY-2 ARRAY FOR SATELLITE TV RECEIVERS

E. A. Soliman,1 A. M. Affandi,2 and K. H. Badr3

1 Physics Department, School of Sciences and Engineering, The American University in Cairo, Cairo 11511, Egypt; Corresponding author: esoliman@aucegypt.edu
2 Electrical and Computer Engineering Department, College of Engineering, King Abdul Aziz University, Jeddah 21589, Saudi Arabia
3 Electronics and Communications Department, Naval Border Guard Institute, Jeddah 21313, Saudi Arabia

Received 19 June 2008

ABSTRACT: A new microstrip antenna element is presented in this article. The proposed antenna is suitable for integration into an array for satellite TV receivers. It has two metal layers only, which reduces its fabrication cost significantly in comparison with other antennas with more layers. The presented results show that the proposed antenna offers wide impedance bandwidth, high isolation between feeding ports, dual-polarization radiation, low cross-polarization level, and high radiation efficiency. A 2-by-2 array based on the proposed element is also presented in this article. Planar corporate feeding networks with new routing approach are used. The presented results of the new array show that it is suitable for use as a building block for a larger array which can replace the parabolic dish reflector in satellite TV receivers. © 2008 Wiley Periodicals, Inc.

Microwave Opt Technol Lett 51: 458–463, 2009; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.24105

Key words: microstrip antennas; dual-polarization; antenna arrays; corporate feeding networks; satellite TV receivers

1. INTRODUCTION

The most commonly used antenna for satellite TV receivers is the parabolic dish reflector. Such type of antenna has the advantage of design simplicity and low cost. However it suffers from a number of disadvantages, such as heavy weight, blockage by the feed horn, sensitivity to focal point, high wind resistivity, and need for a strong mechanical support. These disadvantages result in a great deal of interest in the replacement of the parabolic reflector antenna. The attractive alternative is the light weight, wall-mounted flat microstrip antenna array. As an element in such array, any microstrip dual-polarized antenna with wide bandwidth and good isolation between ports can be used. Dual-polarization is preferable in this application as it doubles the capacity of the communication system by means of frequency reuse.

A lot of research has been performed for dual-polarization microstrip antenna elements. Dual-polarized microstrip antenna fed by slot coupling is first reported in [1]. In [2, 3] the authors show that arranging the positions of the two orthogonal coupling slots into a “T” configuration results in improving the isolation significantly. The same “T” configuration has been adopted in [4] using U-shaped slots. An “H” shape and modified “H” shape slot has been used in [5] and [6], respectively, to further enhance the isolation. The use of crossed slots is reported in [7], where multiple substrates have to be used for carrying the feed lines for each polarization.

The work done in [1–7] has the objective of enhancing the isolation between the two ports of the dual-polarized antenna. There is another trend of research directed toward enhancing the bandwidth of such antennas. To achieve this, several techniques have been reported, including the use of parasitic patches in stacked or co-planar structure [5, 8–10], L-probe feeding [11], or capacitively-coupled feeding [12].

A new dual-polarized antenna is presented in [13]. The radiating slot of this antenna takes the “cusp” shape and placed on one side of a dielectric substrate. It has been demonstrated that such slot shape has two radiating modes which have been referred to as the coplanar and slotline modes. The coplanar mode is excited via a microstrip line running on the other side of the substrate. A slot line is used to excite the slotline mode. This antenna is found very convenient for WLAN applications. In this article, it is developed to be suitable for satellite TV receivers.

Although the concept of replacing the conventional dish antenna with planar array is attractive, there are a relatively few number of publications addressing this topic. A planar wideband circularly polarized 2-by-16 antenna array for Ku-Band satellite communication is presented in [14]. This array consists of four metal layers. The first layer is a directly excited array of bow-tie antenna elements, and the other three layers are carrying a number of microstrip dipoles to work as polarizers. In [15], the authors have presented a flat-array with squinted beam for direct broadcast satellite (DBS) reception. In DBS, the array is required to operate in circular polarization mode instead of the dual-polarization mode required for TV receivers. The circular polarization operation can be obtained from the dual-polarized antenna element via feeding its two ports simultaneously with 90° phase shift. The antenna array presented in [15] consists of a simple traveling wave printed structure comprising a foam/metal sandwich with metal strip polarizer.

The authors in [16] introduce a low side lobe dual-polarized planar antenna array for Ku-band satellite communications. They have developed a dual-polarized antenna element shielded by a cavity, in order to reduce coupling between the antenna elements and feed lines. They also formed the desired aperture distribution by adjusting the number of elements in each row of the array. Wideband aperture-coupled microstrip patch array for satellite TV reception is presented in [17]. Using such array, a gain of 30.5 dBi has been measured. Three metal layers are used to fabricate this array. In [18] the authors have presented a radial line patch antenna (RLPA) for DBS reception. They have used a radial waveguide which couples to two radiating patches of slightly different dimensions to increase the bandwidth. With this RLPA system, a maximum gain of about 29 dBi is measured accompanied by a radiation efficiency of 70%.

A broadband microstrip antenna array for satellite TV reception is presented in [19]. In this array, a dual-polarized aperture coupled microstrip antenna element is used. Using four metal layers, the proposed single element provides 26% bandwidth. A perforated patch is proposed to enhance the isolation between the feeding ports by –11 dB. An 8-by-8 array of circularly polarized stacked slot antenna for DBS application is presented in [20]. This array offers a maximum gain of 25.3 dBi. In [21] the author presented a rhombic broadband planar antenna for DBS reception. This antenna is constructed by arraying a number of linear sub-arrays. The number of elements in each sub-array decreases as we move away from the feeding point which is located at the center of the antenna. This physical taper in amplitude results in a significant reduction in the side lobe level.

To maintain high isolation between the horizontal and vertical polarizations for satellite TV receivers, researchers have always used multilayer designs. In most of these designs four or sometimes three metal layers are used, which increases the overall cost of the array. In this article, a new design which needs only two metal layers, is proposed. This feature of the new antenna reduces...
its fabrication cost significantly in comparison with other designs with more metal layers.

2. SINGLE ANTENNA ELEMENT

Figure 1 shows the geometry of the proposed single antenna to be used as an element in a planar array for satellite TV receivers. The proposed antenna consists of two metal layers and three substrates. The first metal layer is a patch placed on the inner side of the top substrate. The second metal layer is a slot placed on the inner side of the bottom substrate. The used metal layers are copper with 17.5 μm thickness. The top and bottom substrates are RO4003C with dielectric constant of 3.38 and thickness of 0.203 mm. These two substrates are separated by a third one of thickness 5 mm and made of foam with dielectric constant of 1.07.

The proposed antenna has a radiating patch directly fed with a microstrip line, and electromagnetically fed with a slot line running below it. This antenna can be considered the dual version of that presented in [13], whose radiating slot is directly fed with a slot line, and electromagnetically fed with a microstrip line. The radiating patch here, takes the “cusp” shape with an axial ratio modified from unity. This modification is essential to bring the working bands of the two radiating modes together. A rectangular slot of width \( W \) and length \( L \) is etched below the wide edge of the cusp patch, in order to enhance the electromagnetic coupling with the feeding slot line. This rectangular slot is followed by a short circuit stub of length \( l \) to enhance the matching between the antenna and the slot line, as shown in Figure 1.

Like the cusp slot of [13], the modified cusp patch has two orthogonal radiating current modes. The current distributions of these modes are identical to those presented in [13], where the equivalent magnetic current is replaced by electric current. The first mode is equivalent to a vertical \( \lambda/2 \) electric dipole. This mode is excited via the slot line which is running below the patch and assigned to port 1. The second mode is excited with the microstrip line which is directly connected to the path and assigned to port 2. This mode is equivalent to a horizontal \( \lambda/2 \) electric dipole. Since the two modal currents are orthogonal, the proposed antenna is expected to provide the required dual-polarization operation.

Although the previous antenna in [13] is also dual-polarized, it can’t be used for satellite TV receivers as it radiates from both sides of the substrate, which is not required for satellite communications. Since the radiating element of the present antenna is of patch type, it radiates naturally from one side only of the layer structure. Moreover, the antenna used in satellite TV receivers must operate in the frequency band from 10.75 GHz up to 12.75 GHz, which corresponds to an impedance bandwidth of 17%. Such value can’t be achieved using the single thin substrate antenna of [13]. For this reason, a relatively thick foam layer is used here to increase the bandwidth.

The radiating patch of the proposed antenna has five geometrical parameters: the inner and outer diameters of the bigger ellipse \( (D_{\text{out}}, D_{\text{in}}) \), the inner and outer diameters of the smaller ellipse \( (d_{\text{out}}, d_{\text{in}}) \), and the separation between the left-hand side edges of both ellipses \( (s) \), as shown in Figure 1. The selected width for both slot line and microstrip line is 0.2 mm. This value is the minimum safe width offered by the low-cost Printed Circuit Board (PCB) technology which is going to be used for fabricating the antennas. The minimum value is selected in order to reduce the mutual coupling between lines and the parasitic radiation at discontinuities, and to offer sharp electrical lengths for the array’s feeding networks.

The geometrical parameters of the proposed antenna \( (D_{\text{out}}, D_{\text{in}}, d_{\text{out}}, d_{\text{in}}, s, W, \text{ and } l) \) are optimized in order to achieve the best possible S-parameters which meet the required specifications of the satellite TV receivers. It is worth mentioning that the length \( (L) \) of the rectangular coupling slot is dependent on other dimensions, such that: \( L = D_{\text{out}} - d_{\text{out}} - s \). The optimization process is carried out carefully using ADS/Momentum [22]. This full-wave simulator is based on the integral equation formulation solved using the method of moments. For meshing the antenna, mixed rectangular and triangular segments are used. Twenty cells per wavelength combined with a narrow edge mesh are adopted. The optimum dimensions are found to be as follows: \( D_{\text{out}} = 10.186 \) mm, \( D_{\text{in}} = 7.985 \) mm, \( d_{\text{out}} = 6.405 \) mm, \( d_{\text{in}} = 3.486 \) mm, \( s = 0.172 \) mm, \( W = 2 \) mm, and \( l = 4.865 \) mm.

The selected width of feeding lines, 0.2 mm, corresponds to characteristic impedances of 109 Ω and 229 Ω for the slot line and microstrip line, respectively. Although these values of impedances aren’t standard, it should be kept in mind that the proposed antenna is going to be integrated into an array. Consequently, it isn’t important to use standard values at the elements level of the array, while standard values are preferable at the main feeding lines which are connected to the ports of the biggest array.

Figure 2 shows the S-parameters of the optimized antenna element as obtained using ADS/Momentum. In order to validate these results, IE3D [23] is used to simulate the same antenna and its results are also presented in Figure 2. The figure shows reasonable agreement between the two packages. It will be clear later that except for \( S_{11} \) and \( S_{22} \) of the single element, ADS/Momentum and IE3D agree very well. For extracting the characteristic parameters of the antenna, the results of ADS/Momentum are going to be used. The reason for this is that ADS/Momentum allows edge meshing which results in higher accuracy for the same computation expenses [24]. Both \( S_{11} \) and \( S_{22} \) are less than –10 dB along

![Figure 1](image-url) Geometry of the new antenna with optimum dimensions at 11.75 GHz (all dimensions are in mm)
the required working band from 10.75 GHz up to 12.75 GHz. The calculated −10 dB impedance bandwidth at port 1 and port 2 are 23.18% and 17.33%, respectively. At the same time, $S_{12}$ is less than −64 dB over the working frequency band. This means that the proposed antenna satisfies the requirements from the S-parameters point of view. The remarkably low level of coupling between the two ports is a consequence of exciting each mode at the location of the current null or the filed null of the other mode [13].

The radiation patterns of the proposed antenna are calculated at the middle point of the frequency band, which is 11.75 GHz. For each port, the far field components are plotted versus the elevation angle $\theta$ at two values of the azimuth angle $\phi$. These angles are measured as shown in Figure 3. The selected two values of $\phi$ are 0 and 90°, which define two planes named plane 1 and plane 2, respectively.

The radiation patterns of port 1 are presented in Figures 4(a) and 4(b) at plane 1 and plane 2, respectively. The results of both ADS/Momentum and IE3D are shown in this figure. Very good agreement can be observed. As expected from the modal current distribution of port 1, these radiation patterns are similar to those of a $\lambda/2$ vertical dipole whose co-polar components are polarized along $\phi$- and $\theta$-directions in plane 1 and plane 2, respectively. The cross-polarization levels are less than −60 dB and −19 dB over the entire plane 1 and plane 2, respectively. The front-to-back ratio of radiation is 7 dB, where the front- and back-sides are defined as shown in Figure 3. Because of parasitic radiation from the rectangular slot, this value is not very high, but it is still acceptable. This value of front-to-back ratio results in a gain reduction of about −0.8 dB with respect to the ideal case whose ratio is $\approx$ dB.

The radiation patterns of port 2 at plane 1 and plane 2 are presented in Figures 5(a) and 5(b), respectively, as obtained using the two simulators which agree very well with each other. These patterns are close to those of a vertical $\lambda/2$ dipole, as concluded from the corresponding current distribution of port 2. It can be observed that the co-polar components of this port, in both planes, are orthogonal to those of port 1. This ensures that the proposed antenna is dual-polarized. The cross-polarization levels are less than −62 dB and −29 dB over the entire plane 1 and plane 2, respectively. The front-to-back ratio of radiation of this port is higher than 45 dB. This remarkably high value indicates that the
antenna excited from port 2 provides almost pure single side radiation.

The calculated directivity and gain of the antenna as excited from port 1 are 6.47 dBi and 6.44 dBi, respectively. The corresponding radiation efficiency is 99.3%. As for port 2, the calculated directivity, gain, and radiation efficiency are 8.33 dBi, 8.30 dBi, and 99.3%, respectively. The use of relatively thin substrates with low dielectric constant, together with a foam layer with dielectric constant approaches 1, results in such high value of radiation efficiency.

3. TWO-BY-TWO SUB-ARRAY

In this section, four antenna elements are connected together to form a 2-by-2 array. This sub-array can be used as the building block of a larger array for satellite TV receivers. The proposed array is shown in Figure 6, which is fed with planar corporate feeding networks. The first network is made of slot lines and assigned to port 1. The network assigned to port 2 is made of microstrip lines. For these networks, a new approach is used which does not require the conventional quarter wavelength transformers of different characteristic impedances or Wilkinson’s power dividers. Starting from the antennas up to the feeding ports, the first node is a parallel combination of two matched lines, each has a characteristic impedance of \( Z_0 \), as shown in Figure 6. Hence, the parallel combination just after the node is \( Z_0/2 \). This value of impedance is transformed, via a quarter-wavelength line of the same characteristic impedance, to \( 2Z_0 \) just before the second node. Similarly, the same impedance of \( 2Z_0 \) is seen from the other side of this node. The parallel combination seen just after the node is \( Z_0 \), which is matched to the feeding line.

Since lines of different guided wavelengths and characteristic impedances are used for the two networks, each network is designed according to the electrical parameters of its own lines. At the design frequency, the calculated guided wavelengths of the used slot lines and microstrip lines are 20.930 mm and 21.618 mm, respectively. The selected inter-element spacing \( (D) \) is 0.8\( \lambda_0 \), which equals 20.426 mm at 11.75 GHz. Practically, the value of \( D \) should not be less than 0.6\( \lambda_0 \), in order not to affect the array factor by strong mutual coupling between the elements of the array [25]. On the other hand, the value of \( D \) should not be larger than 0.9\( \lambda_0 \) to avoid grating lobes.

The simulated \( S \)-parameters of the 2-by-2 array are presented versus frequency in Figure 7. The figure shows good agreement between the results of ADS/Momentum and IE3D. The return loss of both ports, i.e. \( S_{11} \) and \( S_{22} \), are less than –10 dB over the band of interest from 10.75 GHz up to 12.75 GHz. The calculated –10 dB impedance bandwidths for port 1 and port 2 are 22.72% and 19.15%, respectively. The insertion loss, i.e. \( S_{12} = S_{21} \), is less than –20 dB over the working band. This maximum value of insertion loss is higher than that of the single element (–64 dB). This is mainly due to coupling between the feeding networks. However, –20 dB is considered sufficiently low for most practical applications. The insertion loss of this two metal layers array should not be compared with other four layers arrays, which use additional layer to isolate between the two feeding networks. Such arrays can offer less insertion loss but they are usually much more expensive.

Figures 8(a) and 8(b) show the radiation patterns of port 1 of the array, as calculated in plane 1 (\( \phi = 0^\circ \)) and plane 2 (\( \phi = 90^\circ \)), respectively. Two sets of results are presented, which obtained via the two simulators in use. The degree of agreement is very good. The side-lobe level in plane 1 is less than –13 dB, while no side-lobes are appearing in plane 2. The cross-polarization levels
in these planes are less than $-15$ and $-11$ dB, respectively. In plane 2, grating-lobes start to appear around the endfire elevation angles of $90^\circ$ and $-90^\circ$. Like the single element, the front-to-back ratio of radiation is 7 dB. The main contributors to the unwanted back-side radiation of port 1 are the rectangular slots.

The radiation patterns corresponding to port 2 in plane 1 and plane 2 are presented in Figures 9(a) and 9(b), respectively, as obtained using ADS/Momentum and IE3D. Again, very good agreement can be observed. The side-lobe level is less than $-15$ dB in both principal planes. The cross-polarization levels are less than $-10$ dB and $-10$ dB in plane 1 and plane 2, respectively. The front-to-back ratio of radiation is higher than 27 dB. Such ratio is lower than that of the single element (45 dB), this is mainly due to the increase in coupling between the microstrip and slot line networks.

The calculated directivity, gain, and radiation efficiency of port 1 are 11.32 dBi, 11.19 dBi, and 97.1%, respectively. As for port 2, the corresponding values are 12.84 dBi, 12.83 dBi, and 99.8%, respectively.

4. CONCLUSION

In this article, a new microstrip antenna element and its integration into 2-by-2 planar array are introduced. This array can be used as a building block in a larger array for use in satellite TV receivers as an alternative to the parabolic dish reflector. The proposed element consists of only two metal layers, which makes it cheaper than other elements of more layers usually used for this application. It shows sufficiently high impedance bandwidth, very good isolation between ports, dual-polarization radiation, very low
cross-polarization level, very high radiation efficiency, and it radiates mainly from one side of the layer structure. The used corporate feeding networks for the proposed array are perfectly planar. A new routing method is proposed for this array. The results indicate that the designed array maintains all the appealing features of the single element. Two well-known and trusted full-wave simulators are used to analyze the proposed antennas. The good agreement between them validates the presented results. Using the same routing approach, the proposed 2-by-2 array can serve as the building block of a 16-by-16 array. Such array can provide the required 30 dB gain for satellite TV receivers.

ACKNOWLEDGMENTS

The authors acknowledge King AbdulAziz City for Science and Technology (KACST), Saudi Arabia, for supporting their research under the grant DRP-1–5.

REFERENCES


HORSESHOE-SHAPED ANTENNA FOR DUAL-BAND WLAN COMMUNICATIONS WITH MULTI-L SLOTS

Kyung-Sup Kwak and Sun-Ho Choi
School of Information and Communications Engineering, Inha University, 253 YongHyun-dong, Nam-gu, Incheon 402–751, Korea; Corresponding author: sunnf@daum.net

Received 24 June 2008

ABSTRACT: In this study, a novel horseshoe-shaped antenna with multi-L slots for 2.45/2.4 GHz wireless local area network (WLAN) operations is designed and fabricated. To obtain sufficient bandwidth when return loss (RL) < −10 dB, multi-L slots are inserted (2.4 GHz) in the patch and a coaxial probe source is used. The measured result of the fabricated antenna is a 10.65% bandwidth from 2.38 to 2.51 GHz and a 28.4% bandwidth from 5.10 to 5.88 GHz (RL < −10 dB), the gain 2.04–2.58 dBi. And a good radiation pattern is achieved over the WLAN band (2.4–2.484 GHz and 5.15–5.825 GHz) range. © 2008 Wiley Periodicals, Inc. Microwave Opt Technol Lett 51: 463–465, 2009; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.24096

Key words: horseshoe-shaped; multi-L slots; dual-band; compact; WLAN

1. INTRODUCTION

Wireless local area network (WLAN) is an important application of the wireless communication technology, there are rapid developments, and in order to satisfy the IEEE 802.11 WLAN standards in the 2.4 (2.4–2.484 GHz) and 5 GHz (5.15–5.825 GHz) bands, dual-band operations of the antennas are required. So recently, many laboratories and firms have developed dual-band WLAN antennas satisfying such specifications.

Printed dual-band dipole antennas have been shown to be promising candidates for many WLAN communication devices because of their wide bandwidth, low cost, and easy fabrication.