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Design and Development of a Novel Compact Soft-Surface Structure for the Front-to-Back Ratio Improvement and Size Reduction of Microstrip Yagi Antenna Arrays

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Abstract – A new soft surface (SS) configuration is proposed that can improve the front-to-back (F/B) ratio significantly while maintaining a high gain for any planar antenna array. In addition, the size of this array –including the finite substrate dimensions - has been reduced in comparison to the non-SS design's size. As a benchmark, the proposed SS structure is implemented to the printed microstrip Yagi array design proposed in [1] to achieve a new design with a higher gain and a compact size, that was analyzed for different ground sizes around 5.8 GHz. It is observed that an improvement of at least 3 dB in the F/B ratio and of at least 1 dBi in gain are obtained. Experimental results verify the claims presented in this paper.

I. Introduction

Microstrip patch antennas have many advantages over standard monopole/dipole antennas, such as low-profile, lightweight, low-cost, and easy integrability into arrays with microwave integrated circuits. Meanwhile, Yagi arrays have been utilized in numerous industrial, scientific and medical (ISM) applications due to their high directivity. However, the Yagi arrays currently are too bulky, unsuitable for compact integration with microwave monolithic integrated circuits (MMICs) and RF circuitry due to their size. The design proposed in [1] was able to combine the advantages of Yagi arrays and microstrip antennas to achieve high gain and high directivity with a low profile structure. However, the maximum front-to-back (F/B) ratio (underneath the antenna) was only 15 dB.

There have been a number of efforts trying to further improve the radiation performance of such patch antennas, such as photonic bandgap (PBG), electromagnetic bandgap (EBG), or conventional artificial soft/hard surface (SHS) structure. In [2] a new SHS structure was introduced. It does not requires the substrate thickness to be 1/4 λ_g, allows SHS to be implemented on arbitrary substrate thickness but it was not demonstrated on antennas with arbitrary geometry. In this paper, the authors propose a new soft surface (SS) configuration that can improve F/B ratio (under the antenna as well as on the E-plane side of the antenna) for any arbitrary shape plannar antennas while maintaining a high gain and reasonably low cross polarization. In this geometry, the F/B ratio is the ratio of front side radiation in the range of $0^o \leq \theta \leq 90^o$ to backside radiation (underneath the antenna) in the range of $90^o \leq \theta \leq 180^o$; and the F/R ratio is the ratio of front side radiation ($0^o \leq \theta \leq 90^o$) to rearside radiation in the range of $-90^o \leq \theta \leq 0^o$. As a benchmark, the SS structure is implemented on the microstrip Yagi array antenna design proposed in [1] to form a design with a very high F/B ratio (up to 20 dB), and a size reduction by a factor of 1.5-2, offering unique opportunities for HDTV applications, while enabling the development of ultraband cognitive RF modules. Parametric guidelines for implementation of SS structure on any planar structure are also provided. The SS design in this paper has been designed to resonate at 5.8 GHz, but can be easily scaled to any arbitrary frequency ranges.

II. Implementation of the Soft Surface Structure

The geometry of the soft surface ring surrounding the microstrip Yagi array antenna is shown in Fig. 1. The microstrip feeding line and the slot in the reflector patch have been removed from the design in [1]. Except for small changes, the dimensions of the new structure are the same as those given in [1]. The major difference of this antenna from that in [1] is the feeding mechanism. The driven element, D, is excited by a 50 Ω coaxial line fed through the substrate under the antenna instead of a microstrip line, an essential change necessary for SS ring to be effective. This structure consists of a compact soft surface (SS) rectangular ring , S_i, made of metal strips that are shorted to the ground plane through metalized walls. The walls, S_W, are placed along the outer edge of the metal strips. In fabrication, the metal walls are realized by utilizing vias (8 mils in diameter) with spacing of 10 mils edge-to-edge. All the metal strips have the same optimized width, denoted Q_S, which is λ_g /4. The inner width of the SS ring, W_S, is approximately 5/3 λ_g. The inner length of the SS ring, L_S, is 5/2 λ_g, which is 3/2 of the ring's width (3/2 W_S). The optimized physical dimensions (in mils) are as follows: L_D = 629, W_D = 674, L_{D1}= 610, L_{D2}= 610, W_{D1}= W_{D2} = 448, L_R = 223, W_R = 914, L_s = 3484, W_s = 2242, Q_s = 332, g_r = 558, g_d = 784, g_{d2} = 744.5, g_L = 800, and g_w = 549 as indicated in Fig. 1. Without loss of generality, the structure was designed to have center resonant frequency of 5.8 GHz for WiFi applications. The entire structure was fabricated on a double copper (Cu) clad board of RT/duroid 5880 material (ε_r= 2.2) with substrate thickness of 62 mils.

III. Principles of Operation

Improvement in the radiation characteristics of the antenna arrays is achieved by applying the soft surface to suppress the surface waves, alleviating the diffraction at the edge of the finite substrate. The ground can be truncated to be the same size as the outer perimeter of the SS rectangular ring, thus leading to a significant miniaturization of the antenna design. A plane wave incident on a plane surface reflector with corrugations straight and transverse to the direction of the incident wave was considered by Kildal [3]. The surface can be conditioned to be soft when the depth of the transverse corrugations is a quarter wavelength. In the new proposed configuration (Fig. 1), the surface waves are incident on the shorted metal wall – in a ring configuration - and see an infinite impedance preventing them from propagating beyond the edge of the SS ring due to the quarter wavelength metal strip, thus the waves are trapped by the SS metal strip. The width of the SS ring is taken to be a quarter of the effective wavelength, Q_s= (λ_{eff} /4) where λ_{eff} is $c/(f_r*\varepsilon_r^{1/2})$. The inner length of the ring, L_s, is approximately equal to L_p+ λ_{eff}, where L_p is the total length of the antenna. The antenna is placed about the center of L_s. The optimized spacing is indicated by parameters g_r and g_{d2}. The front metal SS strip (on the + x side) gathers strong current intensity such that it causes interference with the space wave propagating in the + x direction thus reducing the F/B ratio; therefore parameter g_{d2} is bigger than g_r to avoid this interference. The inner width of the ring, W_s , is found to be approximately equal to W_p+ $\lambda_{eff}/2$ where W_p is the total width of the antenna. The antennas are placed precisely at the center of W_s.

IV. Results

A 3D TLM-based simulation package called MicroStripes 7.0 was used to compare the results of the design proposed in [1] (scaled to operate at 5.8 GHz) to that of the model in Fig.1 implemented for two different ground sizes. The E-plane 2D cut of the radiation patterns are plotted in Fig. 2. In this plot, the F/B ratio is the ratio of front side radiation in the range of $0^o \leq \theta \leq 90^o$ to backside radiation (underneath the antenna) in the range of $90^o \leq \theta \leq 180^o$; and the F/R ratio is the ratio of front side radiation ($0^o \leq \theta \leq 90^o$) to rearside radiation in the range of $-90^o \leq \theta \leq 0^o$.The F/B ratios are improved significantly using the SS ring. The F/R ratios are also improved. Maintaining the same ground size as in the model without SS ring (5300x4000 mils from design in [1]), the model with SS ring has a F/B ratio of 19.3 dB; this is an improvement of more than 3 dB compared to that of the model without SS ring, which is 16.1 dB. When the ground size is trimmed to the outer edge of the SS ring (without utilizing the SS strip) the total lateral size of the antenna is 4134.5 x 2904 mils, about 1/2 the size in [1]. For this compact size configuration, the F/B is improved further to almost 20 dB. The F/B and F/R ratios and the gain of the three different models are summarized in Table 1. The cross polarization in the two SS models remains low. The ratios of the peak value of cross polarization to that of co polarization in the model with compact SS ring and in the model with SS ring on the initial ground size are about 21 dB and 23 dB, respectively. The same ratio observed from simulation of the initial design in [1] is about 30 dB.

The return loss of the three models is shown in Fig. 3. The impedance bandwidth of the SS models is smaller than that of the non-SS model. SS ring is a highly frequency dependent structure, at frequencies off resonant SS ring can no longer trap the surface waves effectively. Thus at these frequencies the Q factor due to space-wave loss is increased, thus decreasing the bandwidth. The new antenna bandwidth is limited by the SS bandwidth. The presence of SS ring also contributes a bigger variation of the antenna's input impedance. In addition, the probe feed introduces a probe inductance that also increases Q value.

V. Conclusion

A new soft surface structure was implemented on a microstrip Yagi antenna array for two different ground sizes. With little modifications to the original non-SS design, SS models have been shown to significantly improve the F/B ratio by at least 3dB while maintaining high gain and miniaturize the structure. SS technique was shown to be a robust method that can be implemented on mostly any planar structure to improve gain and F/B ratio, and to reduce the size of the design. Vias can be used to practically realize the metalized walls of the SS structure in a low-loss configuration. The proposed designs in this paper can offer unique opportunities for HDTV applications, integrated with 3D modules that consist of embedded passives, filters, and MMICs and could potentially enable wireless system-on-package (SOP) RF cognitive front-ends for ultrafast applications in WLAN, sensing, multimedia and millimeter-wave applications.

References

[1] G.R. DeJean; T. T. Thai; M. M. Tentzeris; "Design of microstrip bi-Yagi and microstrip quad-Yagi antenna arrays for WLAN and millimeter-wave applications" IEEE Antennas and Propagation Society International Symposium 2006, Albuquerque, NM, July 2006, pp.989-992.

[2] R.L.Li, G.DeJean, J.Papapolymerou, J.Laskar and M.M.Tentzeris, ``Radiation-Pattern Improvement of Patch Antennas on a Large-Size Substrate Using a Compact Soft Surface Structure and its Realization on LTCC Multilayer Technology", IEEE Transactions on Antennas and Propagation, Vol.53, No.1, pp.200-208, January 2005.

[3] P.-S. Kildal; "Definition of Artificially soft and hard surfaces for electromagnetic waves," Electronics Letters, Volume: 24, No. 3, February 1988

Table 1. Summary of F/B, F/R, and Gain

Model	Compact SS ring	SS ring on initial ground size of design in [1]	No SS ring on initial ground size of design in [1]
F/B	19.9 dB	19.2 dB	16.1 dB
F/R	19.59 dB	17.47 dB	18.65 dB
Gain	11.5 dBi	11.47 dBi	11.20 dBi

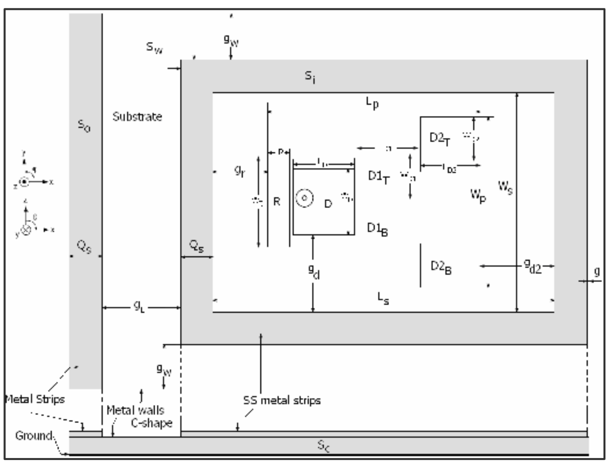

Figure 1. Yagi array Antenna with SS (not for scaling)

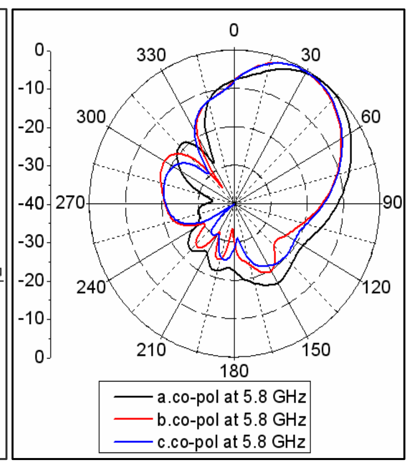

Figure 2. Co-polar plot of Microstrip Yagi Antenna for
a) Model with no SS in initial ground size;
b) Model with SS in initial ground size;
c) Model with SS in compact size

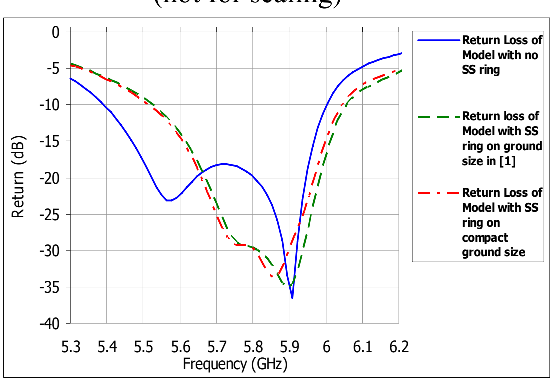

Figure 3. Return loss versus frequency for the three Yagi geometries.