Switched Parasitic Antenna on a Finite Ground Plane With Conductive Sleeve

Robert Schlub, *Member, IEEE,* and David V. Thiel, *Senior Member, IEEE*

***Abstract*—A switched parasitic monopole antenna on a finite ground structure with a conductive sleeve attached to a small, circular ground plane controls the vertical radiation direction. The antenna was designed using a genetic algorithm and finite element (FEM) solver. At 1.575 GHz, the constructed antenna exhibited a front to back ratio of 10.7 dB and gain of 6.4 dBi with no elevation from the horizontal. The switched parasitic nature of the antenna allowed it to steer a directional beam through 5 locations in the azimuth. Incremented from 0λ to 0.45λ, the sleeve was observed to linearly depress the main lobe elevation with little influence on other antenna characteristics such as gain and S_{11}.**

***Index Terms*—Conductive sleeve, finite ground plane, steerable antennas, switched parasitic antennas.**

I. INTRODUCTION

STEERABLE antennas are employed for direction finding applications. Conventionally, beam steering is effected by mechanically aligning a fixed radiation antenna or employing complex feeding networks in phased arrays. While these solutions may be prudent for high performance specialist applications, they are not well suited for low cost systems. For instance, mobile communication or wireless networking systems would benefit significantly from the spatial filtering and directional gain provided by steerable antennas. However, for an antenna to be considered in such applications, allowance for both performance and economics is required. Economic considerations include cost of components, assembly and possible maintenance.

Electronically steerable parasitic arrays offer a promising solution. Similar to the phased array, the radiation direction can be changed in a fraction of a second. In contrast however, the electronics required to do this are simple and inexpensive. This is primarily because the beam-forming elements of parasitic arrays are passive in nature. Therefore complicated, expensive RF feeding circuits are not required.

Electronically steerable parasitic element arrays have been described in the literature [1]–[4]. Milne [5] describes such an array and demonstrates how to steer radiation in both the elevation and azimuthal angle. Harrington [1] introduced the theory of a reactively controlled array of dipoles and provides numerical results demonstrating the directive properties of such arrays. More recently, switched monopole arrays have been examined with the impetus of use in wireless computer and communication networks [3]. Generally though, these arrays have been studied with the assumption that they are composed of dipoles in free space or monopoles on a ground plane of infinite extent. The latter is impractical and adapting these arrays to finite ground structures is an important step in realizing their use in communication systems.

An ideal monopole is defined as a perfectly conducting wire perpendicular to a planar ground of infinite expanse. Such a monopole will exhibit maximum radiation directivity radially from its base toward the horizon. The theory of images allows this ideal monopole structure to be described as a free space dipole twofold in length [6]. Consequently, popular dipole arrays like the Yagi–Uda array [6] can be built with monopole elements on an infinite ground plane. The switched parasitic antenna presented in this article is one such antenna whose design is based on the fundamentals of the Yagi–Uda array.

However, as is the case with a single monopole on a ground plane of finite extent, the characteristics of a monopole array change when the ground plane is limited. Finite ground planes, and especially their impact on monopole radiation pattern and gain, have been examined in detail previously [7]. The influence of the finite ground surface current on the monopole current function was analyzed and numerical results for input impedance and directive gain are also given as a function of the ground plane radius.

Typically, a limited ground surface will introduce a change in the principal direction of the radiation. Unlike the ideal case, the radiation maximum of a monopole or monopole array on a finite ground is elevated above the horizontal. As a consequence, the terrestrial coverage of the radiator will be severely degraded when the antenna is mounted at height above the true ground.

The simple solution to reduce main lobe elevation is to extend the horizontal ground area. This method has obvious practical limits, so an alternative option is to attach a *sleeve* or *skirt* on the perimeter of the ground plane [8], [9]. This effectively enlarges the ground surface, without increasing the antenna's horizontal area. The basic structure of a sleeved monopole that surrounds the source coaxial cable is shown in [10].

This article describes a skirted parasitic array that exhibits radiation controlled by the switching of parasitic antenna elements. The antenna design is the result of a genetic optimization technique employing a finite element (FEM) based cost function. Examination of the sleeve will be performed to determine its effect on antenna characteristics other than the elevation of radiation.

II. ANTENNA DESIGN

Fig. 1 illustrates the antenna, consisting of six monopole elements located on a small, circular, perfectly conducting ground

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The authors are with the Radio Science Laboratory, School of Microelectronic Engineering, Griffith University, Nathan, QLD 4111 Australia e-mail: r.schlub@griffith.edu.au; dthiel@griffith.edu.au).

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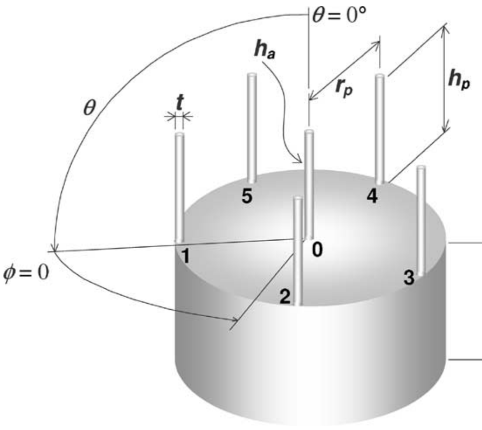

Fig. 1. Switched parasitic monopole array on skirted ground structure.

TABLE I
PROPERTIES OF THE GENETIC OPTIMIZATION

Cost Function	Stopping Criterion	Total Cost Function Computations	Optimization Range				
				h_s	h_p	h_a	r_p
Gain at $\theta = 90°$, $\phi = 0°$	Generation Limit (20)	1092	min (mm)	48	38	38	32
			max (mm)	95	63	63	95

TABLE II
ANTENNA DIMENSIONS OBTAINED BY THE GA

Dimension	mm	Wavelengths (λ)
r_p	48.0	0.2522
h_a	42.5	0.2233
h_p	60.5	0.3178
h_s	58.0	0.3047

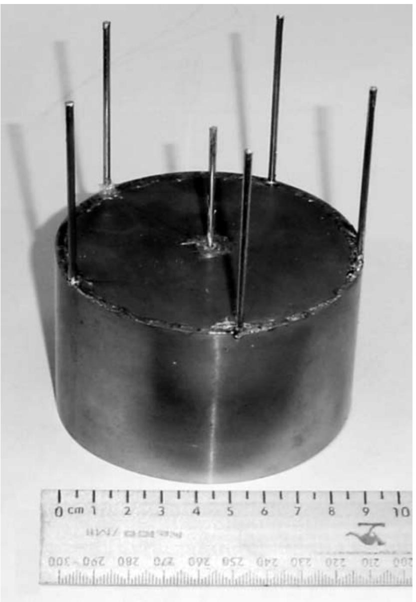

Fig. 2. Constructed antenna – four parasitic (radial) elements are soldered directly to the conducting base while the remaining (upper left) is raised 1.5 mm above the base.

surface. A conductive sleeve bounds the array in order to control the elevation of the principal radiation lobe and to minimize the currents on the central feed cable. A single feed element (*0*) is encircled by five equidistant parasitic elements (*1–5*). Low loss, high isolation RF switches at the parasitic element bases present an optional path to ground. Monopoles routed to ground are reflective, and thus radiation is directed away from these elements. In contrast, an open switch leaves the monopole floating, and radiation passes without significant interference [3]. Different combinations of switched elements allow the formation of different radiation patterns. To form the most directional beam, four of the five parasitic elements are shorted to ground. This pattern can then be steered through the azimuth by alternating the open element in the parasitic ring.

The reflective and directive nature of the parasitic elements mimic those in a Yagi–Uda array. One advantage of the switched parasitic antenna structure lies in its ability to steer radiation around the azimuth. As a consequence, the most directive radiation configuration will be of most interest. Four of the five parasitic elements are reflective to achieve this, so their influence on the radiation pattern will naturally be greater than the remaining directing element. As all parasitic elements must be uniform to maintain rotational symmetry, it follows to design the elements for best reflectivity. The reflective element in a Yagi–Uda array is slightly longer than 0.25λ with a separation of 0.25λ from the feed element. A Yagi–Uda's feed element is slightly less than a quarter wavelength in height. Similar dimensions could be expected for the parasitic radius r_p and monopole heights h_p and h_a if the ground structure were not restricted.

In Fig. 1, the ground boundary will alter the expected currents in the monopoles and the dimensions discussed will no longer be the optimal dimensions for operation. As a complex structure, the analytical solution required to determine the best dimensions is difficult, if not impossible, to achieve. A more appropriate method to find the best dimensions is through an optimization process. A genetic algorithm (GA) was used to tune the active and parasitic monopole heights h_a and h_p, parasitic radius r_p and sleeve length h_s. The horizontal ground radius was kept to a minimum and was restricted to the ring of monopoles. The thickness of the elements t remained constant at 2.3 mm (0.0121λ).

The genetic algorithm technique is a well known and documented optimization method that will not be discussed at length here. For example, switched parasitic antennas have previously been designed using GA's in [11]. The solver used was the finite element based HFSS [12] to calculate radiation characteristics of different antenna structures. From this, a fitness value for the chromosome was determined for each. The aim of the optimization process was to determine those antenna dimensions that resulted in maximum radiation gain in the $\theta = 90°, \phi = 0°$ direction. Table I lists those properties defined in the optimization procedure.

Table II lists the dimensions produced by the GA. The optimization was free to select from a wide range of dimensions (see Table I), and despite the use of the finite ground structure, the derived dimensions were similar to those expected in the ideal infinite ground case.

III. ANTENNA CONSTRUCTION AND TESTING

The antenna defined by Table II was constructed and the performance measured in an anechoic chamber. A photograph of

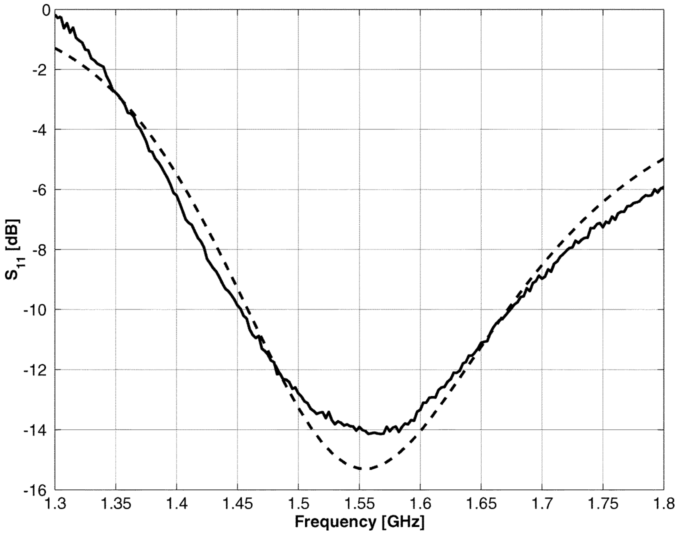

Fig. 3. Antenna reflection response measured experimentally (solid) and simulated with HFSS (dashed).

the antenna is given in Fig. 2. The coaxial feed cable is located centrally inside the conducting cylinder.

Four monopole elements were soldered directly to the perimeter of a circular printed circuit board (PCB) as the reflective elements. The fifth parasitic element (element 1 in Fig. 1) was elevated 1.5 mm above the ground plane and acted as the beam director. The center monopole was fed by an SMA connector attached to the underside of the ground plane. A sleeve of approximately 0.1 mm gauge brass sheet was soldered to the boundary of the ground plane. While this antenna array did not have switching ability, it emulated the most directional configuration of an identical switchable array.

The S_{11}, gain, E plane ($\phi = 0°$) and H plane ($\theta = 90°$) radiation patterns of the constructed antenna were measured and compared to simulation. Fig. 3 shows the measured S_{11} response with its simulated counterpart. Exhibiting a 10 dB bandwidth of 207 MHz, simulation and experimental results are similar. The computed resonant frequency was observed at 1.55 GHz and measured experimentally at 1.56 GHz. The design frequency of 1.575 GHz is well within the bandwidth of the antenna.

The E and H plane radiation pattern measurements are shown in Fig. 4. At 1.575 GHz, the principal lobe gain of the antenna was measured at 6.36 dBi while HFSS predicted 5.76 dBi, a difference of 0.6 dB. Experimental H and E plane 3 dB beamwidths were 106° and 68°, respectively, while the horizontal plane front to back ratio was recorded at 10.7 dB. Two side lobes of significance are evident in the E plane pattern with amplitudes of 7.5 dB and 8 dB below the main lobe gain. The main lobe radiation is depressed under the horizontal by 4°. It will be shown in Section IV that the skirt reduced the principal lobe elevation from 23° above the horizontal.

The simulation procedure can be considered sound given the good comparison with the measured antenna. HFSS accurately predicted the S_{11} and radiation characteristics of lobe direction, shape and gain. As a result, this computational technique was used with confidence when analyzing the sleeve in more detail.

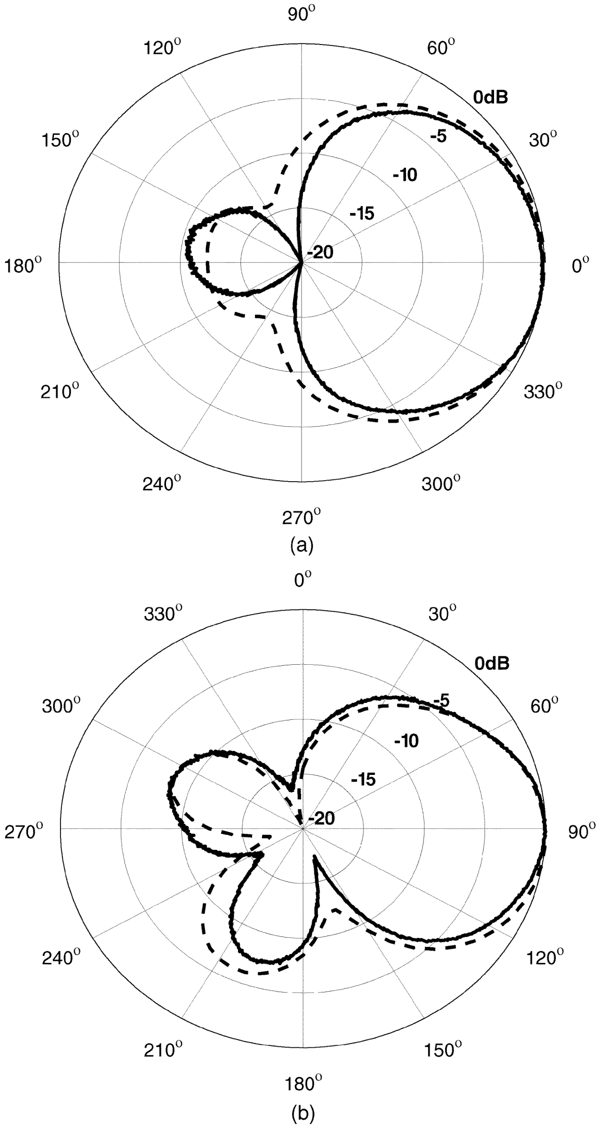

Fig. 4. Normalized (a) H plane and (b) E plane radiation results measured experimentally (solid line) and through simulation (dashed line) at 1.575 GHz. Peak gains of 6.36 and 5.76 dBi were recorded for experiment and simulation, respectively.

IV. SKIRT ANALYSIS

The sleeve attached to the switched parasitic structure removed the radiation elevation typical of a finite ground plane. To clarify this, Fig. 5 presents the simulated E plane radiation pattern of the antenna with and without the skirt. The sleeve has lowered the radiation from $\theta = 66.3°$ to $\theta = 94°$. The reason the optimization overcompensated the skirt length is attributed to the nature of the cost function employed. The cost function fitness was calculated as the gain at $\theta = 90°$, $\phi = 0°$, so antenna efficiency (its match to the feed) as well as directivity contributed to the optimization result. Even though the GA's optimum solution had a depressed principal lobe, its reflection response was better than the solution with a truly horizontal main lobe. As a result, the efficiency offset the gain by 0.1 dB.

To examine the influence of the sleeve in more detail, the sleeve length was incremented from 1 to 146 mm (0.85λ). Each structure was simulated with the main lobe elevation, gain and antenna S_{11} recorded. Fig. 6 displays the results of principal

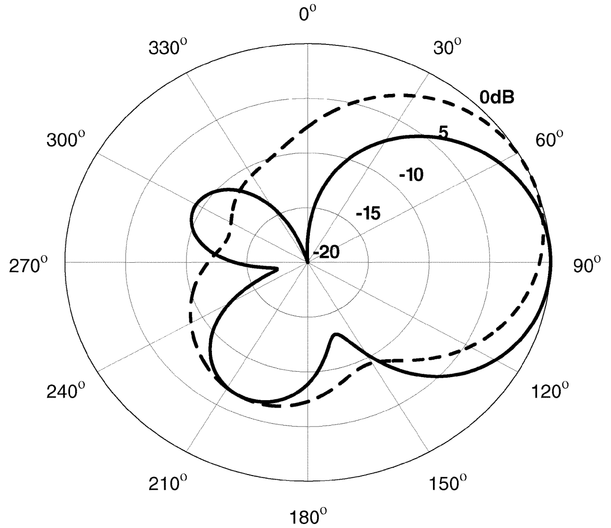

Fig. 5. Normalized simulated E plane at 1.575 GHz of switched parasitic array with (solid line) and without (dashed) skirt.

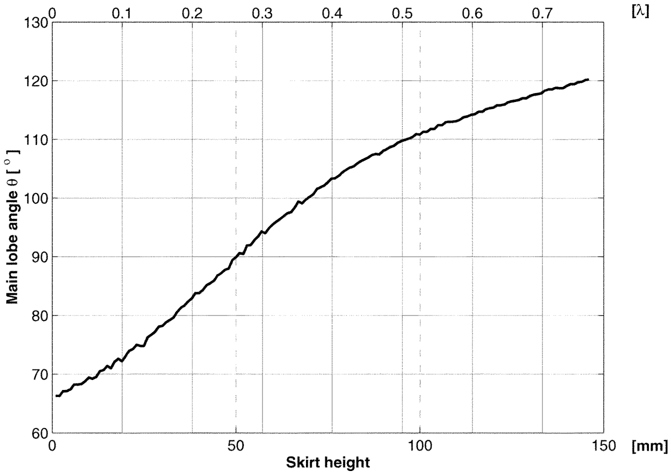

Fig. 6. Skirt effect on main lobe elevation.

TABLE III
ANTENNA CHARACTERISTICS FOR A SLEEVE LENGTH RANGE OF 0λ TO 0.45λ

	Gain (dBi)	S_{11} at 1.575GHz (dB)	E plane Beamwidth (°)
Min	5.7	-15.7	63
Max	6.7	-10.5	84
Range	1.0	5.2	21

lobe elevation dependence on skirt height. Conclusions about these results will only be made for sleeve lengths less than 0.45λ. Above this value, a second major lobe formed above the horizontal ($\theta < 90^\circ$). For sleeve lengths equal to 0.5λ, the second lobe equaled the original in amplitude and as the sleeve length extended beyond, it followed the original's angular descent.

The relationship between skirt height and main-lobe elevation is almost linear up to the 0.45λ boundary with a linear correlation coefficient of 0.9982. At 49 mm, or 0.2574λ, the main-lobe was directed along the horizontal. Before the secondary lobe was formed, the skirt shifted the radiation elevation through 40°, from $\theta = 67^\circ$ with no skirt to $\theta = 107^\circ$ corresponding to a skirt of 0.45λ. To see the influence of the skirt on other electrical characteristics of the antenna, Table III examines the change in gain, S_{11} and E plane 3 dB beamwidths over the 0.45λ range in sleeve length.

With the S_{11} remaining below -10 dB and the gain only fluctuating by 1 dB, it can confidently be said the skirt's primary contribution to the antenna's characteristics is to control the elevation of the main lobe radiation. To a lesser extent, the sleeve reduces the 3 dB beamwidth of the main lobe. Table III shows the E plane beamwidth was reduced from 84° to 63°. This reduction corresponded to an increase in principal lobe gain of 1 dB.

V. CONCLUSION

Switched parasitic monopole arrays that reside on finite ground surfaces have significantly different radiation characteristics than the dipole counterparts their design is derived from. Typically, radiation is elevated from the horizontal limiting the coverage of the surrounding area at ground level.

The radiation can be redirected to the horizontal by skirting the ground plane with a conductive sleeve. A six element, five direction switched skirted monopole array was presented that exhibited a main lobe at $\theta = 94^\circ$, reduced from $\theta = 67^\circ$. A main lobe gain of 6.36 dBi, a horizontal front to back ratio of 10.7 dB and reflection bandwidth of 207 MHz was experimentally measured at 1.575 GHz. H and E plane 3 dB beamwidths were measured at 106° and 68°, respectively.

It was empirically shown through simulation validated by experimental procedure that adding a sleeve to an array structure linearly reduced the elevated radiation without negatively influencing the remaining antenna characteristics. Gain of the antenna's main lobe varied by a maximum of 1 dB while the antenna mismatch remained low with an S_{11} less than -10.5 dB.

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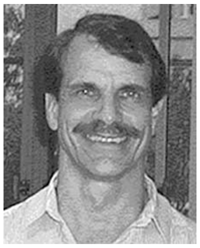
Robert Schlub (M'03) received the B.Eng. degree, with first class honors and the University Medal, in microelectronic engineering from Griffith University, Queensland, Australia, in 1998, where he is currently working toward the Ph.D. degree.

From 2000 to 2001, he was a Graduate Exchange Student at ATR, Japan.



David V. Thiel (M'81–SM'88) received the B.Sc. degree from the University of Adelaide, Adelaide, Australia, in 1970 and the M.Sc. and Ph.D. Degrees from James Cook University, Townsville, Australia, in 1974 and 1980, respectively.

He is currently Head of the School of Microelectronic Engineering, Griffith University, Queensland, Australia, and Director of the Radio Science Laboratory at the same university. His research interests include switchable antennas, numerical modeling in electromagnetics, electromagnetic geophysics and integrated sensor technologies.

Dr. Thiel served on the IEEE Antennas and Propagation Society Ad-Com from 1997 to 1999 and currently Chairs the Wave Propagation Standards Committee.