A Novel Microstrip Feed Based on the Theory of Small Reflection

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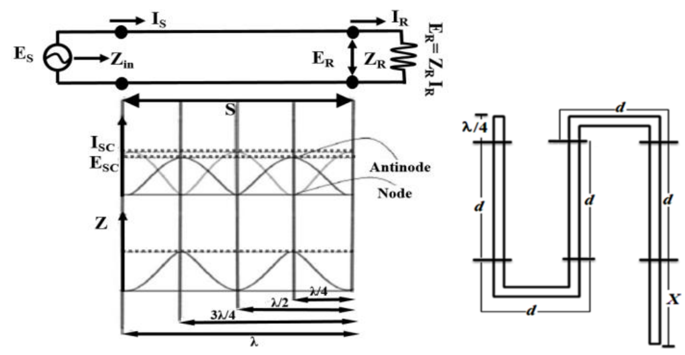
***Abstract*—A six-element microstrip patch antenna based on the theory of small reflection is investigated. The radiators are excited by a novel transmission line. The maxim and minim energy on the proposed transmission line are determined based on voltage allocation on a short-circuited microstrip line. Each radiator, made of a square microstrip patch, is designed to resonate at 5.8 GHz target frequency, with each of them carefully positioned at the maxim in a series-fed array arrangement, in order to catch optimal radiation on excitation of the line. The results obtained are impressive, with an impedance bandwidth of about 6.90%, an aperture size of 1.6λ × 2.1λ and a gain of about 14.2 dBi. The feed demonstrates a compact size advantage, in particular when compared with the conventional series feed network.**

I. Introduction

Antenna arrays have been an indispensable alternative solution to implementing high-gain characteristics, in particular if radiators are small in terms of their aperture size. Small antennas, as a result of their form factor, have low radiative resistance, and hence low gain. One notable alternative to enhance small antennas' gain is to implement an array geometry. Consequently, the idea of realizing low-profile, low-cost, and efficient monolithic arrays has drawn much attention to planar-based arrays using metal radiators. For instance, a corporate feed network was implemented in [1]-[2], conventional series feed in [3]-[4], a series-parallel combination feed network in [5] and a series feed out-of-line network in [6]. The main drawback that serves as a common denominator in all these methods is unavoidable expanse estate area occupancy, which disqualifies them from been integrable into monolithic microwave circuits. In this work, therefore, we present a new series feed topology that can optimize estate area occupancy without compromising directivity.

II. The Design Principle

Voltage allocation on the short-circuited transmission line shown in Fig. 1(a) indicates that antinodes (voltage maxima) repeat themselves at every λ/2 from the generator down the line toward the load completion, and node (voltage minima) at every λ/4. A λ/4 open-ended stub shown in Fig. 1(b), if carefully implemented, could enhance the impedance bandwidth, bearing in mind the effect of fringing fields at the discontinuous open circuit end. To position each radiator carefully at each antinode will require that the input impedance of each radiator be determined, knowing well that the input impedance of a later radiator acts as a load for the former array component. Assume that the admittance of each radiator produces only a small reflection, then the total input impedance of the array can be estimated using Eq. (1).



(a) (b)

Fig. 1: Proposed array. (a) Input impedance, current and voltage variation along short-circuited microstrip line, (b) Element spacing.

$$Z_{in}(\ell_1) = Z_0 \frac{1+\Gamma_{in}}{1-\Gamma_{in}} \quad (1)$$

where

$$\Gamma_{in} = \Gamma\left(1 + e^{-j2\beta\ell_1} + e^{-j4\beta\ell_2} + \ldots\ldots\ldots + e^{-j(N-1)\beta\ell_i}\right)$$

$$\beta = \frac{2\pi}{\lambda}, \quad \ell_i = n\frac{\lambda}{2}, \text{ and } \quad \Gamma_i = \frac{Z_i - Z_0}{Z_i + Z_0}$$

The length of the proposed feed $\ell_i = \ell_1 + \ell_2 + \ell_3 + \ell_4 + \ell_5 + \ell_6$, as shown in Fig. 2, where $\ell_1 = \lambda/2$, $\ell_2 = \lambda$, …… $\ell_6 = 3\lambda$, ……, $\ell_n = n\lambda/2$. For instance, the second element is located at $\ell_2 = \lambda$, with the input impedance Z_{in} given by Eq. (2)

$$Z_{in}(\ell_2) = Z_0 \frac{1+\Gamma_{in}}{1-\Gamma_{in}} \quad (2)$$

where

$$\Gamma_{in} = \Gamma\left(1 + e^{-j2\beta\ell_1}\right)$$

The calculated input impedances at different radiating elements based on Eqs. (1) and (2) are summarized in Table 1. Observations show that the input impedance decreases from the source (the first radiator) to the stub end (the sixth radiator),

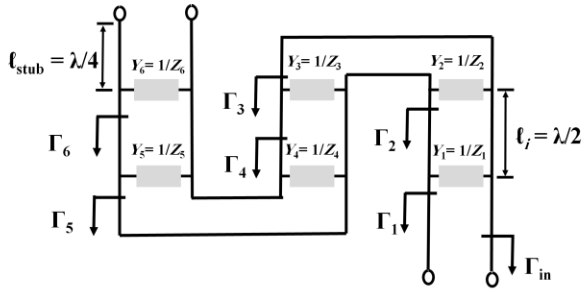


Fig. 2: The input admittance equivalent of the array

whereas the current loading increases correspondingly. Thus, the input impedance of the first radiator is high and the current loading is low. Based on these deductions and calculated parameters, the proposed array is now validated using the full-wave commercially available numerical solver. The resulting design is photo-etched on Roger RO4003C microwave laminate. The design is subsequently measured to determine its reflection coefficient, impedance bandwidth, radiation pattern and antenna gain.

TABLE I. SMALL REFLECTION THEORY VS. PERFORMANCE.

No of Elements	ℓ_i	Γ_i	Γ_{in}	Z_{in}	Freq. GHz	Gain dBi	η_i
1	λ/2	1	-0.013	48.72	5.83	7.20	90.16
2	λ	2	-0.026	47.47	5.78	7.88	87.10
3	3λ/2	3	-0.039	46.25	5.76	8.69	76.74
4	2λ	4	-0.052	45.06	5.82	9.08	73.28
5	5λ/2	5	-0.078	42.76	5.80	10.48	69.18
6	3λ	6	-0.013	41.66	5.76	11.23	66.83

III. THE DESIGN

Each radiator is made up of an 8 × 8 sq mm microstrip patch antenna. The width of the proposed new feed is determined to be equal to 1.9 mm (which is approximately equal to 50 Ω) using the impedance calculator tool available in the commercial solver, and is excited by a coaxial probe. From the open-circuited end, a λ/4 stub is determined toward the generator and the first radiators are positioned at λ/2 each toward the generator,

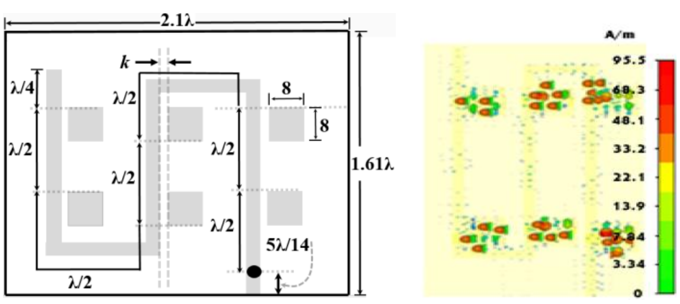


Fig. 3: The input admittance equivalent of the array

bearing in mind the input impedance of the former, as stated in Table 1. A distance of 5λ/14 is maintained between the coaxial probe and the end of the microstrip feed line to avoid more maxima along the transmission line. *k* is optimized to be 0.3 mm in order to achieve optimal capacitive coupling. Fig. 3(b) is the voltage allocation on the microstrip feed line (magnitude) using a numerical computer code. It is evident that that the radiators are appropriately excited.

IV. RESULTS

The $|S_{11}|$ in dB of the proposed design is -58 dB, with an impedance bandwidth pattern of 6.0-5.60 GHz, as shown in Fig. 4(a). The gain is determined to be 14.2 dBi using the absolute gain transfer method. The radiation pattern in the *xy*- and *yz*-planes are depicted in Fig. 5. There is good agreement between the measured and simulated results.

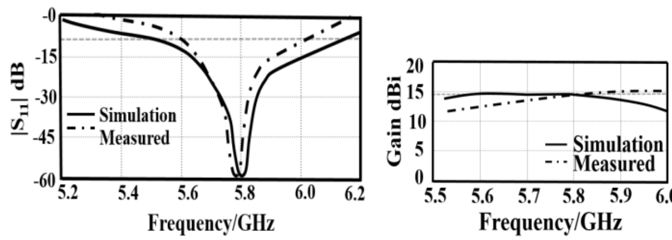


Fig. 4: The $|S_{11}|$ in dB and Gain

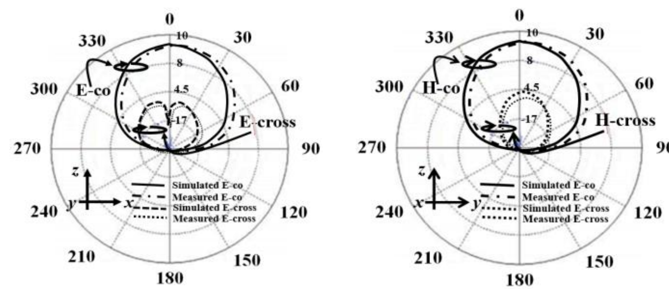


Fig. 5: Radiation Pattern

V. CONCLUSIONS

A novel-fed microstrip feed array based on the theory of small reflection is presented. The resulting design is compact, and it is beneficial where reduced size is a premium requirement.

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