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A Series-fed Patch Array Antenna for Bessel Beam Generation

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Abstract

A dual port series-fed two-port microstrip linear ar- ray capable of generating Bessel beam is presented in this article. The array is amplitude and phase tapered to generate the desired Bessel beam along with the combiner action. The antenna when fed at the ports P_1 and P_2 exhibits a parallel combiner action at the operating frequency with the generation of Bessel beam in the near field. A 16-element array designed at 2.4 GHz is simulated in a 3D EM solver for analysis. The obtained results indicate inherent combiner action along with Bessel beam generation. The dual-port combiner nature of the radiator makes the structure an excellent candidate for transmitter applications for multi-tone signals.

1 Introduction

Microwave wireless systems have evolved significantly in establishing high throughput links between the transmitter and receiver in the past years. Various transmitter and receiver topologies that ensure robust, efficient, yet low operational cost are reported in the literature. However, the beams used for creating a reliable link are not much explored. The conventional beams diffract and lose intensity during the propagation. These diffracted beams lose the transverse beam shape along the wave path and hence, a focused link is difficult to establish with these beams.

Non-diffracting beams can resolve the issue to a great extent [1]. Several non-diffracting beams, such as, Bessel, Math- ieu and Weber are reported in the literature. Of these, Bessel beams have gained popularity due to the transverse beam shape with the central portion holding the maximum intensity. These non-diffracting beams, which are well-known in the optics field, have lately been investigated in the microwave field as well. These non-diffracting beams, well- known in the optical field, have lately been investigated in the microwave regime.

The generation methods of optical Bessel beams employed in the fields of imaging and microscopy[2] are well established. However, generation of Bessel beam in the microwave domain is still in the developmental phase even even though it's the practical scope is enormous which includes focused microwave energy transfer for microwave

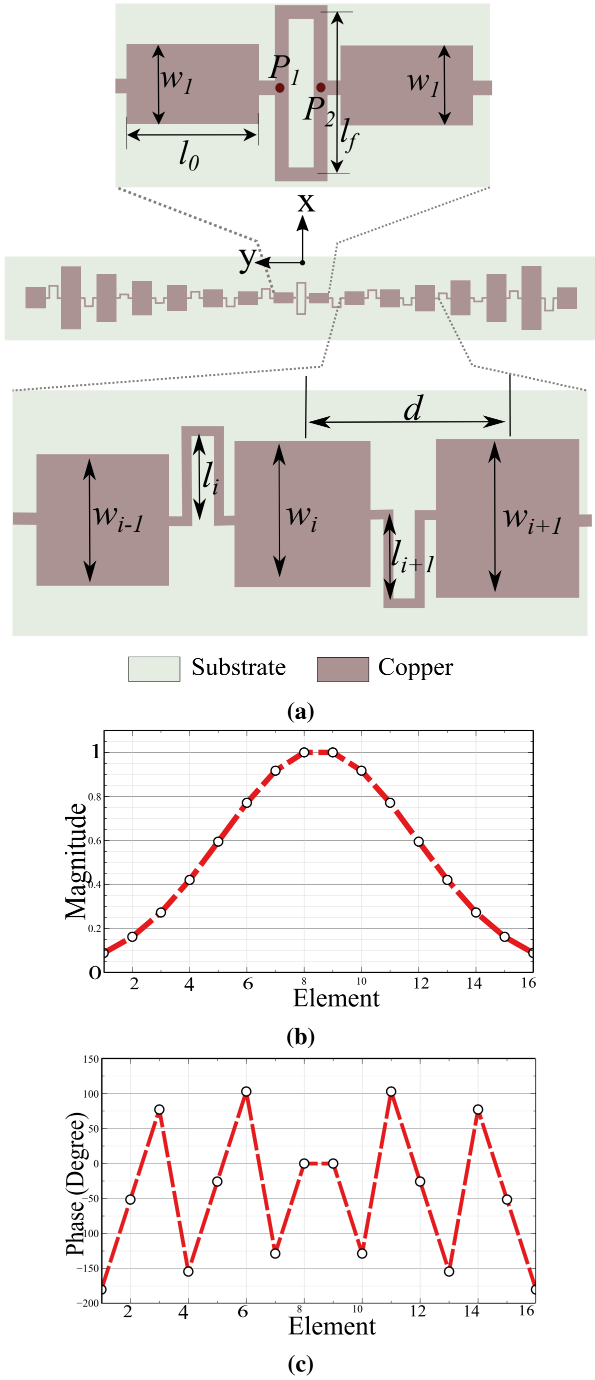


Figure 1. (a) Proposed antenna structure. (b) Normalised magnitude distribution for patch width modulation. (c) Phase distribution for feed length modulation.

drilling in planetary applications [3]. Generation of microwave Bessel beam has been recently attempted using metasurfaces [4] or holographic structures [5]. These structures have a single feed placed mostly on a bottom layer to initiate the TM waves which are modulated by the top layer. This design method does not offer the possibility of integration with the passive networks included in the back end of the antenna system, particularly in a transmitter for multi-tone signals. For multi-tone signals or high peak-to-average power signals, the amplification is done with dual amplifier configurations with a combiner at the output stage [6],[7]. This passive output combiner network can cause parasitic losses leading to significantly degraded results. This may be overcome by integrating multiple ports into the radiator [8],[9]. In this article, a dual-port loop-fed linear array is proposed for generating a Bessel beam along with yielding parallel combiner action.

2 Antenna geometry

The proposed series-fed antenna array is shown in Fig.1a. The 16-element linear microstrip array is amplitude and phase tapered to generate the Bessel beam. The elements of the array are placed with an interelement distance of 'd,' which is half the operational wavelength. The widths of the microstrip patch antennas in the array are governed by the Gaussian distribution whereas the feed lengths of the elements are designed by triangular functions given by,

$$A_i = A_0 exp(\frac{-4ln(2)(i-N/2-1/2)}{(NA_0)^2}). \tag{1}$$

$$\phi_i = -\phi_0 \frac{|i-N/2-1/2|}{(N/2-1)} - \pi \tag{2}$$

where i=1,2..N, with N=16, the total number of elements. 'A_0' and 'ϕ_0' are taken as 0.5 and 900^o (5π rad) respectively. The plots of these distributions are given in Fig.1b and Fig.1c. The widths 'w_i' are calculated with the normalized 'A_i' values computed from (1) and feed lengths are chosen according to the ϕ_i values given in (2). Due to the symmetrical pattern in both the magnitude and phase of the governing functions, the antenna elements' widths and feed lengths are also equal.

A two-port parallel combiner is characterized by its impedance matrix with all the elements equal. Thus, to facilitate the combiner action, the coaxial probe feeds, P_1 and P_2 are placed on a microstrip loop arranged between the centre elements of widths 'w_1'. The length 'l_f' is arranged such that the mean circumference of the loop is an integer multiple of the operating wavelength. This ensures similar field conditions of a port at the other, even when it is in open condition. Thus the parallel combiner action is attained at the operating frequency as all the impedance matrix elements are equal. The radiator structure is designed at 2.4 GHz on a Rogers RO4350B 30 mil thick laminate of size 106.25 × 12 sq. cm. The antenna dimensions are given in Table-1.

Table 1. Proposed Antenna Dimensions

Antenna Dimensions in cm							
w_1 1.91	w_2 2.43	w_3 2.97	w_4 3.52	w_5 4.02	w_6 4.46	w_7 4.76	w_8 4.94
l_1 1.5	l_2 2.40	l_3 2.81	l_4 1.6	l_5 2.1	l_6 2.62	l_7 3.03	l_8 3.47
			l_f 3.63	l_0 2.9			

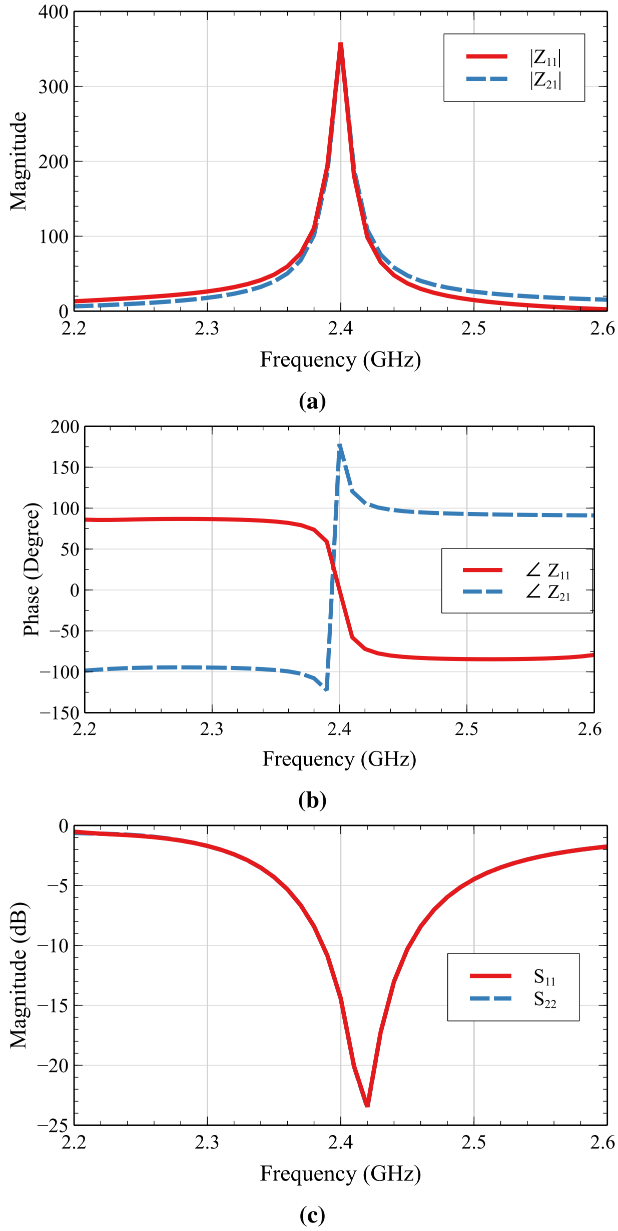


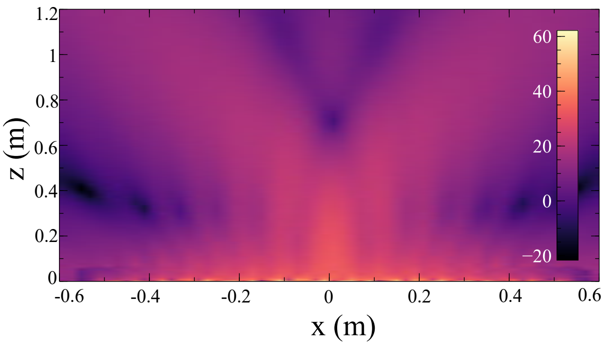
Figure 2. Simulated results of the proposed array at 2.4 GHz: (a) Magnitude of the impedance parameters. (b) Phase of the impedance parameters. (c) Magnitude of input reflection coefficient.

3 Results & Discussion

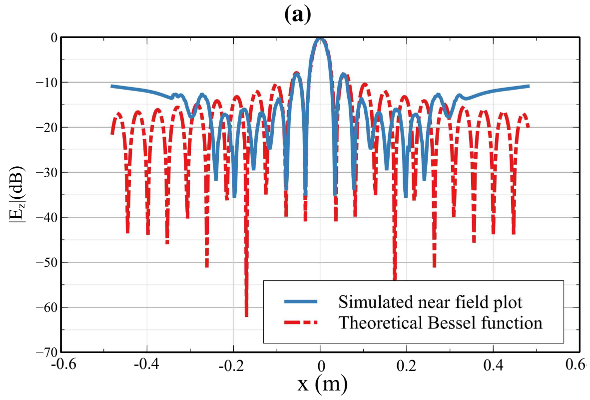
The antenna structure proposed is analysed in a 3D EM solver [10]. The impedance matrix parameters and the magnitude of the input reflection coefficient are shown in Fig.2. As revealed from the plot the magnitude and phase plots of Z_{11} and Z_{21} become equal near the combiner action at a frequency closer to the operating point. Optimization of 'l_f' can shift the combiner action to the desired frequency. The magnitude of input reflection coefficients given in Fig.2c indicates good matching at the operating frequency.

The near field plots of the proposed structure are shown in Fig.3 The rectangular contour plot of the near field electric field indicates the Bessel beam closer to the radiator axis.To validate the performance of the proposed Bessel launcher, the normalized magnitude plot of the near field E_z component at z=35 cm is plotted and compared with the theoretical Bessel function in Fig.3b. For a range of y=-10 cm to y=10 cm, a good match with the desired profile is attained.

The lesser intensity in the contour plot along the propagation length and poor matching along the transverse plane is due to the less number of elements. With more sample points, improved beam generation can be ensured.



(a)



(b)

Figure 3. Simulated near field results of the proposed array at 2.4 GHz: (a) Normalized rectangular contour plot of the near field electric field in YZ plane. (b) Comparative plots of the obtained near field E plots and theoretical squared Bessel function for z=35 cm.

4 Conclusion

The article presents a Bessel beam generator with a series-fed microstrip patch linear array at 2.4 GHz. The travelling wave antenna proposed here is a suitable candidate for transmitters which aims at focused transfer of multi-tone signals. The structure is analysed in a full wave EM simulator and the obtained results indicate the generation of the Bessel function profile for the near field electric field intensity along with combiner action. The simple architecture of the antenna makes the structure suitable for compact low-cost systems.

5 Acknowledgement

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