Design and Implementation of a New One Layer Microstrip Antenna Array with CSC2 Pattern for SSR

M. Abdolahi[1], **Gh. Askari**[2], **and H. Mirmohammad Sadeghi**[2]

[1]Department of Electricaland Computer Engineering
Isfahan University of Technology (IUT), Isfahan 84156, Iran
[2]Information and Communication Technology Institute
Isfahan University of Technology (IUT), Isfahan 84156, Iran

Abstract— In this paper, an antenna with a cosecant squared pattern to work as a radiating vertical array of SSR antennas is designed. A simple microstrip structure is a dopted to design as feed network and 11 half-wave dipoles are selected as radiating elements. In order to achieve desired pattern, amplitude and phase of elements are obtained using a synthesis pattern method. Equal and unequal Wilkins on power dividers are used to prepare desired power amplitudes to feed the elements. The designed antenna has nearly 10 dB gain and its main beam in the elevation plane is 9 degrees above the ground. Its −10 dB Beam width in elevation pattern is 50 deg. and return loss in central frequency is 22 dB. A one element and a two element array are fabricated on RT Duroid5880 ($\varepsilon_r = 2.2$ and $\tan\delta = 0.0009$) with thickness of 31 mil and measured to investigate verification between simulation and measurement and considering mutual coupling.

1. INTRODUCTION

The most common beam shapes found in radar antennas are fan beams which have an upper boundary to detect small and large targets at both short and long ranges. A special case of the fan beam is cosecant squared pattern which has significant features. The cosecant squared elevation beam shape is ideal for detection of small and large targets at both short and long range, including where the antenna is mounted, on a high tower or hill side. In some radars sensitivity time control (STC) is used. STC decreases the sensitivity of the radar at short ranges and increases in long ranges. This system works quite well near the peak of the radar beam, but when used with a cosecant squared pattern, it creates a problem. It decreases the sensitivity of desired targets at high elevation angles where the antenna gain is low. The solution to this problem is to boost the antenna gain at high elevation angles to be considerably higher than requirement for the cosecant squared pattern. In other words, a desired pattern is a cosecant squared pattern which in high elevation angles its gain will be more than a typical cosecant squared pattern [1].

Synthesis of cosecant squared patterns was achieved using reflectors [2], non-uniform arrays [3] and serial fed uniform arrays [4, 5]. The use of microstrip antenna is becoming more and more common nowadays, among others in the area of aviation, telecommunication and radiolocation system. For this purpose, microstrip antennas are used to generate cosecant squared patterns. The typical microstrip implementation is a serial-fed linear array of the type described in [4] and a wideband conformal microstrip array antenna with cosecant-squared beam [6]. The main drawback of a serial fed antenna is being narrowband [4]. Any realization of the cosecant squared antenna using the planar microstrip array would exhibit a narrow bandwidth, even using a parallel-feed network. Shovel-microstrip array which was introduced in [7] is used for solving that problem. This structure has advantage of flexibility of the dielectric substrate, which can easily be shaped.

One of the most uses of cosecant squared pattern is in secondary surveillance radar's (SSR) antennas, these antennas work in two frequencies, 1030 MHz is used to send signals and 1090 MHz for receiving signals is used. A prototype integrated microstrip antenna column [8], a two-layer microstrip antenna for monopulse [9] and microstrip patch that coupling aperture is centered under the patch and feed line is positioned at right angles to the center of slot [10] are some of fabricated antennas for SSR systems. In all of above structures multi layers are used to have an acceptable bandwidth (nearly 8% bandwidth) which for this reason, their fabrication are difficult and have complicate structure. In this paper, a microstrip structure that is simple and works as a radiating vertical array, with printed dipoles as elements, is introduced and a one element and a two element array is fabricated and measured to verify results from simulation and measurement. This new and simple structure has acceptable bandwidth which is one of the most important criteria in design. In first section desired pattern is synthesized with Orchard-Elliot method and amplitude and phase of elements are specified. Next in order to provide our specification for antenna, printed dipole is chosen as element, equal and unequal Wilkinson power dividers are used to provide specified amplitude and phase in elements. Then a special balun for matching feed network with elements is used. Finally result of designed and simulated antenna, result of measurement of fabricated element and array are shown.

2. ANTENNA DESIGN

An antenna with desired pattern (modified cosecant squared pattern) is designed in several steps, at first with a synthesis pattern method, amplitude and phase of elements must be specified. Next feed network for distributing input power to outputs must be designed, then radiating element with considering low mutual coupling and required gain and polarization must be selected and matched with feed network.

2.1. Synthesis of Desired Pattern

Several methods for synthesizing pattern (shaped pattern) can be used. In nonuniformly spaced array antenna, particle swarm optimization (PSO) [13] method and in uniformly spaced array antenna Woodward-Lawson, Fourier series [14], and Orchard-Elliot, ..., methods are used. The pattern synthesis was performed using the Orchard-Elliot method [15]. For this goal, it has chosen to conceive a cosecant squared pattern with $\theta_0 = 9$ deg., since this case seems optimal for SSR systems [5]. An array configuration of 11 elements with $0.6\lambda_0$ distance between elements in 1060 MHz is considered in which required amplitude and phase of elements are obtained. These amplitudes and phases are listed in Table 1.

2.2. Feed Network Design

Weighted power distribution has been used to feed each of elements with specific level of amplitudes and phases. The level of excitation at the inputs for feeding the individual radiators specifies the

Table 1: Amplitude and phase of elements.

El. Num.	Amplitude	Amplitude
1	0.0975	−57.00
2	0.1025	−57.00
3	0.2000	−54.00
4	0.2450	−24.00
5	0.2630	−25.00
6	0.5070	−9.000
7	0.5710	62.00
8	0.4310	121.0
9	0.1550	173.0
10	0.0877	96.00
11	0.1025	156.5

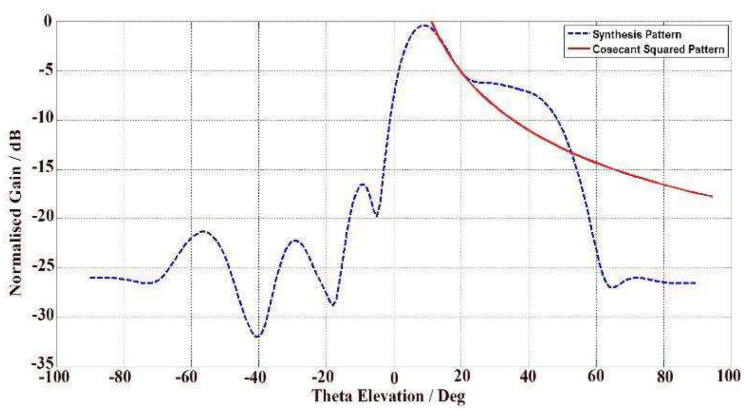
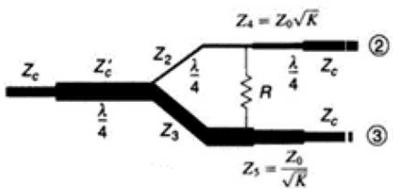


Figure 1: The ideal and synthesized cosecant squared patterns.

radiation characteristics of the array, mainly its effective pattern shape. Array factor which results from this distribution (synthesized pattern), and an ideal cosecant squared pattern are shown in Fig. 1, where beam shaping features can clearly be seen.

The required excitations to radiating elements are provided from input power through some equal and unequal Wilkinson power dividers, which shapes the column's radiation characteristic according to modified cosecant squared function. In order to decrease size of feed network, Wilkinson power dividers from these formulas are designed, shaped and optimized to order in horizontal plane. Designed feed network is shown in Fig. 2.



$$P_3 = K^2 P_2$$

$$Z_3 = \frac{(1+K^2)^{1/4}}{K^{5/4}} Z_c$$

$$Z_c' = \left(\frac{K}{1+K^2}\right)^{1/4} Z_c$$

$$Z_2 = K^{3/4}(1+K^2)^{1/4} Z_c$$

$$R = \frac{1+K^2}{K} Z_c$$

The microstrip feed network have been designed for realizing the array excitations using CST Microwave Studio [12] to provide the required excitation. As it expected, this power distribution should work in two frequencies well; consequently, the output amplitudes should not change in regard to frequency (Fig. 3) and slope of output phase lines should be the same as shown in Fig. 4. These Phase lines have same slope if only length of all paths from input to outputs be the same.

2.3. Antenna Element

The choice of array element is made based on the requirement of bandwidth (10% bandwidth), beam width, desired radiation patterns in E- and H-planes, compatibility with microstrip structures and low mutual coupling for realizing an ultimate low SSL with vertical polarization. Several radiating element candidates exist which can comply with the above requirements. In array applications it is typically necessary to use elements that can be approximately 0.5λ. For this purpose, a parallel

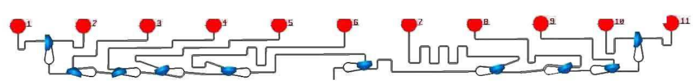


Figure 2: Designed feed network.

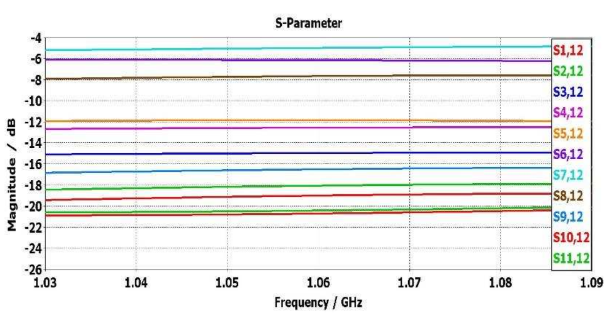


Figure 3: The amplitude distribution.

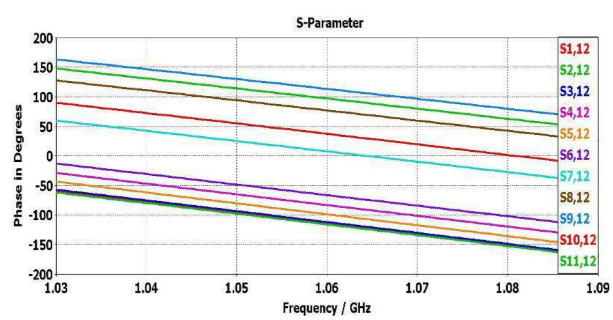


Figure 4: The phase distribution.

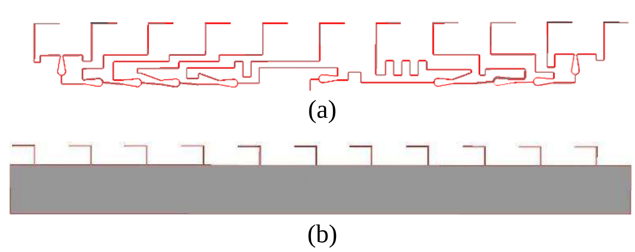


Figure 5: Designed antenna, (a) top view, (b) bottom view.

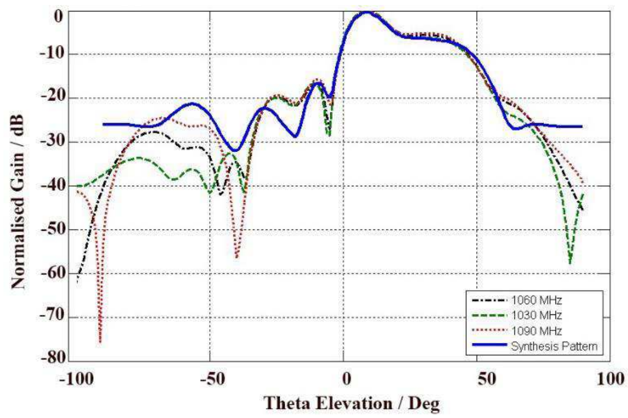
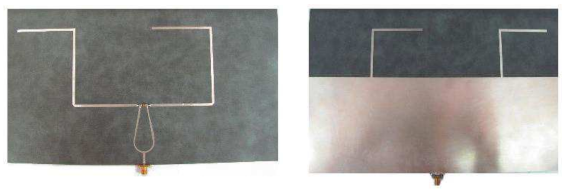
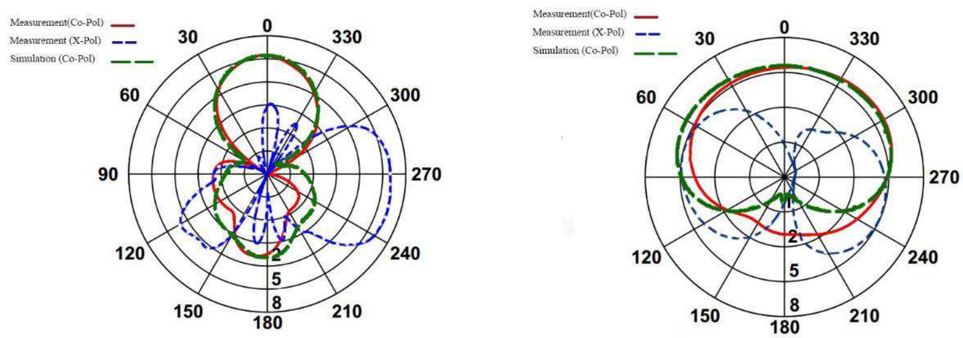


Figure 6: The simulated cosecant squared pattern.



(a) (b)

Figure 7: Fabricated elements, (a) top view, (b) bottom View.



(c) (b)

Figure 8: Result of simulation and measurement of fabricated elements, (a) E-plane, (b) H-plane.

strips printed dipole [11] has been chosen and designed as an array element which satisfies the above requirements. These radiation characteristics of the element are 5.57 dB gain, angular width (3 dB) of 157.5 deg. in the azimuth plane, 72.3 deg. in the elevation plane and with -10.7 dB SLL.

2.4. Microstrip to Parallel Strip Balun

Since half-wave dipole has an impedance nearly $73 + j42$ ohm and it is integrated to 50 ohm line, length of element is decreased to omit imaginary part of impedance and a balun is used for matching microstrip feed network with parallel strips dipole.

3. ANTENNA SIMULATION AND RESULTS

3.1. Analysis and Simulation of Whole Antenna

The designed antenna has been shown in Fig. 5. The feed network and the printed half-wave dipoles are fabricated on RT-Duroid 5880 substrate ($\varepsilon_r = 2.2$ and $\tan\delta = 0.0009$) with 31 mil thickness. Fig. 6 shows simulated elevation pattern for center (1060 MHz) and edge frequencies (1030 MHz and 1090 MHz). It can be seen that beam shaping is obtained according to the objectives in the whole band. In this figure, the synthetized radiation pattern is also shown. It has to be noted that the synthesis was done with considering isotropic elements, therefore the differences between the synthesis and the simulated pattern at out of 10 dB beam width are due to element radiation pattern.

3.2. Array Element Implementation

For investigating the difference between simulation and fabrication and for considering the effect of mutual coupling between elements, two element array of dipoles has been fabricated, measured and compared with simulated design. Structure of fabricated array is shown in Fig. 7 and the result for co-polarization and cross polarization of designed and fabricated array at 1060 MHz are shown in Fig. 8. In order to result be completely obvious, scale of co-pol and x-pol patterns are considered same but actually difference between them is 25 dB. As it is shown, simulated and measured results are almost same.

4. CONCLUSION

A Simple structure with modified cosecant squared pattern for SSR antenna was designed and presented in L band frequencies (1030 ± 10 MHz and 1090 ± 10 MHz). Microstrip structure usually have some limitation in bandwidth but the new structure that was introduced in this paper, solved this problem. In order to achieve specified criteria for element a simple element such as printed half-wave dipole was used in which it is compatible with microstrip structure. The array of these elements has negligible mutual coupling. The simulation results showed that beam shaping is achieved based on the objectives in the whole band.

ACKNOWLEDGMENT

The authors would like to thank ICTI (Information and communication technology institute) to support of this project.

REFERENCES

1. Skolnik, M. I., *Radar Handbook*, 3rd Edition, 2–96, 2–97, McGraw-Hill, 2008.
2. Silver, S., *Microwave Antenna Theory and Design*, Sec. 5.7, McGraw-Hill, New York, 1949.
3. Stutzman, W. L., "Synthesis of shaped-beam radiation patterns using the iterative sampling method," *IEEE Tran. Ant. Prop.*, Vol. 19, No. 1, 36–41, Jan. 1971.
4. Jones, B., Y. M. F. Chow, and A. W. Seeto, "The synthesis of shaped patterns with series-fed microstrip patch arrays," *IEEE Tram. Atit. Prop.*, Vol. 30, No. 6, 206–1202, Nov. 1982.
5. Freytag', L. and B. Jecko, "Cosecant-squared pattern antenna for base station at 40 GHz," *IEEE*, 2004.
6. Madany, M., "The analysis of wideband conformal microstrip array antenna with cosecant-squared beam shaping," *IEEE Trans.*, 2006.
7. Schrank, H. and N. Herscovici, "A simple cosecant squared microstrip array: The shovel microstrip array," *IEEE Antennas and Propagation Magazine*, Vol. 35, No. 4, Aug. 1993.
8. Borowiec, R., A. Jankowski, and Z. Langowski, "Microstrip radio location antenna with electronically controlled beam built using composite technology," *IEEE Trans. Microwave.*, Vol. 57, No. 4, 815–823, 2009.
9. Biswas, D. and R. Vulapalli, "A two-layer microstrip antenna to generate cosecant squared fanbeam for monopulse tracking," *IEEE Proceeding of International Conference on Microwave*, 2008.
10. Kreczkowski, A., T. Rutkowski, and A. Buda, "The microstrip IFF antenna for the airborne radar," *IEEE*, 2005.
11. Garg, R., *Microstrip Antenna Design Handbook*, Artech House, Inc., 2001.
12. CST Studio Suitesoftware, 2012.
13. Zhang, X., K. ManLuk, Q. Wu, and T. Ying, "Cosecant-square pattern synthesis with particle swarm optimization for nonuniformly spaced linear array antennas," *IEEE,* 2008.
14. Stutzman, W. L., *Antenna Theory and Design*, 3rd Edition, John Wiley and Sons, Inc., 2012.
15. Orchard, H. J. and C. Eng, "Optimizingthe synthesis of shaped beam antenna patterns," *IEEE Proceedings*, Vol. 132, No. I, Feb. 1985.