Numerical Solutions and Finding Optimal Quantities for Critical Parameters of TSA End-fire Antennas

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Abstract: Different types of wideband antennas have been designed and studied for different applications. In the first generation of these antennas there wasn’t need to more bandwidth and beam width and they have been developed in Broadside Class. Nowadays, according to the modern requirements, End-fire Class Antennas are suggested because of their more benefits in comparison with Broadside Class and also for their more bandwidth and beam width. At this paper we first study the characteristics of End-fire Antennas briefly. Then, the TSA Antenna in End-fire Class will be studied more carefully and its advantages will be shown. The rest of paper will be continued by studying main parameters in TSA Antenna’s characteristics and computer simulation of its behavior according to these parameters. Simulations have been done by applying practical conditions using FDTD method and the final results have been shown in diagrams for better comparison. By use of Genetic Algorithm, we have tried to gain the best dimensions and parameters for an antenna with minimum SLL. The obtained results have been compared with previous antenna results and optimistic parameters of mentioned antenna have been clarified.

Key-Words: End-fire Antenna, TSA, UWB Antennas, Numerical Solutions, Genetic Algorithm

1. Introduction

Increase of necessity to high frequency services, though in electronic manufactures or in telecommunication areas has caused development of new generation of antennas. For example, some of the most important applications of older broadside antennas are MMIC Circuits, printed dipoles, microstrip patches and ..., in printed dipoles 3-db bandwidth is about 10-15 percent and in addition is low bandwidth and their gain is low too. New applications need a 3-db beam width with sharpness of 12-16 degrees [1], so end-fire antennas can be a good choice. Besides, they have more bandwidth. TSA antenna is in the class of flat antennas designed in the surface of a metal thin film. Several structures of this antenna have been brought in Fig. 1.

As shown in Fig.1, TSA antenna consists of a gap that gradually becomes wider. The thin metal plate that antenna is designed on it, can be either without or with a narrow substrate and without ground plan. Since the gap gets narrower in one side (feeding side), contact of signal source or transmission line with antenna is being adapted well. Input wave in feeding side during its motion along the gradually widens gap radiates in longitudinal form (End-fire).

TSA Antennas are different in appearance and can have different shapes. Some of the most common structures of TSA group are the vivaldy type with exponential profile (Exponential TSA), Linear TSA (LTSA) with flat & linear profiles and Constant Width Slot Antenna (CWSA). Different combinations of the mentioned structures have been suggested in most papers [1].

In TSA antennas just like Yagi-Uda antennas, the traveling wave moves with phase velocity less than light velocity, so they classified as slow wave antennas. Radiated ray of these antennas is
symmetrical. One of the other important benefits of these antennas is their suitable narrow beams. The 3-dB beam width of these antennas is less than 15 degrees in the suitable design case with proper gain. Their bandwidth is proper in the range of HF too (a few octaves). These antennas have the radiation capability with mono or double polarization [2]. In linear polarization mode, the polarization vector is parallel with the gap plate (all capabilities of polarization are obtained in state of TSA arrays).

In integrated circuits, power is radiated or received by an element of antenna. So in the ideal form antenna and its system must be integrated on a single layer or easily join together in different subsystem forms. Because of broadside arrays usage in integrated circuits, analysis of different possible models, design processes and their other specifications in MIC Circuits has been completely done. Research about TSA Antennas hasn’t completed as the older broadside antennas yet. Their end-fire type beam, decreasing unwanted noise, the form of gap and some other practical parameters makes it easier to combine with other MIC integrated circuits. The simplicity of combination in array forms is one of their other advantages for utilization in MICs [3].

In this paper, we have discussed about different practical parameters of TSA antenna and have been specified its critical parameters [4]. Different forms of feeding, number of elements, antenna dimensions, the substrate material and ... are the analyzed parameters. It has been followed by the codes written with FDTD method [5] in workspace of MATLAB software for different cases, either for feeding line or for structure of antenna to analyze current distribution form and radiation pattern of antenna. The effect of different parameters has been analyzed from diagrams and at last the antenna has been optimized according to the obtained results. The structure of paper is as below: in session 2, first the important parameters of antenna are introduced then its key parameters are specified. Session 3 consists of the diagrams and FDTD simulation results. Since the number of diagrams was too much, only some of them have been selected and gathered here. Finally, in sessions 4 and 5, we have the comparison, final results and conclusion.

Fig.1. Taper slot antennas: (a) exponential tapered slot antenna; (b) linear tapered slot antenna; (c) continuous-width slot antenna; (d) dual exponentially tapered slot antenna

2. Antenna Parameters
The most important parameters that we have focused on in this paper are radiation pattern, input impedance and bandwidth.

2.1 Radiation Parameters and its main factors: Since TSA Antennas are from slow wave class, any variation in thickness, dielectric constant and gap curvature form, changes phase velocity and guided wavelength of antenna. Therefore, width and curvature directly affects on radiation pattern, directivity and cross polarization level of antenna. Besides, substrate thickness and ground plate affects on radiation characteristics of antenna. TSA Antenna shows a high level of cross polarization in diametric plates.

2.2 Bandwidth Properties and its main factors: TSA Antenna can generate a vast bandwidth to range of 2 to 90 GHz. To increase the bandwidth, we must have been complete impedance matching both in
feeding line and at the end of gap. Different methods of widening the bandwidth depend on the antenna's feeding procedure types and also bandwidth can be changed by proportion antenna structure modification.

2.3 Design Consideration and Critical Parameters: TSA Antenna consists of a gap that its width gradually increases from the feeding point and its end terminal is generally more than $\frac{\lambda_0}{2}$ as shown in fig.2. Experimental results in different references show that impedance, bandwidth and radiation pattern are commonly affected by slot curvature and gap length. Antenna efficiency is specified by substrate thickness and dielectric electrical permittivity. In fig.2, top view of a linear slot is shown. The hatched region in figure shows the copper segment after the antenna fabrication.

2.4 Curvature Profiles
There are so many curvature profiles for a TSA antenna. In Fig. 1 different designs are shown. In recent years, linear curvature and vivaldy have been taken into consideration more than the other types [4]. TSA antennas have two general properties, first is that the radiation gap acts as the ground plate of antenna and antenna is fed by a balanced slot-line. Second is that by decreasing the substrate dielectric constant impedance matching can be done easily. By design of a substrate with low dielectric constant, high impedance for gap is achieved. If we choose microstrip Feed, the matching will be a difficult problem. By this way transmission from microstrip to gap will limit Nominal bandwidth of TSA antenna.

2.5 Antenna Feed Methods
As a general rule, a slot can feed a TSA antenna (fig.3). Main feed parameters are stripline width and slot width, extended microstrip line and stripline cavity. The extended part of stripline creates series reactance that is independent from scanning angle and other key parameters. Slot line cavity affects on the input impedance of antenna independently. The methods used for antenna's feed generally are coaxial line and microstrip line types. In optimization, the structure of feed method is assumed constant.

2.6 TSA Arrays with Large bandwidth and extensive scanning angle: TSA antenna has many applications in phased array antennas [3]. Because it has large bandwidth and isn’t generated grating lobe in array. In infinite array, input reflection coefficient $\Gamma(\theta, \phi)$ of one element, directly proportion with antenna radiation pattern.

\[ F(\theta, \phi) = (1 - |\Gamma(\theta, \phi)|^2) \cos \theta \]

Therefore, reflection coefficient and element pattern are the factors that indicate the operation of large phase array antennas. Some of key parameters for vivaldy array are shown in Fig. 4.
4. Simulation Results

To assess the efficiency of antenna in the most of calculations (simulation by FDTD method [5]), size of cells are 0.5 millimeters and dimensions of simulated models are:

<table>
<thead>
<tr>
<th>No. of elements</th>
<th>Model cell sizes</th>
</tr>
</thead>
<tbody>
<tr>
<td>One</td>
<td>80 × 80 × 40</td>
</tr>
<tr>
<td>Four</td>
<td>120 × 120 × 40</td>
</tr>
<tr>
<td>Eight</td>
<td>280 × 80 × 40</td>
</tr>
<tr>
<td>Twelve</td>
<td>320 × 80 × 40</td>
</tr>
<tr>
<td>Sixteen</td>
<td>360 × 80 × 40</td>
</tr>
</tbody>
</table>

Feed method and curvature type for all structures are assumed equal and main analyzed parameters are dielectric constant, number of elements, antenna feed excitation phases and dimensions of antenna. Stability of various antenna properties along the bandwidth have been considered.
In Fig. 5 and Fig. 6 effect of element numbers in radiation pattern can be seen clearly. Increase in number of elements makes the pattern sharper and increases directivity of antenna. In this comparison other parameters are assumed constant. In Fig. 7, Fig. 8, Fig. 9, Fig. 10 variation of E and H plan radiation parameters of antenna with frequency analyzed. As we see, in spite of frequency change from 12 to 18 GHz, it isn’t observed considerable variation in E and H plan antenna patterns and the behavior of antenna is assumed constant. Finally, in Fig. 11 and Fig. 12 the optimized antenna is compared with the normal similar designed and its optimization effects are shown clearly. As said, the target is to decrease secondary lobes of antenna. Type of radiation in two mentioned frequencies has been compared with previous antennas to prove the optimization of antenna in comparison with similar design.
5. Conclusion
In this paper different practical parameters of TSA antenna were studied and its critical parameters were specified. Different forms of feeds, number of elements, antenna dimensions, substrate material and … were the parameters analyzed. Then by help of codes written in MATLAB workspace for different states, either for feed line or for structure of antenna, current distribution and radiation pattern were studied and analyzed. Effect of different parameters according to diagrams was produced and at last, specifications of optimized antenna were obtained according to results. To optimize the antenna we used a program based on Genetic Algorithm. Finally, effect of elements array increase on sharpness of beam and constancy of radiation parameters of sample antenna in a frequency bandwidth was shown by simulation and pattern of optimized antenna was drawn with an ordinary antenna in a diagram simultaneously for better comparison.

References: