Design of Low Side Lobe Level Milimeter-Wave Microstrip array antenna for Automotive Radar

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***Abstract*-A low profile array antenna with a low sidelobe was designed using Taylor array pattern synthesis and null filling concept is adopted using genetic algorithm. The antenna column is consists of 18 element antennas, gap coupled antenna is proposed in this paper to obtain low radiation coefficient and direct coupled antenna is used for high radiation coefficient. 45° polarization is added to reduce the interference.**

The antenna has 20.8dBi gain and sidelobe level of elevation direction is under -20dB and azimuth direction is under -25dB.

I. INTRODUCTION

Requirement for a multitude of different automotive radar based comfort and safety functions are compiled[1]. Typical antenna requirements are high gain and moderate to low sidelobes.

While for the long range ACC applications an angular range of ±4° to ±8° is usually sufficient, short or medium range applications have different requirements in distance and angular range.

Planar antennas are common components in sensing applications due to their low cost, low profile and simple integration with systems. The planar antennas are widely used despite the loss that caused by dielectric loss and conductor loss. One special advantage of planar elements is that they can easily adopt array structures combining very simple elements. Due to all these characteristics, planar antennas are very good candidates for mm-wave applications in radar, sensing or communications.

Polarization is also an important factor in automotive radar. Some systems use 45° polarization, so that radar signals from cars travelling in opposite directions and facing each other will be orthogonal polarization to reduce interference[2]. Alternatively, vertical polarization is less prone to multipath propagation between a car's bottom and the road surface.

Pattern synthesis is the process of choosing the antenna parameters to obtain desired radiation characteristics, such as the specific position of the nulls, the desired sidelobe[3] and beam width of antenna pattern. In literature there are many works concerned with the synthesis of antenna array like as binominal distribution, Dolph-Chbyshev ampltitude distribution, Taylor distribution, etc. [4]-[8].

This paper presents straight forward design procedure to synthesize radiation patterns of series fed fish bone array antenna at 76 ~ 77 GHz. The designed antenna which has low sidelobe level is designed using the concept of Taylor pattern synthesis and genetic algorithm. Gap coupled array concept is proposed for low radiation coefficient.

II. ANALYSIS OF ANTENNA DESIGN.

A. TAYLOR DISTRIBUTION

The antenna for automotive radar system typically requirements low sidelobes level to reducing the unwanted reflection. The sidelobes may be included in the angle determination scheme, so that the sidelobe level requirements are rather relaxed.

Taylor synthesis is one of widely used for reduced sidelobes array beam pattern. This is more suitable for series fed from one side due to the array weights for the end elements usually do not increase as much as compared with Chebyshev arrays, although this technique is not optimum in that the relation between beam width and sidelobe level.

Consider a linear array of N-Element, the array weights $\{w_i, i = 1, 2, \cdots, N\}$ are given by

$$w_i = \frac{1}{N}\left\{1 + 2\sum_{n=1}^{\bar{n}-1} f(n, A, \bar{n})\cos\left(\frac{2\pi n z_i}{N}\right)\right\} \quad (1.1)$$

Where the parameter $\bar{n}$ is the number used to decide the number of close-in sidelobes to be set with a constant sidelobe level. Other parts of the preceding expression are defined as

$$z_i = i - \left(\frac{N}{2} + 1\right) \quad (1.2)$$

$$f(n, A, \bar{n}) = \begin{cases} \dfrac{[(\bar{n}-1)!]^2}{(\bar{n}-1+n)!(\bar{n}-1-n)!}\displaystyle\prod_{m=1}^{\bar{n}-1}\left[1 - \left(\frac{n}{u_m}\right)^2\right] & |n| < \bar{n} \\ 0 & |n| \geq \bar{n} \end{cases} \quad (1.3)$$

$$u_m = \begin{cases} \pm a\sqrt{A^2 + \left(m - \frac{1}{2}\right)^2} & 1 \leq m < \bar{n} \\ \pm m & \bar{n} \leq m < \infty \end{cases} \quad (1.4)$$

$$a = \frac{\bar{n}}{\sqrt{A^2 + (\bar{n} - 0.5)^2}} \quad (1.5)$$

$$A = \frac{1}{\pi}\cosh^{-1} R \quad (1.6)$$

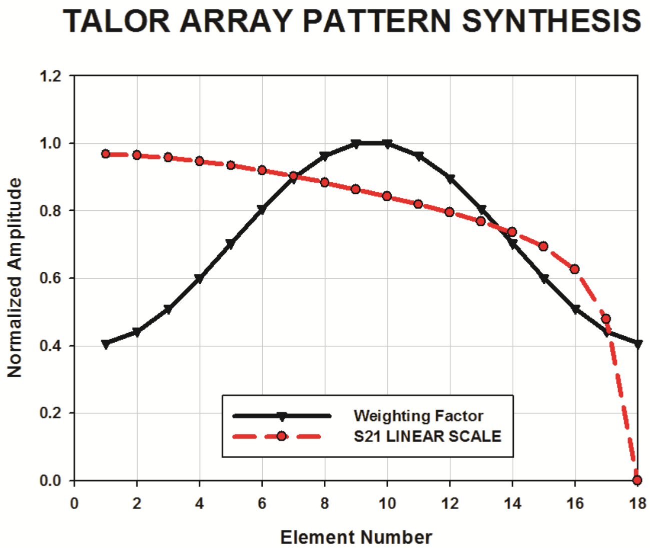

Figure 1. Taylor array pattern synthesis.

$$R = 10^{SLL/20} \tag{1.7}$$

The beam width of the Taylor array in degree is approximated as

$$\Theta_{Taylor} \doteq 2\sin^{-1}\left\{ \frac{a}{L\pi} \sqrt{\left(\cosh^{-1} R\right)^2 - \left(\cosh^{-1} \frac{R}{\sqrt{2}}\right)^2} \right\} \tag{1.8}$$

The weight factor of each antenna element and the transmission parameter,S_{21} are shown in Fig.1. in which the element number increases from bottom to top, and its sidelobe level target is less than -20dB.

B. *ANTENNA ELEMENT DESIGN.*

Series fed microstrip antennas are widely used for many applications. This paper design procedure to synthesize radiation patterns of series fed fishbone type microstrip antennas. 45° polarization is added to this concept by employing inclined antenna elements, which are connected to the feed line on a corner. In order to design an antenna based on the radiation coefficient, the antenna elements which can be tapered without affecting their radiation behavior are designed.

Direct coupled antenna is widely used in microstrip array antenna. However, Taylor array synthesis needs the radiation coefficient from very low to very high. In this paper the gap coupled antenna is proposed for very low radiation coefficient. The gap coupled antenna with 150um coupling gap has the radiation coefficient much smaller than direct coupled antenna with 150um coupling width.

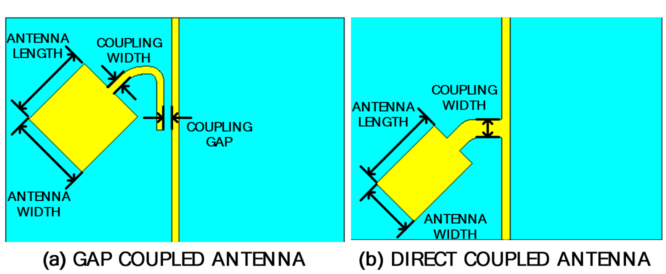

Figure 2. Two types of single element antenna.

A Single element with feed line is here designed and simulated, in order to obtain the optimum parameters when connected in array. I designed the low side lobe level (Elevation: -20dB) antenna which is consists of 4 gap coupled antennas for low radiation coefficient and 14 direct coupled antennas for high radiation coefficient. Each element's antenna width, antenna length and coupling width are tapered to achieve better sidelobe suppression.

C. *WAVEGUIDE TO MICROSTRIP LINE TRANSITION.*

The millimeter wave above 60GHz, SMA connector is not suitable because of its small size and effected electromagnetic field by soldering. Alternatively, waveguide still used in many applications such as millimeter wave system, and in some precision test application. Therefore, waveguide to microstrip line transitions are required to measure the antenna pattern.

A conventional type of transition needs a metal short block with a quarter-wavelength on the substrate[9-10]. In recently the proximity coupling type[11] has been developed. It can be composed of a single dielectric substrate attached to the waveguide without metal short block..

The upper ground pattern with a notch and the microstrip line are located on the upper plane of the dielectric substrate. A coupling patch element which used for coupling the single is patterned on the lower plane of the dielectric substrate and it is overlaps on a microstrip line on the upper plane. Via holes are surrounding the aperture of the waveguide.

The parameters of designed transition are described in Table 1, and S-parameters of the reflection S_{11} and the transmission S_{21} are calculated as shown in Figure 4.

From the results, reflection is under -20dB in desired frequency and the insertion loss in -0.5dB with 6.7mm microstrip line.

Table 1 Parameter of transition.

Parameter	Value	Parameter	Value
ε_r	2.2	WG_X	2.54 mm
Line Gap	0.1 mm	WG_Y	1 mm
VIA Gap	0.7 mm	CP_X	1.716 mm
VIA Diameter	0.3 mm	CP_Y	0.957 mm

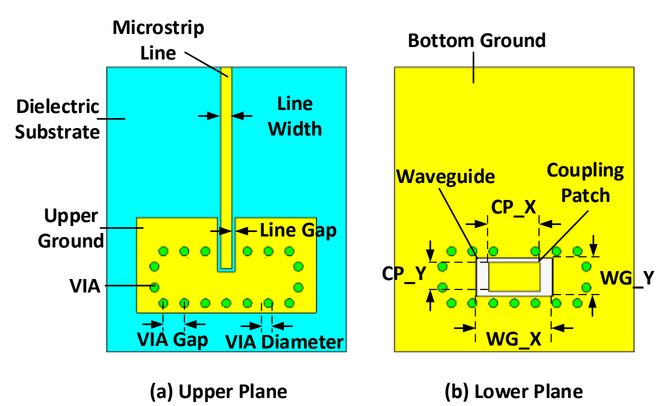

Figure 3. The configurations of transition.

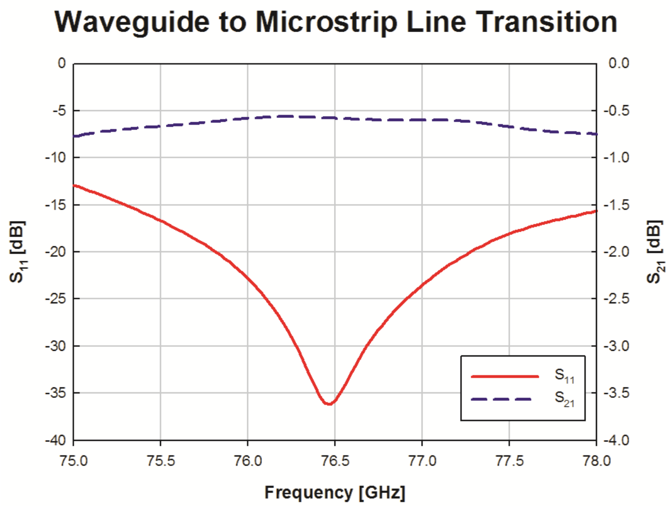

Figure 4. Reflection and insertion loss of transition.

III. ANTENNA DESIGN.

A. *Single Column Design*

The antenna is designed using the dielectric substrate Taconic TLY-5 (thickness : 5mil , dielectric constant : 2.2), and the thickness of the copper layer is 1/2oz. The model consists of the fishbone type microstrip antenna with its initial dimensions. The antenna is connected from both sides with the high impedance microstrip line.

Taylor array pattern synthesis is adopted in this design to obtain the low side lobe level. The radiation coefficient of each antenna is optimized by deducing the suitable coupling widths, antenna width and antenna length of each antenna.

Two types of coupling technique are used for array, one is gap coupled type for low radiation coefficient at first 4 antennas. Other is direct coupled type for large radiation coefficient at last 14 antennas.

The radiation coefficient is determined by adjusting parameter like as coupling gap, coupling width, antenna width and antenna length.

B. *Array Antenna Design.*

The long range radar(LRR) system is sensitively sensing the obstacle that is located at front area by using pencil beam antenna. However, due to null point of radiation, it is vulnerable for sensing the pedestrian or obstacle on the side of road. Some systems add to sensing product for this problem, but it is not good solution because of cost and complexity increasing. So that, I proposed the null filling antenna for complement the weakness of LRR using genetic algorithm for pattern synthesis.

The genetic algorithm proposed to determine the amplitude weight in same phase. First the initial population of chromosomes that are a binary string representing all perturbed weight of each port is randomly generated. Second, the radiation pattern of each chromosome is calculated, and the

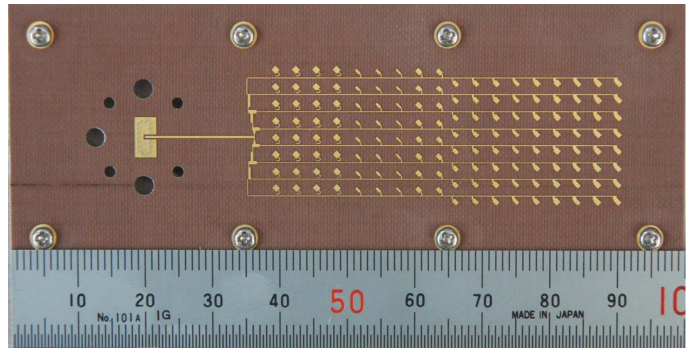

Figure 5. Fabricated antenna.

maximum side lobe level and the null point are founded. Then the fitness of each chromosome is evaluated. Base on the evaluated fitness value, a pair of chromosomes is selected and mated. The selection rule is based on a roulette wheel and the crossover is achieved at a single random point. Then the mated chromosomes can be mutated according to the mutation probability. In this manner a new offspring is generated. The iterations is stopped after the evaluation of fitness.

The calculating conditions are under -40dB sidelobe level, no null point from -40° to 40° and under 10 ratio of weights.

The calculated weight from MATLAB and designed weight are presented in Table 2 in here the port is numbering from left to right.

Figure 6 shows the radiation pattern in azimuth plane. The solid line means the pattern using null filling weight and dash line means the pattern using same weight.

Table 2. Amplitude Weight for Null filling.

Port	Ideal Weight	Designed Weight
P4,P5	1	1
P3,P6	0.2985	0.2871
P2,P7	0.1316	0.1406
P1,P8	0.1286	0.1298

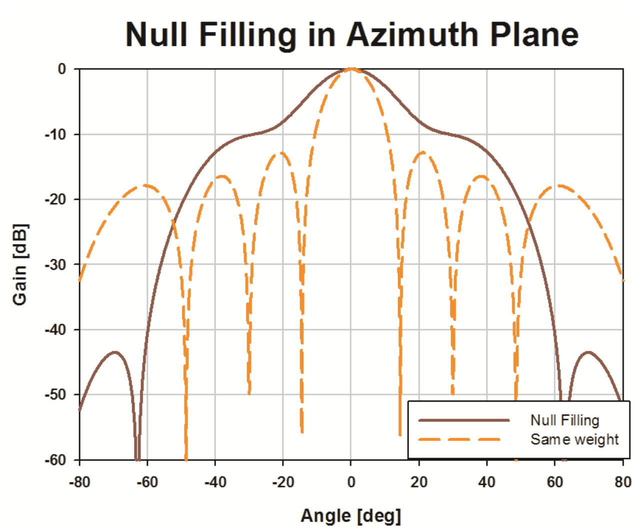

Figure 6. The Calculated Directivity in Azimuth Plane.

IV. RESULT

Fig. 7 and Fig. 8 show the simulated radiation pattern of overall antenna. It can be seen that a high gain of 20.8dBi is obtained at the design frequency of 76.5 GHz.

Fig. 7 shows the measured radiation pattern in elevation-plane of the developed antenna at the design frequency of from 76 GHz to 77 GHz. The half-power beam width is 4.8 degrees and the sidelobe level is reduced to lower than –20 dB.

Fig. 8 shows the measured radiation pattern in azimuth-plane at the design frequency of from 76 GHz to 77GHz. The half-power beam width is 18.3° and the sidelobe level is –25.7 dB. It shows that the null point is not exists in -40° to 40°.

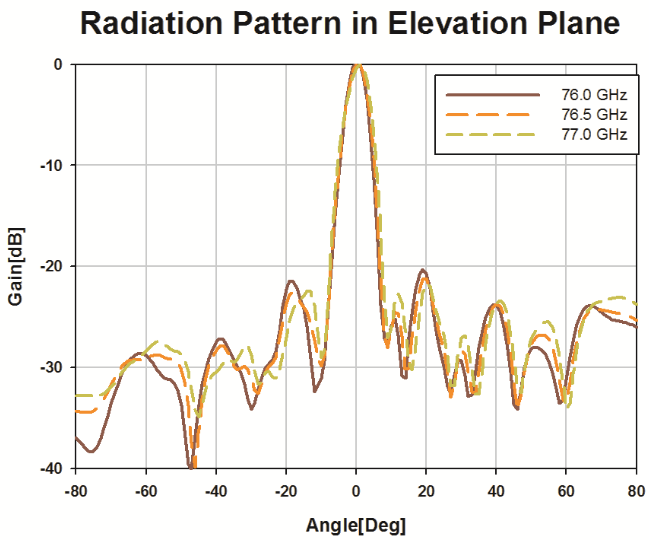

Figure 7. Elevation Radiation Pattern.

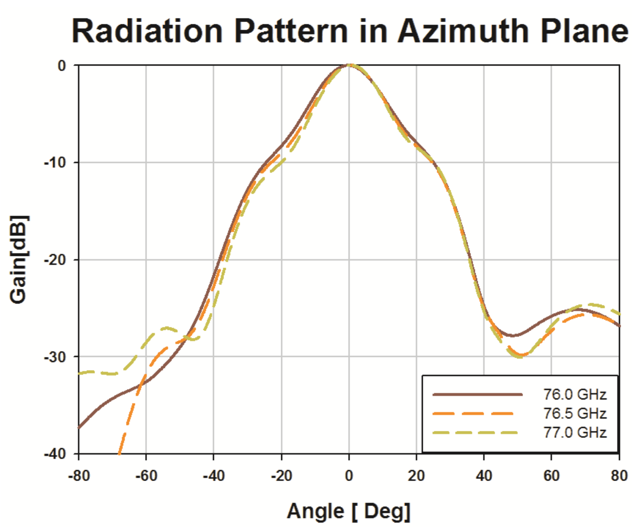

Figure 8. Azimuth Radiation Pattern.

V. CONCLUSTIONS

The automotive antenna is designed in this paper. Taylor pattern synthesis and genetic algorithm are used for sidelobe level reduction. Two types of coupling technique are used for array, one is gap coupled type for low radiation coefficient, another is direct coupled type for large radiation coefficient.

These antenna elements are modeled taken into account the feed line and all other parasitic effects and optimized for the operating frequency as well as for a given radiation coefficient.

As a result of the design, the antenna has a high gain of 20.8dBi and a low sidelobe level. The array antenna designed here will be utilized as not only a fixed beam antenna but also beamforming antenna for automotive antenna.

ACKNOWLEDGMENT

This work was supported by the LG Innotek through the 77GHz automotive radar project under contact G01130026.

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