A MM-WAVE TAPERED SLOT ANTENNA WITH IMPROVED RADIATION PATTERN

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ABSTRACT

We have proposed a new configuration of Tapered Slot Antenna (TSA) with an improved radiation pattern. The new design has a tapered section expressed by the Fermi-Dirac distribution function. At 60 GHz, the H-plane side lobe level of the antenna is 5-dB lower than that of conventional TSA's such as Linearly Tapered Slot Antennas. We also present a new technique for reducing the width of a TSA without degradation of radiation pattern.

INTRODUCTION

Recently, there has been a great deal of interest in planar antennas for millimeter and submillimeter wave circuits, mainly because they are compact and easy to integrate with other planar devices. They are used in many applications including portable products for wireless LAN and mm-wave imaging arrays for remote sensing, radio astronomy, and plasma measurement. TSA's are typical examples of planar antennas, and offer the advantages of wide bandwidth and compactness [1]-[4]. The slotline geometry of TSA's also enables them to be easily integrated with uniplanar circuits. However, these antennas are very sensitive to the thickness and the width of their supporting substrate, and exhibit higher cross-polarized lobes in the D-plane and sidelobes in the H-plane.

In this paper we have present a design for a new TSA with an improved radiation pattern. Antenna patterns have been measured and show good agreement with theoretical analyses. We call this new design a "Fermi antenna". We also present a new technique, using corrugation structures in the sides of an antennas, to improve the radiation pattern for TSA's on narrow width substrate.

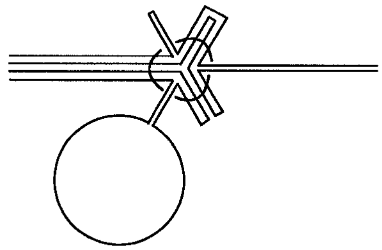

Fig.1 The geometry of the double Y balun for 60GHz

DOUBLE Y BALUN

In our experiments at 60GHz, Coplanar Waveguide (CPW) was used as the main uniplanar transmission line because of the availability of CPW-type probes (UTF3680V) for measuring mm-wave characteristics. A double Y balun [5] was used to couple the CPW to the slotline input of the Fermi antennas.

The most conventional CPW-slotline balun is a uniplanar Marchand balun [6] which uses a right-angle bend in the feed line. In our experiments we used a double Y balun (Fig.1), which offered the advantage of an inline port geometry suitable for array applications. However, it was reported that this design required three tightly-spaced air bridges at one junction, connecting the ground conductors of the CPW stubs and feed, for the purpose of suppressing the CPW odd mode [7]. We have experimentally compared the insertion losses (S21) for a double Y balun, with and without air-bridges. Each balun was fabricated on a copper clad polyimide film with a thickness of 0.05mm (Kapton ε_r=3.5). The line impedances of both the CPW and slotline were chosen to be approximately 120Ω. The distance from the short and open circuits, to the center of the structure, is $\lambda g/8$ at 60

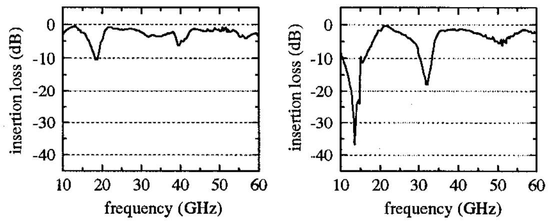

Fig.2(a) with air bridges   Fig.2(b) without air bridges

Fig.2 Insertion loss(S21) of the double Y balun with (a) and without (b) air bridges measured in the back-to-back configuration

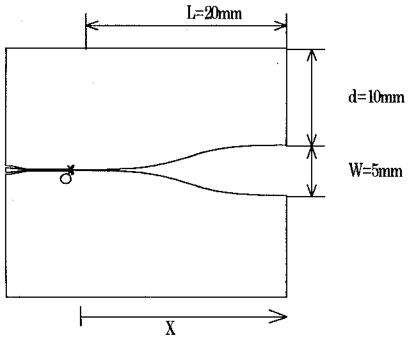

Fig.3 The geometry and dimensions of the Fermi antenna for 60 GHz (d=10mm)

GHz. The experiments were performed in a back-to-back configuration, using a vector network analyzer (WILTRON360B). The system was calibrated from 10 to 60GHz using the LRL method, with the reference plane located where the CPW feed connects with the balun. The measured insertion losses (S21) is shown for two double Y baluns, one with and one without airbridges, in Fig.2 (a) and (b), respectively. Within about 10 % of the 60 GHz design frequency, the difference in insertion loss for the two cases is smaller than 1 dB. Consequently, we used the balun without air-bridges throughout the experiments described below.

FERMI ANTENNA

Several different TSA designs have been reported; they are LTSA (Linearly Tapered Slot Antenna), Vivaldi (Exponentially Tapered Slot Antenna), CWSA (Constant Width Slot Antenna) and BLTSA (Broken Linearly Tapered Slot Antenna) [1]-[4]. These antennas have nearly symmetrical radiation patterns. However, side lobes in the H-plane for these antennas are higher than those in the E-plane. We present here a design for a TSA which improves on this characteristic. The shape of the tapered section in our design is described by the

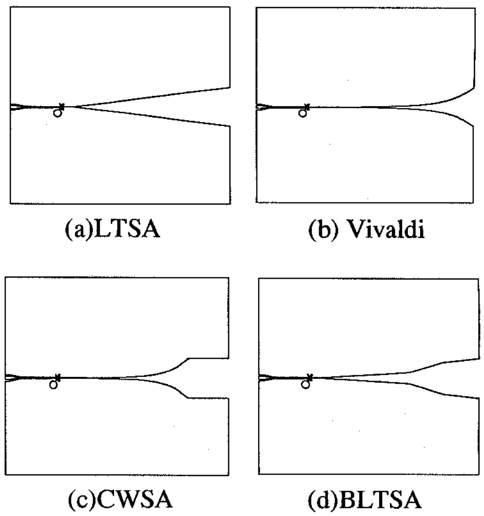

Fig.4 Geometries of TSA's with the aperture size of λ_0 and antenna length of $4\lambda_0$ fabricated for comparison

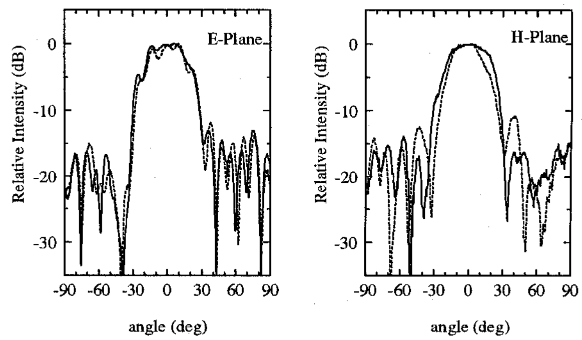

Fig.5(a) Comparison between measured radiation patterns of the Fermi antenna (solid line) and LTSA (dotted line)

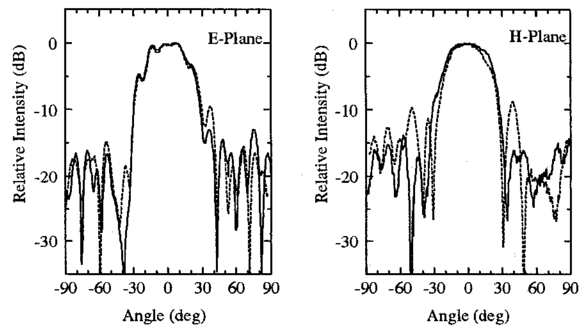

Fig.5(b) Comparison between measured radiation patterns of the Fermi antenna (solid line) and BLTSA (dotted line)

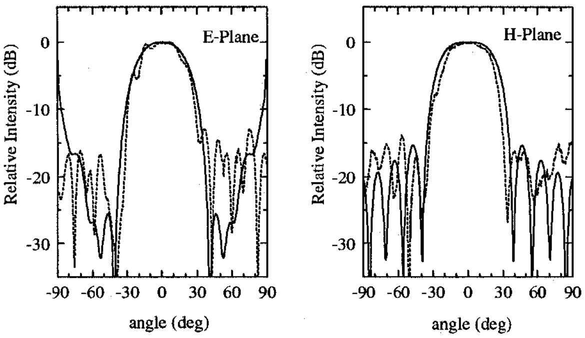

Fig.6 Comparison of the Fermi antenna radiation pattern between theoretical analyses (solid line) and experiments (dotted line).

following function:

$$\frac{a}{1+e^{bx+c}}$$

where x is a variable (Fig.3) and a, b, and c are constants. This function is the Fermi-Dirac function frequently used in solid state physics. Fig.3 shows the geometry and dimensions of the "Fermi antenna" used in our experiments at 60GHz (a=2.5mm, b=0.5mm^{-1}, c=-5). The antenna was fabricated on a copper-clad polyimide film with a thickness of 0.05mm (Kapton ε_r =3.5). The length L of the antenna is 20mm ($4\lambda_0$), the aperture of the antenna, W, is 5mm (λ_0), and the distance from the aperture edge to the substrate, d, is 10mm ($2\ \lambda_0$). The double Y balun, followed by the CPW feed line, connects to the slotline feed of the Fermi antenna.

For comparison, LTSA, Vivaldi, CWSA, and BLTSA antennas with the same aperture size and antenna length as that of the Fermi antenna were also fabricated(Fig.4), and their radiation patterns were measured at 60GHz. Of these four antennas, the LTSA and BLTSA exhibited better directivity and their patterns are plotted (dotted lines) in Figs. 5 (a) and (b), respectively. Measured radiation patterns for the 60GHz Fermi antenna are also shown in Fig.5 (solid line). In these measurements, the TSA's were used in the receiving mode. The resulting patterns for the Fermi antenna were more symmetrical and had lower side lobe levels than the others. The first side lobes in the H-plane of the Fermi antenna are as low as -15dB, which is about 5dB lower than that of LTSA and BLTSA. The theoretical radiation pattern for the Fermi antenna is plotted in Fig.6 (solid line) and shows good agreement with the measured pattern (dotted line). The theoretical curve was calculated by the two-step method [7]. In this calculation the Fermi antenna is approximated by 20 slot sections (5 sections per free space wavelength).

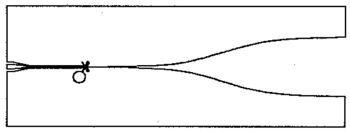

Fig.7 The geometry of the Fermi antenna with narrow width (d=2.5mm, L=20mm, W=5mm)

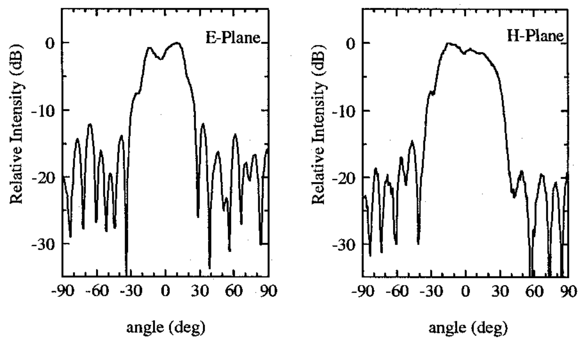

Fig.8 Measured radiation patterns of the Fermi antenna with narrow width

CORRUGATION STRUCTURE FOR REDUCING ANTENNA WIDTH

The TSA width, d, measured from the aperture edge to the substrate edge (see Fig.3), should be larger than $2\lambda_0$, as degradation of the radiation pattern has been observed for narrower width TSA [7]. This degradation was also observed for the Fermi antenna. The geometry for a Fermi antenna with narrow width (d=2.5mm, 1/4 of that for the Fermi antenna in Fig. 3) is shown in Fig.7, and its measured 60 GHz radiation patterns are shown in Fig.8. The E-plane side lobe level was higher than for the wider antenna, and the main beam in the H-plane was broader. These degradation in the radiation pattern which is associated with reduced antenna width is a significant problem for the design of compact TSA's. However, Antenna width reduction is necessary when forming antenna arrays, especially for mm-wave imaging applications.

We present here a new technique for reducing the width of TSA without degrading their antenna patterns. The technique uses a "corrugation structure" which consists of a periodic arrangement of slits in the sides of the Fermi antenna substrate, as shown in Fig.9 (L=20mm, W=5mm, d=2.5mm). The dimensions of the slits are 0.2mm x 1mm, with a 0.4mm period. The measured

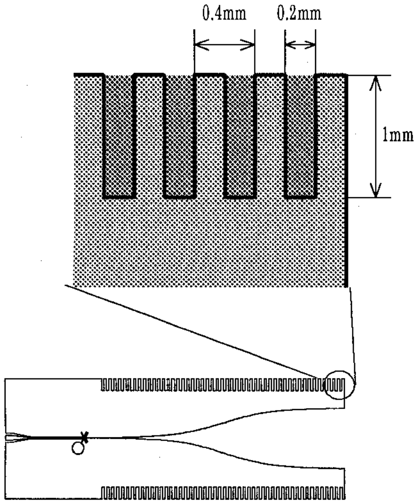

Fig.9 The geometry of the Fermi antenna with the corrugation structure (d=2.5mm, L =20mm, W=5mm)

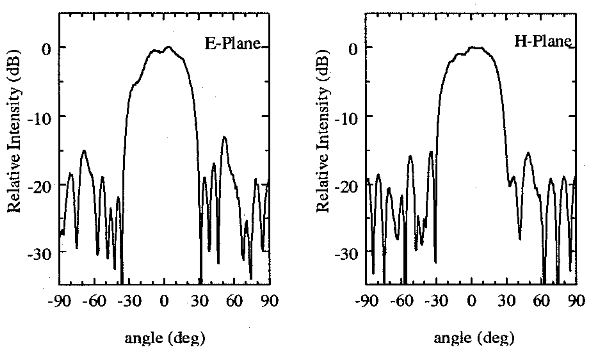

Fig.10 Measured radiation patterns of the Fermi antenna with the corrugation structure

antenna patterns for a Fermi antenna with this corrugation structure are shown in Fig.10. A substantial improvement in the patterns for narrow width antenna can be achieved using this corrugation structure, making this technique suitable for the formation of antenna arrays where small spacing between antennas is needed, as in the case of mm-wave imaging arrays.

CONCLUSION

We have presented two methods for improving antenna radiation patterns for TSA. A new TSA design, called the "Fermi antenna", has been demonstrated and its H-plane side lobe levels were shown to be lower than those of an LTSA. We have also demonstrated a new technique for improving the radiation patterns for narrow width TSA by using a corrugation structure at the sides of the antenna substrate. This technique provides an effective means for producing TSA which are suitably narrow for the formation of compact mm-wave imaging arrays.

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