A Vertical W-band Surface-Micromachined Yagi-Uda Antenna

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Abstract-A vertical W-band surface-micromachined Yagi-Uda monopole array is proposed and implemented for the first time. The monopoles stand on a high-*k* soda-lime glass substrate and are fed by a coplanar waveguide. The geometry functions as a vertically placed Yagi-Uda antenna due to the image theory. The performance of the vertical Yagi-Uda is to be superior to conventional W-band printed antennas due to minimum substrate wave effects. A successful implementation of the vertical Yagi-Uda structure is demonstrated using high-aspect-ratio surface micromachining fabrication technologies. The test results of a 5 element structure demonstrate a 10-dB-impedance-bandwidth of 12% at 100 GHz. A directivity of 8.2 dBi is projected for this prototype.

I. INTRODUCTON

In W-band applications, huge reflector antennas are widely used for space exploration and radar systems, while printed planar antennas are preferred in compact systems due to simple fabrication process and low cost. However, printed antennas often suffer from narrow bandwidth, low efficiency, and perturbation of radiation pattern due to surface waves in high-ε_r substrates, which limits their application in broadband modules and have brought about various bandwidth and radiation pattern improvement techniques [1]. Alternatively, three-dimensional (3-D) radiators extruded into the air would be a good candidate for broadband and high efficiency applications. However, the characteristic length of the antenna in W-band, is in the order of millimeter, and vertical 3-D antennas are quite difficult to implement by conventional printing circuit methods and little research has been put forth to investigate the feasibility of replacing printed antenna by 3-D counterparts.

Recently, a 3-D W-band surface micromachined monopole antenna on high-ε_r soda lime glass substrate has been reported [2,3]. It demonstrated desirable broad bandwidth (76-95 GHz) and low-loss performance. However, in certain applications requiring high directivity, such as local chip communication or directional radiation with a low power budget, the omni-directional monopole antenna is not appropriate, but a monopole array providing more directivity will be necessary. By placing various parasitic monopoles on the ground plane nearby the driving poles, directivity will be increased in the same rule applied to the conventional dipole driven Yagi-Uda antenna with directors and reflectors. With the help of the ground as a mirror plane, a monopole driven vertical Yagi-Uda antenna can be simply implemented.

Using the monopole architecture as a driving source, in this paper, we are proposing and implementing a vertical Yagi-Uda antenna for W-band application. High-aspect-ratio surface micromachining technology is the key enabling technology for this structure. This architecture provides several benefits. First, the radiation signal is radiated directly from the extruded monopole to the air, by which the antenna is experiencing minimum substrate effects and providing high radiation efficiency. Second, this configuration uses a CPW-fed monopole as the driving source, which does not require a complicated transformation scheme to connect it to other circuits/components as in the case of Yagi-Uda dipole antennas, resulting in simple structure. Third, the process is low-temperature and CMOS compatible, allowing easy integration on other RF chips as a post process.

II. DESIGN OF THE VERTICAL YAGI-UDA ANTENNA

The proposed Yagi-Uda structure is shown in Fig.1. It consists of one driving monopole, one reflector and several directors. It is implemented on the ground plane metal on top of the substrate. According to the mirror theory, in the upper half space, it is equivalent to a dipole Yagi-Uda array. The coplanar waveguide (CPW) feeding is connected with driving monopole.

Yagi-Uda antenna performances depend on individual elements heights and the spacing between adjacent elements; much design guidance can be found in the literature [4]. In this work, we focus our design on both performance and ease of fabrication to demonstrate the feasibility of the idea. The design priority is put on bandwidth, then micromachinability, and then directivity. The heights of all directors are chosen to the same value to facilitate the micromachining process and can also be different in future batch process.

Full wave electromagnetic optimizations have been performed using both Ansoft high frequency structure simulator (HFSS) 9.1 and Flomerics Micro-stripes 6.5. The spacing between adjacent elements is set to 480 µm. The height for reflector, driving monopole and directors are 800 µm, 715 µm, 560 µm, respectively. The predicted return loss and a radiation pattern for a 5-element Yagi-Uda antenna are plotted in Figures 2a and 2b, respectively. The simulated radiation pattern gives a maximal directivity of 8.2 dBi in horizontal axis. The end-fire radiation pattern is a unique feature compared to the conventional broadside radiation of the patch antenna.

III. IMPLEMENTATION AND MEASUREMENT

Figure 3 displays the fabrication process for the vertical Yagi-Uda antenna. Metal coated epoxy core concept is used [5]. Three layers epoxy photoresistor SU-8 are spin coated and photopatterned on the substrate one by one to define the height of the directors, the driving monopole, and the reflector, respectively. Detail fabrication process are similar to ones in [2,3]. Fig. 4 is the photo of the fabricated prototype utilizing this process.

The fabricated prototype was characterized using an Agilent 8510XF network analyzer and Cascade ACP 110 probes with 150 µm pitch. The NIST Multical TRL algorithm [6] was used to calibrate the measurement system. Figure 5 shows the measured return loss between 50 GHz and 110 GHz for a 5-element Yagi-Uda antenna. It shows a radiation resonance at approximately 100GHz with a return loss of 18 dB, demonstrating a good agreement with the simulated results. A very wide 10-dB bandwidth of 12% has been achieved. The frequency response is slightly shifted because of the small geometry disparity between the fabricated prototype and the simulated one. The broadband feature is superior to that of a conventional printed antenna having a narrow band nature. Radiation pattern measurements are in progress.

IV. CONCLUSION

In this paper, a vertical W-band surface-micromachined Yagi-Uda monopole array is reported for the first time. This structure has low surface-wave effects due to its air extruded geometry when compared with conventional planar devices. The driving monopole is fed by a co-fabricated CPW line facilitating the antenna's easy connectivity to other components as well as easy fabrication. Alternatively, a via-through-substrate approach can be used as a different feeding scheme. Since the fabricated monopole antenna is achieved by a low-temperature, foundry-compatible process, fully-integrated millimeter-wave systems are feasible. A prototype consisting of 5 elements shows a 12% bandwidth at 100 GHz and 8.2 dBi directivity in the endfire direction.

References:

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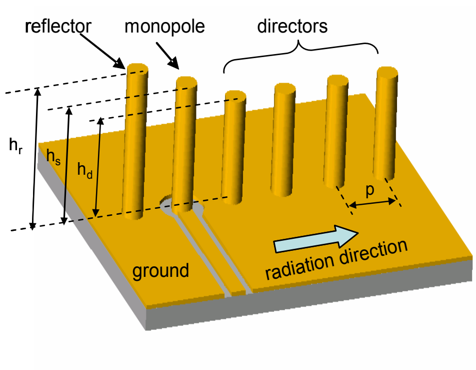


Fig.1. Proposed W-band vertical Yagi-Uda antenna structure

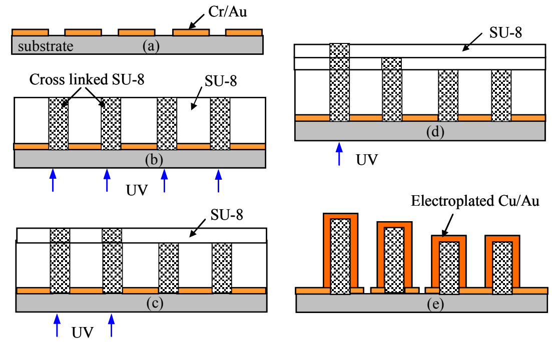
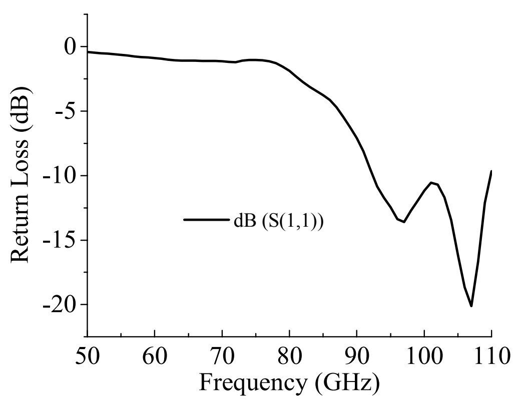
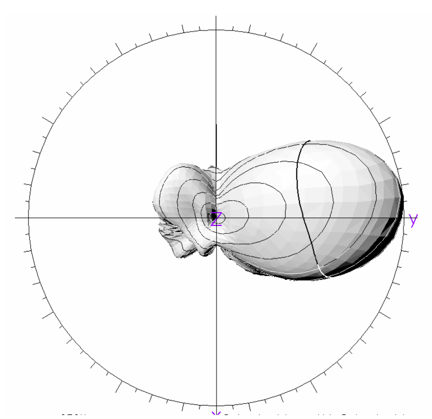


Fig. 3. Fabrication steps



(a)



(b)

Fig. 2. Simulated performance of 5-element array (a) Return loss (b) Top view radiation pattern at 95 GHz

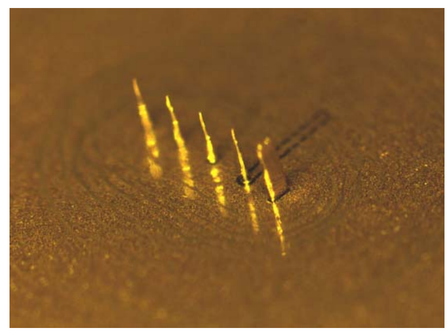


Fig. 4. Photo of the fabricated 5-element prototype

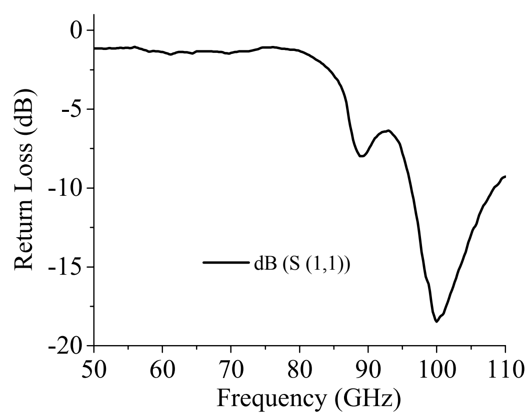


Fig. 5. Measured return loss over 50-110 GHz