PROCEEDINGS OF ISAP '96, CHIBA, JAPAN

TWO-DIMENSIONAL Vs THREE-DIMENSIONAL QUASI-OPTICAL ACTIVE ANTENNAS

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Abstract

To date, most of the quasi-optical active antennas are physically three-dimensional. Recently, there is a growing interest in implementing the active antennas in the two-dimensional media. In this paper, an evaluation of the two-dimensional and three-dimensional active antennas has been made. Their advantages and disadvantages will be highlighted. Circuit examples will be presented to highlight some issue presented.

1. Introduction

Active antennas have shown great potential in quasi-optical power combining. As operating frequency approaches millimeter-wave spectrum, high conductor and dielectric losses limits the power combining efficiency. Also, the power generated by a single active device decreases with frequency. To date, most of the active antennas are three-dimensional in nature, such as the wave beam type [1] and grid type [2]. Three-dimensional (3-D) circuits radiate and combine the signal in free-space. Recently, active antenna has been implemented on the dielectric slab-beam waveguide (DBSW) [3-6]. Being a waveguide, two-dimensional (2-D) circuits are guided structures. An oscillator [3] and three amplifiers [4-6] have been implemented using the DBSW.

It is the purpose of this paper to present the advantages and disadvantages of these two classes of design approach to the problem of active antennas. Circuit examples will be presented to assist in the highlight of some issues discussed.

2. Comparison of 2-D and 3-D Active Antennas

A. Device Integration

The main objective in quasi-optical active antennas is to generate or amplify signals. Due to the limited signal power generated by a single active device at millimeter-wave spectrum, there is a need to integrate more devices in an active antenna circuit.

In 3-D active antennas, such integration can be implemented at several levels. Being a 3-D circuit, the devices elements can be distributed over a 2-D space. This naturally increases the number of active devices. Oscillators [2,7] and amplifiers [8-9] have been implemented in this manner. To further increase the output power and gain, cascaded stages of active antennas has been sought [10]. Lastly, at unit cell level, more devices can be integrated with a single antenna [8-9]. Rectangular patch [8] and slot [9] antennas have been used for such integration. Fig. 1 shows the schematic diagram of the high device packing density slot antenna [9].

However, the 2-D active antennas do not have the same degree of freedom in the device integration. Due to its two-dimensional structure, the active devices can only be distributed in a linear array. Fig. 2 shows the layout of the 10-element active lens amplifier in [6]. But, cascade of the amplifier stages is feasible.

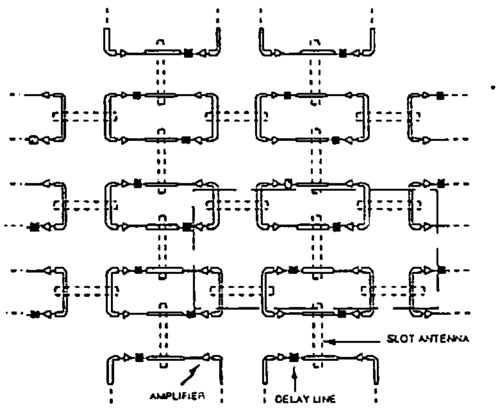

Figure 1 : High device packing density active slot antenna.

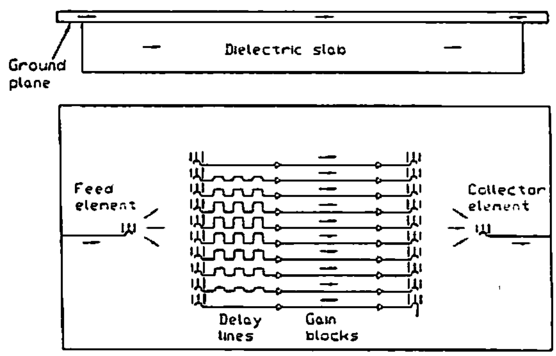

Fig. 2 : Physical layout of the DBSW amplifier.

B. Device layout

Linked closely to the above issue is the physical constraints of the layout of the circuit. In 3-D structures, the inter-element spacing is bounded by the grating lobe criteria. This limits the real-estate of the active device circuit. As such, simple matching networks are used, compromising the electrical performance of the system. Layout of the DC biasing network in a two-dimensional space is also restrictive. Multi-layered structures may be used to solve these problems partially. In 2-D approach, this constraint is lifted. As shown in Fig. 2, the amplifiers can be multi-stage and have space-consuming matching networks. In both approaches, as the devices are spaced wider apart, the end elements receive less power than that at the center. Therefore, the center elements saturate much faster than the end elements. Proper design of amplifier gain distribution is essential to maintain good overall power-added efficiency.

C. System layout

At the system level, 3-D active antenna poses more complex layout requirements than that of the 2-D one. Non-planar lenses are need to focus the signal to the beam-waist at the input and output. To provide isolation, polarizers are used. All these components require mounting structures. The alignment of these components is also critical. Being planar, the 2-D circuit can be implemented on a substrate with precise fabrication of the antenna elements. This makes two-dimensional structures compatible with monolithic technology.

D. Heat-sinking and Support

Due to poor power-added efficiency of solid-state devices at millimeter-wavelengths and dense integration of active devices, heat sinking is an issue. In 3-D active antennas, a layer of heat-conductive substrate can be placed on the ground plane. This is particularly suited for slot antenna as it serves as a heat sink as well as a mean to focus the radiation in one direction. For two-dimensional structures, the material of the slab can be chosen to be heat-conductive, without compromising the RF performance.

Another issue is that of the support of the amplifier circuit. As mentioned above, the system layout of a 3-D active antenna is complex. Mounting structures must be designed to hold the components firmly to pass environmental specifications. Due to the ground plane and thick slab, 2-D active antenna lends itself as a well-supported unit.

E. Others

As the 3-D active antennas rely on the radiation characteristics of the antenna element, measurement of the system gain is a difficult task. Various definitions and parameters have been developed to allow some consistency and standardization [11]. In contrast, the 2-D structure behaves like a guided structure and system gain is easy to quantify and measure.

One concern about 2-D active antenna is the ability to excite the desired DBSW mode. It is difficult to excite cleanly such modes without low scattering losses This poses a problem of isolation between input and output. Using the same mode at the output may result in some signal leaking through the lens and coupling to the output. This restricts its use in the design of mixer circuits where LO-RF isolation is critical. 3-D active antennas rely on the different polarization of the input and output fields to provide the isolation. As opposed to 2-D structures, surface wave modes are unwanted as such substrate coupling can be disastrous to circuit design [12].

Lastly, 2-D structures may suffers spurious reflections from the side of the substrate, resulting in internal resonances. This can be solved by placing absorbers on the side of the circuit.

3. Conclusion

A comparison between the 3-D and 2-D active antennas have been made. Considerations, both electrical and mechanical in nature, have been discussed. Advantages and disadvantages of 2-D and 3-D active antennas were also presented.

4. Acknowledgment

This work is supported by US Army Research Office under contract DAAH04-93-G-0068 and in part by the Joint Services Electronics Program F49620-96-C-0002.

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