A Three-Dimensional Active Antenna for a High-Speed Wireless Communication Application

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ABSTRACT

This paper proposes a three-dimensional active antenna configuration for a front-end module of a high-speed wireless communication system at millimeter and quasi-millimeter-wave frequencies. The active antenna is integrated with a microstrip antenna array on multilayer alumina-ceramic, individual MMIC chips including transmit/receive amplifiers, time division duplex switches, and a filter on multilayer polyimide. The three-dimensional structure achieves an unrestricted RF-circuit design on multilayer polyimide.

INTRODUCTION

System studies and hardware investigations of indoor high-speed wireless communication are being conducted at millimeter and quasi-millimeter-wave frequencies [1],[2]. Such systems must offer data transmission rates of 10 Mbps or more, thus making anti-multipath and anti-shadowing techniques necessary. One solution is to narrow the beamwidth of the base station and personal station antennas by about several tens of degrees [3]. However, when phased-array or sector antennas are employed in order to track the beams, the loss of the phase-shifter and the beam-switching circuits cannot be ignored at these frequencies. Therefore, it is difficult to compress the noise figure of the system. Thus, it is necessary to connect the radiation element directly to the MMIC chip including the low-noise receiving amplifier and the power amplifier to avoid loss of the beam tracking circuits and the feeding cables. In addition, to construct a practical module for wireless communication, in order to perform transmission diversity, time division duplex (TDD) switches are required. It is also necessary to place a filter at the front of the these amplifiers to suppress unwanted higher harmonics and images. Previously, some active antenna schemes had been proposed. The radiation elements were directly connected to low noise amplifiers, mixers, and oscillators [4]-[6]. However, these active antennas were not entirely satisfactory because they did not achieve the aforementioned functions. At millimeter and quasi-millimeter-wave frequencies, the size of the active antennas is more than several centimeters. This is especially so when constructing entire array antenna on one GaAs MMIC substrate which incurs the demerit of high cost. To address this problem, this paper proposes a three-dimensional active antenna integrated with a microstrip antenna (MSA) array, individual MMIC chips including amplifiers for transmitting and receiving, TDD switches, and a filter to suppress unwanted harmonics and images on the multilayer alumina-ceramic/polyimide substrate.

DESIGN CONCEPT

Fig. 1 shows the target structure of the three-dimensional active antenna, and the function block diagram is shown in Fig.2. An MSA array is placed on/in the multilayer alumina-ceramic substrate (ε_r = 9.0, tanδ = 0.001 at 10 GHz) . The individual MMIC chips integrated with amplifiers for transmitting and receiving, TDD switches, a filter, antenna feeding circuits, and other RF/IF functional circuits such as beam switching circuits are placed on/in the multilayer polyimide substrate (ε_r = 3.2, tanδ = 0.002 at 10 GHz) . The individual MMIC chip of few millimeters square is connected to circuit terminals using Au-wirebonding that is commonly used to mount LSIs. The polyimide substrate has simply constructed multilayers, and it easily achieves a level of precision of several micrometers for

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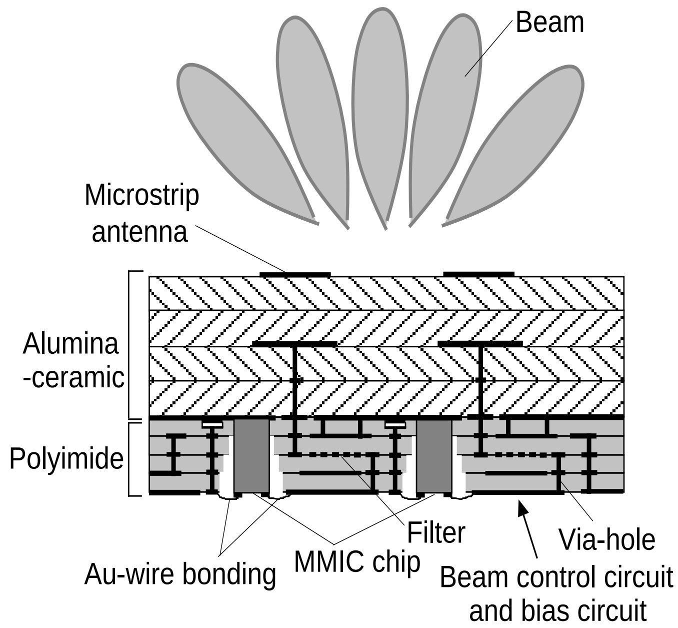


Fig. 1 Schematic diagram of proposed three dimension active antenna

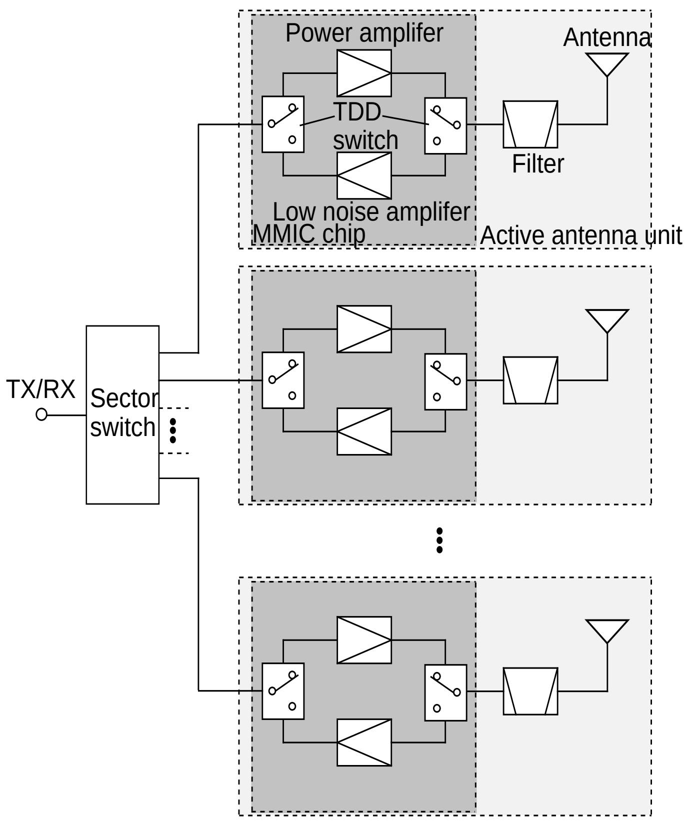


Fig. 2 Function block diagram

a transmission line and a high-frequency circuit. Recently, a lower-cost technology has been developed for three-dimensional connections between layers using via-holes [7]. It also makes it possible to construct a filter and antenna feeding circuits on an alumina-ceramic substrate. The characteristics of this active antenna structure are described below.

(1) The loss of the beam forming and feeding circuits does not influence the NF and the EIRP.

(2) It is possible to achieve a lower cost because the area required for GaAs can be reduced.

(3) The wiring of the RF/IF circuit and DC bias can be accomplished in a simple manner.

(4) It is possible to achieve transmission diversity.

Generally up to now, the MSAs of an active antenna were placed on a substrate at a lower level of permittivity to take into consideration the radiation efficiency and the bandwidth [8]. However, in most cases this does not pose a practical problem in the construction of MSAs on a high permittivity substrate. It is easy to construct via-holes in an alumina-ceramic substrate just as in the polyimide substrate, accordingly, the MSAs can be fed by the via-holes. In conventional active antennas the slot-coupled feeding method is used [9], but it is possible to use pin-fed MSAs to eliminate the coupling caused by unwanted radiation in the polyimide substrate. Since the thermal expansion coefficient between the polyimide and the alumina-ceramic substrate is different, it causes a distortion at the boundary of the two substrates in the sintering process of the alumina-ceramic substrate. Hence, a problem occurs in that a via-patch with the minimum size of 1 mm x 1 mm is required to make the via-hole of 200mmϕ in a 100 mm x 100 mm substrate. The next chapter describes the MSA design which takes into consideration the influence of the via-patch.

DESIGN AND EXPERIMENT OF MSA ON THE ALUMINA-CERAMIC SUBSTRATE

Fig. 3 shows the structure of the pin-fed MSA. In this figure, the radiation element is fed through the via-hole which interconnects the microstrip line and the radiation element constructed in the middle layer of the alumina-ceramic substrate. The impedance of the antenna is determined by the position *d* of the via-hole. In addition, a parasitic element is used for the uppermost alumina-ceramic layer in order to achieve a wider bandwidth. This design and analysis takes into consideration the fact that the via-patch constructed between the alumina-ceramic and the polyimide substrate is needed in the manufacturing process. We use the spectrum domain moment method for the antenna analysis. Here, the size of the via-patch is 1 mm x 1 mm square. The analysis parameter is the square slot width *s* (Fig. 3) between the via-patch and the ground plane constructed in the boundary layer. The radiation element sizes are adjusted for each slot width. Fig. 4 shows the return power

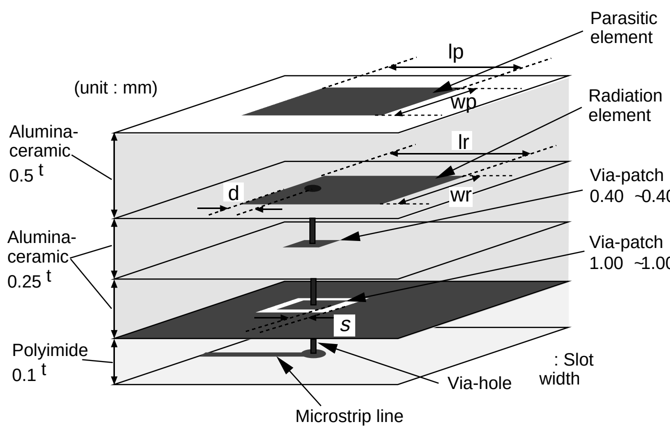


Fig. 3 Structure of pin-fed microstrip antenna

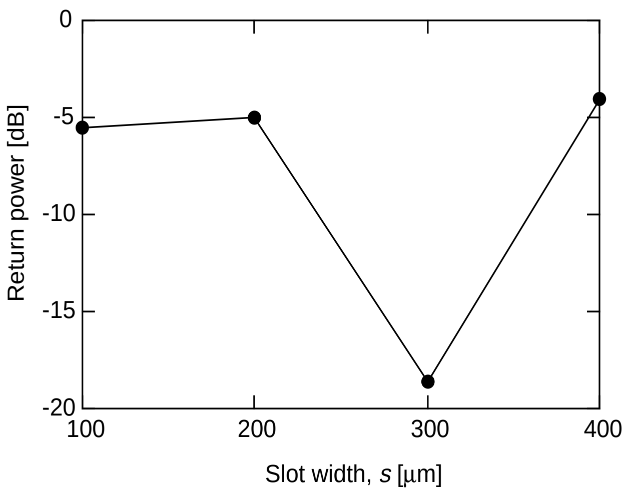
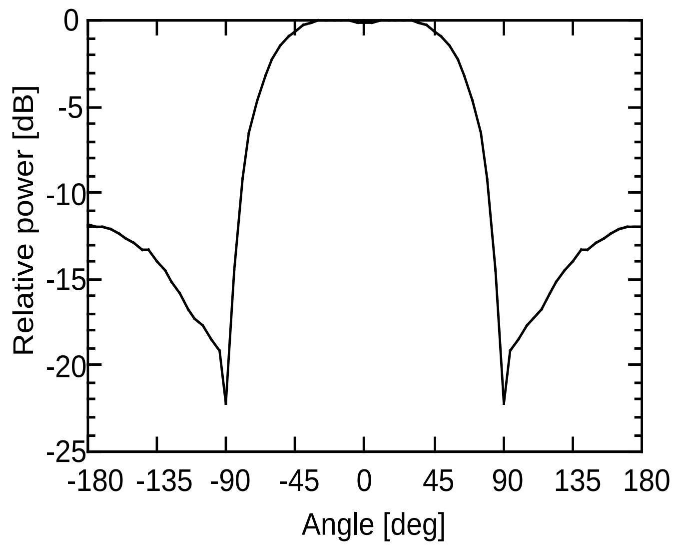
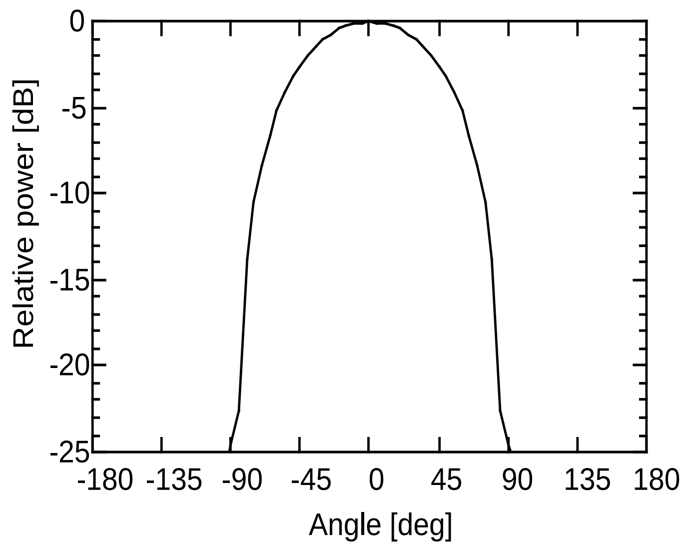


Fig. 4 Calculated return power versus slot width

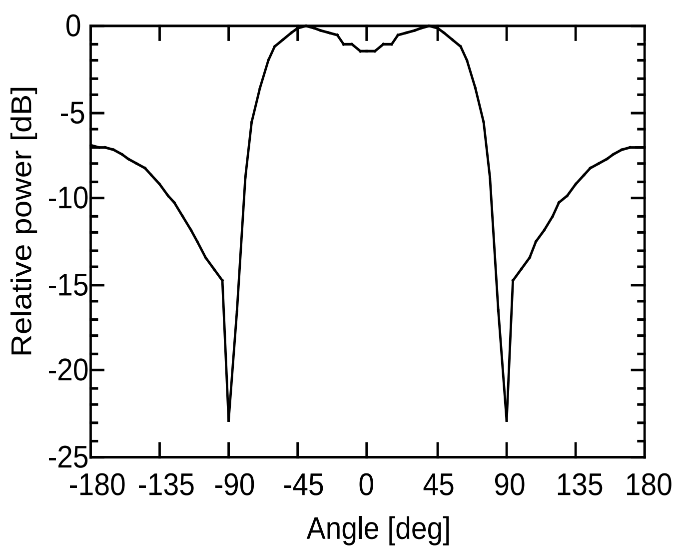
versus the slot width. In this figure, when the slot width is 300 µm, the return power is less than -18 dB. Fig. 5 shows the H-plane radiation patterns in which the slot width changes from 200 to 400 µm. In these figures, when the slot width is 300 µm, it is clear that the MSA characteristic is satisfactory. However, when the slot width is 200 and 400 µm, the mainlobe has a notch and the backlobe level is large. It is thought that the coupling between the via-patch and the ground plane constructed boundary of the two substrates is large when the slot width is 200 µm. On the other hand, when the slot width is 400 µm, the large back lobe is thought to be caused by that the MSA is operated using an equivalently small ground plane. Fig. 6 shows the experimental result of the frequency characteristics at 20-GHz band of the return power with the slot width of 300 µm. The dimensions of the radiation element are 1.96mm(L) x 1.96mm(W), and the parasitic element are 2.16mm(L) x 2.16mm(W). In this figure, the measured data agree well with the calculated values, and confirm that the design method is reasonable.



(a) s = 200µm



(b) s = 300µm



(c) s = 400µm

Fig. 5 Comparison of calculated H-plane radiation patterns for various slot widths

CONCLUSION

We proposed a three-dimensional active antenna configuration for a front-end module of a high-speed wireless communication system at millimeter and quasi-millimeter-wave

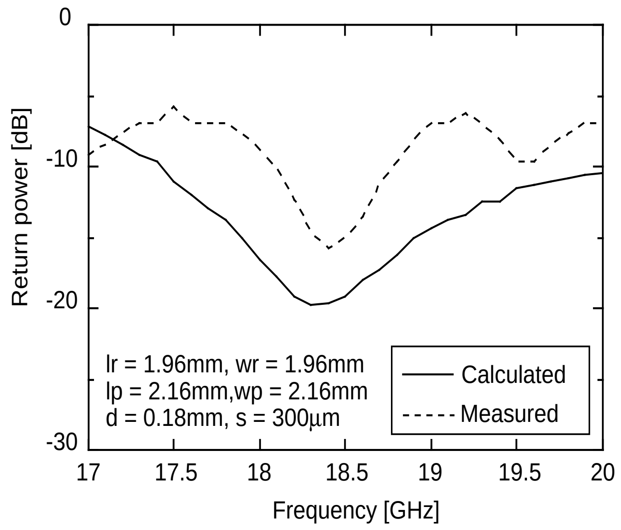


Fig. 6 Calculated and measured return power

frequencies. This configuration is integrated with an MSA array on/in the multilayer alumina-ceramic substrate, individual MMIC chips including amplifiers for transmitting and receiving, TDD switches, a filter for suppressing unwanted higher harmonics and images on/in the multilayer polyimide substrate. We designed and analyzed the MSA with a parasitic element for the fundamental part of the active antenna at 20-GHz band including the via-patch constructed between the alumina-ceramic and the polyimide layer that is necessary in the manufacturing process. When the slot width around the 1mm x 1mm via-patch was 300 µm, the good radiation pattern and impedance matching condition were achieved. We examined the impedance characteristics of the antenna, and confirmed the validity of the analysis method. The evaluation of the whole mounted three-dimensional active antennas is future work.

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