30-GHz Multibeam Antenna Using Bi-layer Butler Matrix Circuits

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I. Introduction

System studies and its hardware investigations of indoor high-speed radio communication are being conducted in millimeter and quasi-millimeter-wave frequencies. Such systems must offer data transmission rates of 10Mbps or higher, so anti-multipath and anti-shadowing techniques are necessary. One solution is to narrow the beamwidth of base stations and personal station antennas. However, pencil-beam antennas require beam-control and severely limit the mobility of the radio communication systems. Figure 1 shows a future indoor high-speed radio communication system using a non-wired wireless relay station. This system has the potential to successfully achieve macroscopic diversity[1]. We need to develop a multibeam antenna for base stations in a system that connects independent relay stations and that can easily set the beam-direction.

Perpendicularly mounting a digital phase-shifter of several bits on a phased-array antenna is a well-known technique for multibeam antennas. However, these antennas have two problems. The first problem is that the digital phase-shifters on each element are excessively large. The other is that the control circuits for the mounted phase-shifters are excessively large. The dimensions of the feeding circuits can be miniaturized by using microwave monolithic integrated circuits (MMIC). A phased array antenna using a digital phase-shifter, however, is not efficient because it incorporates more functions. We use the Butler matrix for multibeam feeding circuits because the feeding circuits can be simply and inexpensively constructed using hybrids and microstrip lines. The Butler matrix becomes complex when employed for over 4 ports. In most cases, it is virtually impossible to construct feeding circuits without vias and airbridges. This not only increases the number of manufacturing processes but also results in inferior feeding circuits characteristics due to discontinuous impedance points on a microstrip line. Our research attempts to configure a bi-layer structure using a bi-layer structure hybrid without crossing a microstrip line.

This paper proposes a 30-GHz multibeam antenna that achieves a planar bi-layer 8-port Butler matrix by adopting a slot-coupled hybrid without vias and airbridges. In addition, this paper presents the performance results for these feeding circuits.

II. Construction

The azimuth and elevation that compose the base station beamwidth are both 10 degrees. The beam scan is ± 30 degrees as performed in 10 degrees unit, and the tilt of the elevation is +5 degrees.

We use the Butler matrix feeding circuits for available several several beam scans[2]. The 8-port Butler matrix is constructed using only branch-line hybrid as shown in Figure 2. This figure shows that the 8-port Butler matrix cannot be constructed using single layer microstrip circuits without vias and airbridges. Since the phase characteristics of the Butler matrix antenna ports are determined by the selected input port, the scan angle of the array antenna depends on the array element space. Therefore, there are no restrictions for the beamwidth, scan angle for mutual coupling, and the grating lobe.

The 8-port Butler matrix constructed by adopting slot-coupled hybrids and branch-line hybrids without vias and airbridges is shown in Figure 3. The 3-dB slot-coupled hybrid is described in reference[3]. Some of the slot-coupled hybrids in the Butler matrix exchange two-output terminals in order to avoid crossing the microstrip lines with the delay line adjustment. In most cases, it is virtually impossible to construct an 8-port Butler matrix without crossing the microstrip line. Using the aforementioned terminal exchange facilitates the construction of the 8-port Butler matrix. This feeding circuits structure is useful in decreasing the number of manufacturing processes used to make airbridges compared with monolayer substrate structure constructed by branch-line hybrid only.

We have analyzed slot-coupled hybrids and branch-line hybrids using the spectrum domain moment method [4]. The design frequency is 30 GHz, and the substrates are RT/duroid 5880 (ε_r=2.20±0.015, tan δ =0.0009 at 10 GHz). Figure 4 shows the model for a slot-coupled hybrid. Figure 5 shows the analytical results of the slot-coupled hybrid. Then model contains a bonding film that binds these two substrates. This figure clearly shows that the insertion losses are approximately 4.0 dB and the phase difference of the two output-ports is about 90 degrees.

We use a rectangular slot-coupled microstrip antenna as an array element. The array structure is determined to be 8 elements in both the horizontal and vertical directions, and a 0.7 λ_0 space in the array occurs because the beamwidth is constricted to 10 degrees in both the horizontal and vertical directions. The degree of tilt in the horizontal pattern is determined to be 5 degrees in order to achieve a peak pattern of 0 degrees. The degree of tilt in vertical pattern is determined to be 5 degrees in order to direct the signal from the base station on the wall to the relay station located on the ceiling. Figure 6 shows the analyzed amplitude and phase characteristics of the Butler matrix for port 6. This figure clearly shows that the phase characteristics are close to the desired values and the amplitude has a deviation of 1.8 dB. It is considered that the principal origin is the distributed deviation of hybrids. Figure 7 shows the calculated characteristics that were calculated from analyzed amplitude and phase characteristics of the Butler matrix. This figure clearly shows that these feeding circuits achieve the desire scan angle. It is confirmed that the output-characteristics of the Butler matrix is sufficient.

III. Experiment and results

Figure 8 shows the structure of the multibeam antenna. This figure is constructed without vias and airbridges in the feeding circuits. Figure 9 shows the experimental horizontal pattern of terminal port 6 designed with a +20 degrees scan angle. This figure are made out sufficiency of phase characteristics using for multibeam feeding circuits by achieving scan angle[5]. Since the Butler matrix can use multiple ports simultaneously, this characteristic is passed on to the antenna. Figure 10 shows the experimental characteristics of this antenna. It is clear that the deviation between the experimental and designed scan angles is less than 3.0 degrees, and the deviation of the beamwidth is less than 2.0 degrees. These results clearly show that the phase characteristics of this Butler matrix are sufficiently accurate.

IV. Conclusion

We proposed a 30-GHz multibeam antenna constructed using an 8-port Butler matrix of bi-layer microstrip circuits with branch-line hybrids and slot-coupled hybrids. This feeding circuits do not require the use of vias and airbridges to avoid microstrip line crossing.

The design of the overall antenna makes use of the spectrum domain moment method and the analysis effects of a bonding film for binding the two substrates.

We manufactured this antenna, and we confirmed that the deviation between the experimental and designed scan angles is less than 3.0 degrees.

Judging from results, the bi-layer 8-port Butler matrix feeding circuits are useful for a multibeam antenna to reduce the number of manufacturing processes.

References

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[2] N. Inagaki, H. Takeda, and Y. Mikuni, "Antenna Feed Technologies," Trans, IEICE., Vol. J71-B No.11, pp.1228-1236, Nov. 1988.

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[4] T. Seki, K. Uehara, and K. Kagoshima, "Bi-layer Architecture for Planar Butler Matrix Circuits," Proceedings of The 1995 IEICE General Conference, B-64, 1995.

[5] T. Seki, K. Uehara, and K. Kagoshima, "Multibeam Antenna Using Bi-layer Architecture for Planar Butler Matrix Circuits," Proceedings of The 1995 Communications Society Conference of IEICE, B-101, 1995.

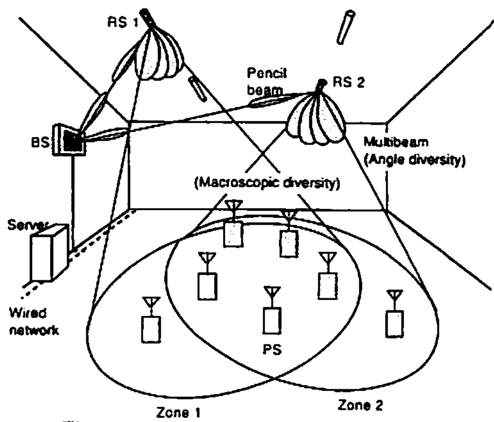

Figure 1. Future indoor high-speed radio comunication system

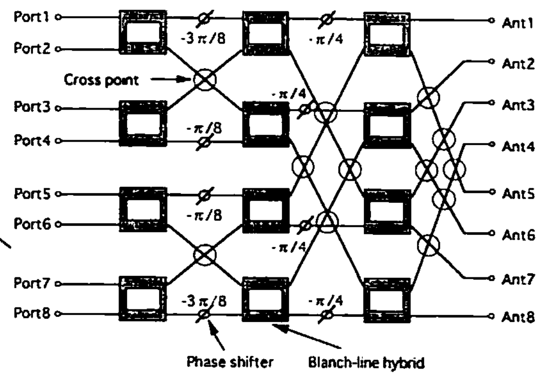

Figure 2. 8ports Butler matrix

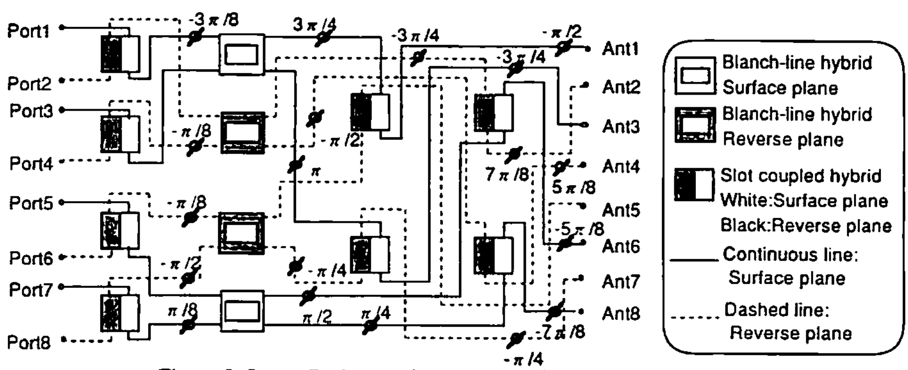

Figure 3. 8ports Butler matrix constructed by bilayer substrates

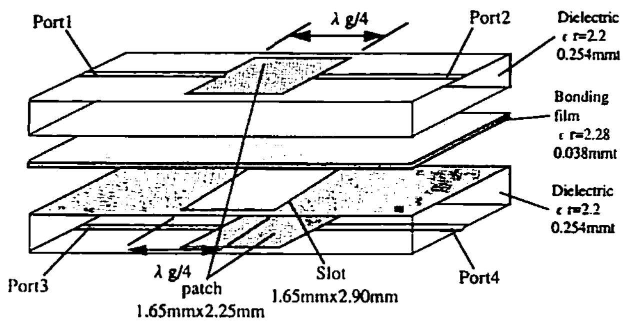

Figure 4. Analysis model of slot-coupled hybrid

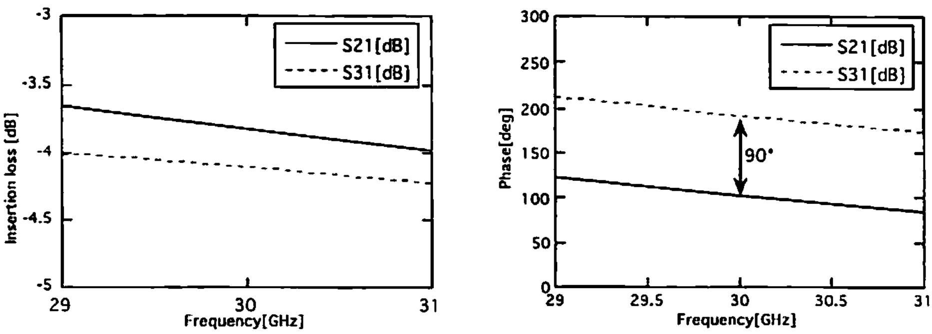

Figure 5. Analysis characteristics of slot-coupled hybrid

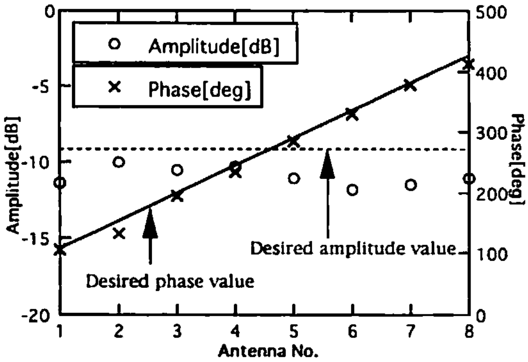

Figure 6. Calculated characteristics of the Butler matrix

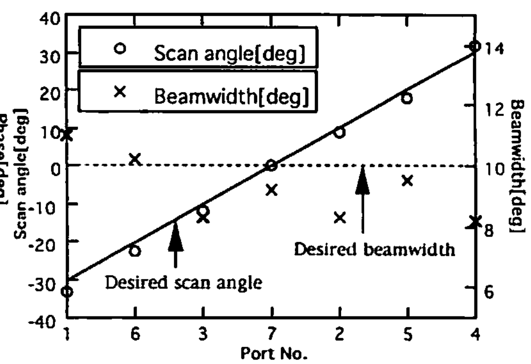

Figure 7. Calculated results of the Butler matrix

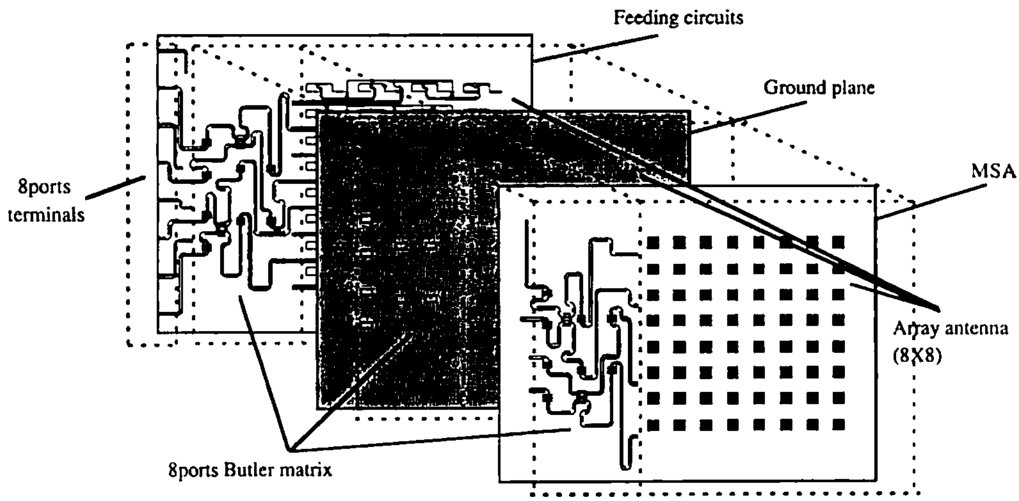

Figure 8. Multibeam antenna

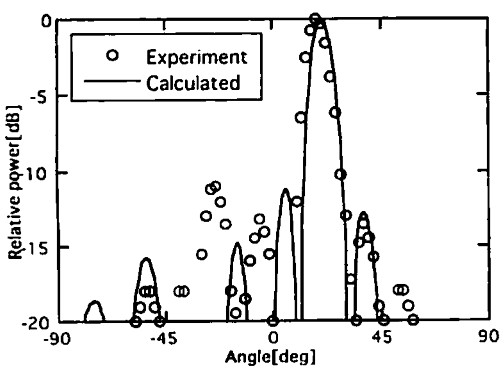

Figure 9. Horizontal pattern of multibeam antenna (Designed scan angle is +20degrees)

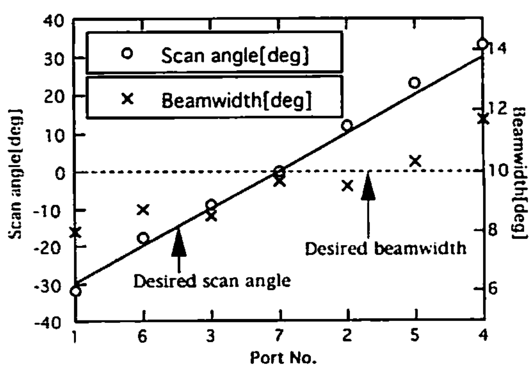

Figure 10. Measurement results of multibeam antenna