A Planar Direction-Finding Antenna with Reconfigurable Circuit for Scan Range Extension

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***Abstract*—A direction-finding antenna that estimates an angle of arrival (AoA) in wide angles is proposed. The antenna contains four quasi-Yagi antennas and a beamforming circuit that includes phase shifters, power dividers, and SPDT switches. The SPDT switches reconfigure the number of elements to be excited. The simulation results verify the null steering range is enhanced as double as the antenna without the circuit.**

***Keywords*—Quasi-Yagi antenna, direction-finding antenna, antenna radiatoin patterns, reconfigurable SPDT circiuts**

I. INTRODUCTION

Direction-finding (DF) antenna is widely used to search emitting radio sources. In practical situations where fast response is required, electronic scan and wide scan range are desirable. This paper proposes a DF antenna that scans a null widely by a reconfigurable circuit. The antenna has four antenna elements to scan the main beam with 10 dBi directivity. When steering a null, two antenna array scans a null wider than four antennas. Fig. 1 shows null position changes as a function of phase differences. Calculations are based on array factor, and δ indicates phase differences. A two elements array scans a null three times wider. We design an antenna so that two elements are excited for steering a null, while four elements are excited for scanning a beam.

II. ANTENNA DESIGN AND RESULTS

Fig. 2 shows the proposed antenna system and the design. The antenna is designed on an FR-4 substrate whose permittivity is 4.2, the thickness is 0.80 mm, and the tangent loss is 0.018. The 3-bit switched line phase shifters [1] determine total phase shifts. In the design, each has phase shifts of 30, 60, and 90 degrees. The additional 90 degrees phase shifters are inserted to scan a beam in 30 degrees. In doing so, the antenna scans a beam $\pm$ 30 degrees when the switches are turned on. When the switches are turned off, only internal two antennas are excited and steers a null $\pm$ 60 degrees. Quasi-Yagi antennas [2] are designed in the 2.4 GHz band. The directivity is 6.3 dBi, while antenna efficiency is 80 % due to the loss in the FR-4 substrate. The beamforming circuit and the antenna array are designed separately. The simulation results of the quasi-Yagi antenna array are first shown. Fig. 3 is S-parameters of the quasi-Yagi antenna array. The designed frequency band is indicated as BW in the graph. The reflection coefficients, S_{11} and S_{22} are under -10 dB in the frequency of interest. The mutual couplings are less than -15 dB. Fig. 4 (a) shows radiation patterns when the antenna scans the main beam. All antennas are excited, and phase differences δ of 0, 30, 60, 90 degrees are applied between neighboring antennas. The main beam is scanned from broadside to 30 degrees as the phase differences are changed. Fig. 4 (b) shows when the antenna steers a null. The null positions are moved to the broadside as the phase differences increases. The formed null is very sharp and deep enough to obtain a higher estimation accuracy than using the main beam for direction-finding.

The beamforming circuit was designed, fabricated, and tested. The simulation results will be shown in the presentation due to space limits. Fig. 5 shows a photograph of a fabricated beamforming circuit, including bias circuits. There are a total of fourteen phase shifters and two SPDT switches. Port numbers are labeled at input and output ports to be referred to as measurement results in the following figure. The measurement results of phase shifts and insertion loss are shown in Fig. 6. The relative phase shifts are lower than desired phase shifts by five degrees due to fabrication error. The insertion loss variation is less than 0.8 dB. The transmission characteristics are almost the same in all ports. It is worth noting that the transmission coefficients, S_{21} and S_{51}, are lower than -25 dB when the switches are turned off. It is verified that the circuit characteristics are affordable to enhance the null steering range with few drawbacks.

III. CONCLUSION

A planar direction-finding antenna using the quasi-Yagi antenna array and the reconfigurable beam-forming circuit have been presented. Not only the detection range is enhanced, but the antenna components are fabricated readily on a low-cost planar substrate is attractive. Future work is to test whole performances including the circuit and the antenna.

ACKNOWLEDGEMENT

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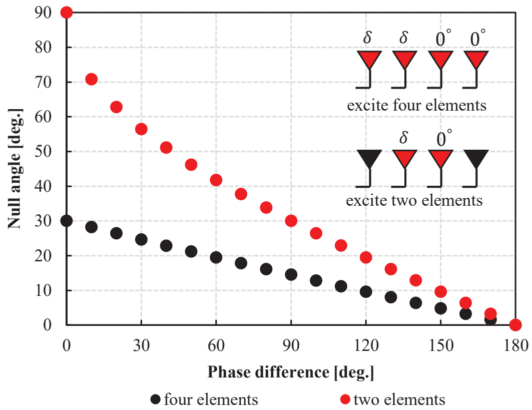

Fig. 1. Null position changes as a function of phase differences of antenna arrays. Black dots show those when four antenna elements are excited, while red dots show when the internal two antenna elements.

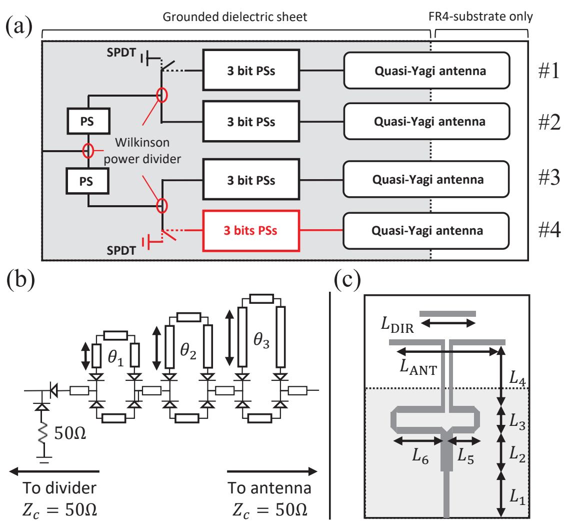

Fig. 2. (a) Block diagrams. (b) Schematics of a feeding circuit. (c) Antenna geometries. The schematics show where 3-bit phase shifters and SPDT switche are included. The antenna geometries are as follows: $L_{DIR} = 36.0$, $L_{ANT} = 54.0$, $L_1 = 30.0$, $L_2 = 18.0$, $L_3 = 6.60$, $L_4 = 35.8$, $L_5 = 9.45$, and $L_6 = 27.5$ (all dimensions are in millimeters.)

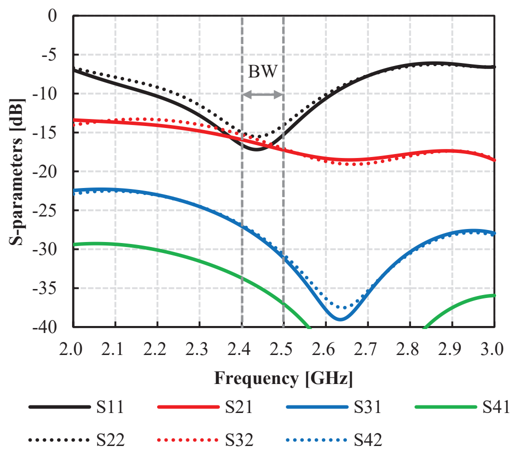

Fig. 3. S-parameters of the quasi-Yagi antenna array. Each port number corresponds to the output ports #1, #2, #3, and #4 shown in Fig. 2. The feeding circuit is not under consideration here.

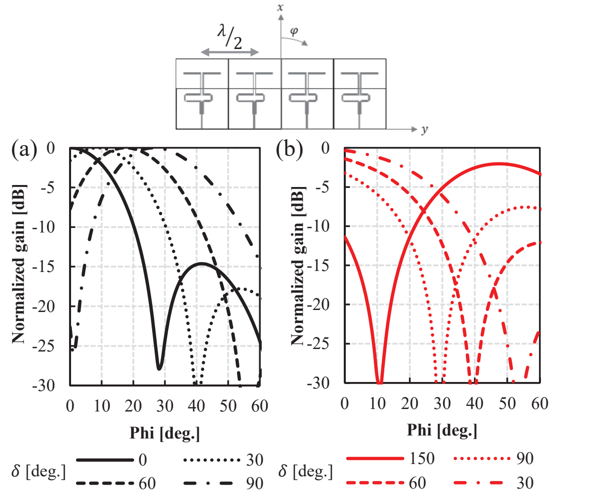

Fig. 4. Antenna radiation patterns of the quasi-Yagi antenna array: (a) beamforming; (b) null steering. The antenna element spacing is $\lambda/2$. Phase differences δ of 0, 30, 60, and 90 degrees are applied for beamforming while those of 30, 60, 90, and 150 degrees for null steering.

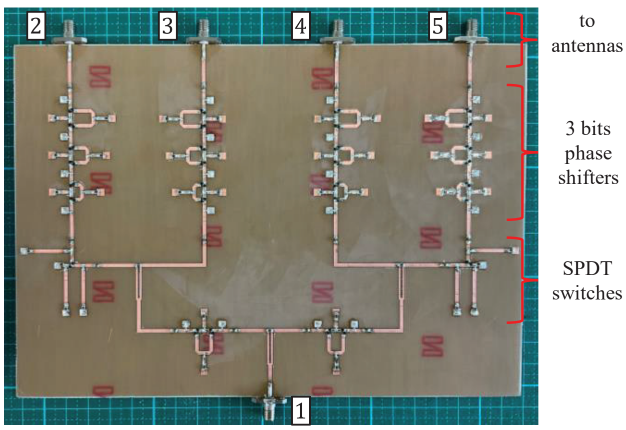

Fig. 5. A photograph of a fabricated beam-forming circuit.

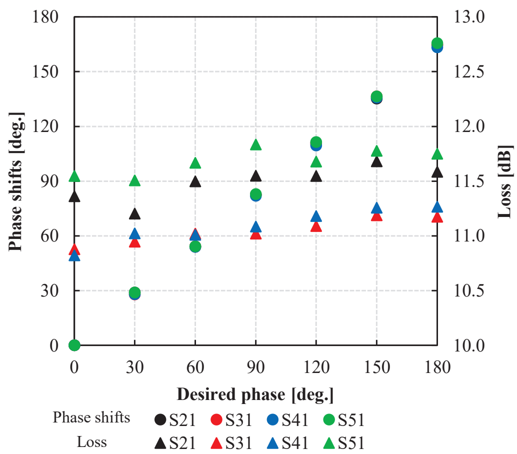

Fig. 6. Measurement results of phase shifts and loss in the circuit. The horizontal axis shows desired phase shifts for the designed one, while the left vertical axis shows measured phase shifts. The port numbers correspond to the numbers of Fig. 5.