2023 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting (USNC-URSI) | 978-1-6654-4228-2/23/$31.00 ©2023 IEEE | DOI: 10.1109/USNC-URSI52151.2023.10237845

A Switched-Beam Yagi-Uda Antenna Array for Dual Channel mm-Wave Communications

Ectis Velazquez, Jr., Murat Yuksel, and Xun Gong
Department of Electrical and Computer Engineering, University of Central Florida, Orlando, FL 32816 USA

***Abstract*—A Yagi-Uda array is proposed for dual channel mm-Wave communications. The array is comprised of four Yagi-Uda antennas, each with a driven element and a ground plane reflector. The array is reconfigurable and employs a switched-beam architecture to allow two signals to be transmitted and/or received at once. This preliminary design establishes 360° coverage in simulation. When used in conjunction with a software-defined radio (SDR) system it has the potential to double the processing throughput by using two antennas at once.**

***Index Terms*—antenna, beamforming, dual channel, mmWave, SDR, switched-beam, Yagi-Uda**

1. Introduction

In an effort to harness more bandwidth for attaining gigabit-per-second transfer rates, the wireless community has been turning to the millimeter wave (mm-Wave) frequency bands, particularly 30-100 GHz, for a solution. There continues to be an increasing demand for low-cost, beam-steerable antennas that can be software controlled. Software-defined radio (SDR) platforms are envisioned to be part of mainstream solutions where physical components are controlled by algorithms to utilize spectral resources. A key premise of mm-Wave bands is building directional antennas which enable higher spatial reuse. In [1] and [2], many challenges to SDR testing platforms at mm-Wave frequencies are discussed both from SDR hardware/software perspectives and the physical electromagnetics/antenna perspective, including (i) handling *mobility* of nodes causing frequent beam search and alignment, and (ii) designing *cost-efficient hardware* that can take advantage of the high spatial reuse potential of the directional beams. Algorithmic methods running SDR platforms offer promising solutions for the former. However, antenna system designs for the latter are mostly lacking or limited to a single beam. Existing mm-Wave antenna systems can only transmit/receive a single beam at a time. This significantly limits the spatial reuse as there can be multiple simultaneous mm-Wave communication links across the azimuthal plane. This work will focus on the challenge of attaining simultaneous mm-Wave data transfers/links with neighboring nodes, which requires new antenna system designs that give the SDR platform the capability to control which beam is being used for which data transfer. Among possible solutions, Yagi-Uda antennas are of particular interest due to their high directivity in end-fire array applications. A system comprised of several Yagi-Uda antenna elements is also advantageous due to being able to use a single substrate board to cover the entire azimuthal plane, which is not possible with broadside antenna arrays. In this paper, we design such a Yagi-Uda antenna system that allows processing of multiple signals at once in an attached SDR platform.

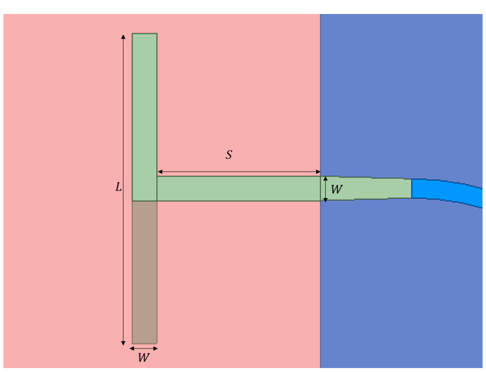


Fig. 1: Yagi-Uda Antenna with microstrip feeding. Substrate is made transparent to show the bottom arm of the driven element. $L = 4.08$ mm, $W = 0.32$ mm, $S = 2.16$ mm,

2. Switched-Beam Array Design

A. Antenna Design

In [3], a microstrip fed Yagi-Uda antenna design was presented where one arm of the driven element was located on the bottom surface of the dielectric substrate, and the other arm on the top surface. The design described a Yagi-Uda antenna with one director element, one driven element, and one ground plane reflector. This design methodology presents a planar Yagi-Uda antenna that can be made on a printed circuit board (PCB) and operates at 11 GHz. In [4] a similar Yagi-Uda antenna design was presented with higher gain for mm-Wave applications. This design achieves a gain of 10.9 dBi at 24 GHz using 5 director elements. This design also has a half-power beamwidth (HPBW) of 44°.

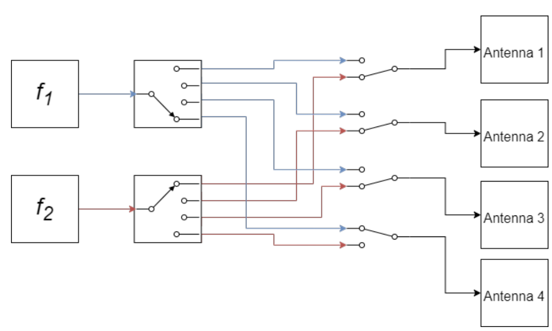
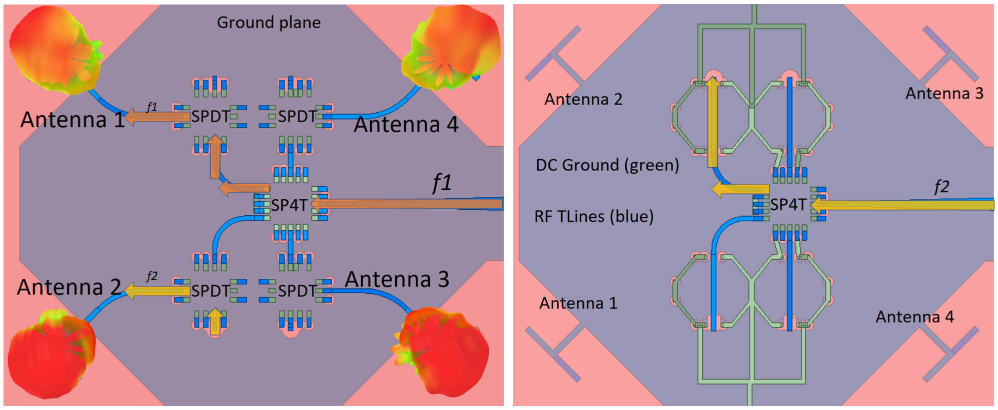


Fig. 2: Block diagram showing the intended use of the array with two simultaneous signals.



(a) Top view (b) Bottom view

Fig. 3: Top and bottom views of full array configuration including transmission lines and radiation patterns. Gain = 5dBi, HPBW = 88°. Example paths for f_1 in orange and f_2 in yellow.

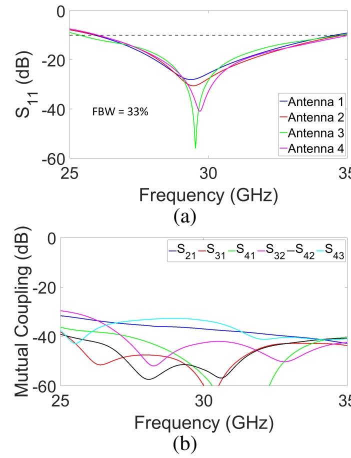


Fig. 4: (a) S_{11} of each antenna (b) Mutual coupling between antenna elements.

In this work, the switched-beam array covers 360° in the azimuthal plane. To achieve this, multiple Yagi-Uda antenna elements must be used, and their beamwidths should be wider than previous designs to reduce the number of antenna elements. Four antenna elements are chosen where each will have a HPBW of 90° to reduce the number of transmission lines and the complexity of the switching network, which is further discussed in Section 2-B. This leads us to create Yagi-Uda antenna elements with driven and ground plane/reflector elements for operation at 30GHz as shown in Fig. 1.

B. Switching Network

Four antennas and two beams were chosen to reduce the complexity of the system and fabrication of a blocking switching matrix. In theory a switching matrix of $2^m \times 2^n$ can be designed, but this can very quickly become prohibitively complex. A more complex blocking switching matrix is demonstrated in [5]. Here the proposed matrix was a 4×4 matrix design (scalable up to 32×32) which used eight switches and 22 layers to ensure there was no crossover between the switch RF and DC signal and ground routing. By beginning with only four antenna elements and two beams, we are able to reduce the system to three conductive layers and six switches. The top and bottom layers consist of the top arm of each driven element, transmission lines, and most of the switches. The center layer consists of the ground plane and the other arm of each driven element. The bottom layer consists of one switch, transmission lines, and DC ground lines. Looking at Fig. 2 the 2×4 blocking switching matrix is shown. In this configuration, each input is connected to all four outputs, but they cannot be accessed at the same time. To achieve this in the antenna feeding network, it can instead be thought of as two independent single-input four-output networks since the two input lines are isolated. Each antenna is terminated with a single pole double throw (SPDT) switch which has two input terminals connecting them to two separate single pole four throw (SP4T) switches on the top and bottom surfaces of the substrate.

The full array configuration is shown in Fig. 3 with two case examples: suppose the signal f_1 (in orange) was passing from the SDR platform to Antenna 1. The signal would proceed on the top surface of the board through the SP4T and then the SPDT at Antenna 1. A signal f_2 (yellow) to Antenna 2 will traverse the bottom of the board through the SP4T on the bottom, and then through a via to the SPDT on Antenna 2.

3. Simulation Results

The array is simulated in ANSYS High Frequency Structure Simulator (HFSS). From Fig. 4(a), the fractional bandwidth (FBW) can be calculated as 33%. Fig. 4(b) indicates sufficiently low mutual coupling between antenna elements. From Fig. 3 the radiation pattern of each antenna can be observed showing a gain of 5dBi for each antenna element with >96% radiation efficiency across the bandwidth and 88° coverage at 30GHz. Using the switching network to control two beams, any two antennas can be used simultaneously to transmit/receive two different signals. In combination with a SDR system this can double the processing throughput compared to a single channel system.

References

[1] K. Zheng et al., "Software-defined Radios to Accelerate mmWave Wireless Innovation," 2019 IEEE International Symposium on Dynamic Spectrum Access Networks (DySPAN), Newark, NJ, USA, 2019, pp. 1-4, doi: 10.1109/DySPAN.2019.8935877.

[2] Niu, Y., Li, Y., Jin, D. et al. A survey of millimeter wave communications (mmWave) for 5G: opportunities and challenges. Wireless Netw 21, 2657–2676 (2015). https://doi.org/10.1007/s11276-015-0942-z

[3] G. Zheng, A. A. Kishk, A. B. Yakovlev and A. W. Glisson, "Simplified feed for a modified printed Yagi antenna", Electron. Lett., vol. 40, no. 8, pp. 464-465, Apr. 2004.

[4] R. A. Alhalabi and G. M. Rebeiz, "High-Gain Yagi-Uda Antennas for Millimeter-Wave Switched-Beam Systems," in IEEE Transactions on Antennas and Propagation, vol. 57, no. 11, pp. 3672-3676, Nov. 2009, doi: 10.1109/TAP.2009.2026666.

[5] A. Barigelli et al., "Scalable Ka band switch matrix in compact LTCC package for satellite communication application," 2017 47th European Microwave Conference (EuMC), Nuremberg, Germany, 2017, pp. 1073-1076, doi: 10.23919/EuMC.2017.8231032.