Novel Yagi-Uda Direction Finding Antenna Backed by Software Defined Radio

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***Abstract*—A novel two-element front-end of squinted-beam monopole Yagi-Uda antennas is proposed to perform amplitude-only direction finding from 3.1 GHz to 4.2 GHz. The system makes use of the inherent beam squint resulting from diffraction from a finite ground plane. The beam squint and peak directivity are stabilized across frequency, varying less than 4° and 1.5 dB, respectively. Simulation results indicate a 74° unambiguous field-of-view over the band. Amplitude only direction finding with software defined radio receivers is also discussed.**

Keywords—Yagi-Uda; software defined radio; amplitude only direction finding

I. INTRODUCTION

Radio direction finding (DF) is integral to many commercial, scientific, and military uses. As the number of transmitters increases, the demand for such systems also rises in kind. Therefore, the development of new systems that are simple, wide bandwidth, and low cost is of great importance. The system proposed herein is composed of two squinted-beam Yagi-Uda antennas (Fig. 1) which feed two software defined radio (SDR) receivers. Typically, squinted beam DF systems are made of two antennas physically tilted in space [1], occupying a substantial volume. A smaller form factor is achieved here by imaging the antenna and harnessing the diffraction from the finite ground [2] to produce beam squint.

Monopole Yagi-Uda antennas are selected to demonstrate this concept, however, the approach is extendable to other antenna types as well. SDR receivers allow for streamlined development and the implementation of several DF algorithms. However, for purposes of this work, the scope is limited to amplitude only direction finding, offering advantages in terms of size, weight, power, and cost (SWAP-C). As such, the SDR emulates a receiver system with band division filters (e.g. multiplexers) feeding into amplitude detectors, which can offer improved accuracy when antenna patterns vary with frequency. Tests on fabricated prototypes agree well with theory.

II. YAGI-UDA ANTENNA SYSTEM

A design of the Yagi-Uda is presented, which improves fractional bandwidth at the cost of decreased gain. The Yagi-Uda is ostensibly a narrowband antenna with moderate gain, however, there are design modifications which can leverage this tradeoff to increase the bandwidth. Decreasing the distance between the driver and director elements, as well as decreasing the director element length both contribute to an increase in bandwidth [3]. The elements are brass and have a 3mm diameter ($0.036\lambda_{3.65\,GHz}$), which is larger than typical. Rather than a single reflector, a split configuration is used to provide increased front-to-back ratio. The chosen reflectors topology also further improves the bandwidth. Reflector length is increased ($0.285\lambda_{3.65\,GHz}$) to provide further improvement in bandwidth, at the cost of maximum realized gain [4]. A split reflector geometry also enables a coaxial feed along the ground plane, allowing for the two thin ground planes to be fastened together resulting in a smaller profile.

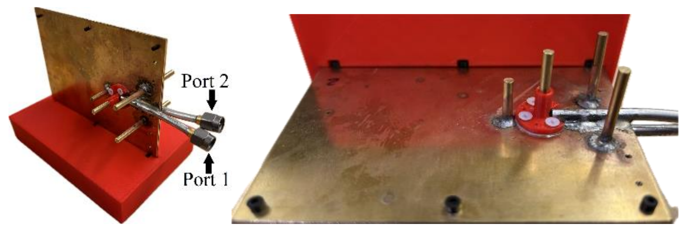

Figure 1. Fabricated monopole Yagi-Uda antennas.

An impedance bandwidth of 29% is achieved in both simulation (Ansys HFSS) and measurement (Fig. 2). The two antennas furthermore exhibit low coupling, less than -20 dB, which aids in the overall system's signal-to-noise ratio (SNR).

Scattering of currents on the finite ground plane introduces a squinting of the main lobe of this antenna, contributing to the field-of-view of the DF system. Stable beam squint (varying less than 4°) and HPBW (varying less than 5°) from 3.2 GHz to 4.2 GHz results in a more accurate DF system independent of frequency information. The peak directivity is greater than 7 dBi and stable over the band (Fig. 3). Additionally, the front-to-back ratio is greater than 10dB from 3.2 GHz to 4.47 GHz.

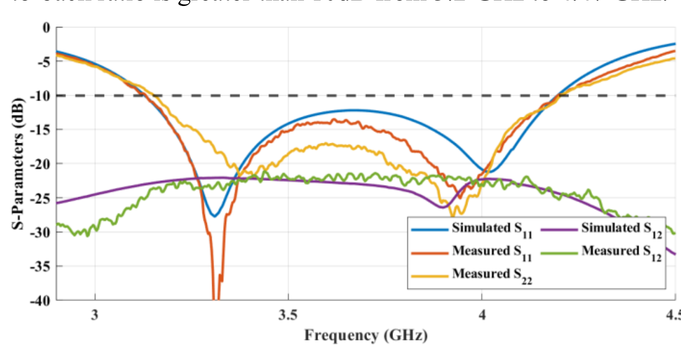

Figure 2. Simulated and measured S-parameters of the antenna.

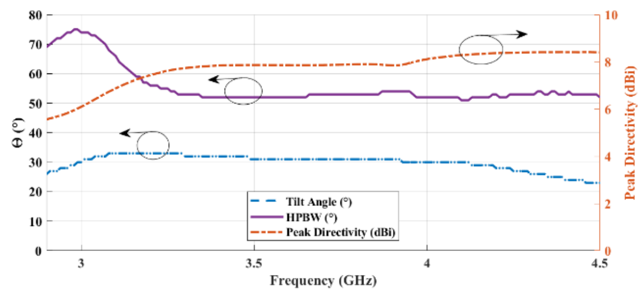

Figure 3. Peak beam angle, half-power beamwidth (HPBW), and peak directivity versus frequency.

III. Software Defined Radio Receiver

The receiver utilizes two HackRF One software defined radios [5], with clocks synchronized via SMA connection. The receiver feeds data into GNU Radio Companion where signal processing algorithms are implemented. Complex voltage samples are first collected in the form of I/Q data, and used to find voltage magnitude and phase. This is done by applying the Goertzel algorithm [6] to discern magnitude and phase at a single frequency bin of a discrete Fourier transform, wherever the signal peak is detected. In this way, amplitude, phase, and frequency information is collected for an incident signal.

In this application, the capabilities of SDR allow for a low cost receiver with easy implementation, emulating a receiver system involving band division filters and analog amplitude detection. To that end, amplitude-only DF also allows for the implementation of a low-complexity DF algorithm, providing proof of concept for the SDR as a viable alternative to a tradional analog receiver. However, more generally, the collection of these various signal parameters enables other direction finding approaches to also be explored.

IV. Direction Finding

A direction finding function (DFF), shown in Fig. 4 is calculated as [1]:

$$DFF_{dB} = 10\log_{10}\left(\frac{A_R}{A_L}\right). \quad (1)$$

Where A_R and A_L are the amplitudes of right and left beams, respectively. To closely fit the discrete data for the DFF calculated from the far field simulation results (Fig. 4), a cubic regression is chosen. To produce an angle-of-arrival, the minimum solution to this equation is evaluated.

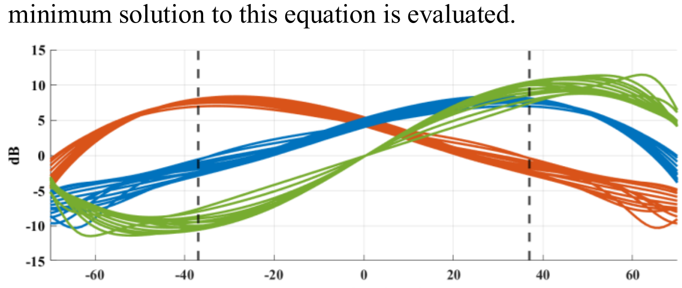

Figure 4. Port 1 (orange) and port 2 (blue) radiation patterns and DFF (green). Curves with 100 MHz increment are overlaid to show behavior across the bandwidth. The unambiguous FOV is indicated by dotted lines.

The DFF slope, or the rate of change of (1) with respect to θ, is shown with respect to angle-of-arrival, and frequency in the contour plot of Fig. 5. In general, an increased DFF slope implies that a lower received signal-to-noise ratio is tolerable, which will improve the performance of direction finding by lowering the RMSE [7]. The unambiguous field-of-view is defined by where the DFF has slope greater than 0°.

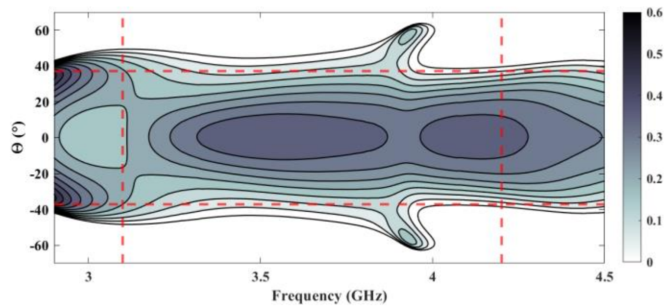

Figure 5. DFF slope vs. θ and frequency. The unambiguous FOV is indicated by horizontal dashed lines whereas the impedance bandwidth is between the vertical dashed lines.

V. Conclusions

A DF system with two monopole Yagi-Uda antennas employing a finite ground plane to deflect the main beam is proposed. The beam squint varies by only 4° across the bandwidth. Results show DF is possible from 3.1 GHz to 4.2 GHz, with an unambiguous field-of-view of 74°. SDR receivers emulating band division and amplitude detection are used to complete the system. Future research will make use of the ampltiude, frequency, and phase granted by SDR to perform DF with other techniques.

Acknowledgment

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