Mutual Coupling Compensation in Receiving Arrays and Its Implementation on Software Defined Radios

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***Abstract*—Mutual coupling is compensated in a four element uniform linear receiving array using software defined radios. Direction of arrival (DoA) is estimated in real-time for the array with spacing $d=\lambda/4$. The decoupling matrix was measured using a VNA for only one incident angle. After compensation the error in DoA estimation was reduced to 5%. Comparing the DoA results with $d=\lambda/2$ spaced Uniform Linear Array (ULA), 1.2% error was observed. Although, the experiment was performed indoors with a low SNR, the results show a substantial improvement in the estimated DoA after compensation.**

***Index Terms*—Direction of Arrival, LabView, Mutual Coupling, Receiving Antenna Arrays, SDR.**

I. Introduction

Direction of Arrival is an important aspect when considering receiving antenna arrays. However, mutual coupling is a notorious problem in estimating the accurate angle of arrival, if the elements of the array are placed closer than $\lambda/2$ [1]. Using Software Defined Radios (SDR), Direction Finding (DF) can be accomplished using the high-speed FPGA of the SDR or doing the computation offline on a host computer using Matlab, LabView or GNURadio [3]. SDR and Universal Software Radio Peripheral (USRP) are often used analogous, however, USRP paired with a host computer creates a complete SDR system. In DoA estimation using SDR, the receiving ULA are spaced $\lambda/2$ or greater to avoid coupling [3–5]. The received voltages must be decoupled to estimate the DoA, for spacing less than $\lambda/2$. In this work, for the first time, mutual coupling has been compensated in real-time using SDRs for a four element ULA with inter-element spacing of $\lambda/4$ in receiving case and DoA is estimated. For this, the ULA is illuminated by a plane wave and mutual impedances are measured. After finding the decoupling matrix [1], the real-time received voltages acquired by the SDRs are decoupled. These voltages are then given as an input to MUSIC algorithm to detect the DoAs. The implementation is done using NI USRP and LabView.

II. Proposed System Design

The block diagram of the system is shown in Fig. 1. A total of six USRPs are used along with OctoClock-G CDA-2990 and a Gigabit Ethernet Switch (GbE) connected to a host computer. Here, we use four NI USRP 2930 as RF receivers and NI-USRP 2932 and Ettus USRP B210 as RF transmitters. NI-USRP 2932 is used for calibration as Reference (Ref) signal in order to synchronize the phase of all the RF receivers. The phase is calibrated by physically wiring a 10 kHz tone Ref signal from the USRPs TX1/RX1 port to each RX2 port of the four receiving USRPs using a 4 port Wilkinson Power Divider. Phase synchronization is the most important part of the setup since this is the basic assumption for many DF algorithms. Four antennas are attached to each RX1/TX1 port of the four RF receivers. Furthermore, an external high accuracy time and frequency reference (Octoclock) is used for RF local oscillator synchronization and ADC timestamp alignment for the RF receivers. This can be achieved by connecting the 10 MHz reference clock and 1 PPS signal generated by the Octoclock to the RF receivers. Since, we have used the NI USRP 2930 which is a combination of (N210+WBX+GPSDO), therefore, the GPSDO must be manually disconnected in order to connect the external reference clock and external PPS ports of the four receiving USRPs with those of Octoclock, respectively. The second transmitting USRP B210 is used as the incident target source which transmits a tone of 100 kHz. The measurements were taken for a fixed elevation angle $\theta=90°$ and the distance between the transmitter (target) and receiving array was fixed at 1 m for optimum results [3]. The details of the equipment are mentioned in Table 1. The complete system can be seen in Fig. 2. It should be noted that, all the measurements were taken indoors in the Istanbul Medipol University (IMU) campus building corridor which is a noisy atmosphere with multi-paths, standing waves, and interference. Hence, the readings are more realistic and the compensation in such a scenario shows the robustness of the applied method.

III. Mutual Impedance Measurements

The same ULA with four antennas at 2 GHz is considered with a spacing $d=\lambda/4$. In this section, we first measure the isolated voltages received by the four element ULA using a VNA by measuring the S-parameters (S_{21}) of the array [2]. A Log Periodic antenna was placed 1 m away to act as a plane wave source with $\theta = 90°$ and $\phi = 90°$. Using the method in [1], we find the decoupling matrix, which was

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used in LabView to decouple the received voltages at the RF receivers. These measurements were performed separately but in the same noisy environment as in Sec. II.

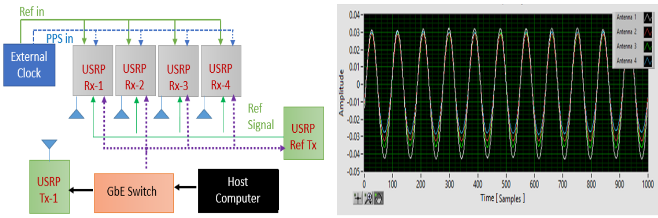

Fig. 1: Block diagram of DoA estimation system (*left*). Received signal amplitude after calibration (*right*).

TABLE I: Experimental Setup

Item	Detail
SDR	NI USRP 2930 * 4, NI-USRP 2932*1, B210*1
Antenna	JCG401 GSM Antenna*4, LogPeriodic LP0965*1
Frequency-Time Module	OctoClock-G CDA-2990
Gigabit Ethernet Switch	Tplink TL-SG108
Carrier Frequency	2 GHz
Antenna Array Spacing	$\lambda/2$, $\lambda/4$
MUSIC snapshot	3000
Sampling Rate	1 MHz
Platform	LabView

IV. Experimental Results

At the receiver, two signals are received, Ref signal and target signal (Tx-1). These signals are separated using a digital filter. The Ref signal is used for phase synchronization by estimating the phase shift and then calibrating the phase and gain of all the four receivers. The received signal before and after phase synchronization is shown in Fig. 1 (right) and Fig. 3. The target signal is also calibrated and decoupled using the measured decoupling matrix before being given as an input to MUSIC algorithm. Two ULAs, with inter-element spacing $d{=}\lambda/2$ and $\lambda/4$, were used for measurements. First,

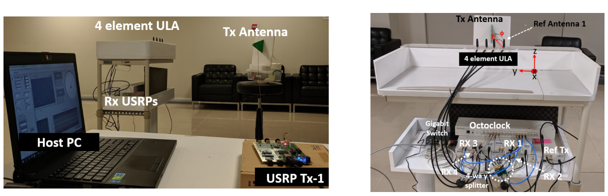

Fig. 2 Experimental setup for direction of arrival estimation.

the general case of $d=\lambda/2$ was considered and DoA was calculated for angles 0 to 60^o in steps of 5^o. Without using a decoupling matrix, the target signal is directly fed to the MUSIC algorithm. Next, the ULA with $d{=}\lambda/4$ is used and DoA is estimated without using the decoupling matrix. Finally, the mutual coupling is compensated by using the decoupling matrix and the DoA is estimated. The results are shown in Fig. 4 (left). The percentage error for $d=\lambda/2$ is 3.52%. The results are highly erroneous when $d=\lambda/4$, with 9.81% error and after compensation of mutual coupling the error is reduced to 4.72%. The MUSIC spectrum for the case when DoA is from $\phi = 60^o$ is shown in Fig. 4 (right). It can be seen that the compensated results for $d{=}\lambda/4$ are in close proximity to those measured when ULA with $d{=}\lambda/2$ is used.

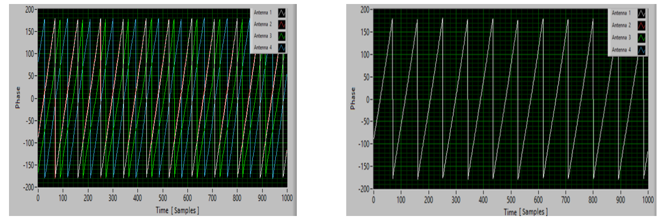

Fig. 3 Received signal. Before (*left*) and after (*right*) phase calibration.

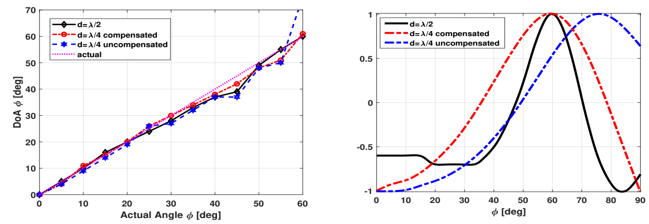

Fig. 4: DoA estimation for a four element ULA with $d{=}\lambda/2$ and $d{=}\lambda/4$ (with and without mutual coupling compensation). Estimated DoA vs Actual DoA for $\theta = 90^o$ (*left*). Spatial spectrum of MUSIC algorithm for DoA detection of signal from $\theta = 90^o$, $\phi = 60^o$ (*right*).

V. Conclusion

Mutual coupling is compensated in a four element receiving ULA using SDR. Two ULAs were studied to see the effect of coupling using a general case of $d = \lambda/2$ and coupled case of $d{=}\lambda/4$ inter-element spacing. The decoupling matrix was measured for the case of coupled ULA and then used to decouple the received voltages in real-time. The initial results show promising improvement in DoA estimation. Further testing using different arrays and experimental testbeds will be carried out in future work.

Acknowledgment

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