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# Self-Interference Mitigation in Full-Duplex Base-Station using Dual Polarized Reflect-Array

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***Abstract*—This paper proposes the use of reflect-array to mitigate self-interference in the propagation domain aiming to achieve a full-duplex mobile system. An ultra-wideband reflect-array is designed to enable full-duplex in an indoor/outdoor LTE base-station with half-duplex users. The antenna design is customized to meet the full-duplex requirements by generating two cross-polarized beams using two separate feeders to achieve high isolation between the downlink and uplink signals. The paper also analyzes the components of self-interference in the direct and back-scattered paths, and the amount of isolation that can be achieved in a wideband system. Both reflect-array and full-duplex technologies are strong candidates to be used in 5G.**

***Index Terms*—reflect-array, full-duplex, self-interference, 5G**

## I. INTRODUCTION

The existing generations of mobile communication depend completely on half-duplex (HD) transmission schemes, in which the transmitted and received signals are separated either in time, Time Division Duplexing (TDD), or in frequency domain, Frequency Division Duplexing (FDD). This causes an obvious limitation in resource utilization as these systems invest only half of the available resources. Moreover, most of the traditional approaches for increasing spectral efficiency, such as Adaptive Coding and Modulation (ACM), Multiple Input Multiple Output (MIMO) and smart antennas, have nearly reached their maximum limits [1]. Therefore, there is a major interest in restructuring communication systems to enable In-Band-Full-Duplex (IBFD), or shortly known as (FD). FD communication implies the possibility to double the capacity of wireless communication, and it is considered as a key technology for 5G systems.

The main challenge facing FD system design is how to suppress the self-interference (SI) signal, i.e. the transmitted signal that leaks from the transmitter into the receiver of the same device. Suppressing such interference is the crucial key issue of FD realization, taking into consideration that the transmitted signal power is about 80-120 dB higher than the power of the desired received signal from the remote node in most of standard systems [2]. In 5G systems, the trend is mainly towards short-range coverage, where the cell-edge path loss is less than that in traditional cellular systems, making the problem of SI suppression more solvable [1].

Generally, self-interference cancellation (SIC) is implemented in three domains: propagation, analog, and digital domains. None of these domains can meet the required cancellation value per se. Therefore, hybrid solutions are proposed in the literature [1]. In propagation domain, several SIC techniques has been presented to mitigate SI, for example: Antenna conditional placement [3], [4], Directional isolation [5], [6], Absorptive/Reflective Shielding [7], [8], and Cross-polarization [8], [9]. In average these techniques can achieve about 15 dB of isolation practically. Few works reached almost 70 dB but in optimal conditions, like using anechoic chamber with narrow band signals. This urges to think about other antenna techniques that can achieve higher SI isolation in practical conditions. Massive MIMO systems have been proposed for 5G due to their compatibility with small cells. However, Massive MIMO is complex and less adaptable with shorter wavelengths [10]. Meanwhile Reflect-Array (RA) is getting the attention again because it is much simpler, more flexible, and considerably cheaper compared to Massive MIMO. This makes RA a strong candidate technology in some 5G scenarios [10].

A reflect-array consists of an array of radiating elements that provides an adjusted phasing to form a focused beam when it is illuminated by a feed. Printed RAs combine certain advantages of reflector antennas and phased arrays [11]. Reflect-array can perform like a phased array antenna but without the use of any power divider or additional phase shifters. The simple design of RA and its low power consumption make it economically more applicable in 5G systems [10]. Moreover, its adaptability to high frequencies makes it suitable for high gain and high bandwidth operation. Previously, RA was considered a narrow bandwidth antenna, and this well-known limitation was due to the narrow band nature of the microstrip patches and different spatial phase delays between the feed and each element of the reflect-array [12]. Recently, many works have been done to have better performance of RA in wide/ultra-wide bands (UWB) such as [13]–[16]. The high gain performance can be obtained by increasing the size of the RA which can produce sharp beams, however, this would also increase the different spatial phase delays between the feed and each element of the reflect-array [17].

The novelty of this paper is that it proposes, for the first time, the use of RA to mitigate SI in propagation domain for mobile communication. The UWB RA designed in [13] is considered to enable FD in an indoor/outdoor base-station. The antenna design is customized to meet the FD requirements, where two cross-polarized RAs and two feeders are used to generate DL and UL beams from and to HD users. The paper also analyzes the components of SI in the direct and back-scattered paths, and the amount of isolation can be achieved using reflect-arrays in a wideband system.

The rest of the paper is organized as follows: In Section II the system is modelled within two parts, the dual-polarized RA, and the equivalent baseband system. Then Section III describes the simulation setup. The results of simulation are presented in Section IV. Finally Section V discusses the advantages and disadvantages of the approach and concludes the paper.

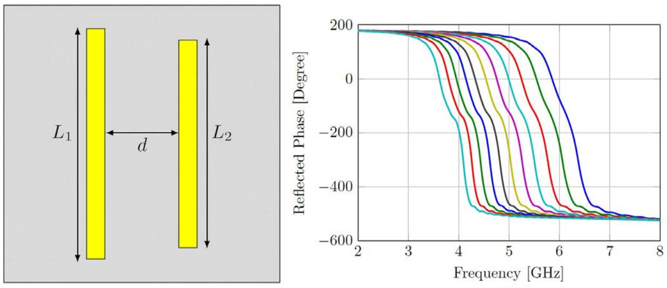
## II. SYSTEM MODEL

### A. *Dual Polarized Reflect-Array Antenna*

The low cross-polarization level is essential to isolate the UL and DL beams. Therefore, an UWB orthogonal beams RA antenna is developed. The double ring structure could be utilized as the array cell by cutting gaps across the rings in the cross-polarized direction. Thus, the cross-polarization patterns are cancelled. However, a polarization selective dipole is preferred to increase the isolation level between the co-polarized and cross-polarized re-radiated fields.

The basic cell is described in Fig. 1.a, where the 360 degree phase response is acquired using two closed resonant dipoles. The orthogonal polarization is produced by using these two dipoles in a vertical arrangement for the co-polarization beam and in a horizontal arrangement for the cross-polarization beam. Therefore, the best cell dimensions and substrate parameters for one polarization are first calculated and optimized for bandwidth enlargement. After that, these lengths are calculated to produce the cross-polarized beams at two different directions to minimize the cross-polarization levels.

The cross-polarized RA antenna configuration is described in Fig. 2, where two spatially separated orthogonal feeders are utilized to feed the RA surface and in accordance different beam in each polarization is produced. Thus, the cross-polarization levels are further reduced. The relative dipole lengths are calculated to produce an offset beam directed at, for example, ($\theta = 30°$, $\phi = 0°$) for the vertical polarization and the other horizontally polarized beam is directed at ($\theta = -30°$, $\phi = 0°$), where $\theta$ and $\phi$ are the azimuth and the elevation angles respectively.



(a) (b)

Fig. 1: UWB RA cross-polarized cell: (a) Cell shape consists of two coupled dipoles with relative lengths $L_2 = 0.9L_1$. (b) Reflected phase with the frequency at different lengths of the first dipole.

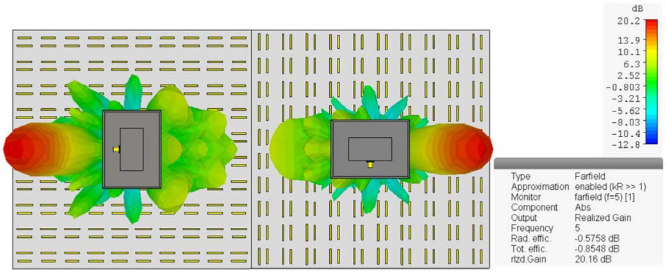


Fig. 2: The radiation patterns of the cross-polarized reflect-arrays.

### B. *The Baseband Model*

The received signal at the base-station can be modelled as:

$$\mathbf{Y}_{UL} = \sum_{i=1}^{U} \mathbf{H}_{u,i}\mathbf{X}_{u,i} + \mathbf{H}_{SI,d}\mathbf{X}_{DL} + \sum_{j=1}^{D} \mathbf{H}_{SI,s}\mathbf{X}_{d,j} + \mathbf{W} \quad (1)$$

where $\mathbf{X}_{u,i}$ is the desired signal from the user $i$ and $\mathbf{H}_{u,i}$ is the related UL channel. $\mathbf{X}_{d,j}$ is the DL signal to the user $j$, meanwhile $\mathbf{X}_{DL}$ is the sum of all DL signals. $\mathbf{H}_{SI,d}$ is the direct SI channel, and $\mathbf{H}_{SI,s}$ is the back-scattered SI channel. $U$ and $D$ are the numbers of uplink and downlink users respectively. $\mathbf{W}$ is the white Gaussian noise. For the simplified case studied in this paper, one user for each direction, the received signal at the base-station from the UL user (TxUE1) is:

$$\mathbf{Y}_{UL} = \mathbf{H}_{u,1}\mathbf{X}_{u,1} + (\mathbf{H}_{SI,d} + \mathbf{H}_{SI,s})\mathbf{X}_{d,1} + \mathbf{W} \quad (2)$$

Meanwhile the received signal at the DL user (RxUE2) is:

$$\mathbf{Y}_{d,2} = \mathbf{H}_{d,2}\mathbf{X}_{d,2} + \mathbf{H}_{IUI}\mathbf{X}_{u,1} + \mathbf{W} \quad (3)$$

where $\mathbf{H}_{IUI}$ is the channel from UL user (TxUE1) to the DL user (RxUE2) that carries the interference.

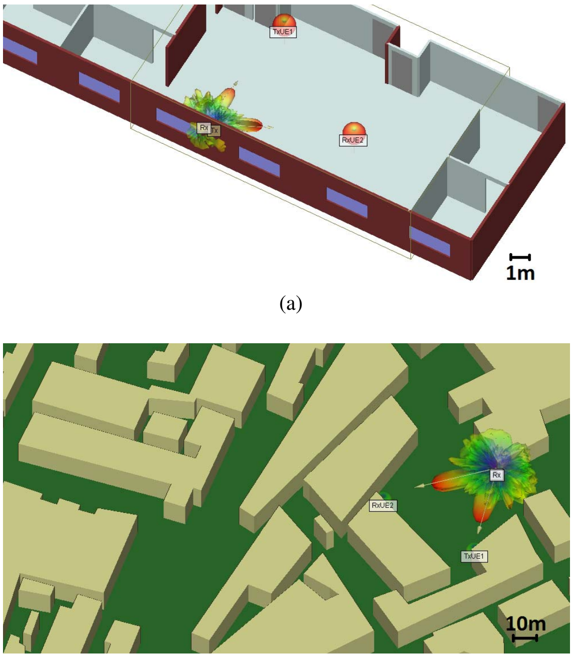
## III. SIMULATION SETUP

Computer Simulation Technology (CST) microwave studio is used to design the UWB RA and generate the radiation patterns. The considered base-station scenarios are carried out using Wireless Insite at 5 GHz, then the DL, UL, and SI channels coefficients are exported to MATLAB for the baseband processing. Fig. 3 shows the simulated environments in (a) indoor as a multi-room office, and in (b) outdoor as an urban area. This simulation is confined to one user in each direction with different distances of the two users and omni-directional antennas.

The baseband system is a Long Term Evolution (LTE) link which is based on QPSK OFDM with 5/10/20 MHz bandwidth and sampled by 30.72 MHz. The transmitted power from each transmitter is 0 dBm.

## IV. RESULTS

The simulation results of the antenna design are presented in Fig. 4, where the cross-polarized patterns are defined based on Ludwigs third definition [18]. These results at $\theta = \pm 30°$ indicate that the cross-polarization level is less than 40 dB.



(a)

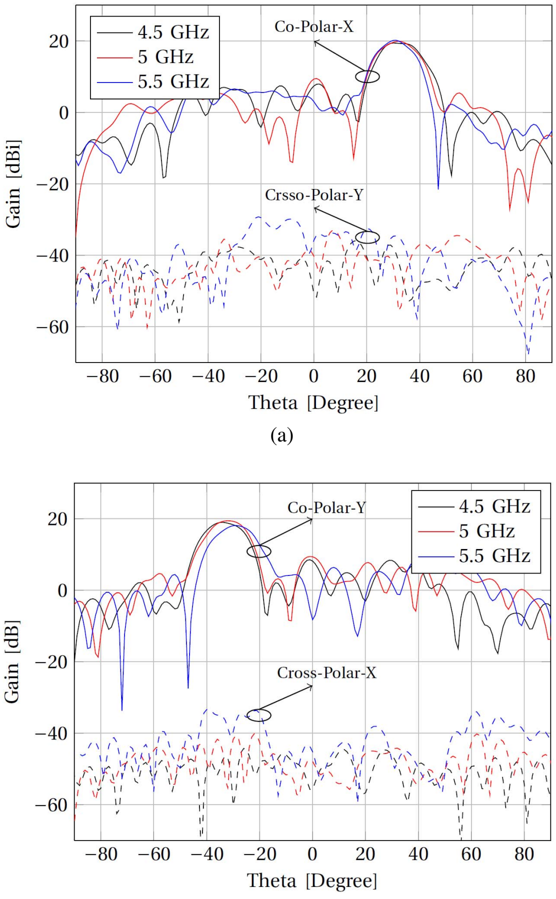
(b)

Fig. 3: The environment of simulation: (a) Indoor (b) Outdoor.

The Side Lobe Level (SLL) is less than -10 dB, and the RA antenna gain is about 20 dB which is 4 times higher than the feeder gain. Furthermore, the bandwidth of operation is about 1 GHz for both polarizations. The asymmetry in horizontal and vertical polarization patterns is produced because of feeder and cells asymmetry.

Table I shows the average received power of the four signals in line-of-sight propagation and the components of SI. The first column shows equal values of the DL received power at the DL user (RxUE2), and the UL received power from the UL user (TxUE1). The next four columns show respectively the total power of SI, the signal to self-interference ratio (SSIR), the direct SI, and the strongest scattered path of SI. Finally the IUI is in the last column. It can be noticed that:

- The received downlink and uplink signals are weaker in the outdoor due to the longer paths. The path-loss is about 20 dB more. The average distance at indoor is about 3m and at outdoor is 30m.
- The direct SI, caused by the side lobes, is fixed in both environments. The cross-polarization provides 103 dB mitigation of the direct SI meanwhile it is only 50 dB with co-polarized arrays.
- Also the use of cross-polarization provides higher mitigation of IUI (from TxUE1 to RxUE2). The mitigation enhancement in cross-polarization compared to co-polarization is $-62 - (-101) = 39$ dB in the indoor and 34 dB in the outdoor.
- The rich scattering environment in the indoor causes higher scattered SI compared to the outdoor.
- The FD system cannot perform without the cross-polarization as SSIR is very low with co-polarization.



(a)

(b)

Fig. 4: The simulated polarization radiation patterns of the dual-polarized RA antenna illustrating the UWB operation: (a) horizontal (b) vertical.

TABLE I: The average power of the four received signals and the signal to self-interference ratio.

| $\theta = \pm 30°$ $P_T = 0$ dBm LoS | **UL & DL (dBm)** | **Total SI (dBm)** | **SSIR (dB)** | **SI direct (dBm)** | **SI 1st scatter (dBm)** | **IUI (dBm)** |
|---|---|---|---|---|---|---|
| | **Indoor** | | | | | |
| **Co-polar** | -41 | -45 | 4 | -50 | -72 | -62 |
| **X-polar** | | -94 | 53 | -103 | -89 | -101 |
| | **Outdoor** | | | | | |
| **Co-polar** | -63 | -49 | -14 | -50 | -86 | -78 |
| **X-polar** | | -101 | 38 | -103 | -110 | -112 |

The average isolation ratio of SI achieved by cross-polarization is 53 dB at the indoor, and 38 dB at the outdoor. Such values could be achieved with two horn antennas instead of the reflect-arrays, however, the later allow to do beamforming electronically and that cannot be performed by horn antenna without a complicated and impractical mechanical system. Finally, the two remaining figures evaluate the use of the proposed antenna design with an LTE system. Fig. 5 shows that the bit error rate (BER) of the FD system is almost the same as it is without SI in the HD system. However, a slight loss of performance occurs at higher signal to noise ratio

(SNR) where the self-interference becomes dominant instead of the white noise.

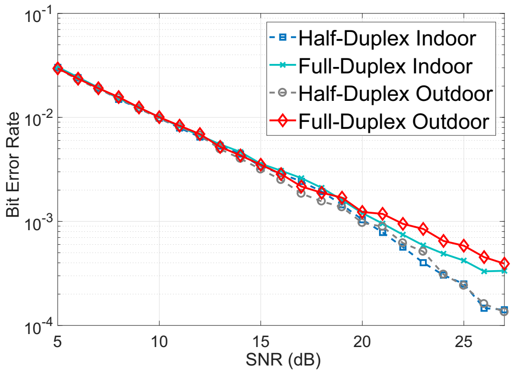


Fig. 5: Bit error rate of FD and HD OFDM systems using cross-polarized RA.

Fig. 6 shows the sum rate of the system. The enhancement of the system capacity is a little less than a double due to residual SI that may be cancelled by traditional SIC digital schemes. Such enhancement is expected to be lower when realizing the setup due to the hardware impairments.

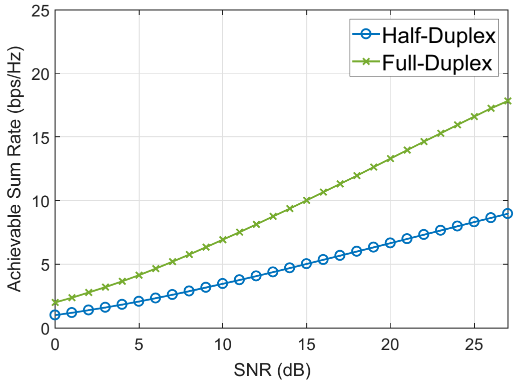


Fig. 6: Achievable sum rate of FD and HD OFDM systems using cross-polarized RA.

## V. CONCLUSION

This paper verified the benefit of using reflect-array in FD mobile systems. Dual-polarized reflect-arrays were designed to be used in the simulation of a wideband full-duplex base-station with two HD users. The self-interference components were analyzed in indoor and outdoor environments. The system performance was evaluated by studying the BER and the sum rate in a simple case of two users and 60° of separation. The achievable mitigation in this case with cross-polarized arrays was between 38 and 53 dB which allowed increasing the total sum rate. As the simulation was confined to a simple case, further work can be done like increasing the number of users and performing the beam-forming for different users' positions. Also the system performance can be enhanced by applying digital cancellation schemes to remove the residual self-interference.

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