In-Band Full-Duplex Array Architectures and Performance Survey

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***Abstract*—Emerging wireless systems demand the ability to simultaneously host multiple applications on common hardware and spectral resources. Both of these challenges can be mitigated through the incorporation of in-band full-duplex (IBFD) technology, which allows devices to break traditional time- and frequency-division paradigms by concurrently transmitting and receiving within the same frequency band. While research has focused on omnidirectional IBFD systems, directional alternatives offer the ability the extend the range capabilities. This paper discusses the architectural options for IBFD arrays and presents a performance survey of state-of-the-art prototypes.**

I. Introduction

Next-generation wireless applications are demanding access to limited spectral resources, and have opened research in the area of combining multiple functions within the same system and frequency band [1]. These may entail radar, communications and/or other applications that can leverage common RF hardware and frequency bands to enhance the capabilities of single devices. The challenge of integrating multiple functions within the same system is that they often have independent pulse and packet schedules that contend for the same hardware and spectral resources, which requires that the underlying waveforms be modified and/or their performance sacrificed.

In-band full-duplex (IBFD) technology allows systems to concurrently transmit and receive on the same frequency channel, which can facilitate the combination of multiple applications within a single system. This simultaneous transmit and receive (STAR) capability requires that the self-interference (SI) resulting from the transmitter is reduced to avoid saturation of the receiver. Many researchers have previously demonstrated the ability to mitigate SI and enable IBFD operation for omnidirectional systems focused on communications [2]. The investigation of directional IBFD systems, however, is much less common. This directionality offers the ability to focus signals spatially, which is useful to improve the range capabilities for both radar and communications applications.

This paper discusses IBFD directional array architectures and presents a survey that highlights the measured isolation performance for state-of-the-art prototype systems. The remaining part of this paper is organized as follows: Section II will provide an overview of IBFD array options, Section III will focus on the performance survey, and Section IV will derive conclusions.

II. Array Architectures

When considering how to design a directional system that can simultaneously transmit and receive, there are several different options that depend on the SI mitigation approach utilized. A straightforward method to reduce SI is to physically separate the transmit and receive arrays. While this efficiently increases the path loss between them and may not necessitate additional SI cancellation, it requires an installation location that can accommodate two unique arrays and their separation. This physical constraint limits the deployment scenarios, and thus, this option will not be further discussed here.

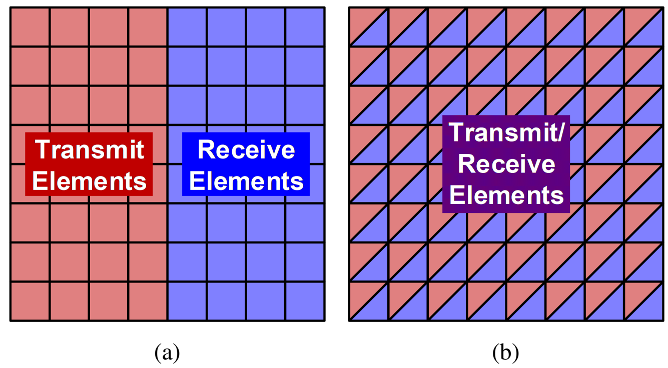

Fig. 1: IBFD array architectures, highlighting the different transmit and receive elements for: (a) aperture-level and (b) element-level designs.

For IBFD designs within a single array, one can consider either aperture- or element-level architectures, as illustrated in Fig. 1. The aperture-level approach divides the elements into subarrays that create unique transmit and receive zones, as shown in Fig. 1a. This architecture is intended for fully-digital arrays that have data converters at every element [3], and allows for the suppression of SI through the combination of adaptive transmit and receive beamforming as well as reference-based digital cancellation. Furthermore, the digital nature allows the array partitions to be dynamically reconfigured such that additional elements can be assigned to transmit or receive depending on the specific application need for a given time instance. Since IBFD operation is provided at the aperture-level, such that each element is only transmitting or receiving during a given time, this architecture minimizes the use of IBFD-specific parts behind each of the elements. This benefit also highlights the drawback of this approach, in that splitting the array into dedicated transmit and receive zones reduces the gains for each modality.

The alternative method of enabling IBFD for a single array is to avoid this subarray concept and allow every element to simultaneously transmit and receive, as depicted in Fig. 1b. This provides element-level IBFD operation and eliminates the gain-reduction associated with splitting the elements between transmit and receive assignments. For this architecture, the SI must be suppressed at each individual element since all of them are simultaneously transmitting and receiving. This necessitates the use of unique RF/analog circuits, such as high-isolation circulators, cancellers and/or in-band filters, to enable IBFD operation. The insertion loss introduction and complexity of these additional components must be considered when designing element-level IBFD arrays.

III. Performance Survey

While there have been multiple IBFD array simulations conducted, the key to understanding the performance possibilities and limitations of the aforementioned approaches lies in looking at measured results of prototype systems. To date, there have been publications of six aperture-level designs with total numbers of array elements that varied from 8 to 72 [3]–[8] as well as two element-level designs with 3 and 8 elements [9], [10], as plotting in Fig. 2. This figure depicts the total isolation (or SI mitigation) between the transmit-receive subarrays and elements for the indicated aperture- and element-level architectures, respectively. It can be seen that most designs have been demonstrated with less than 20 total elements, which highlights one of the challenges of creating these multichannel systems, namely, increasing the number of channels can become cost prohibitive.

Not captured in this plot are some of the other measurement parameters, such as the transmit output power and instantaneous bandwidth, which directly impact the amount of total isolation achievable. Specifically, systems with high output powers and narrow instantaneous bandwidths have large dynamic ranges and offer the ability to provide higher amounts of isolation. For instance, a prototype with 33 dBm of output power for each element and a 1-MHz instantaneous bandwidth produced the highest total isolation of 160.8 dB [5]. Overall, both aperture- and element-level IBFD array architectures have been proved to sufficiently suppress SI for different array sizes, which can increase their flexibility in future multifunction scenarios.

IV. Conclusion

Upcoming wireless systems could benefit from the incorporation of IBFD technology that allows them to integrate multiple applications within a single device by allowing their transmissions and receptions to occur independently. Research on IBFD arrays has been limited, but has shown potential for providing sufficient SI cancellation to provide extended link ranges. This paper discussed IBFD array architectures and presented a survey of the measured performance of several prototype systems. Future work in this area will include enhancing the maturity of IBFD arrays through scalability and advanced demonstrations.

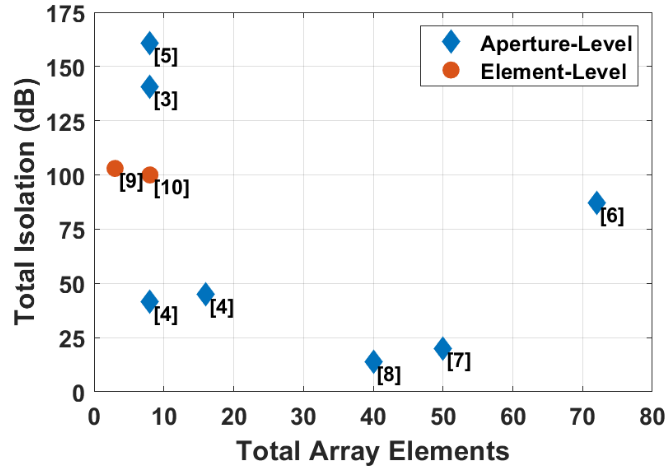

Fig. 2: Survey of total isolation versus the total number of array elements for measured IBFD array systems with aperture- and element-level designs referenced.

Acknowledgment

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