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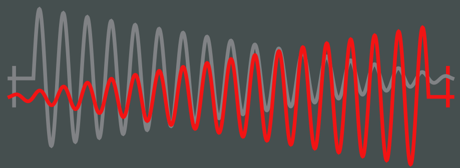

Full-Duplex
Wireless Communication Systems

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What is Full-Duplex?

Full-duplex is a shifting paradigm duplexing scheme in the wireless communication networks. This innovative scheme will allow future wireless networks to exploit the valuable frequency resources in highly efficient manner, as well as it will significantly reduce the connection latencies. The full-duplex scheme enables the communicating wireless nodes to exchange their data bidirectionally over the same frequency band and without any discontinuities in time. You can imagine a scene where the humans are able to talk while they still understand what they are hearing at the same time, that how full-duplex systems are designed to operate.

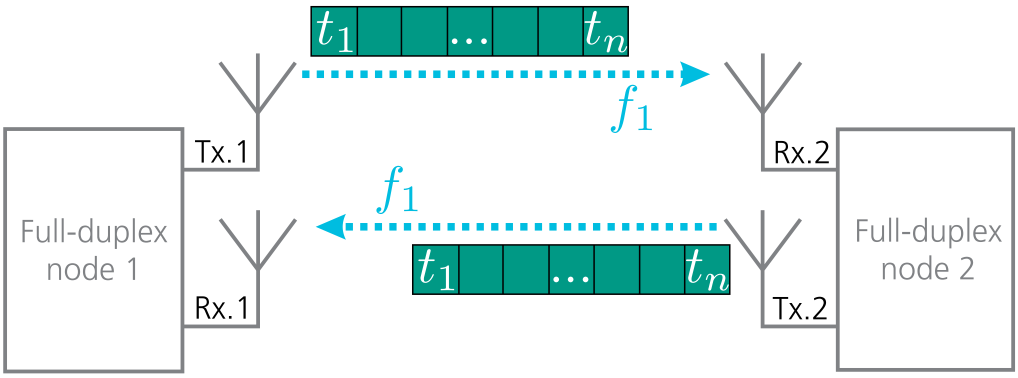


Figure 1: Full-duplex wireless communication scheme in point-to-point scenario, where the two nodes communicate over the same frequency and the time slots are fully occupied in both directions.

A Supersede Duplexing Scheme

Schemes to optimize radio resources in time, frequency and space are well understood for years; nevertheless state-of-the-art wireless duplexing schemes suffer from a specific limitation in resource utilization—namely simultaneous transmission and reception on the same frequency and time resource. Currently-deployed solutions are either time division duplex (TDD), e.g., WiFi® and LTE-TDD or frequency division duplex (FDD) as in GSM, UMTS and LTE-FDD schemes. Such systems are called half-duplex since transmission and reception are not performed at the same time and frequency. A system immanent component for such systems is a TDD switch

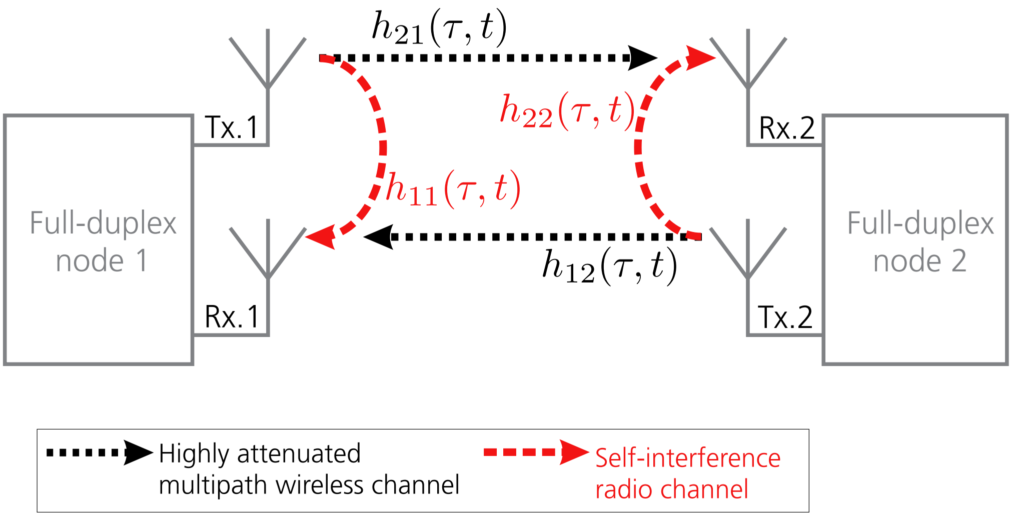
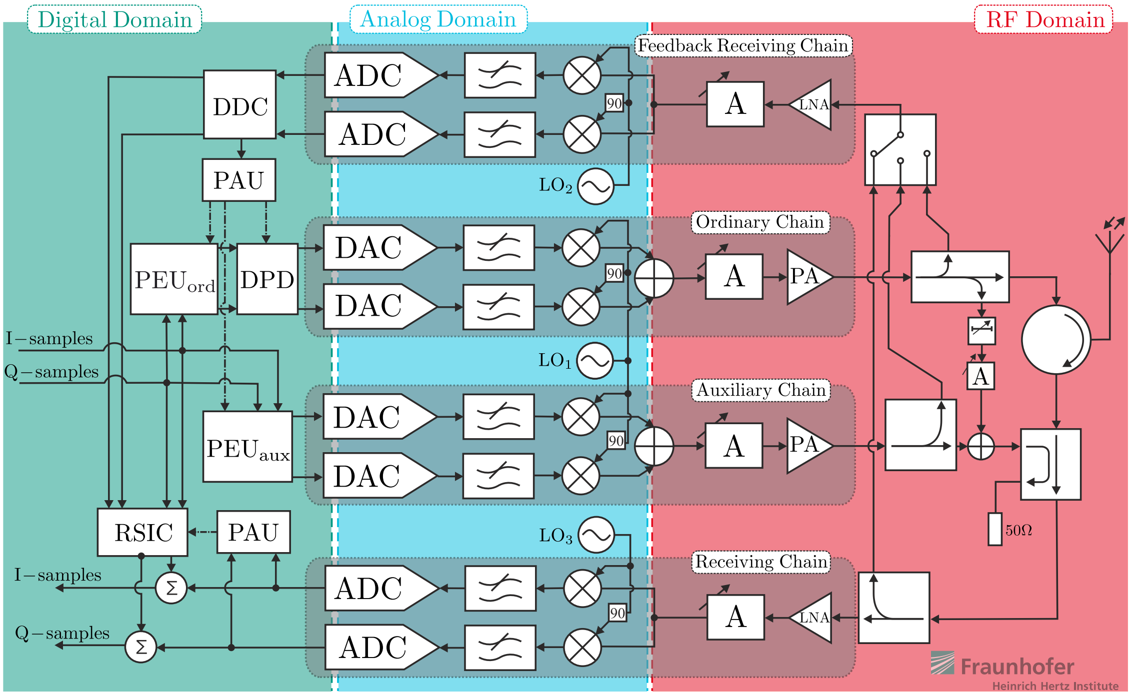


Figure 2: A point-to-point scenario between two full-duplex nodes shows the reception of own transmission signal (self-interference), which prevents the local node from sensing remotely-generated signal.

or a frequency separation filter (duplex-filter) where the later has to meet stringent out-of-band emission masks, making it often expensive and bulky especially for high power operation. The biggest drawback of such systems is that such duplexing settings e.g. duty cycle between uplink and downlink have to be coordinated over a large part of the cellular network or are just fixed by standardization for duplex filters. The full-duplex scheme will introduce unprecedented flexibility to the future wireless systems, as they will be able to choose uplink and downlink or forward and reverse link frequencies preferably without restrictions time wise. This would allow a much better utilization of spectrum resources. In fact, full-duplex scheme unlocks the potential to double the spectral usage efficiency as a complete reuse of the available spectrum is offered within such a duplexing scheme. Ideally, frequency duplex filters become obsolete or at least the filter mask requirements could be relaxed dramatically due to the advancement in the self-interference cancellation mechanism—the key enabling mechanism for full-duplex. This would reduce number and size of cavity filters at multiband base stations and associated costs significantly and reduce the number of duplex filter banks in multi-band and multi-standard handhelds drastically.

Self-Interference Cancellation is the Key

The main challenge that made the full-duplex wireless communication systems impractical to realize is the overwhelming nature of the self-interference. However, the anticipated spectrum crunch that is expected to occur in the 5G networks made the effort of realizing such systems actually worth it by its entire means. Canceling the self-interference is the key-enabling technique for full-duplex. The underlying principle of canceling the self-interference is devised from the fact that any wireless transceiver has a perfect knowledge about its own transmission signal. Hence, a cancellation signal that has an identical waveform with negative magnitude can be simply added to the received signal to eradicate the self-interference. This theoretical and novel principle is applicable to a clean self-interference signal in its baseband form, while in practice the up-converted interference signal has an RF-dirty form [6]. The RF domain self-interference cancellation is compulsory in any full-duplex transceiver architecture in order to avoid saturating the receiving chain. Such practical considerations make the realization of full-duplex scheme a bit more difficult and requires a better understating of the self-interference signal characteristics in its dirty RF form.



DPD : Digital Pre-Distorter
PAU : Parameter Acquisition Unit
RSIC: Residual Self-Interference Canceller
DDC: Digital Down Converter
PEU: Pre-Equalization Unit

Figure 3: The 5G agile full-duplex wireless transceiver concept in one of his constellations. A direct-conversion architecture has been adopted by the transceiver's chains. The transceiver comprises two transmission chains and another two receiving ones [ASKH16].

Wireless Transceiver Concept and Working Prototype

At Fraunhofer HHI laboratories, years of extensive research made us able to come up with a wireless transceiver concept that would enable a seamless integration of the full-duplex scheme in future wireless networks. The transceiver is not only designed to bring the life to the full-duplex scheme, however, it is also backward compatible to the currently-deployed wireless duplexing schemes, i.e., the TDD and FDD. Moreover, the transceiver is designed to enhance on those schemes by taken advantage of the self-interference cancellation mechanism.

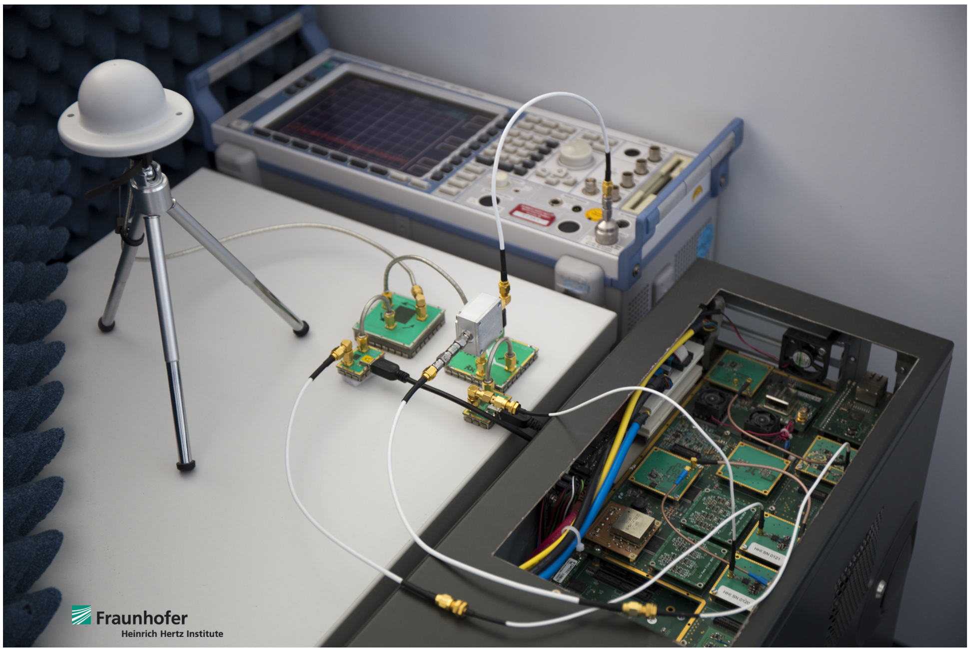


Figure 4: A working prototype of a full-duplex wireless transceiver build out of off-the-shelf components. The HIRATE platform is used to construct the transceiver front-ends.

Several working prototypes of the partial constellations of the agile full-duplex transceiver have been developed and tested at the laboratories of Fraunhofer HHI. Ongoing research is being carried out by a multidisciplinary team of scientists to develop a full constellation agile full-duplex wireless transceiver that allows a ubiquitous connectivity of such in the future and beyond wireless networks.

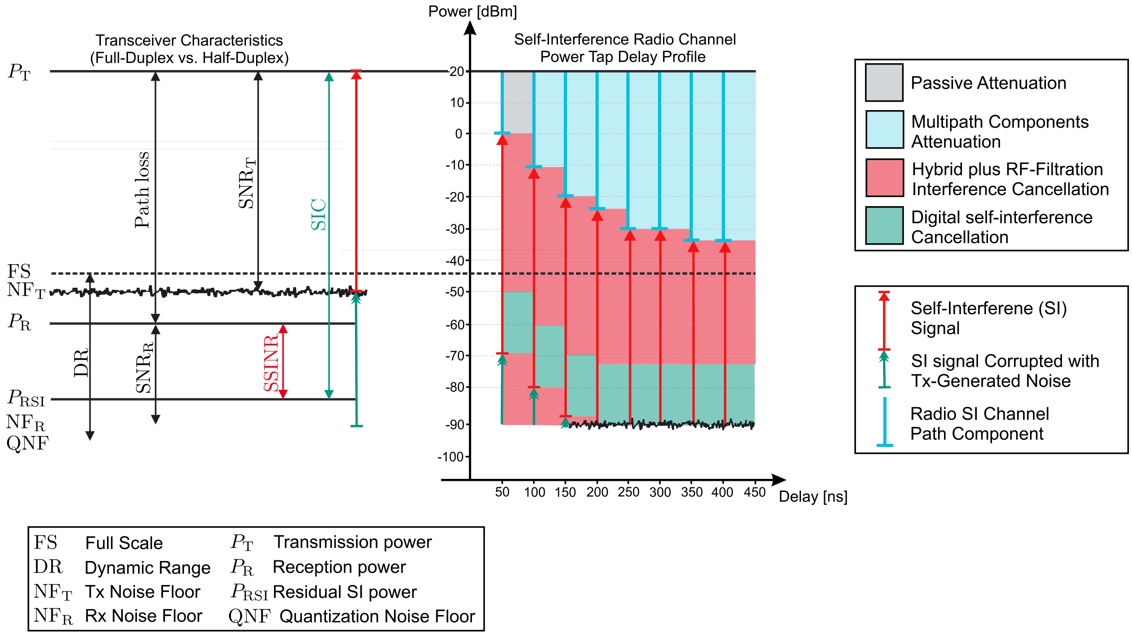


Figure 5: Self-Interference assessment for full-duplex wireless transceivers. The chart depicts two linked diagrams: The left diagram shows the SNR loss in a full-duplex transceiver in comparison to half-duplex one, and the right diagram illustrates realistic requirements form each self-interference cancellation technique considering the specifications of a WiFi® transceiver [ASKH16].

Self-Interference Cancellation Requirements and Realization Mechanism

Does the transceiver design have whatever it takes to reach the anticipated level of self-interference suppression in order to get close enough to the theoretical gain of the spectrum reuse? Answering this question requires a detailed assessment of the self-interference amount and nature that a full-duplex transceiver is usually suffering from. Furthermore, the cancellation techniques need to be sorted out with respect to their effectiveness against each emerged dirty version of the self-interference signal. The limitation factors and minimum requirements of the self-interference cancellation techniques have to be drawn to ensure robust transceiver self-interference cancellation functionality under various conditions concerning the channel characteristics and transceiver specifications.

Passive cancellation techniques are beneficial among the cancellation techniques due to its steadiness, and immunity against the nondeterministic self-interference signal components such as the transmitter-generated noise [4]. However, such techniques suppress only the direct path self-interference channel component, and they have a minor influence on the rest of multipath components, at least in point-to-point scenarios.

The RF-filtration techniques cancel the self-interference in the RF domain and have the potential to suppress the unwanted parts that usually accompany the transmission signal [2, 7]. However, they are not that flexible and difficult to adapt. Moreover, they would complicate the RF structure, in particularly as the number of antennas grows [1].

The hybrid (active) interference cancellation technique is pretty flexible and capable of mimicking the self-interference channel in its multipath model [AKS+14] [3]. The drawback of such technique is the inability to mimic the nondeterministic disturbances, which also must be canceled [8, 9, 5].

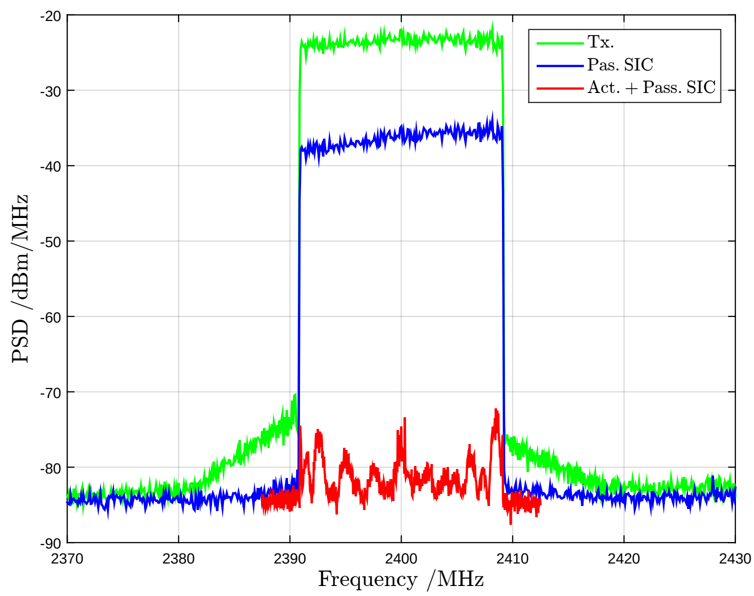


Figure 6: Spectra were measured by means of R&S® FSQ26 spectrum analyzer. The green spectrum shows the self-interference before cancellation, where the blue and red curves show the measured spectra after cancellation [ASKH15].

All aforementioned interference cancellation techniques target the self-interference signal in the RF domain and try to cancel it before it would desensitize the receiver low-noise amplifier (LNA). The residual self-interference signal can be further suppressed in the digital domain in order to compensate the loss in the signal-to-self-interference-plus-noise ratio (SSINR), which is occurred due to the incomplete cancellation of the self-interference signal at the RF domain.

The deficiency of the cancellation techniques in suppressing the self-interference at once makes the concatenation of several techniques a prerequisite in realizing a reliable full-duplex transceiver design. The minimum requirements that are demanded from each cancellation technique can be empirically estimated based on the previous assessment as in figure 5.

Preliminary results of a laboratory experiment that shows the RF-domain suppression of the self-interference are shown in figure 6. The measured spectra reported around 12 dB of passive self-interference suppression, which is done by means of 3-port RF circulator. Two successive stages to self-interference cancellation techniques—the passive followed by the hybrid—reported around 54 dB of overall self-interference suppression in the RF domain as an advanced DSP algorithm was implemented [ASKH15, AZS+14].

Publication Related to the Field

[AKS+14] Ramez Askar, Thomas Kaiser, Benjamin Schubert, Thomas Haustein, and Wilhelm Keusgen. Active self-interference cancellation mechanism for full-duplex wireless transceivers. In *Cognitive Radio Oriented Wireless Networks and Communications (CROWNCOM), 2014 9th International Conference on*, pages 539–544, June 2014.

[ASKH15] Ramez Askar, Benjamin Schubert, Wilhelm Keusgen, and Thomas Haustein. Full-Duplex Wireless Transceiver in Presence of I/Q Mismatches: Experimentation and Estimation Algorithm. In *IEEE GC 2015 Workshop on Emerging Technologies for 5G Wireless Cellular Networks - 4th International (GC'15 - Workshop - ET5G)*, December 2015. (In press).

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