Limits on Simultaneous Transmit and Receive

The Challenge

To understand the fundamental limits on our ability to emit and receive radio signals at the same frequency and at the same time (i.e. in same-channel full duplex mode) using a transceiver radio system.

For this challenge we want to focus not on improving the technology but on finding the fundamental mathematical limits on what can be achieved — limits that will apply whatever technology is used: limits perhaps analogous to Cramer-Rao lower bounds on variance, or the Shannon-Hartley limit on information rate.

Overview

The ability to Simultaneously Transmit and Receive (STAR) signals in the radio band of the Electromagnetic (EM) Spectrum (EMS) offers huge benefits to civil and defence applications. Current approaches[1] achieve this through time ***or*** frequency division duplexing. However, same-channel full-duplex (i.e. working simultaneously in frequency ***and*** time) offers huge efficiencies and system performance benefits compared to frequency or time–division duplexing.

The current state-of-the-art in academic and industrial STAR research shows that ~120dB of isolation depth can be achieved in a relatively narrow operating bandwidth. Whilst we seek to extend both isolation depth and operating bandwidth (our current aspirations are for 150dB of isolation depth over 160MHz of operating bandwidth), we need to understand what the theoretical limits are in order to direct our research investment.

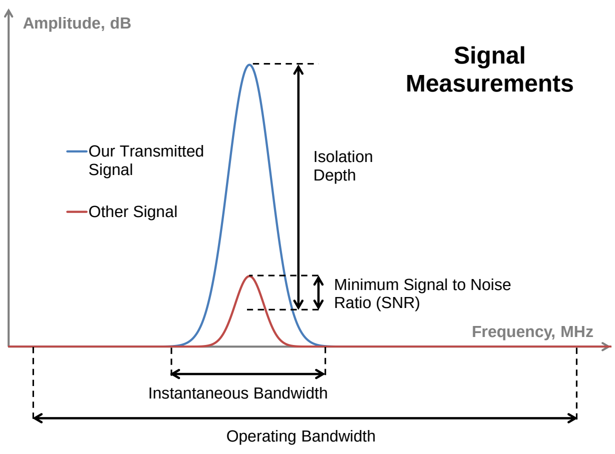

Figure 1: - Diagram of Signal Measurements

There is some analogy here to noise cancellation, such as used in commercial noise-cancelling headphones. However, in this case we generate the primary interferer (the noise) that we want to cancel. Cancellation performance will, therefore, be limited by our ability to

[1] A Survey of Self-Interference Management Techniques for Single Frequency Full Duplex Systems - Nwankwo 2017 - http://eprints.gla.ac.uk/151582/7/151582.pdf

accurately model our own emissions and the changes that happen to them after they are transmitted into the Electromagnetic Environment (EME).

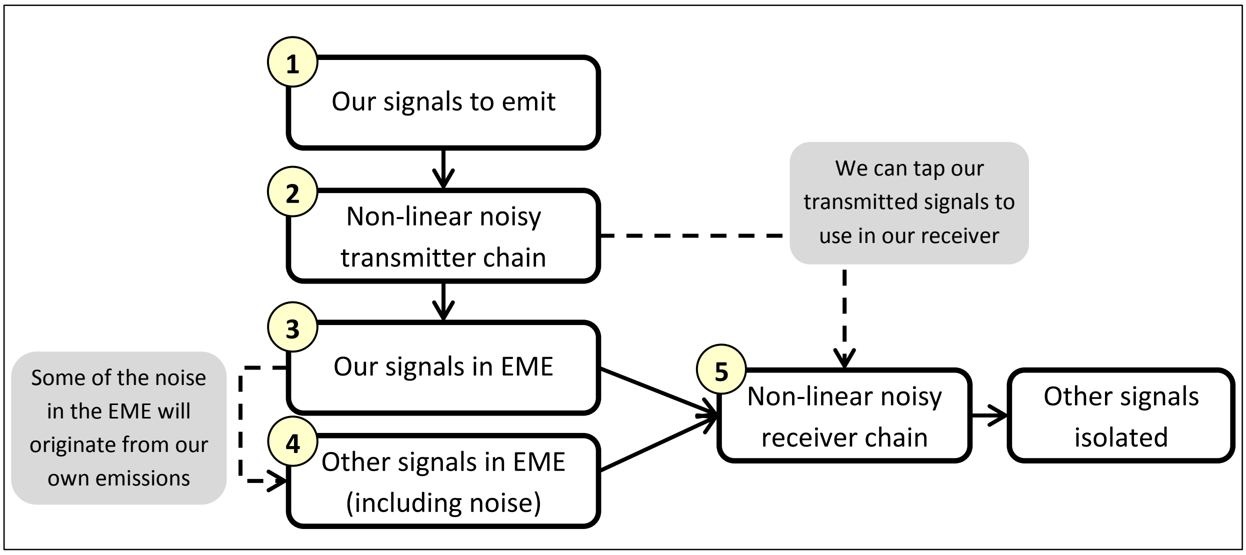

Figure 2: Flow model for the challenge

A simple information flow model for this challenge is presented at Figure 2. It shows:

1. **Our Signals** - that we wish to emit to the EME.
2. **Non-Linear Noisy Transmitter Chain** - our signals pass through this to enter the EME.
3. **Our Signals in EME** - Once in the EME, our emitted signals can couple or propagate to our receiver chain (coupling and propagation is used here to differentiate between energy coupling due to near-field or far-field EM physics, respectively) along with any other signals, including noise, that are present in the EME.
4. **Other Signals in EME** – As well as our own emissions there may be other signals in the EME (the signals we want to detect)
5. **Non-Linear Noisy Receiver Chain** - All the signals pass through our own noisy receiver chain from which we wish to detect the presence of other signals: signals that are at the same frequency as our own emitted signals at the same time. We are able to tap signals off our noisy transmitter chain at any stage and use this information within our receiver chain.

The references to noise in Figure 2 highlight that the knowledge of our transmitter and receiver chains and of the EME may not be perfect. For example, although we know the properties of the signal that we emit it will pass through the EME before it reaches our receiver. In the environment it will experience non-linear effects (i.e. reflections, diffraction, attenuation, signal conversion) that mean what is received is not identical to what we emitted. We need to be able to model these effects to be able to cancel out our signals and detect the other signals that we are interested in. The limits of the model will infer the limits of our capability.

Physical Aim	Design Approach
1. EM Protection layer – Stop the emitters 'frying' the sensors.	E.g. Antennas, circulators - high transmit to receive isolation
2. EM Linearity layer – Maintain the sensor systems in linear region.	Analog processing e.g. Interference cancellation, (passive or active).
3. EM Own signals layer – See through own platform emissions.	Digital processing e.g. signal cancellation, adaptive isolation
4. EM Known signals layer – Seeing through known signals in environment.	Digital processing e.g. coded cancellation, side-channel cancellation

Figure 3: Layered model for STAR

An engineering approach to exploiting the information flow within this challenge, as outlined at Figure 2, is expressed at Figure 3. This model highlights opportunities for achieving STAR in a layered approach.

Layer 1. Methods for protecting receiver equipment from our own strong in-band signals are considered...

Layer 2. Ensure sub-systems also function without saturation so that behaviours are predictable and further noise (including harmonic and intermodulation signal products) is mitigated.

Layer 3. See underneath our own emission signals

Layer 4. Use prior knowledge of other signals in the EME in which we are operating in order to see signals of interest underneath them.

Commercial drivers for STAR (for example in internet Wi-Fi) consider energy and radio channel efficiency (radio channels are expensive to access). Metrics for such commercial applications may be measured in: J/Bit and Bit/s/Hz.

The primary military benefit is measured through an ability to continually sense anywhere in the EMS irrespective of our emissions.

How would a mathematical approach define this challenge in order to determine the limits of performance for STAR?

We expect the limits to be derived from combinations of factors such as:

- Nonlinearity in the transmitter and receiver circuitry
- Poor isolation between the transmitter and receiver resulting in coupling
- Thermal noise
- Modulation of our own signal
- The magnitude of signal to noise ratio we need to detect the other signal

Other Useful Reading:

A Widely Tunable Full Duplex Transceiver Combining Electrical Balance Isolation and Active Analog Cancellation – Laughlin 2015 - https://ieeexplore.ieee.org/abstract/document/7145660

Full-duplex Wireless: Design, Implementation and Characterization – Duarte 2012 - https://scholarship.rice.edu/bitstream/handle/1911/70233/DuarteM.pdf