Imperial College London

SIGNAL DESIGN FOR WIRELESS INFORMATION AND POWER TRANSFER

Author: **Yang Zhao (yang.zhao18@imperial.ac.uk)** ***Supervisor:*** **Dr Bruno Clerckx and Dr Morteza Varasteh**

MOTIVATION

Energy-constrained wireless networks are conventionally powered by batteries that require frequent recharging or replacement. As a promising alternative, Radio-Frequency (RF) wave is with lower power level (µW to W) and decent coverage (up to hundreds of meters) (Ng et al., 2019). It has been widely used in wireless communications and can be extended to Wireless Information and Power Transfer (WIPT). With the significant drop of power consumption in electronics, RF signal is anticipated to power billions of mobile devices wirelessly while keeping them online.

RECTENNA MODEL

- Rectenna = antenna + rectifier

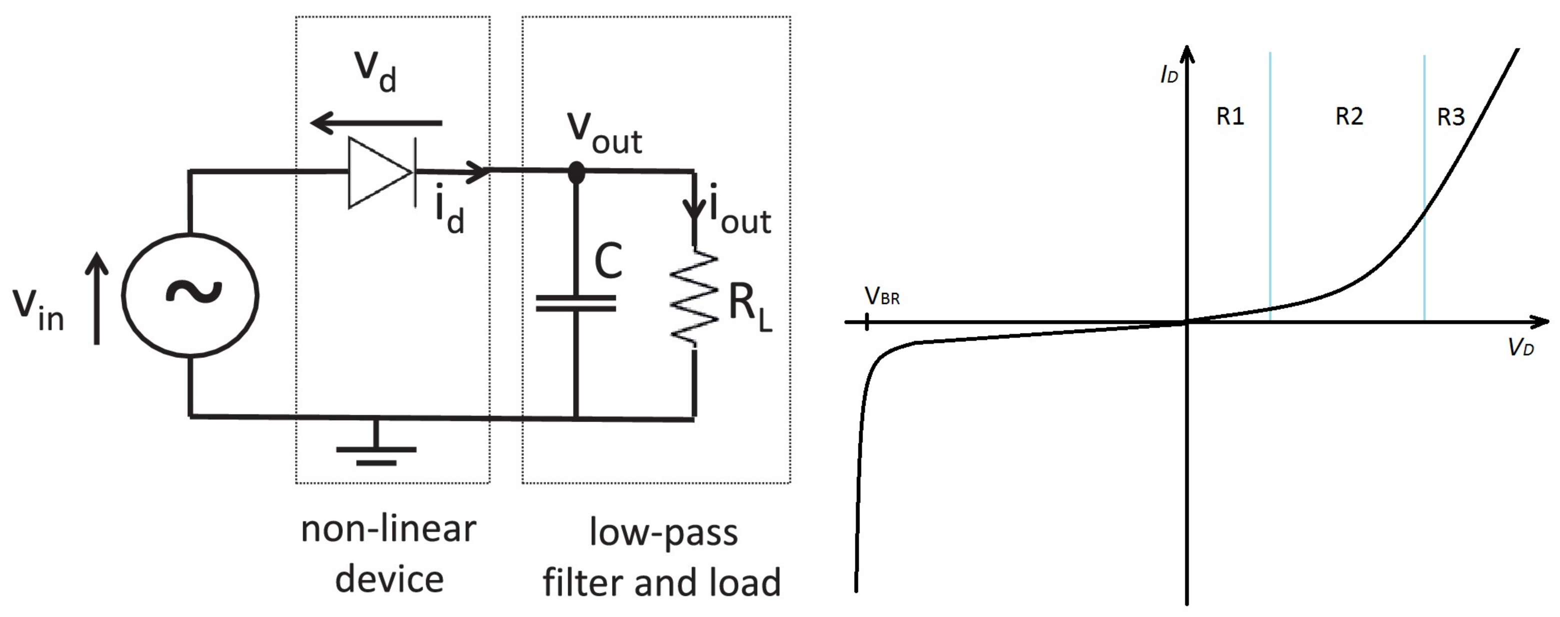


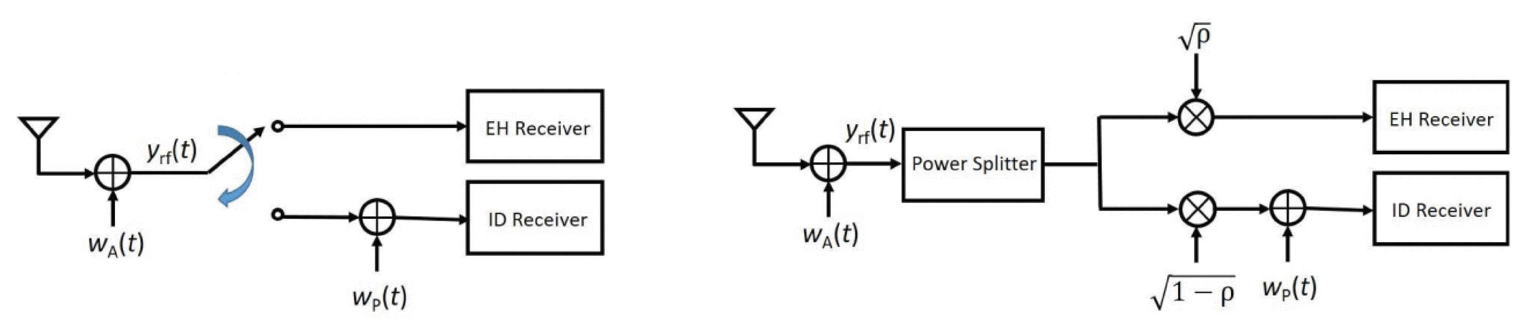
Figure: Single diode rectifier (left) and diode $I-V$ characteristics (Clerckx et al., 2018). The diode accounts for harvester nonlinearity. R1 and R2 correspond to the diode linear and nonlinear model. The diode behaves as a resistor in R3.

We approximate the diode characteristic equation by Taylor series and truncate the result to n_o-th order to obtain:

- **Diode linear model ($n_o = 2$)**: the total power equals the sum of subband portions and is proportional to the rectifier input power.
- **Diode nonlinear model ($n_o > 2$)**: capture the cross contribution of different frequencies on the harvested power.

RECEIVER ARCHITECTURES

- **Time Switching (TS)**: divide the transmission block into power and data slots, then optimize the signal individually.
- **Power Splitting (PS)**: split a portion of the signal to information decoding (ID) receiver and the rest to energy harvesting (EH) receiver. The waveform is jointly optimized for WIPT.

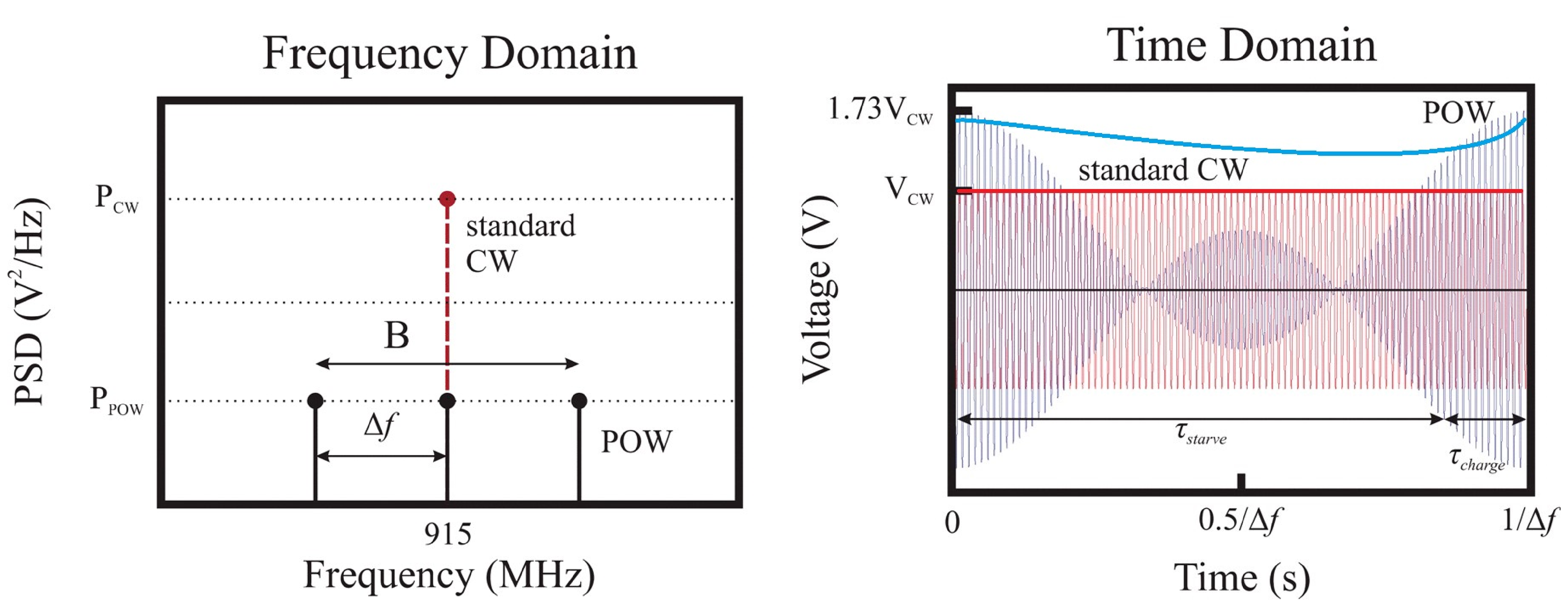


(a) Time Switching (TS) (b) Power Splitting (PS)

Figure: Receivers (Clerckx et al., 2018): (a) TS switches between energy harvester and information decoder; (b) PS splits the signal into separate portions.

SIGNAL DESIGN

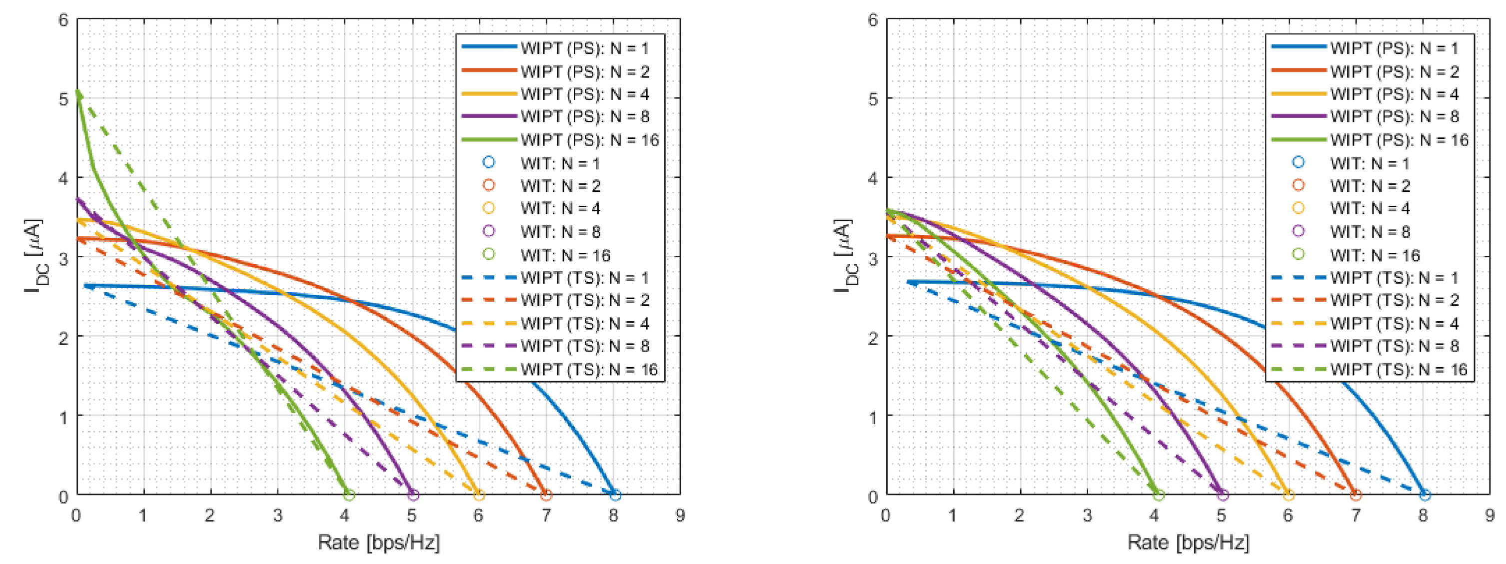
- Superposed waveform = multi-carrier **multisine** + **modulated**
- Multisine: deterministic, high PAPR, with concentrated power



(a) Frequency domain (b) Time domain

Figure: Comparison of 3-subcarrier multisine (POW) and single-sine (CW) (Trotter, Griffin, and Durgin, 2009). The thick lines indicate the rectifier output voltage.

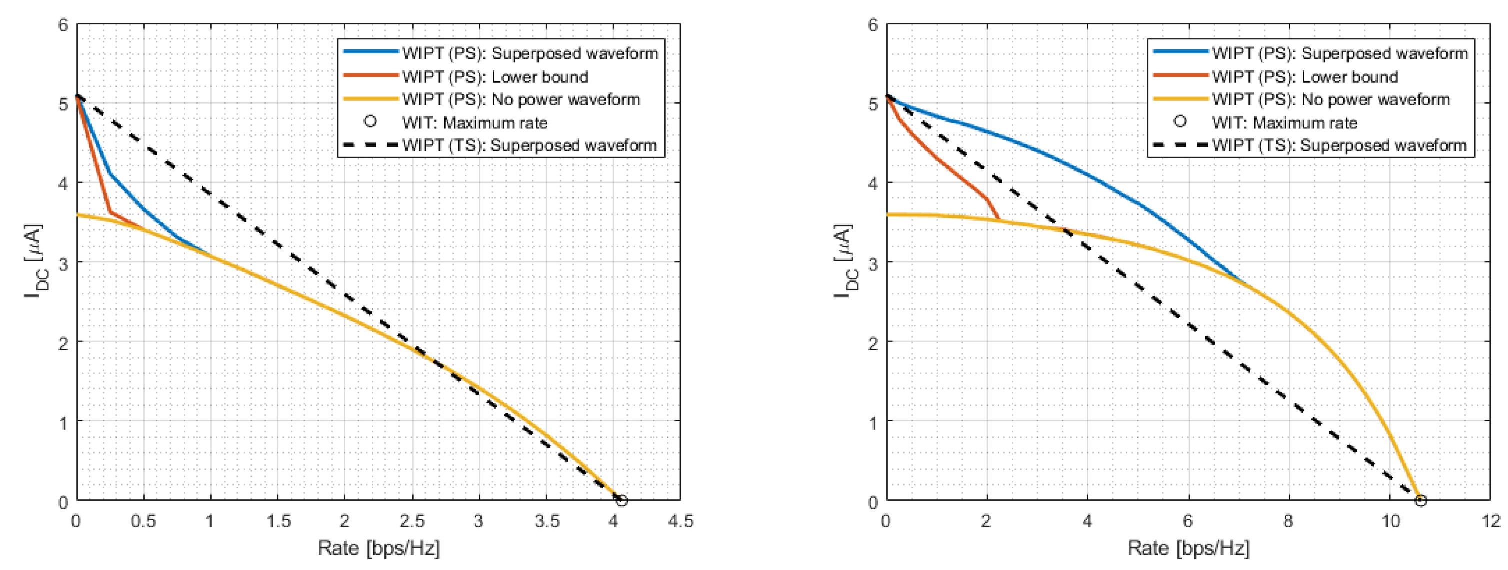
RATE-ENERGY TRADEOFF



(a) Superposed waveform (b) No power waveform

Figure: [SISO-FS] R-E region vs **subband** N for $B = 1$ MHz and SNR = 20 dB

- The superposed waveform enlarges the R-E region for subband sufficiently large ($N > 4$).
- PS is preferred for small N while TS is favored for large N. A combination is optimal for medium N.



(a) SNR = 20 dB (b) SNR = 40 dB

Figure: [SISO-FS] R-E region vs **SNR** for $B = 1$ MHz and $N = 16$

- There is no rate loss as multisine creates no interference to the modulated waveform.
- For a sufficiently large N, TS is favoured at low SNR and PS at high SNR.

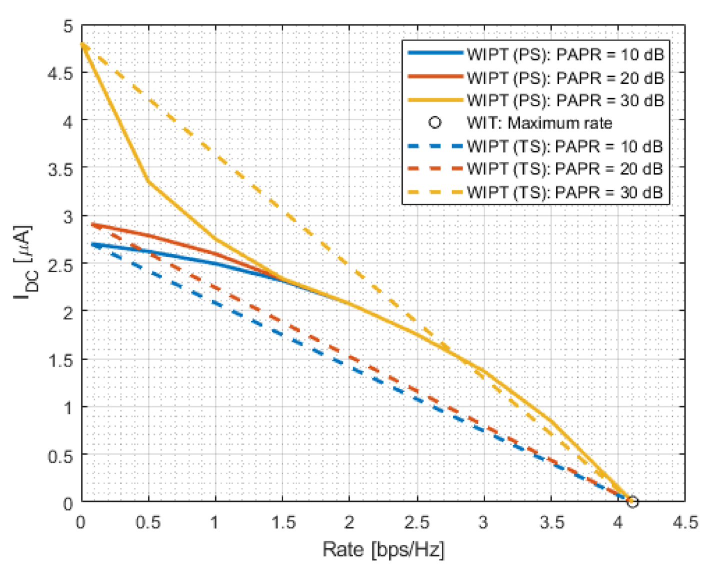


Figure: [SISO-FF] R-E region vs **PAPR** for $N = 16$

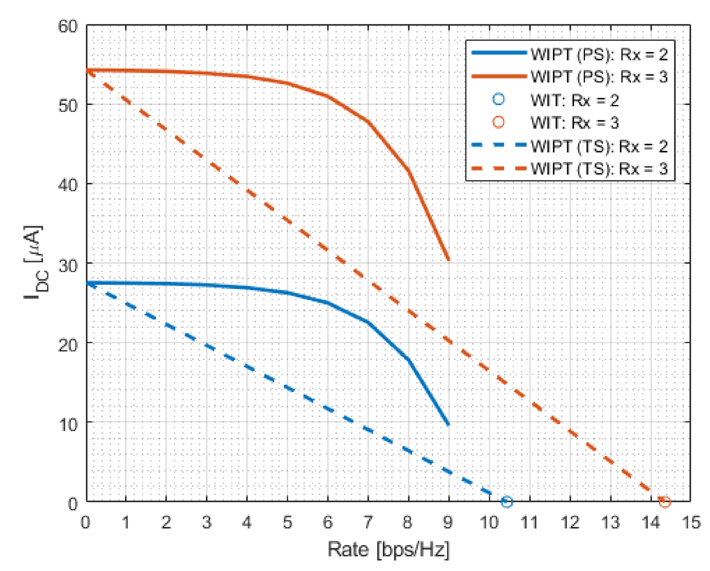


Figure: [MIMO-FF] R-E region vs **Rx** for Tx = 2 and $N = 16$

- High PAPR is required to enjoy the power benefit of multisine.
- Geometric Programming (GP) approach is suboptimal for MIMO.

REFERENCES

Clerckx, Bruno et al. (2018). "Fundamentals of wireless information and power transfer: From RF energy harvester models to signal and system designs". In: *IEEE Journal on Selected Areas in Communications* 37.1, pp. 4–33.

Ng, Derrick Wing Kwan et al. (2019). *Wireless Information and Power Transfer: Theory and Practice*. Wiley-IEEE Press. ISBN: 1119476798.

Trotter, Matthew S, Joshua D Griffin, and Gregory D Durgin (2009). "Power-optimized waveforms for improving the range and reliability of RFID systems". In: *2009 IEEE International Conference on RFID*. IEEE, pp. 80–87.