Enabling Multicarrier Backscattering Communications

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LEADERS IN IDEAS AND SOLUTIONS

Outline

- Introduction
- Backscatter modulation SOTA and motivation for multicarrier
- Multicarrier backscattering solution
- Simulation results
- Conclusion and future work

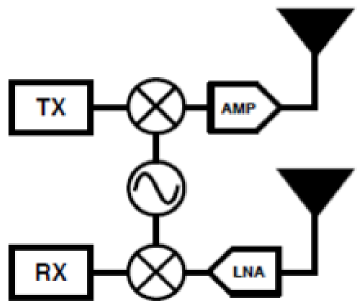
Introduction

- Massive IoT sensor nodes deployment

- **Challenges**:
  - Cost
  - Power consumption
  - Maintenance (battery replacement)
  - Bandwidth utilization

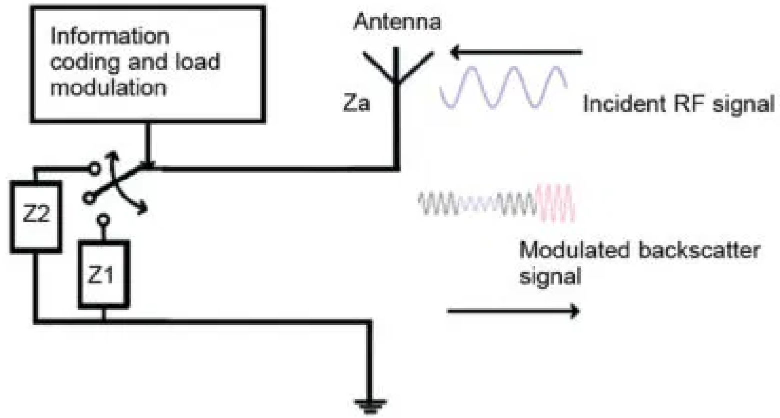
Introduction

- Backscatter: Shifting the power-consuming radio frequency (RF) carrier synthesis functions to carrier emitters (can be dedicated or ambient)



Conventional active radio

- Power hungry
  - ➢Mixers
  - ➢Power amplifiers



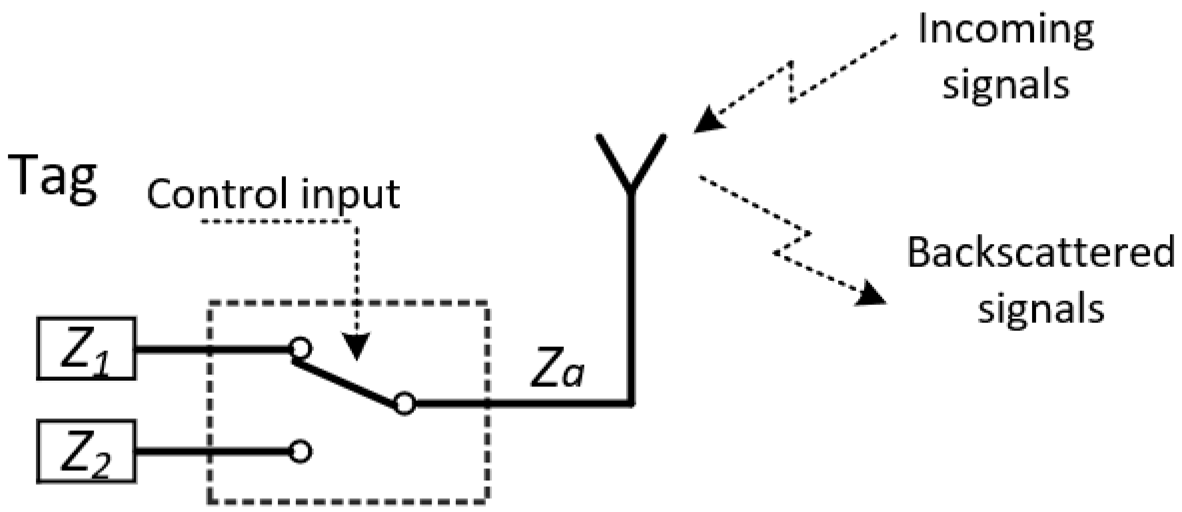
Backscatter passive radio

- No power hungry active RF components

- Backscatter communication technology removes the costly and power-hungry RF frontends, e.g. mixers and power amplifiers.

Backscatter Modulation

Generic backscatter tag



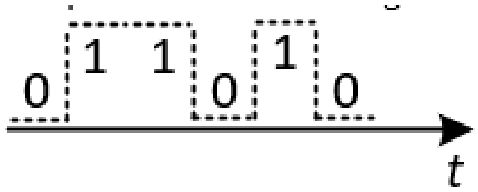
Backscatter Modulation

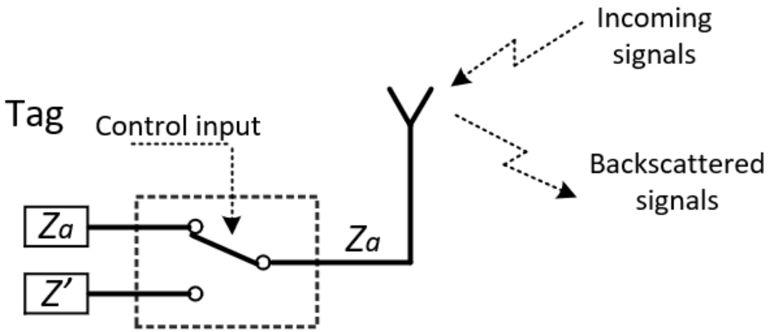
ASK backscatter modulation

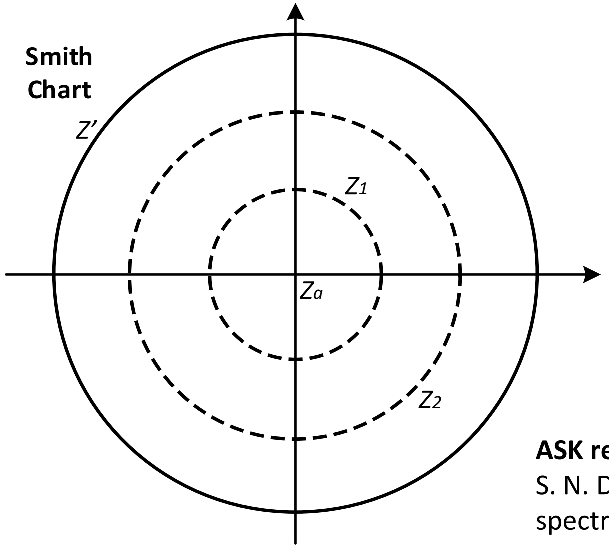
Control input

0 1 1 0 1 0 ...

Envelope of backscattered signals







Design guidance on antenna termination impedance for ASK modulation. Z_a and Z' for OOK, and Z_a, Z_1, Z_2 and Z' for 4PAM.

ASK references:

S. N. Daskalakis, R. Correia, G. Goussetis, M. M. Tentzeris, N. B. Carvalho and A. Georgiadis, "4-PAM modulation of ambient FM backscattering for spectrally efficient low power applications," *IEEE Trans. Microw. Theory Tech.*, vol. 66, no. 12, pp. 5909–5921, Dec. 2018.

B. Kellogg, A. Parks, S. Gollakota, J. R. Smith, and D. Wetherall, "Wi-Fi backscatter: Internet connectivity for RF-powered devices," in *Proc. ACM SIGCOMM*, Chicago, IL, USA, Jun. 2014, pp. 1–12.

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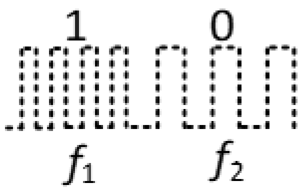
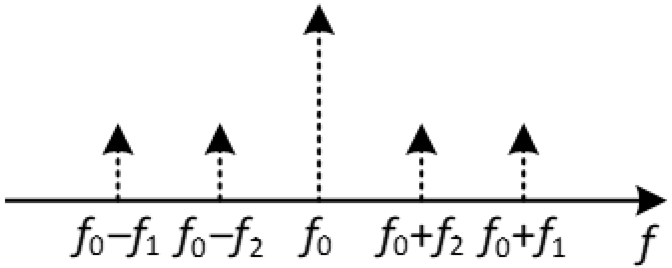
Backscatter Modulation

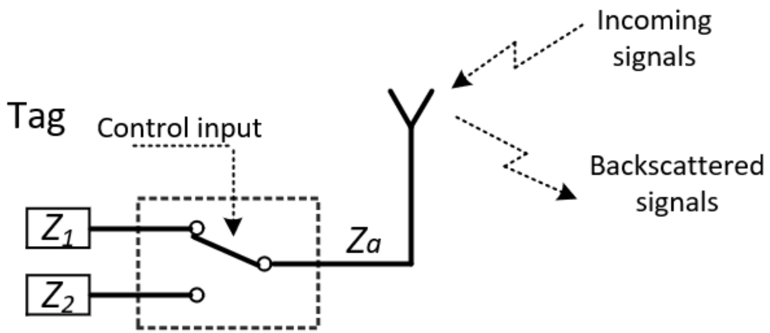
FSK backscatter modulation

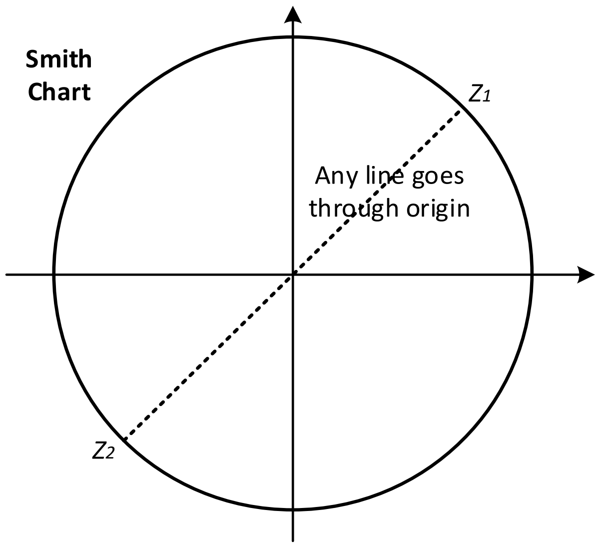
Control input



Spectrum of backscattered signals







Design guidance on antenna termination impedance for 2FSK modulation.

FSK references:

A. Varshney, C. Pérez-Penichet, C. Rohner, and T. Voigt, “LoRea: A backscatter architecture that achieves a long communication range,” in *Proc. ACM Embedded Netw. Sensor Syst.* (SenSys), Delft, Netherlands, Nov. 2017, pp. 1–14.

V. Liu, A. Parks, V. Talla, S. Gollakota, D. Wetherall, and J. R. Smith, “Ambient backscatter: wireless communication out of thin air,” *ACM SIGCOMM Comput. Commun*. Rev., vol. 43, no. 4, pp. 39–50, Oct. 2013.

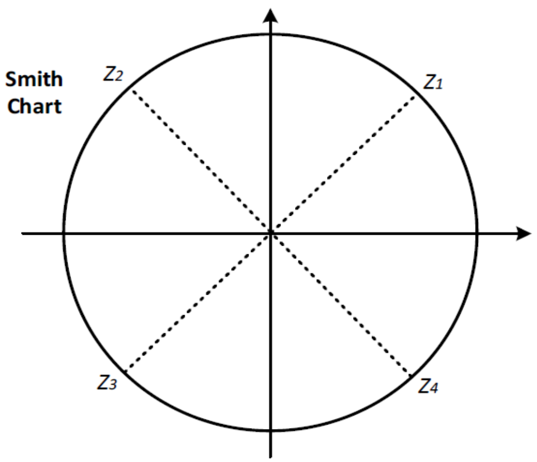
Backscatter Modulation

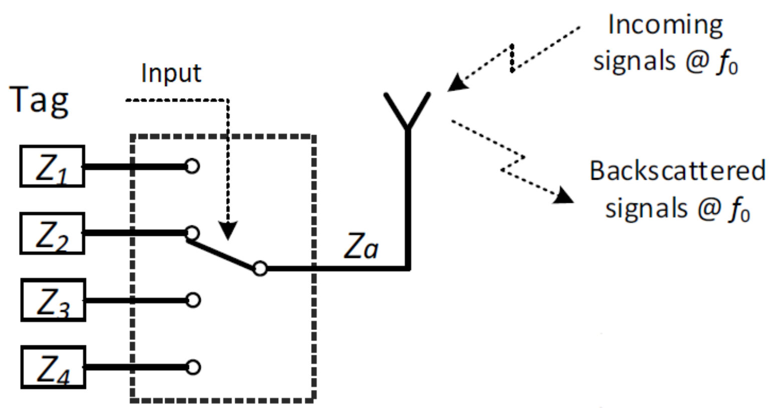
QPSK/4QAM backscatter modulation

Control input

11: select Z_1
01: select Z_2
00: select Z_3
10: select Z_4

Constellation of backscattered signals





Design guidance on antenna termination impedance for QPSK/4QAM modulation.

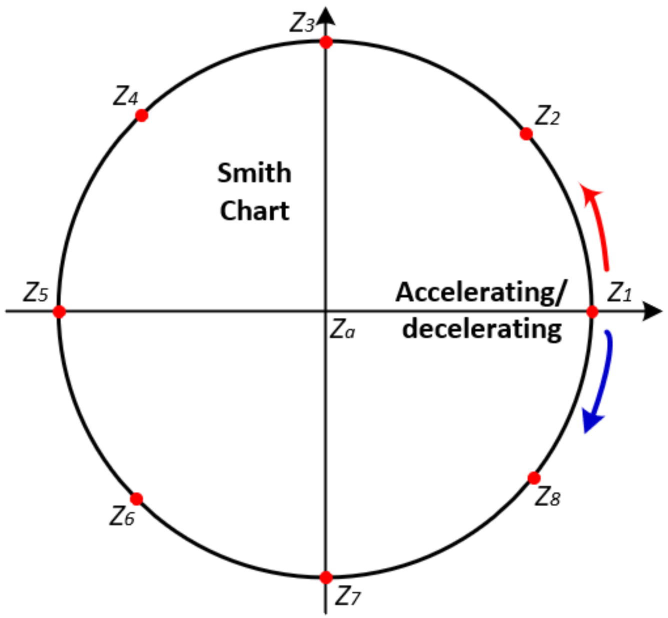
PSK/QAM references:
R. Correia and N. Borges Carvalho, “Design of high order modulation backscatter wireless sensor for passive IoT solutions,” in *Proc. IEEE Wireless Power Transf. Conf.* (*WPTC*), May 2016, pp. 1–3

Backscatter Modulation

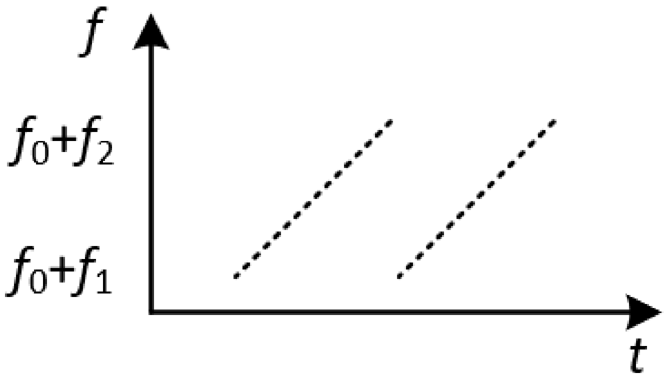
CSS backscatter modulation

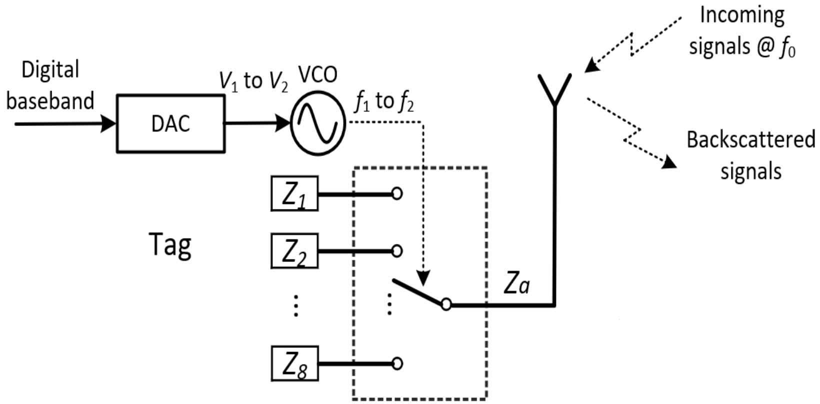
Control input

Voltage controlled oscillation



Spectrogram of backscattered signals





Design guidance on antenna termination impedance for CSS modulation.

CSS references:

V. Talla, M. Hessar, B. Kellogg, A. Najafi, J. Smith, and S. Gollakota, “LoRa backscatter: Enabling the vision of ubiquitous connectivity,” *Proc. ACM Interact. Mobile Wearable Ubiquitous Technol.*, vol. 1, no. 3, Sep. 2017

Backscatter Modulation

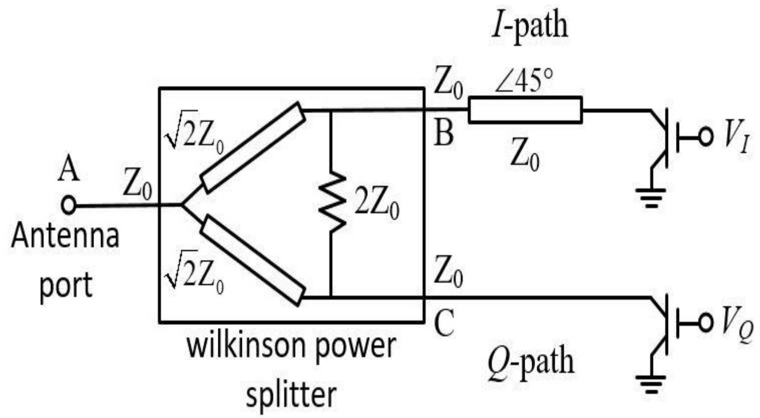
Summary of SOTA backscatter modulations

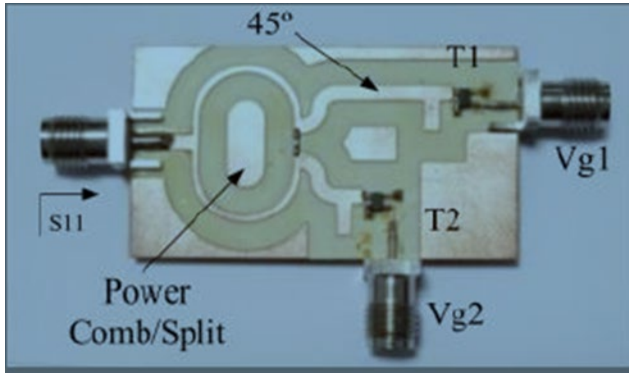
- ASK: simple, but susceptible to noise
- FSK: resilient to noise
- PSK: complex hardware
- QAM: complex hardware, but higher bit rate
- CSS: is resilient to interference

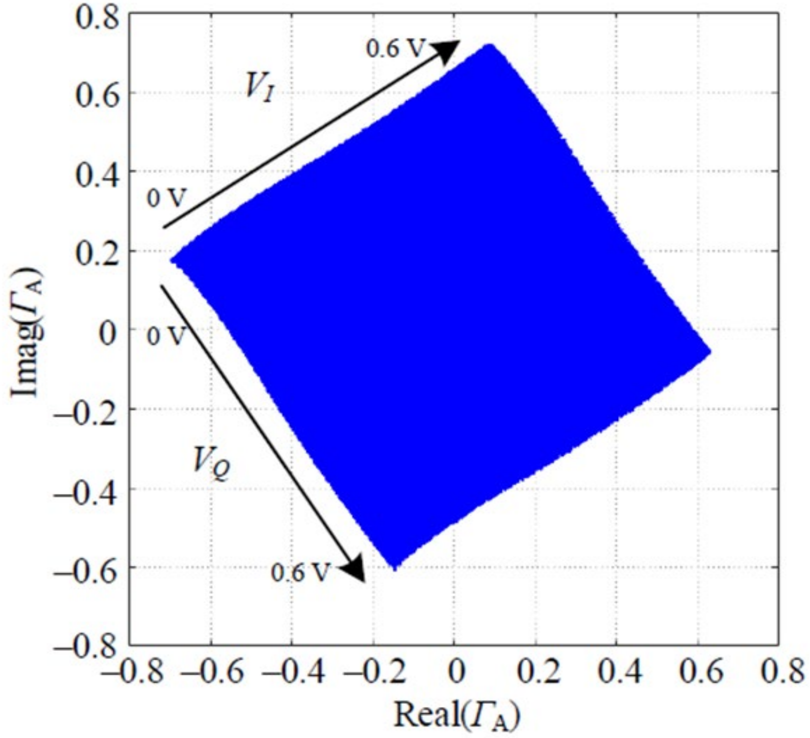
All the above techniques uses **single carrier** backscatter modulation

Further enhance the spectrum efficiency: **Multicarrier** backscatter modulation, e.g. OFDM

IQ Backscatter Modulator







V_I and V_Q of two transistors (ATF-54143) are swept from 0 to 0.6 V with step of 1mV

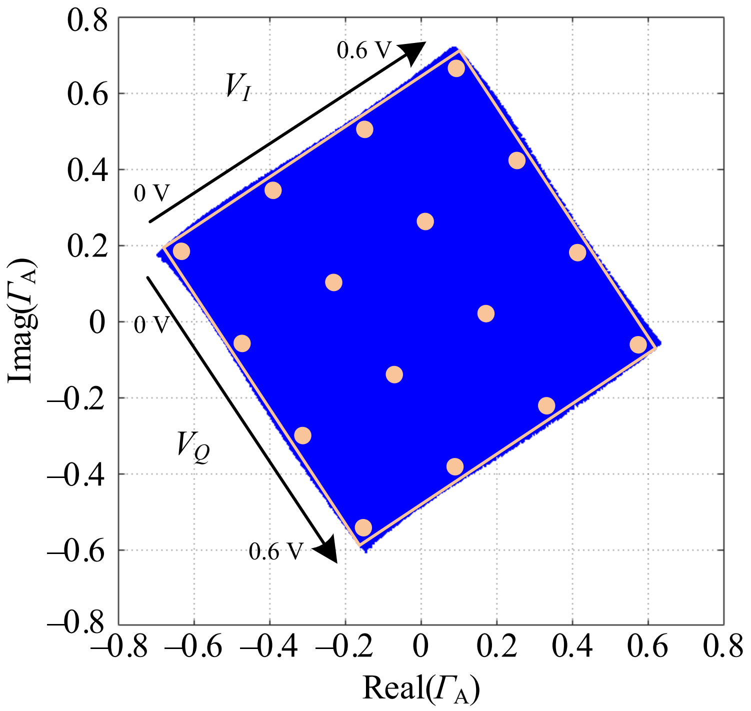
Reflection coefficient observed at antenna port A when V_I and V_Q of two transistors (ATF-54143) are swept from 0 to 0.6 V.

Reference:

R. Correia, A. Boaventura and N. Borges Carvalho, "Quadrature Amplitude Backscatter Modulator for Passive Wireless Sensors in IoT Applications," *IEEE Trans. Microw. Theory Tech.*, vol. 65, no. 4, pp. 1103-1110, April 2017

IQ Backscatter Modulator (original use)

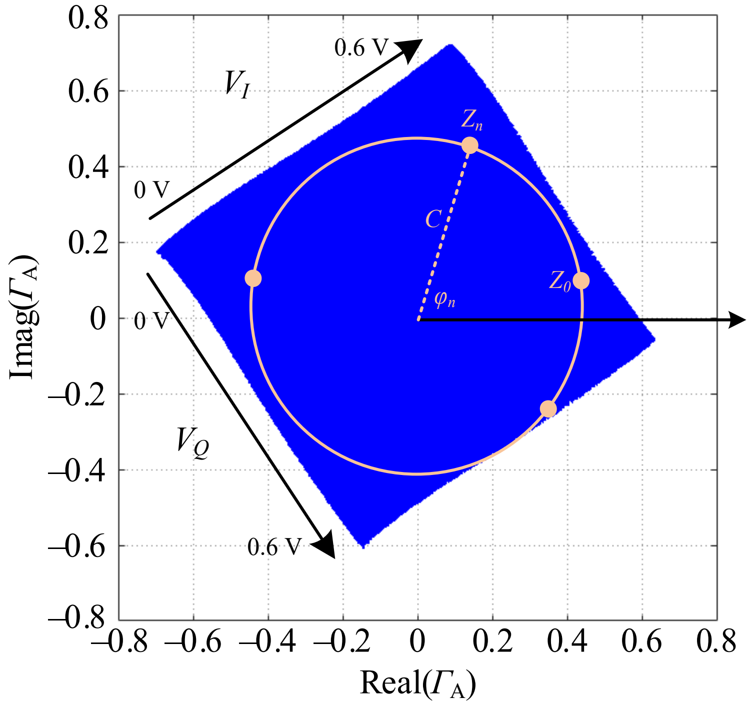
QAM backscatter modulation



Reference:
R. Correia, A. Boaventura and N. Borges Carvalho, "Quadrature Amplitude Backscatter Modulator for Passive Wireless Sensors in IoT Applications," *IEEE Trans. Microw. Theory Tech.*, vol. 65, no. 4, pp. 1103-1110, April 2017

IQ Backscatter Modulator (original use)

CSS backscatter modulation



$$S_{bs}^{(n)}\Big|_{t=\frac{n}{\Delta f}} = C \cdot \exp j2\pi\left(f_0 + \frac{\varphi_n \Delta f}{2\pi n} \right) t$$

C: magnitude of reflection coefficient circle

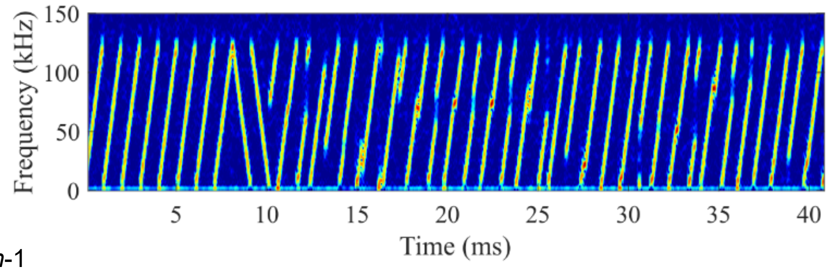
φ_n: angular displacement between Z_n and Z_{n-1}

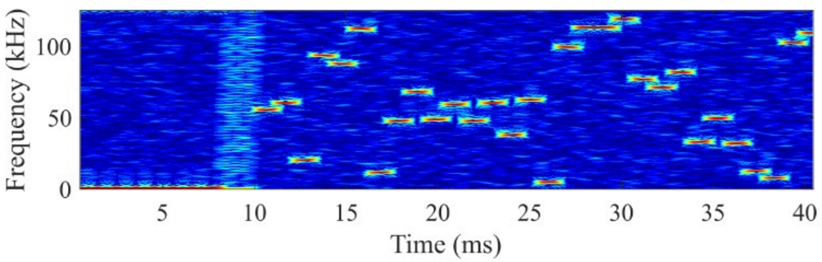
$$\frac{\varphi_n \Delta f}{2n\pi} = \mathrm{A} \cdot n + \mathrm{B}$$

$$\Rightarrow \quad \varphi_n = \frac{2\pi \mathrm{A}}{\Delta f} \cdot n^2 + \frac{2\pi \mathrm{B}}{\Delta f} \cdot n$$

A: starting frequency

B: bandwidth

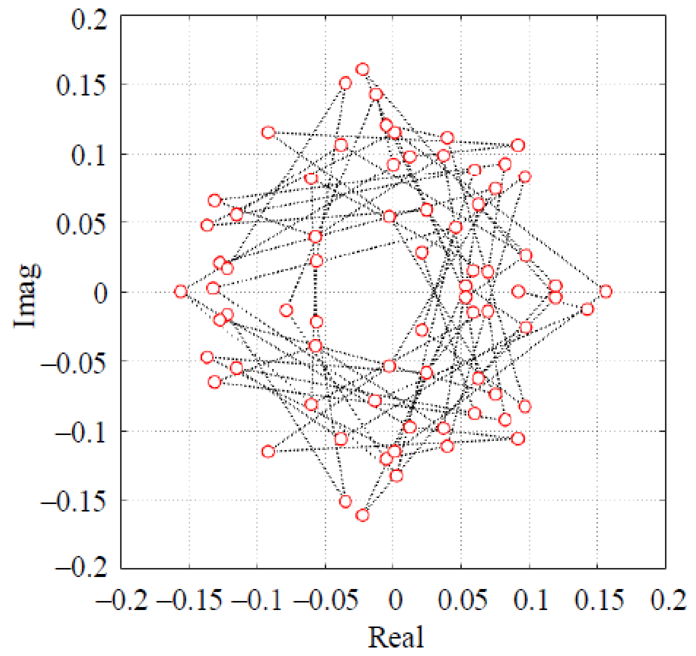




Reference:

Daniel Belo, Ricardo Correia, Yuan Ding, Spyridon N. Daskalakis, George Goussetis, Apostolos Georgiadis, and Nuno B. Carvalho, “IQ impedance modulator front-end for low-power LoRa backscattering devices,” *IEEE Trans. Microw. Theory Tech.*, vol. 67, no. 12, pp. 5307–5314, Dec. 2019.

IQ Backscatter Modulator



Multicarrier OFDM backscatter modulation

IEEE 802.11g (WiFi3) Preamble generation

- Short training symbol

  [0 0 1+j 0 0 0 -1-j 0 0 0 1+j 0 0 0 -1-j 0 0 0 -1-j 0 0 0 1+j 0 0 0 0 0 0 -1-j 0 0 0 -1-j 0 0 0 1+j 0 0 0 1+j 0 0 0 1+j 0 0 0 1+j 0 0]
- 64-point IFFT (convert from frequency to time)
- Select the first 16 samples, and copy for 10 times (in time domain)
- Long training symbol

  [1 1 -1 -1 1 1 -1 1 -1 1 1 1 1 1 1 -1 -1 1 1 -1 1 -1 1 1 1 1 1 -1 -1 1 1 -1 1 -1 1 -1 -1 -1 -1 -1 1 1 -1 -1 1 -1 1 -1 1 1 1 1]
- 64-point IFFT (convert from frequency to time)
- Cascade short training samples and long training sample + guard samples

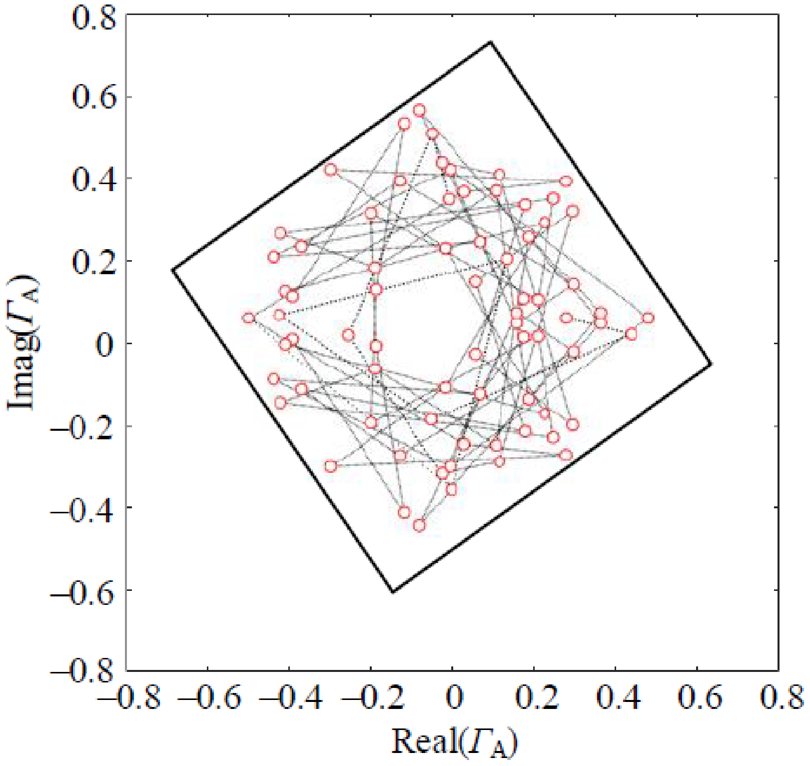
  (Total: 320 complex-valued samples in time domain

IQ Backscatter Modulator

Multicarrier OFDM backscatter modulation- Scaling

- IFFT output is scaled-up to fit in to the reflection coefficient area to achieve maximum power

- Using the same approach, OFDM payload can be backscattered



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Conclusion

- Achievement
  - ➢ Multicarrier backscatter for the first time
  - ➢ WiFi-compatible
  - ➢ No dedicated reader is required

Future work

- IEEE 802.11g PHY implementation
- Over the air test
- Adapting to other multicarrier commercial wireless systems

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Questions?