Implementation of Multi-Access Tag Based on OFDM

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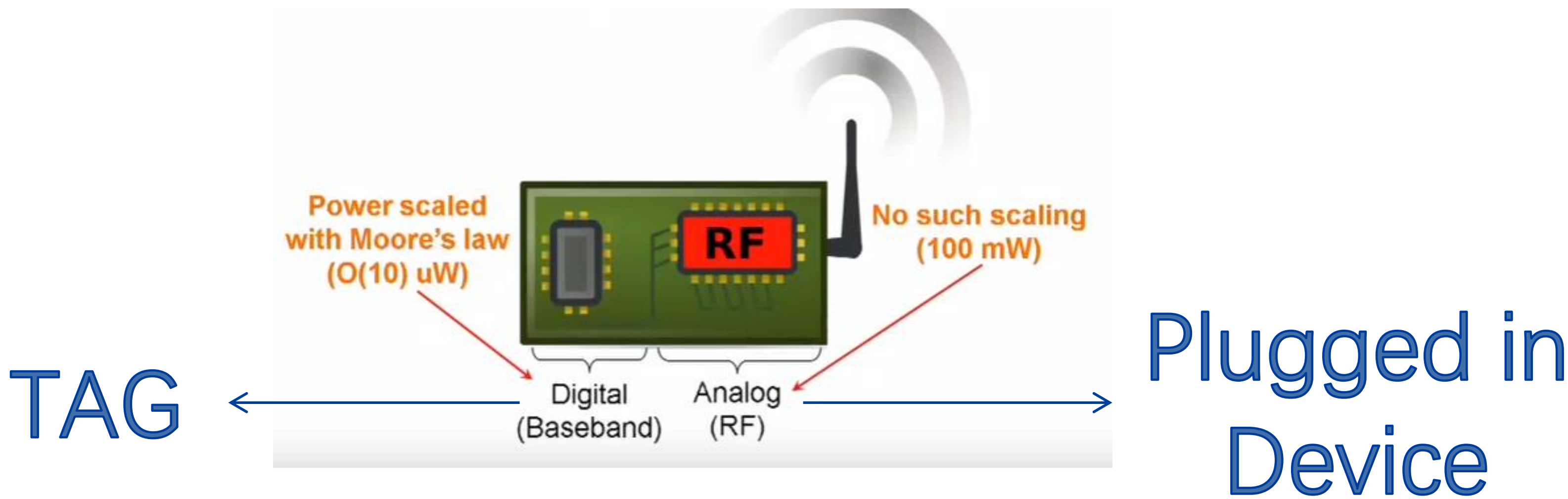
Overview

Traditional Wi-Fi routers have been considered power-consuming device thus cannot be used in the field of IOT. In order to achieve the low-power feature required in IOT, power hungry RF component and low-power consuming digital components of traditional Wi-Fi transmitter are separated. This semester I built a prototype hardware.



Background Information

- OFDM

OFDM stands for **Orthogonal Frequency Division Multiplexing**, which is a modulating technique used in Wi-Fi signal transmission. OFDM signal is multi-carrier modulated signal, which means it has multiple subcarriers to transmit the signal. Take Wi-Fi transmission as an example, in each channel of the total three channel of Wi-Fi, there are 52 subcarriers, thus the transmitted signal x(t) can be expressed as follows,

$$x(t) = \sum_{n=-26}^{n=26} x_k(t) = \sum_{n=-26}^{n=26} X_k e^{j2\pi(f_c + k f_0)t}$$

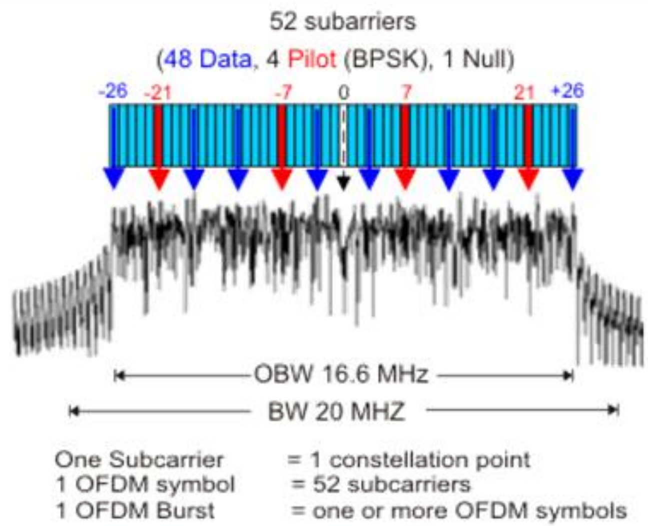
Where X_k is the symbol transmitted on k_{th} subcarrier, $f_c = 2.4GHz$ and $f_0 = 312.5KHz$ in the case of Wi-Fi transmission

Background Information

- OFDM

Note that $X_0 = 0$ and $x_{-21}(t), x_{-7}(t), x_7(t), x_{21}(t)$ are served as pilot signal used for synchronization and contain no data.

802.11a OFDM PHY Parameters	
BW	20 MHZ
OBW	16.6 MHZ
Subcarrer Spacing	312.5 Khz (20MHz/64 Pt FFT)
Information Rate	**6**/9/**12**/18/**24**/36/48/54 Mbits/s
Modulation	BPSK, QPSK, 16QAM, 64QAM
Coding Rate	1/2, 2/3, 3/4
Total Subcarriers	52 (Freq Index -26 to +26)
Data Subcarriers	48
Pilot Subcarriers*	4 (-21, -7, +7, +21) *Always BPSK
DC Subcarrier	Null (0 subcarrier)



802.11a OFDM Physical Parameters

Background Information

- Backscatter

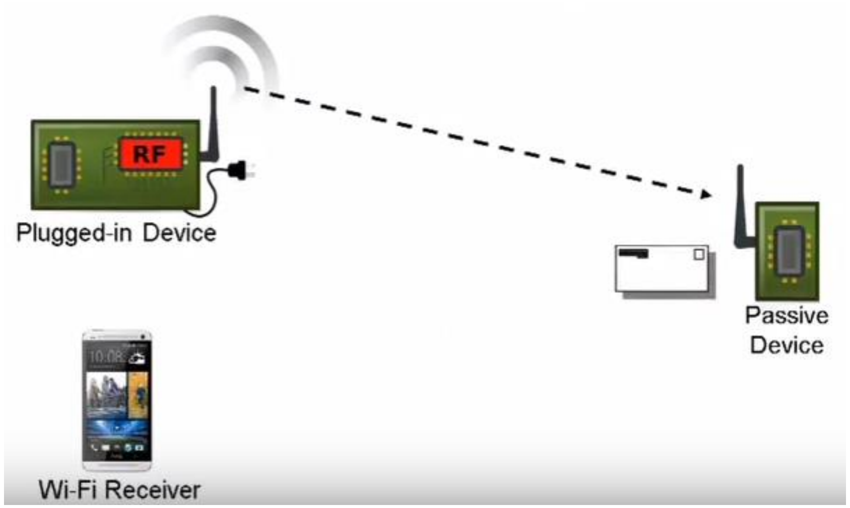
Unlike traditional Wi-Fi transmitter, instead of generating RF signal directly, tags in our system modulate the radar cross-section of the antenna to change the reflected signal. This is achieved by switching the impedance of the circuits followed by the antenna, when changing such impedance, the reflect coefficient is altered as well. The backscattered signal can be expressed as follows

$$S_{backscatter} = \Gamma \cdot S_{incident}$$

where $\Gamma = \frac{Z_a - Z_c}{Z_a + Z_c}$, Z_a, Z_c is the impedance of the antenna and the impedance of the circuit followed by the antenna, in most cases, $Z_a = 50\Omega$.

Basic Principle

The process of our system is first to generate a single-tone RF signal in the transmitter side, then shift the frequency to the desired 48 frequencies of subcarriers that contain data and modulate data we want to transmit on shifted signals. Therefore, there are two function of tags in our system, frequency shifting and modulating.



Basic Principle

- How do we shift the single-tone frequency to desired 48 frequencies?

We need to use two equations show as follows

$$2sin2\pi f_c t \cdot sin2\pi\Delta f t = \cos 2\pi(f_c - \Delta f)\, t - \cos 2\pi(f_c + \Delta f)\, t$$

$$Square(\Delta f t) = \frac{4}{\pi}\sum_{n=1,3,5\ldots}^{\infty}\frac{1}{n}sin2\pi n\Delta f t$$

If we suppose $S_{incident} = \sin 2\pi f_c t$ and replace Γ in previous slide with $Square(\Delta f t)$, according to the trigonometry equation shown above, we obtain

$$S_{backscatter} = Square(\Delta f t) \cdot sin2\pi f_c$$

$$= \frac{\pi}{4}[cos2\pi(f_c - \Delta f)t - \cos 2\pi(f_c + \Delta f)\, t]$$

Desired Component

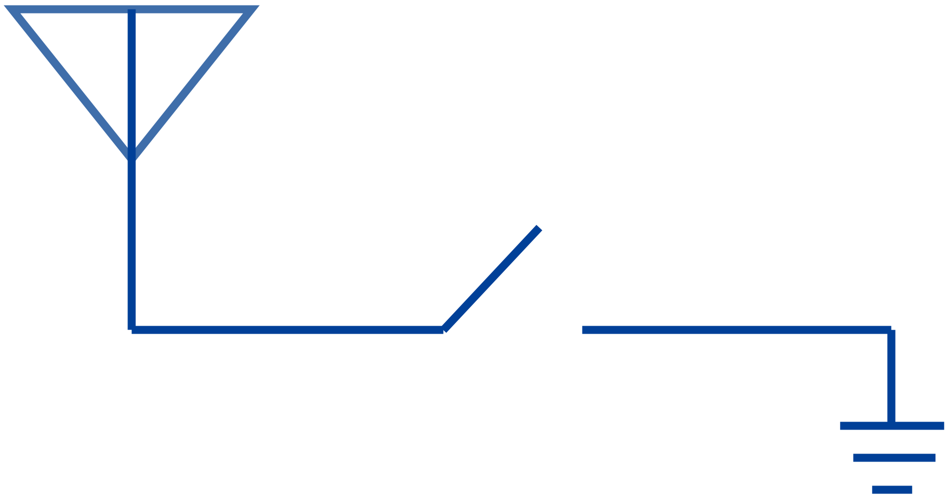
Harmonics

$$+\frac{\pi}{4}\sum_{n=3,5\ldots}^{\infty}[cos2\pi(f_c - n\cdot\Delta f)t - cos2\pi(f_c + n\cdot\Delta f)t]$$

Basic Principles

- How do we shift the single-tone frequency to desired 48 frequencies?

The period toggle (frequency Δf) between +1 and -1 of reflective coefficient Γ can be realized by a RF switch which toggle between the state of short circuit and open circuit.



$$\Gamma = +1$$

Basic Principles

- How do we shift the single-tone frequency to desired 48 frequencies?

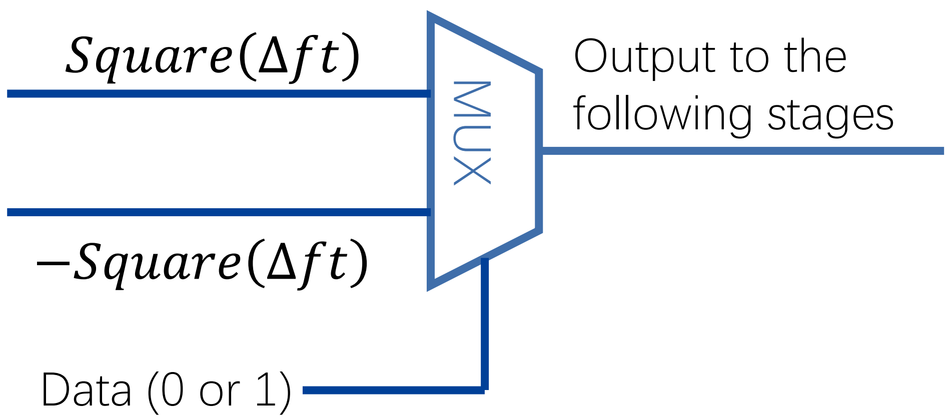
The period toggle (frequency Δf) between +1 and -1 of reflective coefficient Γ can be realized by a RF switch which toggle between the state of short circuit and open circuit.

$\Gamma = -1$

Basic Principles

- How to modulate?

We only want to implement the simplest case of digital modulation - BPSK in our system. The two phases required in BPSK is 0 (data 1) and π (data 0), which means the desired signal is $\cos 2\pi(f - \Delta f)t - \cos 2\pi(f + \Delta f)t$ and $-(\cos 2\pi(f - \Delta f)t - \cos 2\pi(f + \Delta f)t)$ respectively. Accordingly, the square waves corresponding to the two different phases are $Square(\Delta f t)$ (data 0) and $-Square(\Delta f t)$ (data 1).



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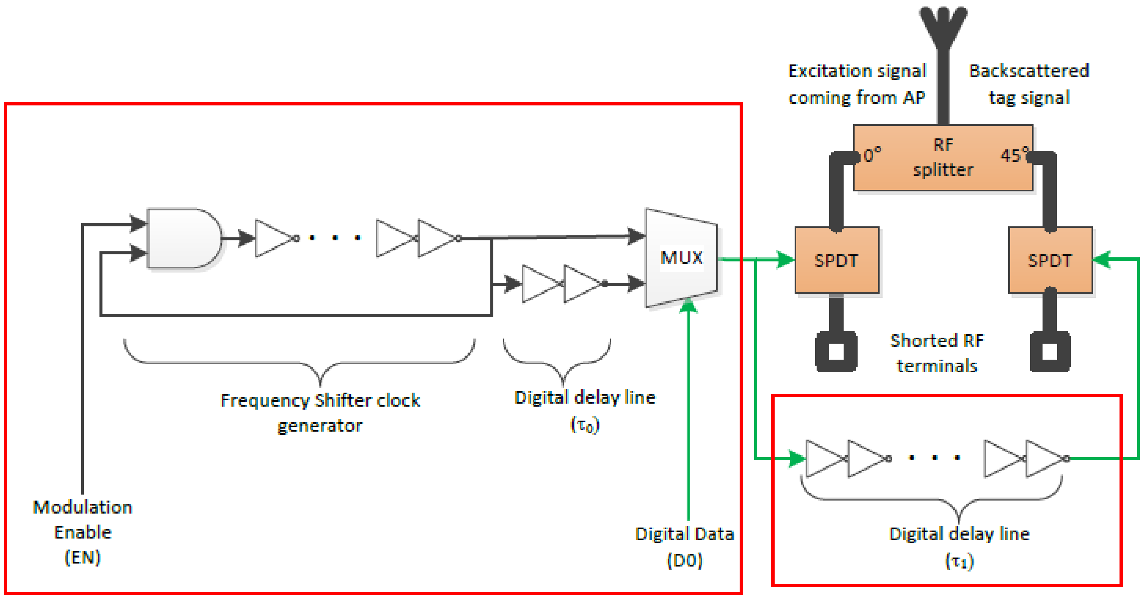
Basic Principles

- How to solve the problem of spectrum waste?



In the diagram, τ_0 is used to create phase π in BPSK modulation and τ_1 is used to change the expression of square wave from $\frac{4}{\pi}\sum\frac{1}{n}sin2\pi n\Delta ft$ to $\frac{4}{\pi}\sum\frac{1}{n}cos2\pi n\Delta ft$.

Basic Principles

- How to solve the problem of spectrum waste?

The incoming signal: $S_{incident}(t) = \sqrt{2}Asin2\pi f_c t$

Output signal of RF splitter: $r_1(t) = r_2(t) = Asin2\pi f_c t$

$$r_1(t)\angle 45^\circ = Asin\left(2\pi f_c t + \frac{\pi}{4}\right), r_2(t) = Asin2\pi f_c t;$$

$$r_{1backscatter}(t) = r_1(t)\angle 45^\circ \cdot \frac{4}{\pi}\sum\frac{1}{n}sin2\pi n\Delta f t$$

$$\approx -\frac{2A}{\pi}cos[2\pi(f_c + \Delta f)t + \frac{\pi}{4}] + \frac{2A}{\pi}cos[2\pi(f_c - \Delta f)t + \frac{\pi}{4}]$$

$$r_{2backscatter}(t) = r_2(t) \cdot \frac{4}{\pi}\sum\frac{1}{n}cos2\pi n\Delta f$$

$$\approx \frac{2A}{\pi}sin[2\pi(f_c + \Delta f)t] + \frac{2A}{\pi}sin[2\pi(f_c - \Delta f)t]$$

Basic Principles

- How to solve the problem of spectrum waste?

$$S_{backscatter}(t) = r_{1backscatter}(t)\angle 45^{\circ} + r_{2backscatter}(t)$$
$$= \frac{4A}{\pi} sin2\pi(f_c + \Delta f)t$$

As you can see from the final result, there only exists frequency component $(f_c + \Delta f)$ and the 'mirror' component, $(f_c - \Delta f)$, is eliminated.

Hardware Implementation

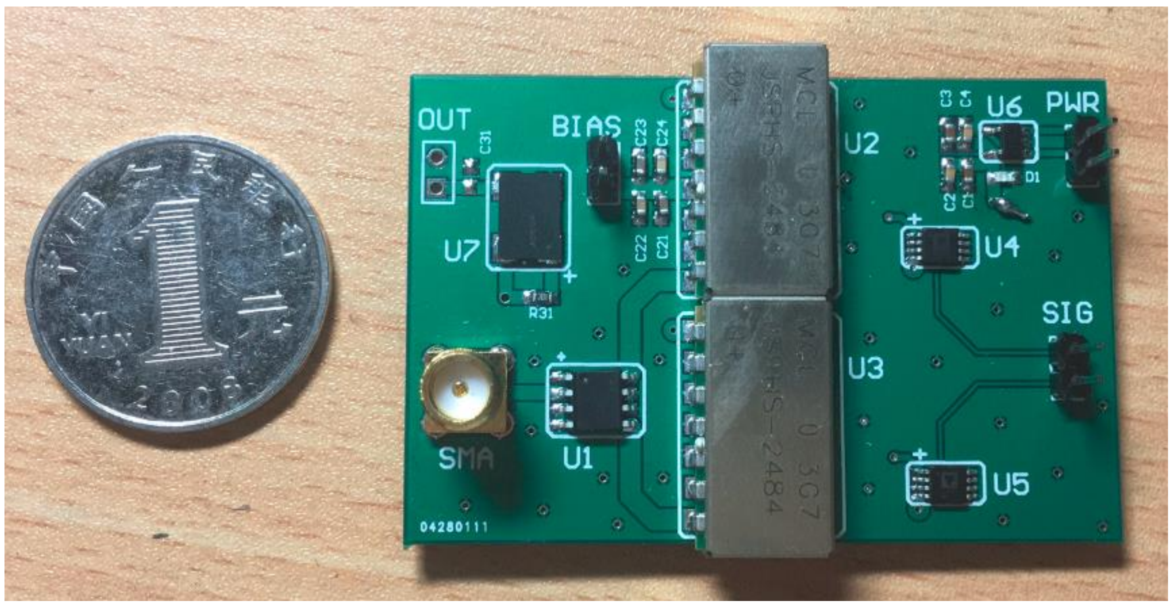
According to the diagram, the devices we need to build the hardware of the tag are: one RF splitter/combiner, two RF phase shifter(one create 45°and the other create 0°, considering the insertion loss caused by the device, I chose two of such device to make sure the amplitude of output of the two phase shifter are approximately the same), two SPDT/SPST switch and the list of device I choose are shown as follows.

Devices	Models
RF splitter/combiner	BP2U+
RF phase shifter	JSPHS2484+
RF switch	ADG902

Hardware Implementation

The clock management part, which is circled red in previous diagram, is written in VHDL and implemented on Nexys 3 FPGA board.

The prototype I built is shown below.

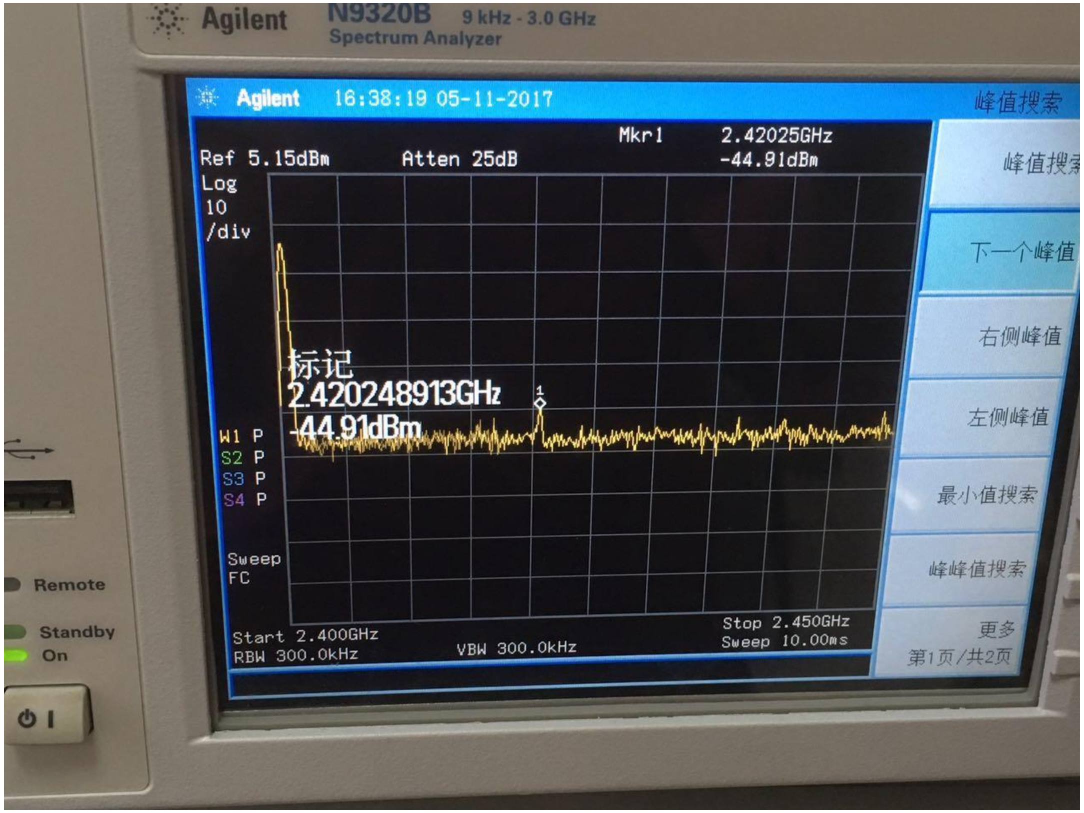


Test Result

- **Test Environment** - Lab 4-103, SEIEE Building
- **Test Instrument** - Spectrum analyzer and RF signal generator
- **Test Date** - May 11, 2017
- **Test Parameters** - $f_c = 2.4GHz, \Delta f = 20.3125MHz, P_{transmit} = 20dBm$
- **Test Distance** - Very close(less than 10cm)
- **Test Results** - $f_{backscatter} \approx 2.42GHz$, $P_{received} = -8dBm$
  $P_{backscatter} = -45dBm$

Test Result

- The test phenomenon is shown as follows



Follow-up Work

- Increase the power of the backscattered signal and SNR
- Further test the function of modulation
- Combined test with other parts of our system

Conclusion

- Implement a prototype of low-power, multi-access tag based on OFDM. The feature of low-power is achieved since we have removed the power hungry RF component.
- I take the hardware diagram of [2] as a reference and design our own tag. The tag can serve the function of frequency shifting and the problem of spectrum waste caused by ’mirror’ component generated in the process of frequency shifting is solved as well.
- The other function, modulating remain tested.

Reference

[1] Bryce Kellogg, Vamsi Talla, Shyamnath Gollakota, and Joshua R Smith. Passive wi-fi: Bringing low power to wi-fi transmissions. 2016.

[2] Pengyu Zhang, Dinesh Bharadia, Kiran Joshi, and Sachin Katti. Hitchhike: Practical backscatter using commodity wifi. In ACM SENSYS, 2016.

Q & A

Thank You