RF 101 - from Hz, to GHz in 1h

You can't smell it unless you got burned

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Who am I?

- Hacker
- I am addicted to cool hobies
- No formal education in RF
- I learn by doing
- My employer does not care if my opinion is considered to reflect theirs

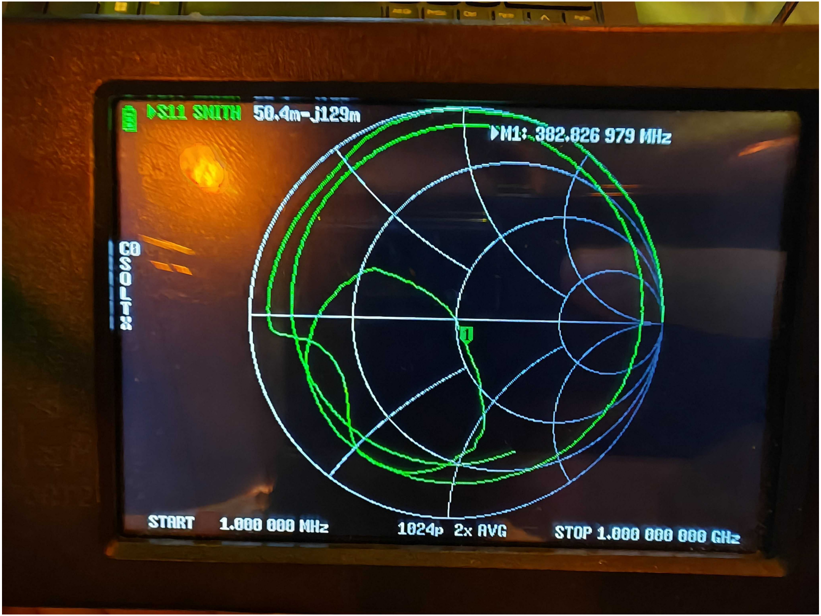
Oscillation

- Constant - does not carry any information (DC)
- Sinewave (or any other kind)

Resonance

- Capacitance
  - Reservoir and water that changes flow speed
- Inductance
  - Heavy pendulum and inertia
- Capacitance and inductance cancel each other out and we get resonance
- Antenna "likes" to *transmit* and *receive* energy of that frequency
- Antenna can be RF antenna, microphone/speaker, light source/sensor, etc.

Smith chart



S11 SMITH 50.4m-j129m
M1: 382.826 979 MHz
CO
SOLTX
START 1.000 000 MHz
1024p 2x AVG
STOP 1.000 000 000 GHz

Frequency and wavelength

- Frequency is how many times per second oscillation happens (Hz)
  - Hz, kHz, MHz, THz...
- Wavelength is how much wave travels during one oscillation (m)
- Higher frequency - shorter wavelength

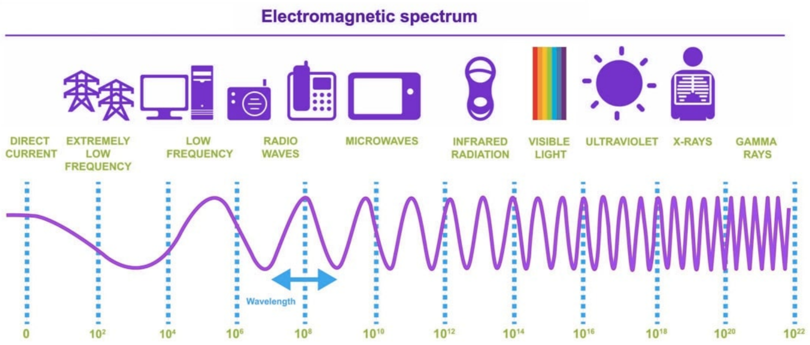


Figure 1: Spectrum example

Amplitude

- In case of sound, it is air pressure (dBA)
- In case of RF, it is dBm
- What is dB?
  - 0dB = 1x
  - 10dB = 10x
  - 20dB = 100x
  - 30dB = 1000x
- Scale is log, not linear
- Why dB?
  - Huge amount of dynamic range
  - Inverse square law - not linear
- What is dBm then?
  - dBm is power compared to 1mW
  - -10dBm = 0.1mW
  - 10dBm = 10mW

Filtering

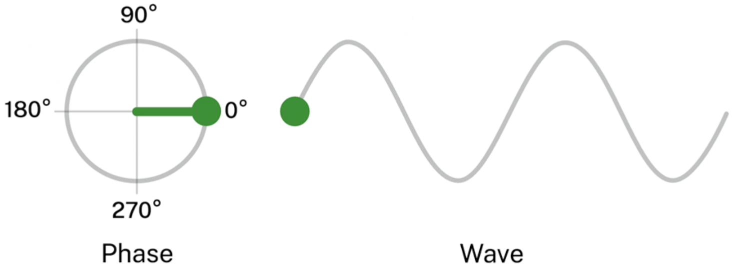
- When you transmit, you just add your oscillation to sum of all other oscillations around
- You can extract that oscillation from sum of a lot of oscillations
- Antenna is a filter
- Frequency response

Modulation

- How do we encode useful data in oscillation
- We turn it on/off?
- We change amplitude?
- We slightly change frequency?
- We slightly change phase?
- Some combination?
- Multiple carriers?
- No carrier? (or a lot of carriers?)
- FM (frequency modulation), AM (amplitude modulation), PM (phase modulation) - you can modulate both analog and digital waveform

What is phase?

- Rewinding or jumping around sinewave



Digital modulation, and effects of square signal on RF (harmonics)

- Squarewave signal contains frequency elements of a lot of frequencies
- More bandwith
- Filtering before transmitting (Filter 10kB/s signal to 20kHz - low pass)
  - Note: 1 bit == 1 symbol

Mixing

- You can shift around that oscillation to other frequencies
- New signal is sum and difference of new signals
- Warning (DC offset) - it is good idea to stay away from exactly 0Hz and to remove DC

IQ signal

- When mixing in the middle of some signal, it gets reflected on both sides of 0Hz
- To combat that, we mix it with same frequency, with 90 degrees offset and we digitize it as 2 different signals
- This allows us to have negative frequencies

Digitizing

- Nyquist rule
  - 20MSPS ADC can reliably capture 10Mhz signal
- ADC (analog to digital converter) is a filter
- Frequency response of ADC
- Dynamic range
- AGC (automatic gain control)

Digital filtering

- Imperfect, just as analog filtering
- CPU intensive

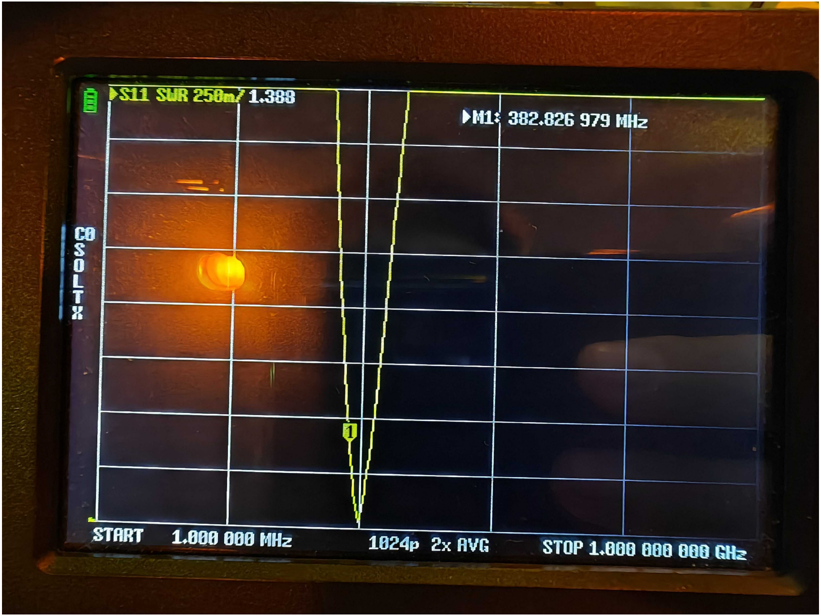
Digital mixing

- Really simple
- Just multiply IQ with LO signal

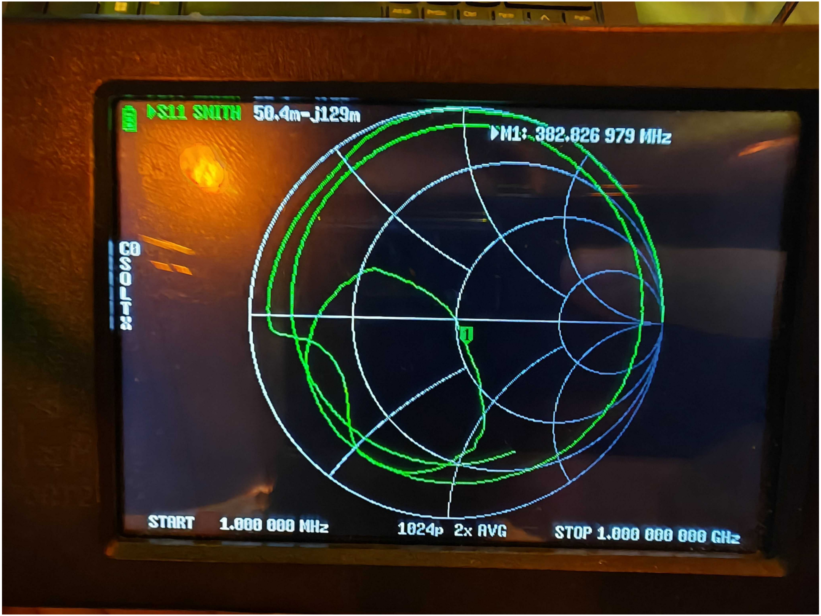
Impedance and impedance matching

- Impedance match == you are sending V that is "expected" further on in the circuit
- When you turn on circuit, you see ringing, that is caused by impedance mismatch
- We induce current in return path, in reverse direction
- We "prepare" flow of current for impedance of termination (antenna)
- 50Ohm as standard - good balance between power handling and loss
- VSWR (or SWR, as hams call it) - difference between expected impedance (50Ohm -> 75Ohm == 1:1.5 VSWR)
- Reflection can fry transmitter
- Reflections cause distortion
- Smith chart

VSWR


S11 SWR 250m/ 1.388
M1: 382.826 979 MHz
START 1.000 000 MHz
1024p 2x AVG
STOP 1.000 000 000 GHz

Smith chart


S11 SMITH 50.4m-j129m
M1: 382.826 979 MHz
START 1.000 000 MHz
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Tuning antenna

- Antenna is “terminator” for transmission line
- Needs to be the same impedance as transmission line (or we need impedance transformer)
- We are measuring how good antenna terminates circuit, but not really how good antenna is (50Ohm resistor)
- Antenna radiation pattern and gain
  - Reference antenna - dBd and dipole - dBi isotropic antenna (does not exist)
- Field strength measurement (0dBi antenna)

Spectrum analysis

- We can measure power over frequencies
- FFT - Converts time domain to frequency domain
- Swept spectrum analyzer (with filter and RF detector)

Modulation analysis

- Modulation examples:
  - FSK (Frequency shift keying)
  - ASK (Amplitude shift keying)
  - PSK (Phase shift keying)
  - QAM (Quadrature amplitude - both phase and amplitude)

  ...
- Eye diagram
- Constellation diagram

SDR uses for hackers

- Replay attack
- Using URH (universal radio hacker) to figure out modulation parameters and demodulate data
- YardStickONE and other based CC1101 or similar chips for TX and RX
  - Once you know modulation parameters, fastest way to implement RX and TX is using modems that are premade
- Tools like flipper zero try to take data, recognize it and understand the meaning
  - Rolling code
  - Encryption (Keeloq)
- Rolljam (Samy Kamkar)

Recommended tools

- VNA
  - NanoVNA
  - LiteVNA if you want more from it
- Spectrum analyzer
  - TinySA Ultra
- SDR
  - RTLSDR Blog V4 - On cheap
  - BladeRF - for best experience
  - HackRF - If you want something that works on cheap

Contact

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