

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 hobbies
- ▶ No formal education in RF
- ▶ I learn by doing
- ▶ My employer does not care if my opinion is considered to reflect theirs

## About presentation

- ▶ Questions will be on the end
- ▶ Idea is, hopefully anyone from beginner to advanced RF guy will learn something
- ▶ It is just introduction, to give you basic intuitive understanding of RF

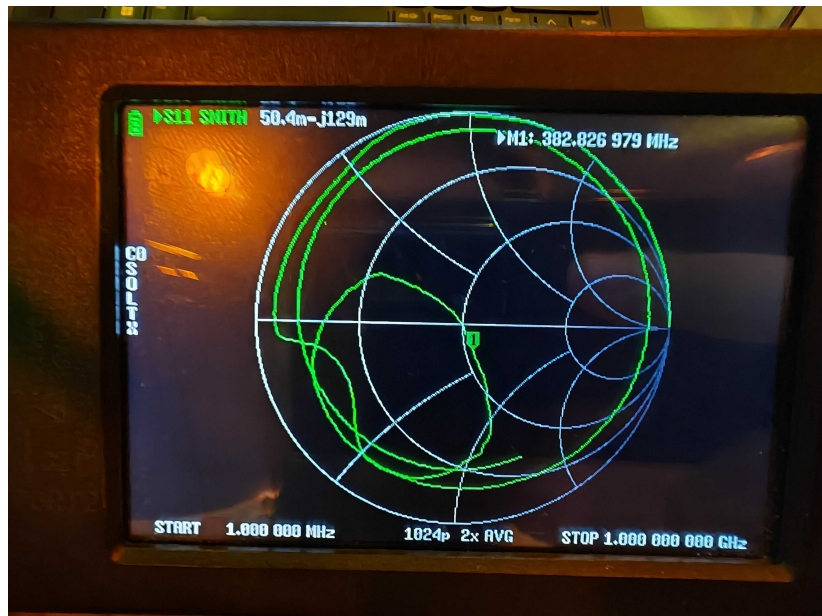
# Oscillation

- ▶ 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



# 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

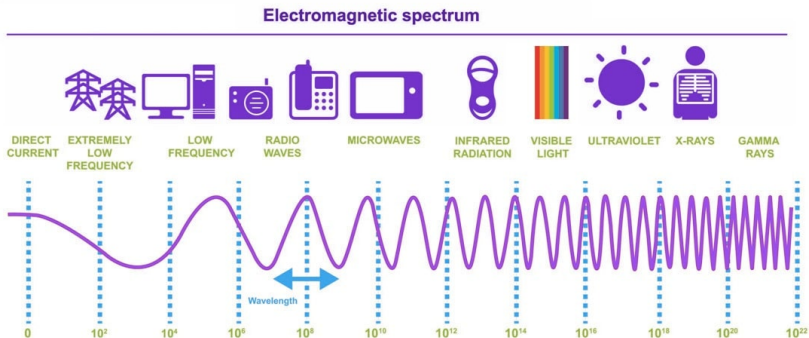


Figure 1: Spectrum example

# Amplitude

- ▶ In case of sound, it is air pressure (dBA)
- ▶ In case of RF, it is dBm
- ▶ What is dB?
  - ▶  $0\text{dB} = 1\text{x}$
  - ▶  $10\text{dB} = 10\text{x}$
  - ▶  $20\text{dB} = 100\text{x}$
  - ▶  $30\text{dB} = 1000\text{x}$
- ▶ 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
  - ▶  $-10\text{dBm} = 0.1\text{mW}$
  - ▶  $10\text{dBm} = 10\text{mW}$



## Filtering

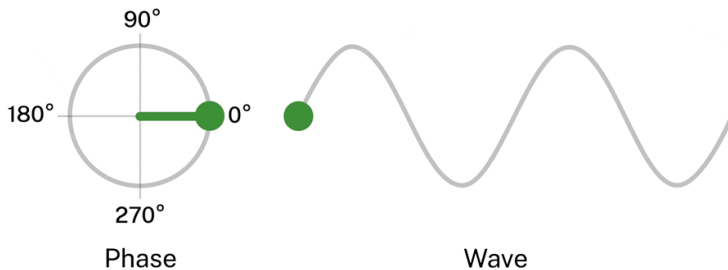
- ▶ When you transmit, you just add your oscillation to sum of all other oscillations around
- ▶ You can extract that oscillation from sum of a lot of oscillations
- ▶ Antenna is a filter
- ▶ Frequency response

# 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

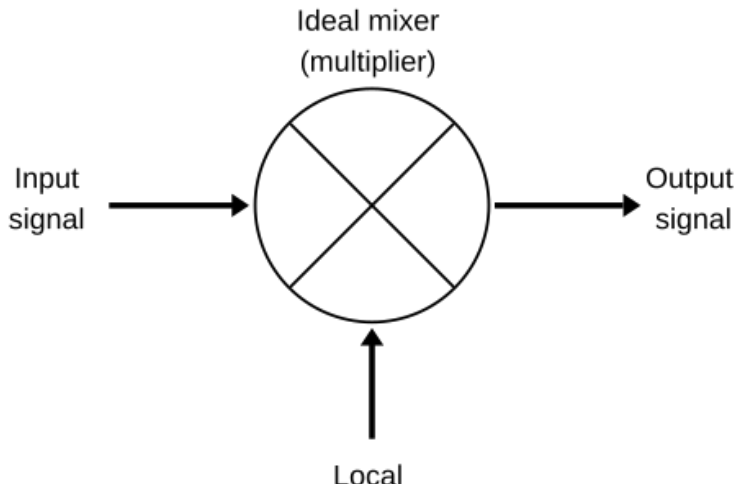


## Digital modulation, and effects of square signal on RF (harmonics)

- ▶ Squarewave signal contains frequency elements of a lot of frequencies
- ▶ More bandwidth
- ▶ 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



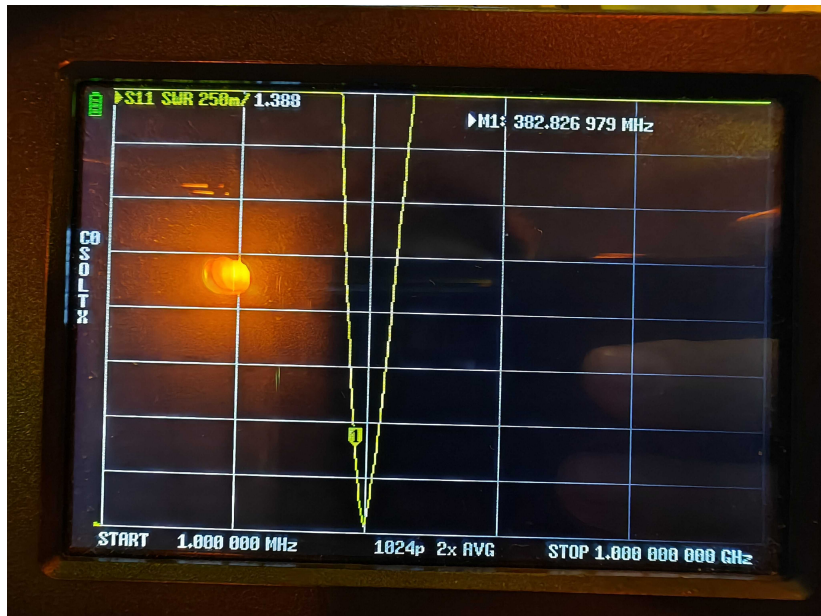
## Digital mixing

- ▶ Really simple
- ▶ Just multiply IQ with LO signal

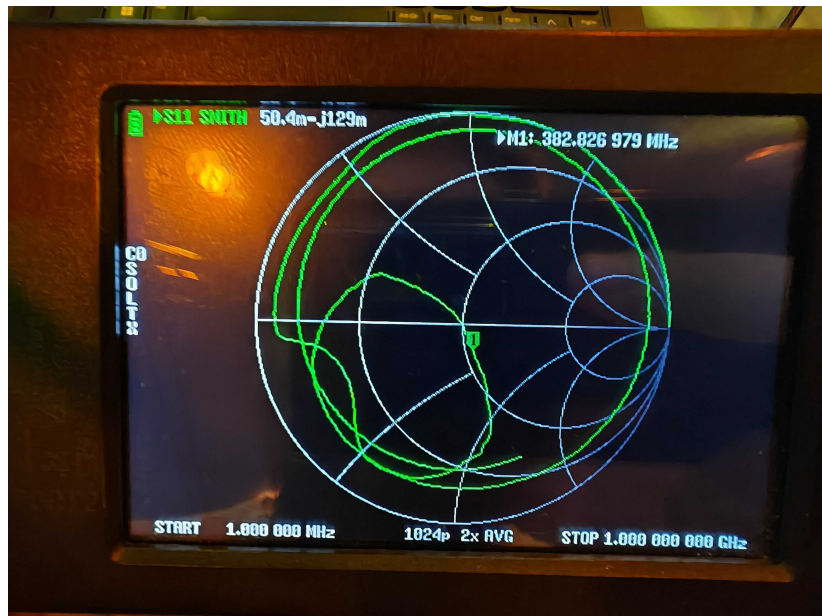
## Impedance and impedance matching

- ▶ 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  $\rightarrow$  75Ohm == 1:1.5 VSWR)
- ▶ Reflection can fry transmitter
- ▶ Reflections cause distortion
- ▶ Smith chart

# VSWR



## Smith chart



# 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
- ▶ Pre made modems
  - ▶ YardStickONE
  - ▶ Evil RF Crow
- ▶ Software
  - ▶ SDR++ - Best overall performance
  - ▶ SDRAngel - Ready to use demodulators/modulators, but, a bit unstable
  - ▶ GNURadio - Building block of great things, but, a bit limited
  - ▶ URH (Universal radio hacker) - for reversing 433MHz

# Contact

- ▶ [github.com/nemanjan00](https://github.com/nemanjan00)
- ▶ [x.com/nemanjan00](https://x.com/nemanjan00)

Questions!