Software Defined Radio Primer + Project

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Overview

- What is SDR?
- Why should I care?
- SDR Concepts
- Potential SDR project

Approach:
This topic is too large and complex to cover comprehensively in a single short presentation. I will try to pick relevant examples to highlight the key elements of SDR

If you have questions…
ask them!

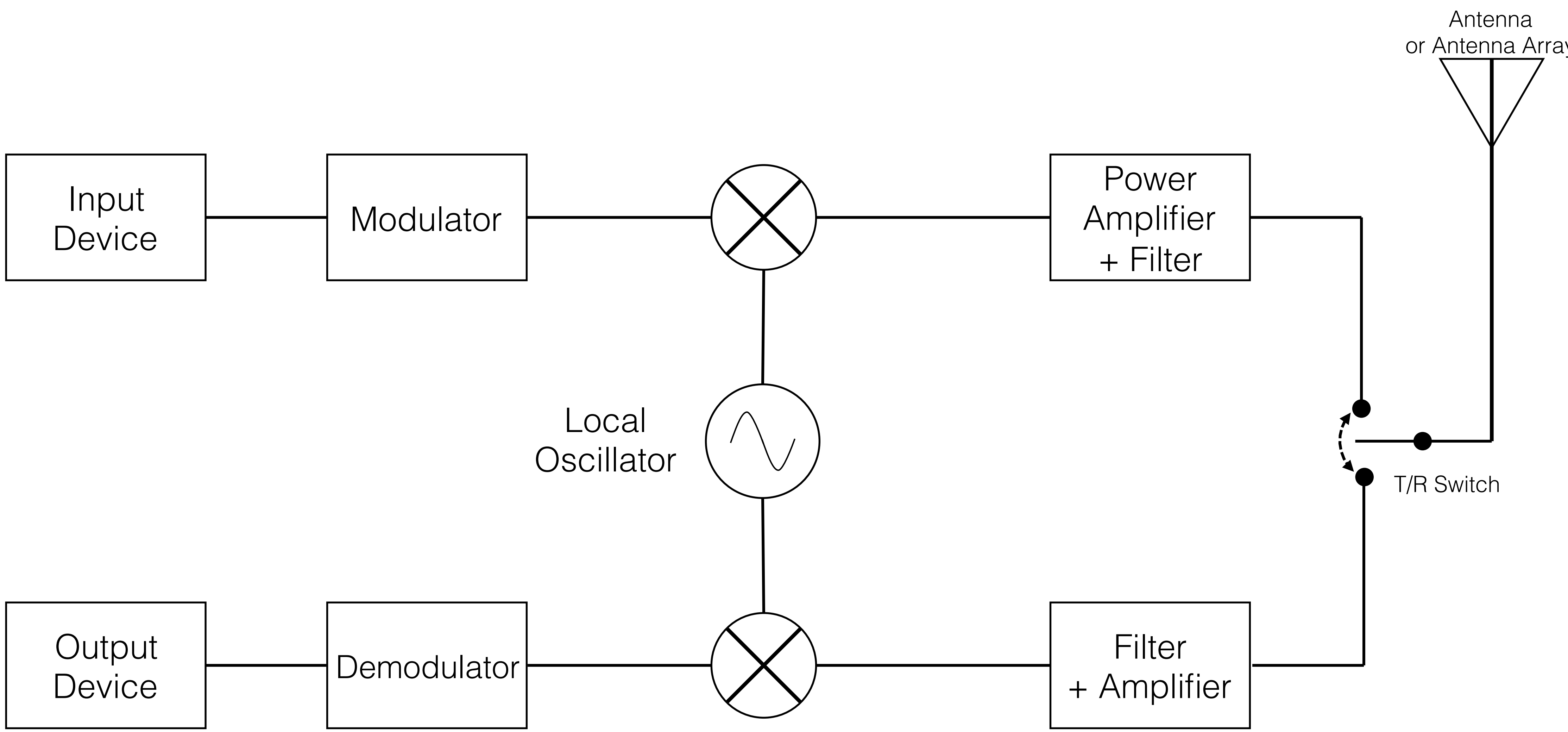
What is SDR?

- SDR substitutes software algorithms for functions historically performed by (usually analog) hardware components

- Allows for changing major radio functions with little or no change radio in hardware
  - Eliminates the need for multiple modulation circuits in multi mode transceiver (CW, SSB, AM, FM, RTTY, etc.)
  - Can perform functions difficult or impossible to realize using analog components (certain types of filters, complex modulation techniques, adaptive antenna arrays, etc.)

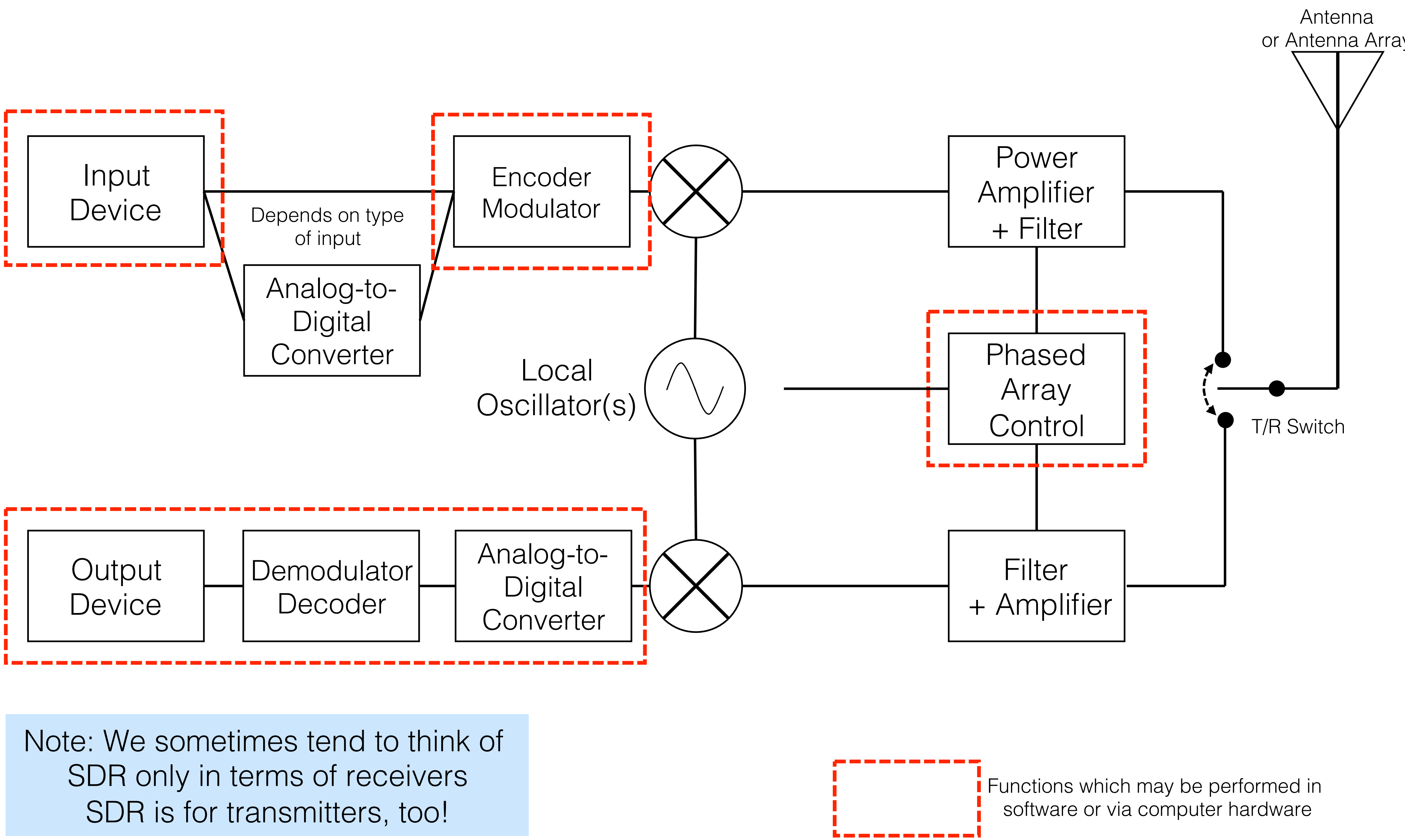
What is SDR?

Classic Analog Radio



What is SDR?

Software Defined Radio



Note: We sometimes tend to think of SDR only in terms of receivers
SDR is for transmitters, too!

What is SDR?

- Functions typically performed to software (or computer hardware):
  - Analog-to-digital conversion (and often digital-to-analog conversion
  - Modulation
  - Demodulation
  - Filtering
  - Message coding and decoding
  - Control of phased array antennas (becoming common in new generations of home routers)
  - Radio controls and displays

Can pick and choose which functions to computerize based on operating and design goals

What is SDR?

- Largely eliminates component tolerance issues when performing signal processing
  - Device bias, phase inaccuracies, filter tuning, etc.
- Very complex math can be performed…it's just math!
- With a fast enough computer, a whole band (or even all of HF) can be acquired and processed in parallel
  - Can even record the data and play back later!
- The ability to store and analyze captured signals allows a computer to perform functions that would require “going back in time” for an analog system
- Can perform statistical analysis to do noise reduction

What is SDR?

- Functions still typically performed in hardware:
    - RF signal amplification (both transmit and receive)
    - Filtering associated with analog RF amplification (low pass, high pass, band pass, band stop)
    - Audio amplification
    - Power supplies

Why Should I Care?

- Future
  - SDR is the future of most ham radio equipment
- Cheaper
  - Eventually (if not already) SDRs will be cheaper than classic circuits due to reduced parts counts and fewer circuits requiring post-assembly testing and adjustment
- Flexibility
  - You can do things with SDRs that are difficult or impossible or unaffordable with analog equipment
- Expectations of future hams
  - The next generation of hams will expect more cell phone-like equipment operation (and cell phones already are SDRs...)

Why Should I Care?

- What solutions are likely to remain analog for a while?
  - Super high performance receivers
  - Super cheap systems
  - Static or targeted-use solutions (e.g., FM repeaters)

Role of Analog-to-Digital Conversion

- Why?
  - Radio communications always involves some sort of analog signals
  - Computers operate on discrete values
  - Somewhere in the middle analog must be converted to digital (and generally vice versa)
  - Amateur radio involves signals over a wide dynamic range – often greater than A/D converters can adequately manage by themselves
- Cost vs. performance
  - A/D converters used to be expensive
  - Converters covering audio frequencies now pretty cheap
  - High-resolution, high accuracy converters covering high RF frequencies can still be somewhat expensive
  - The processing to handle all that data can also be relatively expensive

You pay for what you get in SDR

Time Domain vs. Frequency Domain

- In analog systems, we normally do all processing of signals as they exist in the time domain (i.e., as a function of time)
- In SDR, we often process signals in the frequency domain (i.e., as a function of frequency)
  - Conversion from time to frequency and back via a function called the Fast Fourier Transform (FFT)
  - Possible to do frequency domain processing in analog systems, but very complex and expensive (example: Navy F-14 radar)
- Frequency domain processing allows determination of frequency and phase of all signals in the passband

Coherent vs. Non-Coherent

- Coherent demodulation uses "exact" knowledge of carrier phase to perform demodulation and decoding
  - Allows receiver to integrate (add up) signal over time to improve performance in noise and signal degradation
    - Can receive signals that are substantially weaker than the band noise!
  - Allows the use of exact phase in performing demodulation - mandatory for certain digital communications protocols
  - Harder to do (particularly with analog circuits)

- Non-coherent demodulation does not use exact phase information
  - Doesn't mean phase is ignored altogether
  - Normally uses instantaneous demodulator output (no integration) that results in poorer performance with noise and signal degradation
  - Easier to do

Weak signal work is greatly improved by using coherent detection

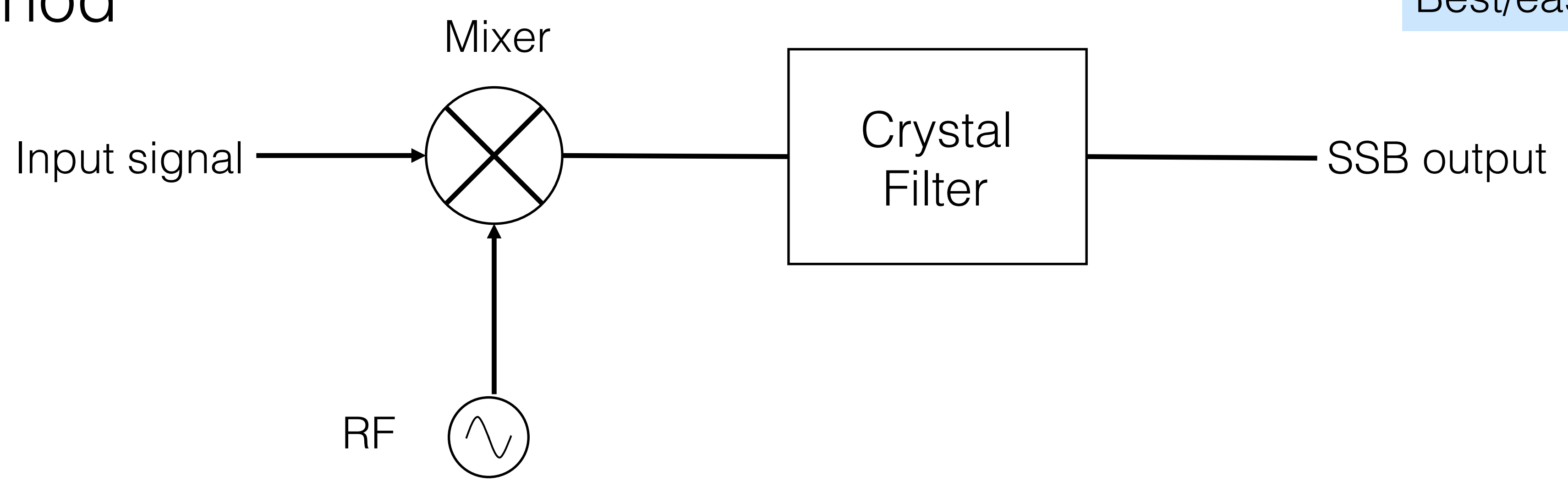
SSB Example

- SSB is created by multiplying the input (usually voice) by an RF signal and then eliminating the unwanted sideband
- Two primary methods of eliminating the unwanted sideband:
  - Filter method
    - Most popular
    - Requires expensive crystal filters
  - Phasing method
    - Generated by phase shifting the input and the RF signals and canceling out the unwanted sideband
    - Hard to do in analog circuitry
    - Pretty easy to do in SDR

SSB Block Diagrams

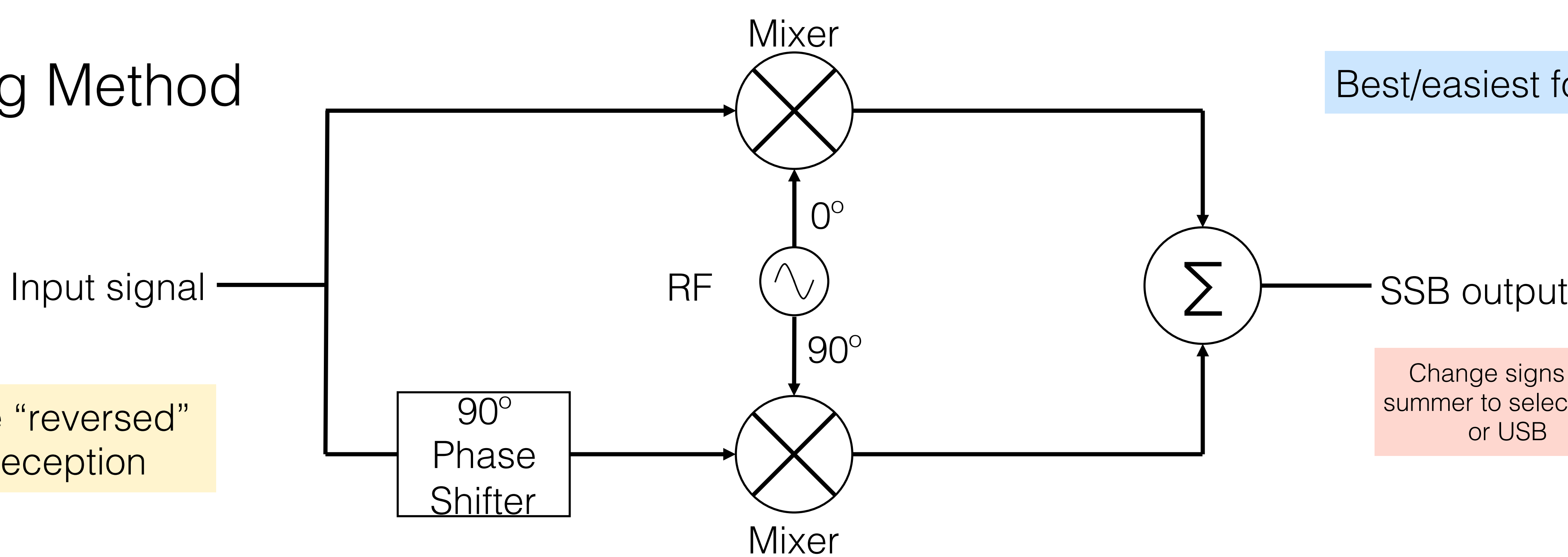
Filter Method

Best/easiest for analog



Phasing Method

Best/easiest for SDR



Can be "reversed" for reception

Change signs on summer to select LSB or USB

SSB Trivia Question

Historically, why was 9 MHz chosen as the “standard” intermediate frequency for HF radios?

Potential Project

Now let's put this together into a ham radio project

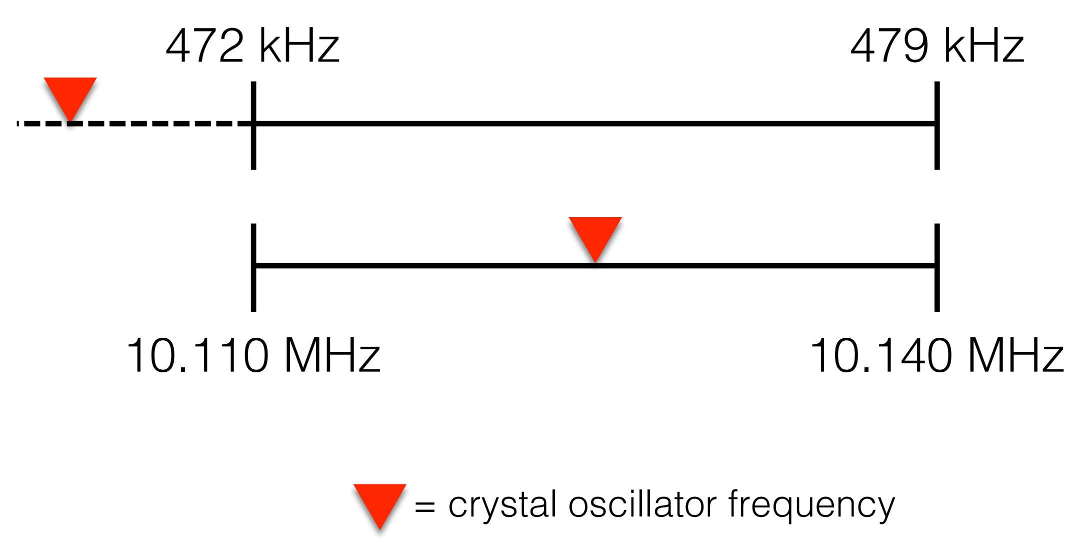
Project Goals

- Transceiver - not just a receiver like the low-cost "TV dongles" popular today
- QRP - must run on the power available from a standard USB 2.0 port (max 2.5 W total power available to all components in the radio)
- Small physical package – mobile, mobile, mobile (okay, ham shack, too!)
- Predictable, medium/long distance, data communications (even if data rate is slow)
- Software must run unmodified on as many platforms as practical - no drivers other than those built into the operating systems
- No complex software installation, configuration, or operating steps
- Transceiver hardware should NOT require a microcontroller
- Hardware must be under $100 and preferably under $50

Design Choices

- Hardware
  - Assume a single-band, crystal-controlled, direct conversion receiver (and transmitter)
    - Use phasing approach to generate and receive SSB-like signals
    - Tuning controlled by audio frequency (max freq <±20kHz or maybe <±10kHz)
    - Radio-to-computing device interface exclusively via stereo audio in-out
  - Candidate bands
    - 630 meters (472 - 479 kHz)
    - 30 meters (10.1 - 10.15 MHz)

30 meters is better for first attempt

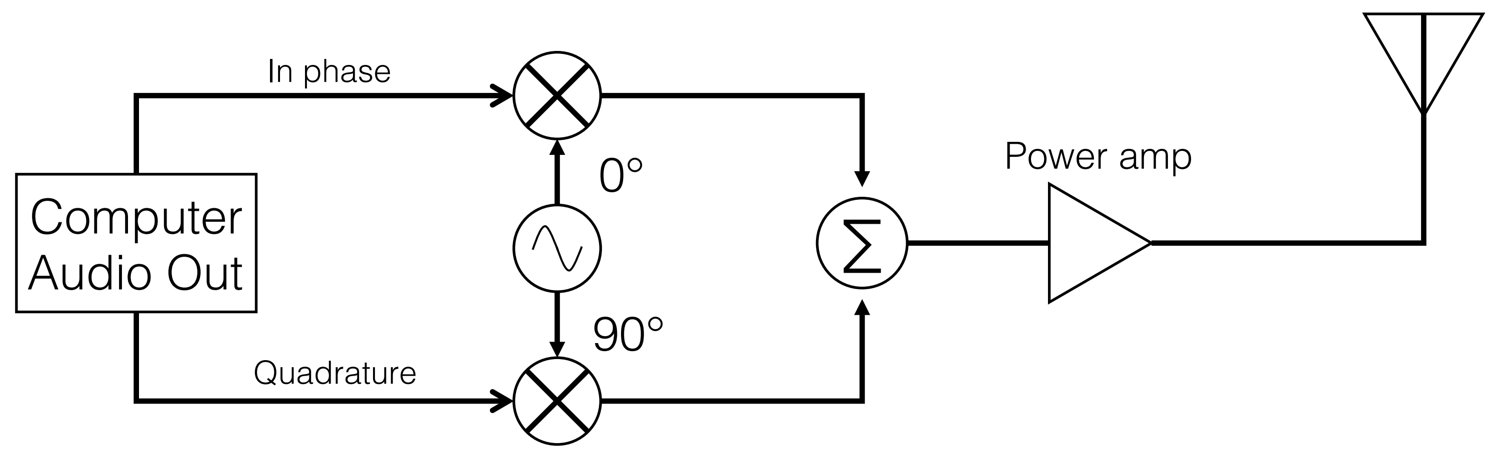


Design Choices

- Candidate software platforms
  - Web Audio platform using JavaScript in a browser
    - Should support Mac, Windows, Linux, Android, iOS (eventually)
  - Java application using the Java sampled sound API
    - Should support Mac, Windows, Linux, Android (maybe...)

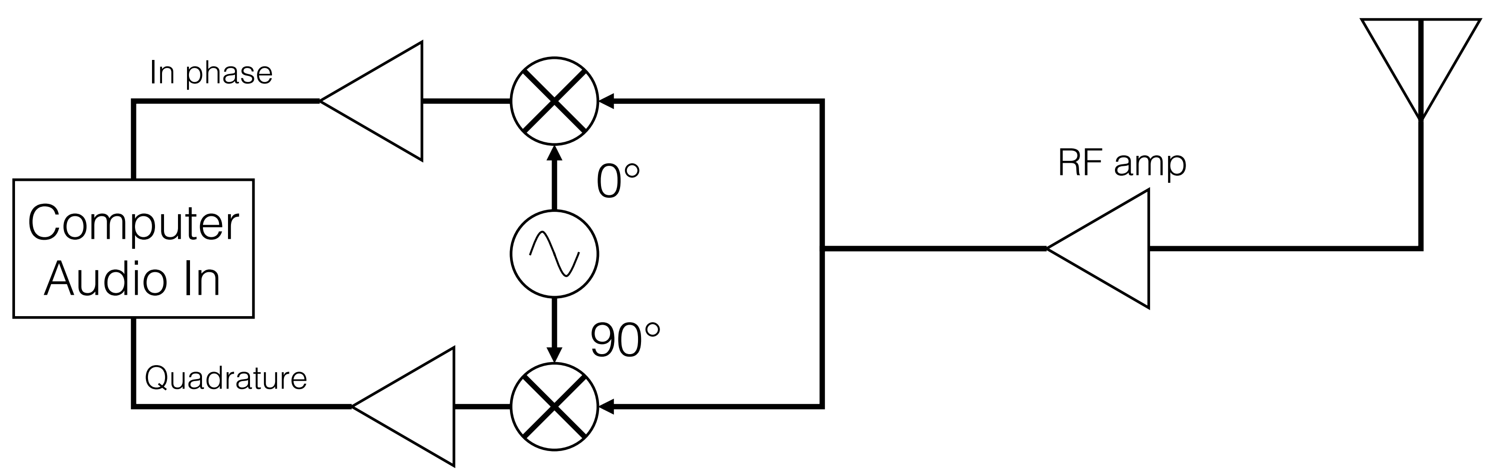
Simplified Block Diagrams

Transmit



VOX switches between the two circuit configurations
Reuse oscillator, mixers, and maybe some amplifiers between transmit and receive

Receive



Candidate Hardware Components

- Mixers/multipliers
  - Expensive – AD834 – highly linear, minimal filtering ($30+ each - ouch!)
  - Mid-range – AD8333 – has two mixers plus oscillator 90° phase shifter built in
  - Cheap – SA612 – used as switching mixer, lots of filtering
- Small signal amplifiers
  - A little more expensive – nice video amplifiers, such as AD8055
  - A little cheaper – Mini-Circuits amplifiers – MAR-1, MAR-2, etc.
- Power amplifier – really tough due to 5V supply limitations
  - MAX 2602 – intended for cell phone applications (low voltage)
- Electronic switches – ADG904, as example
- Crystal oscillator – Digi-Key sells programmable oscillators dirt cheap (~$3 each) that they will pre-program for you
  - Example – Cardinal Components CPP series
  - Open question – will these have too much phase noise???

Protocol Selection

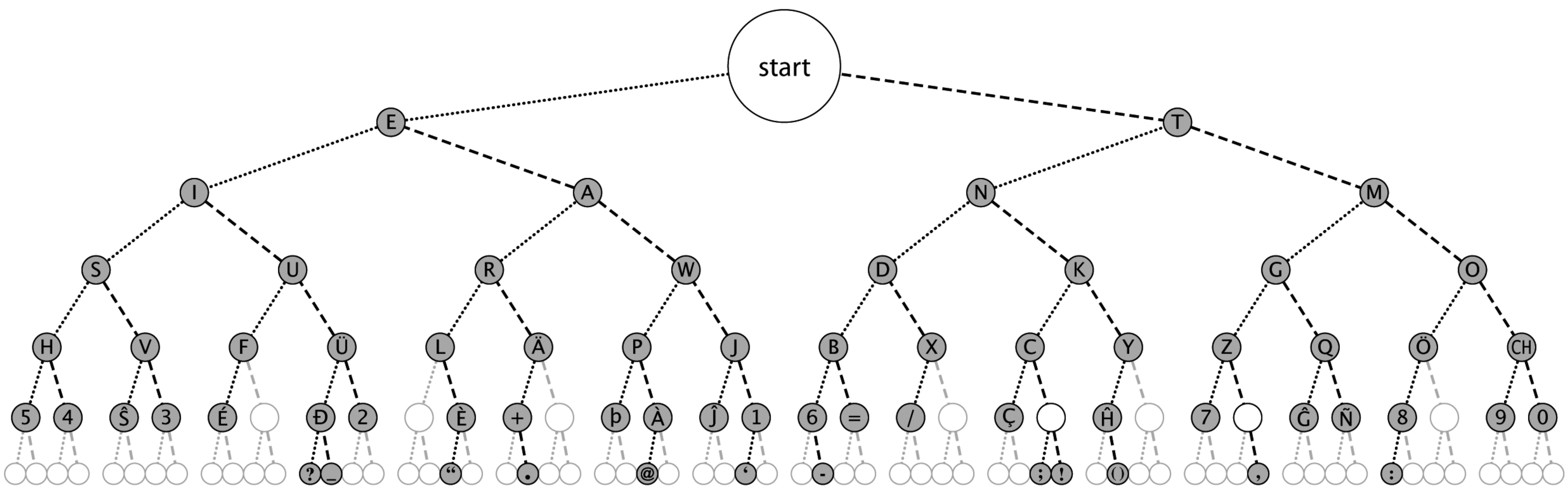
- Characteristics
  - Single tone at a time - allows for non-linear amplification (higher efficiency)
  - Suitable for weak signals and slow transmission over HF and MF
  - Small bandwidth
  - Must support IQ inputs and outputs
  - Must have thorough specification (too laborious to reverse engineer code)
  - Must be compliant with regulations

Protocol Selection

- Strategy
  - Start with Morse code
    - Variable speed
    - Could be as slow as 1 WPM or less at poor signal-to-noise ratios
  - Add option to enhance using two tones rather than on/off
  - Add option to use enhanced character set
    - There are ~60 unused characters at up to 6 dots/dashes
  - Consider other popular weak signal protocols at a later date

Protocol Selection

Morse Code Binary Tree



Protocol Selection

Morse Code

- Pros:
  - While not the most efficient protocol, Morse code is surprisingly efficient
  - When using “pure” Morse code, transmissions are legal on virtually all amateur frequencies
  - Morse code extensions allow for a very large symbol base
  - Can easily add error detection – I call it “MorseTOR”
  - Does not rule out human decoding (by ear or “waterfall” display) when signal strength is good (try that with an MFSK signal!)
  - Can use non-linear power amp – better efficiency
  - Simple protocol, well known, no reverse engineering necessary
- Cons:
  - Other weak signal modes have proven to be better performers

Wrap Up

- SDR is the future of radio…embrace it!
- Prices will come down as competition heats up
- You can use SDR principles to homebrew pretty sophisticated gear on the cheap

Questions?

I hope you enjoyed the presentation!