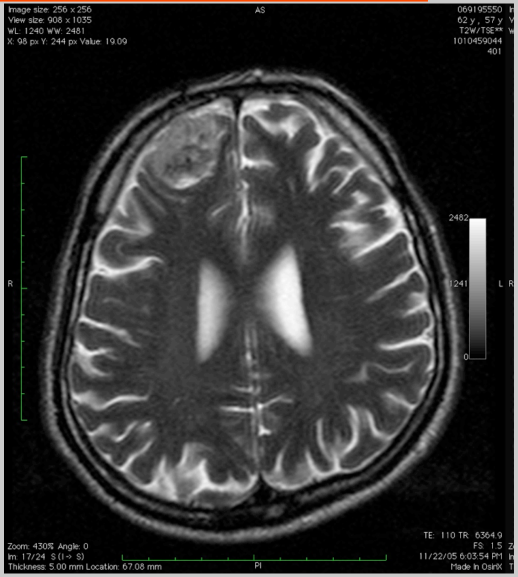
EE123
Digital Signal Processing

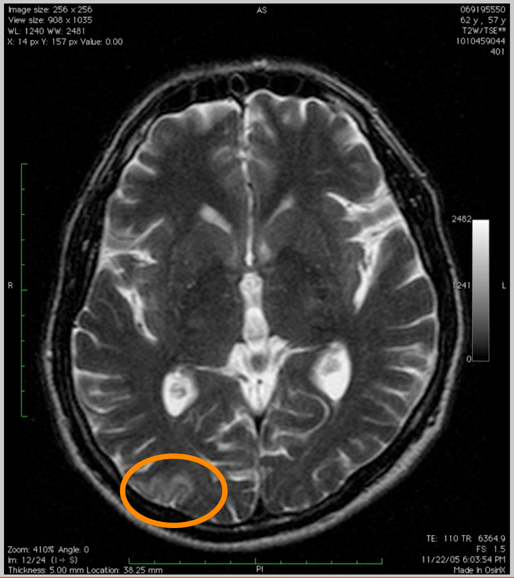
Lecture 26

Based on lecture notes by Prof. Murat Arcak

Why I Love MRI



Where’s the stroke?



Where is the stroke?

Lab 3 - Part I

- Purpose is to test your radio interface
  - Learn about what you can do
  - Work with the SDR and the radio
- Start working on it now!

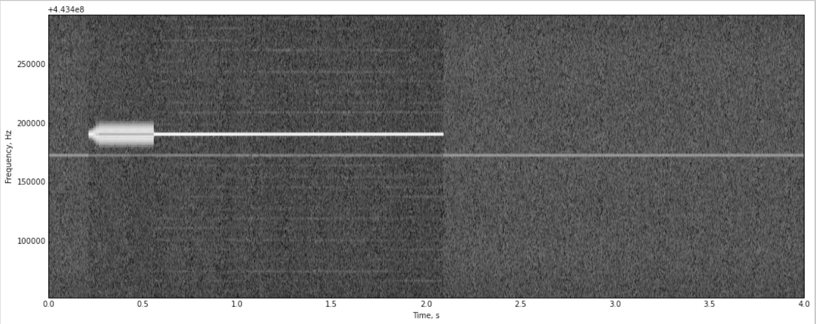
Buffered Audio I/O processing

```
Qin = Queue.Queue()
Qout = Queue.Queue()
# create a pyaudio object
p = pyaudio.PyAudio()

# find the device numbers for builtin I/O and the USB
din, dout, dusb = audioDevNumbers(p)
# initialize a recording thread. The USB device only supports 44.1KHz sampling rate
t_rec = threading.Thread(target = record_audio,   args = (Qin,   p, 44100, dusb  ))
# initialize a playing thread.
t_play = threading.Thread(target = play_audio,   args = (Qout,   p, 44100, dout  ))
# start the recording and playing threads
t_rec.start()
t_play.start()
# record and play about 10 seconds of audio 430*1024/44100 = 9.98 s
for n in range(0,430):
    samples = Qin.get()
    # You can add code here to do processing on samples in chunks of 1024
    # you will have to implement an overlap an add, or overlap an save to get
    # continuity between chunks
    Qout.put(samples)
p.terminate()
```

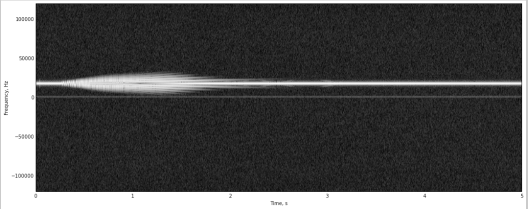

Testing VOX transmit

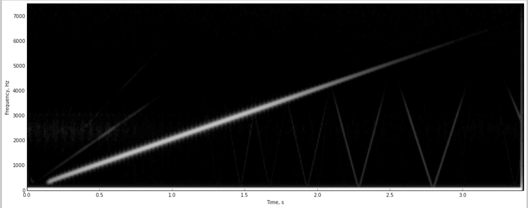
- You want to find the pulse length that is:
  - Long enough to activates the VOX
  - Short enough that radio does not start transmitting the tone
  - Add zeros so the signal sent immediately after will be heard -- good to have extra delay to let squelch on reciev radio to open



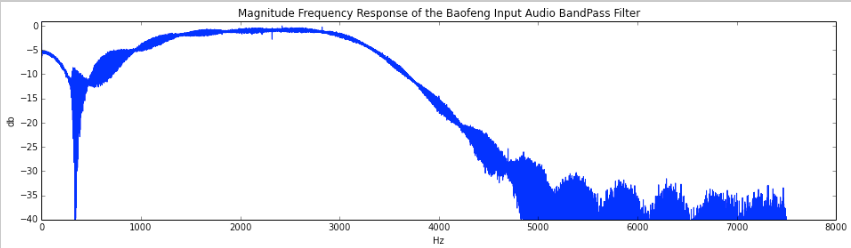
Measure Frequency Response

- Of the Radio Audio input
  - Play a chirp
  - Listen using SDR
  - Demodulate

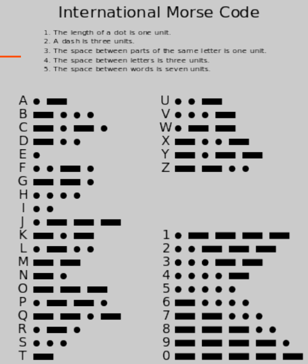




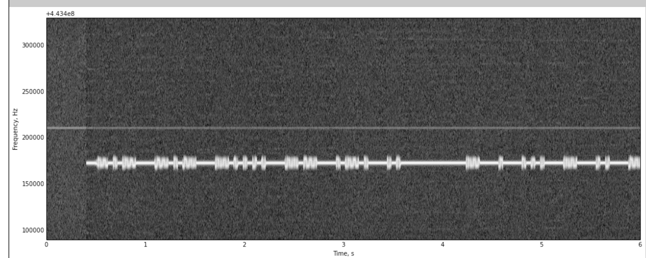
Frequency Response



Morse Code Function



- Write a function
  - Converts text to morse
  - Transmit and receive

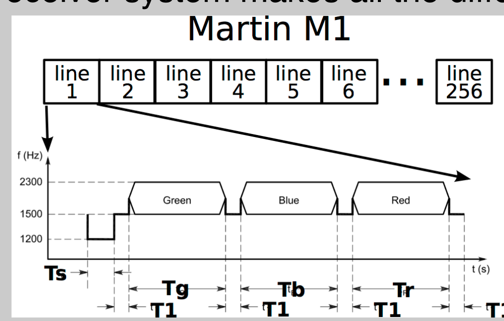


Projects

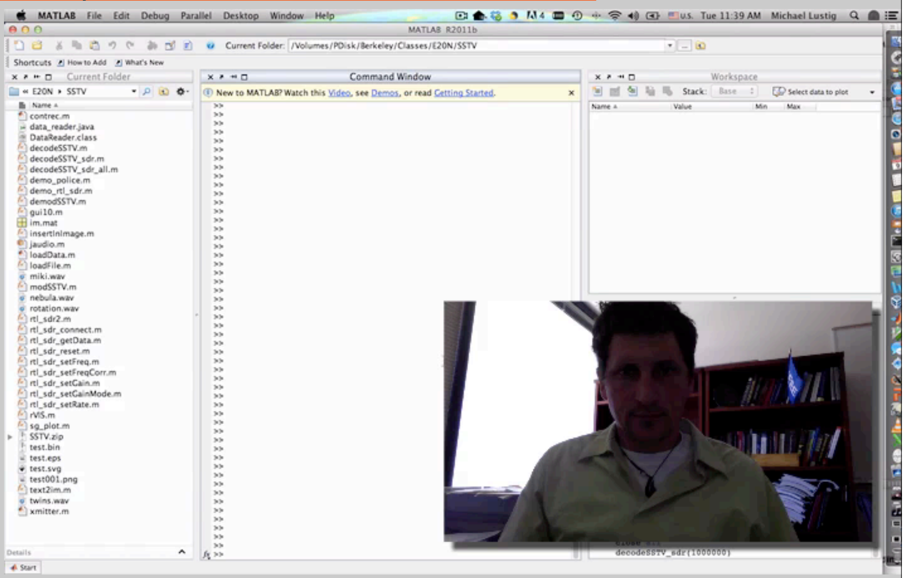
- Select a project by next Friday
  - Submit 2 paragraph project proposal on b-space
  - Includes Topic and the scope of the project
- Project Deliverables
  - Software
  - Demo
  - A few slides / Poster

Project Topics

- Default: SSTV Transceiver System
  - Implement a Xeiver for one of the ham SSTV protocols. For example Martin M1/ Scottie S1-4
  - Transmitter straightforward
  - Good receiver system makes all the difference



Example From last Year



A Lot about the receiver.....

More project ideas

- DTMF/Voice Controlled something
  - Message board
  - Answering system
  - Voice Mail
- Cross-band FM repeater chat room with a control channel
  - SDR receives large band
  - Transmits combined signals on another channel
  - Need to register or have a code to join... maybe?

Other Project Ideas

- Come up with a new SSTV Protocol
  - Analog or Digital
- Video Protocol
- Methods to overlay digital information over voice
- Digital Voice - Implement an algorithm or come up with your own

More Projects

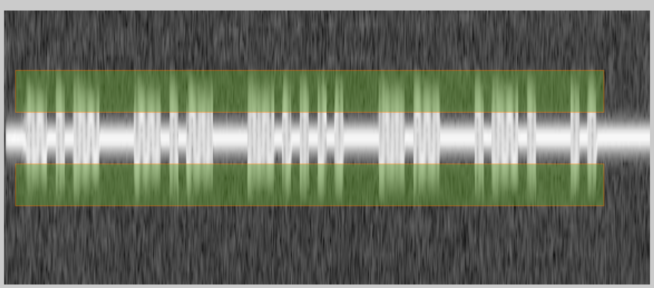
- Simple voice recognition
- Implementation / Invention of ANY useful ham protocol
- High-Quality audio by time-stretching or scrambling

More Challenging Projects

- Separation of two interfering FM signals for repeaters
- A fancy communication channel OFDM/ QAM over voice
- Phased Array RTL-Receiver
  - Passive Radar
  - Direction detection
- Weak signal Communication with FM radios and SDR

Weak Signal

- Can be extremely low-rate
  - Telemetry
  - Bounce
  - Use AM receive with FM transmitters



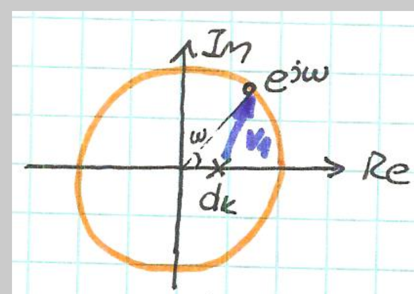
Magnitude Response

Magnitude of products is product of magnitudes

$$|H(e^{j\omega})| = |\frac{b_0}{a_0}| \cdot \frac{\prod_{k=0}^{M} |1 - c_k e^{-j\omega}|}{\prod_{k=0}^{N} |1 - d_k e^{-j\omega}|}$$

Consider one of the poles:

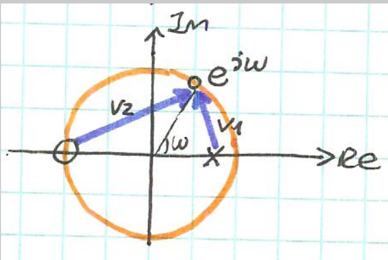
$$|1 - d_k e^{-j\omega}| = |e^{+j\omega} - d_k| \;\; = |v_1|$$

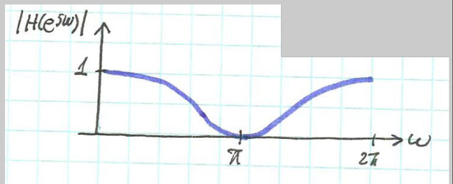


Magnitude Response Example

Example: $$H(z) = 0.05\frac{1+z^{-1}}{1-0.9z^{-1}}$$

$$|H(z)| = 0.05\frac{|v_2|}{|v_1|}$$





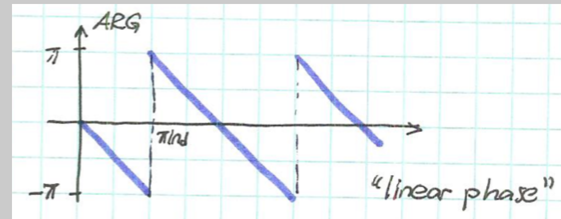
Phase response

Example: $H(e^{j\omega}) = e^{j\omega n_d} \quad \leftrightarrow \quad h[n] = \delta[n - n_d]$

$$|H(e^{j\omega})| = 1$$

$$\arg[H(e^{j\omega})] = -\omega n_d$$

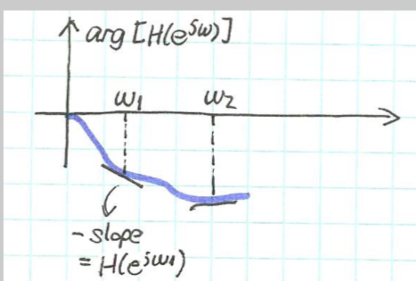
ARG is the wrapped phase
arg is the unwrapped phase



Group delay

To characterize general phase response, look at the group delay:

$$\text{grd}[H(e^{j\omega})] = -\frac{d}{d\omega}\{\arg[H(e^{j\omega})]\}$$

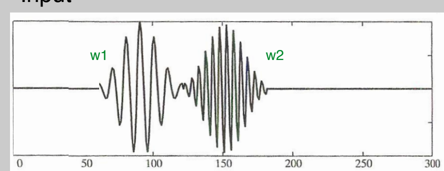


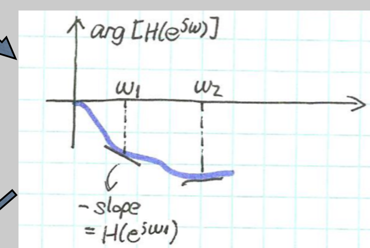
For linear phase system, the group delay is n_d

Group delay

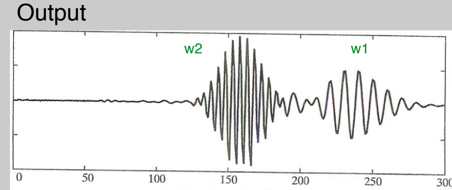
$$\text{grd}[H(e^{j\omega})] = -\frac{d}{d\omega}\{\arg[H(e^{j\omega})]\}$$

Input





Output



For narrowband signals, phase response looks like a linear phase

Group delay math

$$H(z) = \frac{b_0}{a_0} \frac{\prod_{k=1}^{M} (1 - c_k z^{-1})}{\prod_{k=1}^{N} (1 - d_k z^{-1})}$$

arg of products is sum of args

$$\arg[H(e^{j\omega})] = -\sum_{k=1}^{N} \arg[1 - d_k e^{-j\omega}] + \sum_{k=1}^{M} \arg[1 - c_k e^{-j\omega}]$$

$$\text{grd}[H(e^{j\omega})] = -\sum_{k=1}^{N} \text{grd}[1 - d_k e^{-j\omega}] + \sum_{k=1}^{M} \text{grd}[1 - c_k e^{-j\omega}]$$

Group delay math

$$\text{grd}[H(e^{j\omega})] = -\sum_{k=1}^{N} \text{grd}[1 - d_k e^{-j\omega}] + \sum_{k=1}^{M} \text{grd}[1 - c_k e^{-j\omega}]$$

Look at each factor:

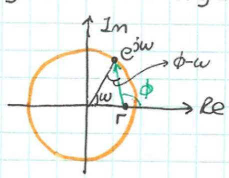
$$\arg[1 - \underbrace{re^{j\theta}}_{c_k \text{ or } d_k} e^{-j\omega}] = \tan^{-1}\left(\frac{r\sin(\omega-\theta)}{1 - r\cos(\omega-\theta)}\right)$$

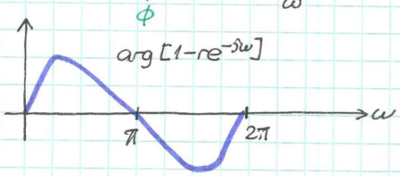
$$\text{grd}[1 - re^{j\theta} e^{-j\omega}] = \frac{r^2 - r\cos(\omega-\theta)}{|1 - re^{j\theta}e^{-j\omega}|^2}$$

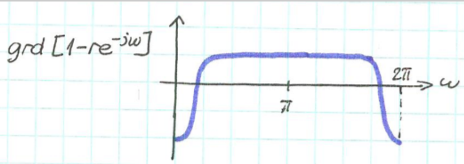
Look at a zero lying on the real axis

Geometric Interpretation (for $\theta = 0$)

$$\arg[1 - re^{-j\omega}] = \arg[(e^{j\omega} - r)e^{-j\omega}] = \underbrace{\arg[e^{j\omega} - r]}_{\phi} - \underbrace{\arg[e^{j\omega}]}_{\omega}$$







$\theta \neq 0 \Rightarrow$ shift to the right by θ