MIT IAP 2011 Laptop Based Radar: Block Diagram, Schematics, Bill of Material, and Fabrication Instructions*

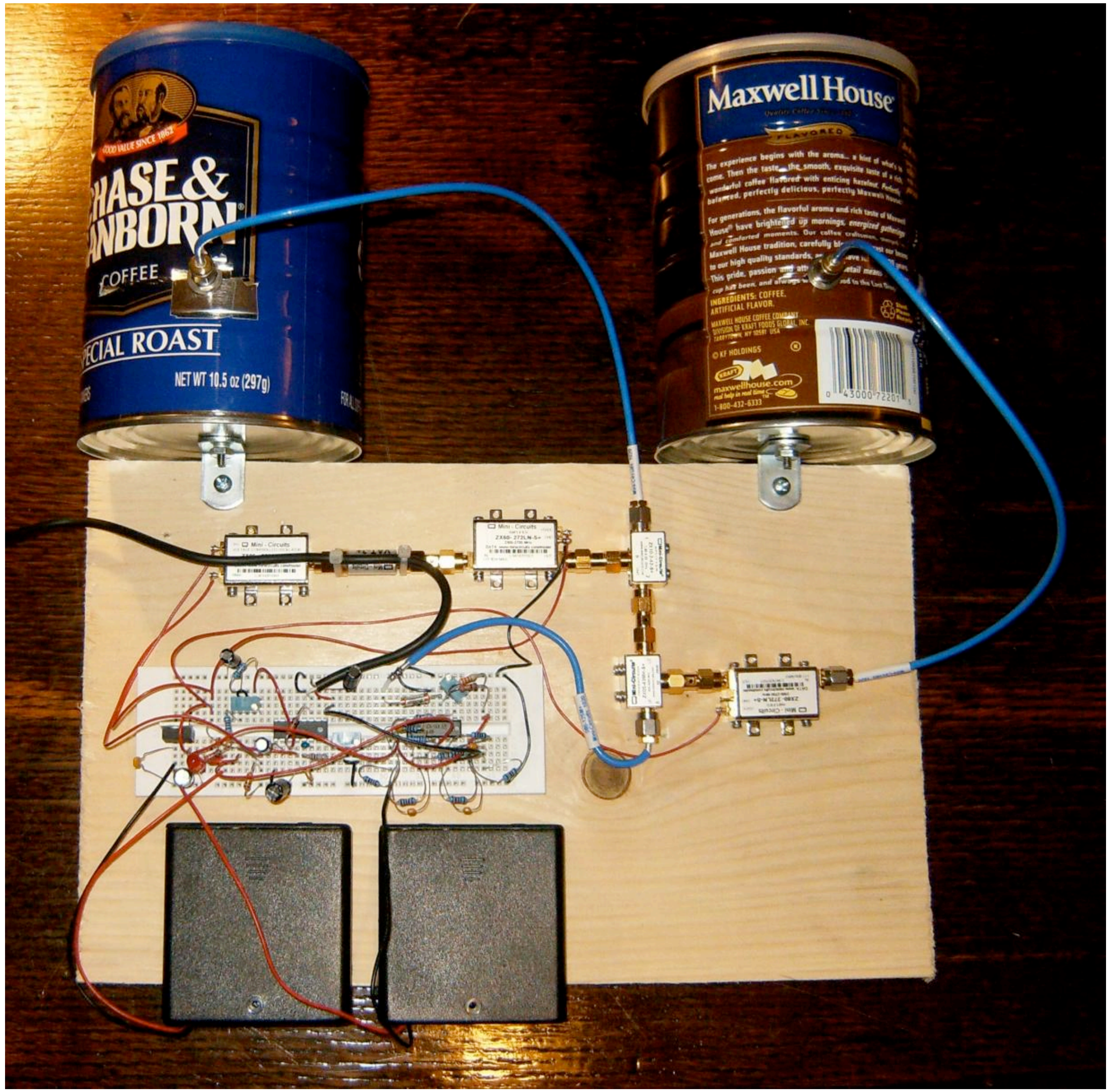
Presented at the 2011 MIT Independent Activities Period (IAP)

Gregory L. Charvat, PhD
MIT Lincoln Laboratory

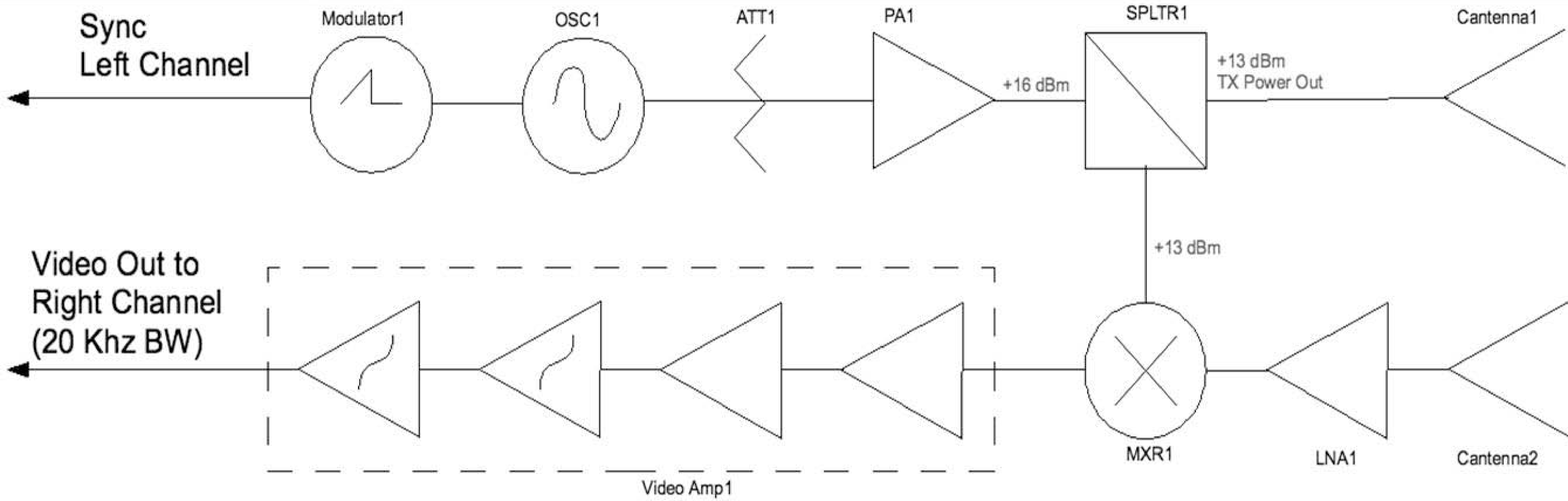
10-28 January 2011

*This work is sponsored by the Department of the Air Force under Air Force Contract #FA8721-05-C-0002. Opinions, interpretations, conclusions and recommendations are those of the authors and are not necessarily endorsed by the United States Government.

Fully Assembled Radar Kit



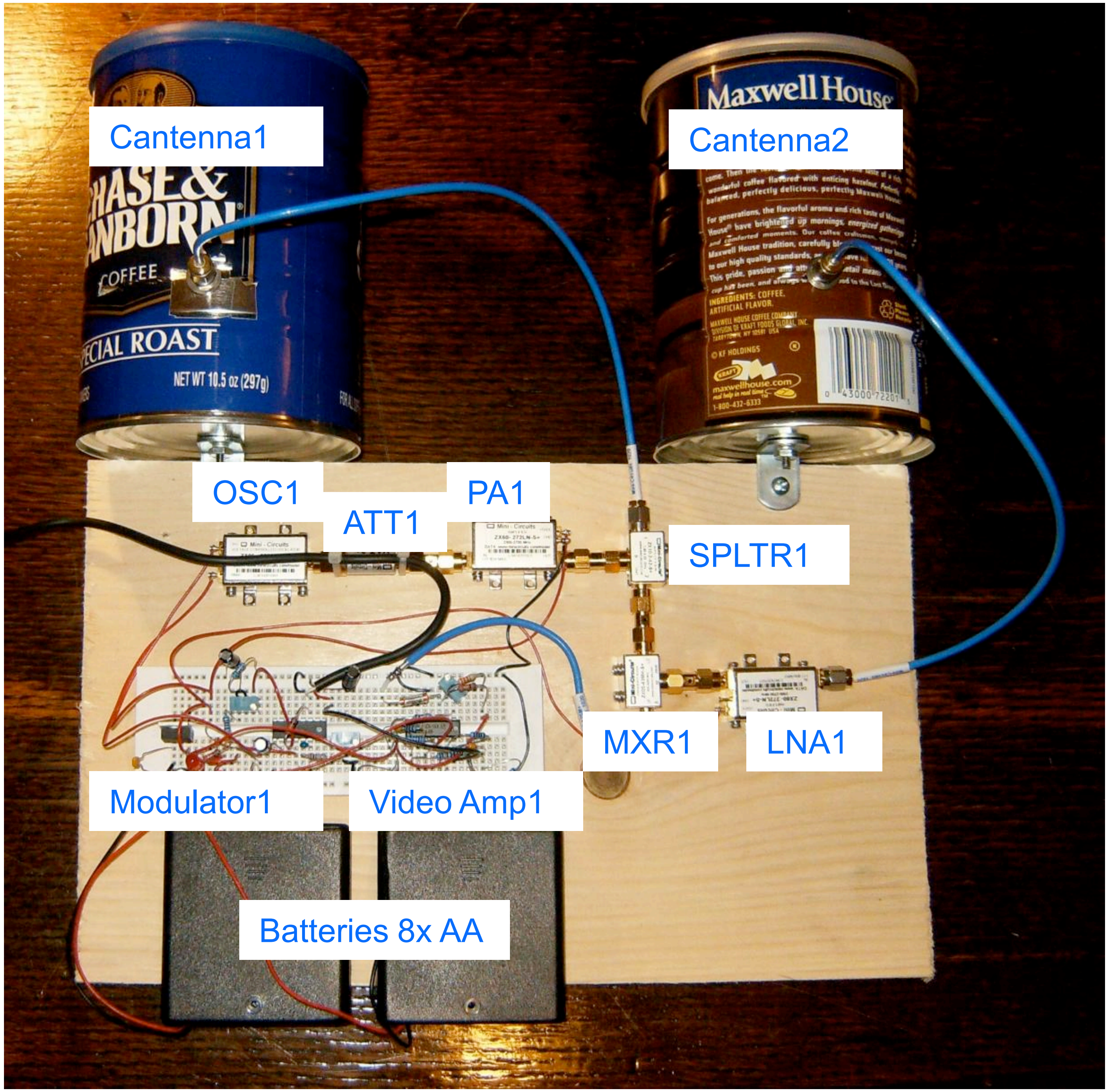
Block Diagram



- **FMCW**
- **Operates in ISM band of 2.4 GHz**
- **approximately 10 mW TX power**
- **Max range approximately 1 km for 10 dBsm**
- **Data acquisition/signal processing in MATLAB**
  - **sound card digitizes sync pulse and de-chrip**

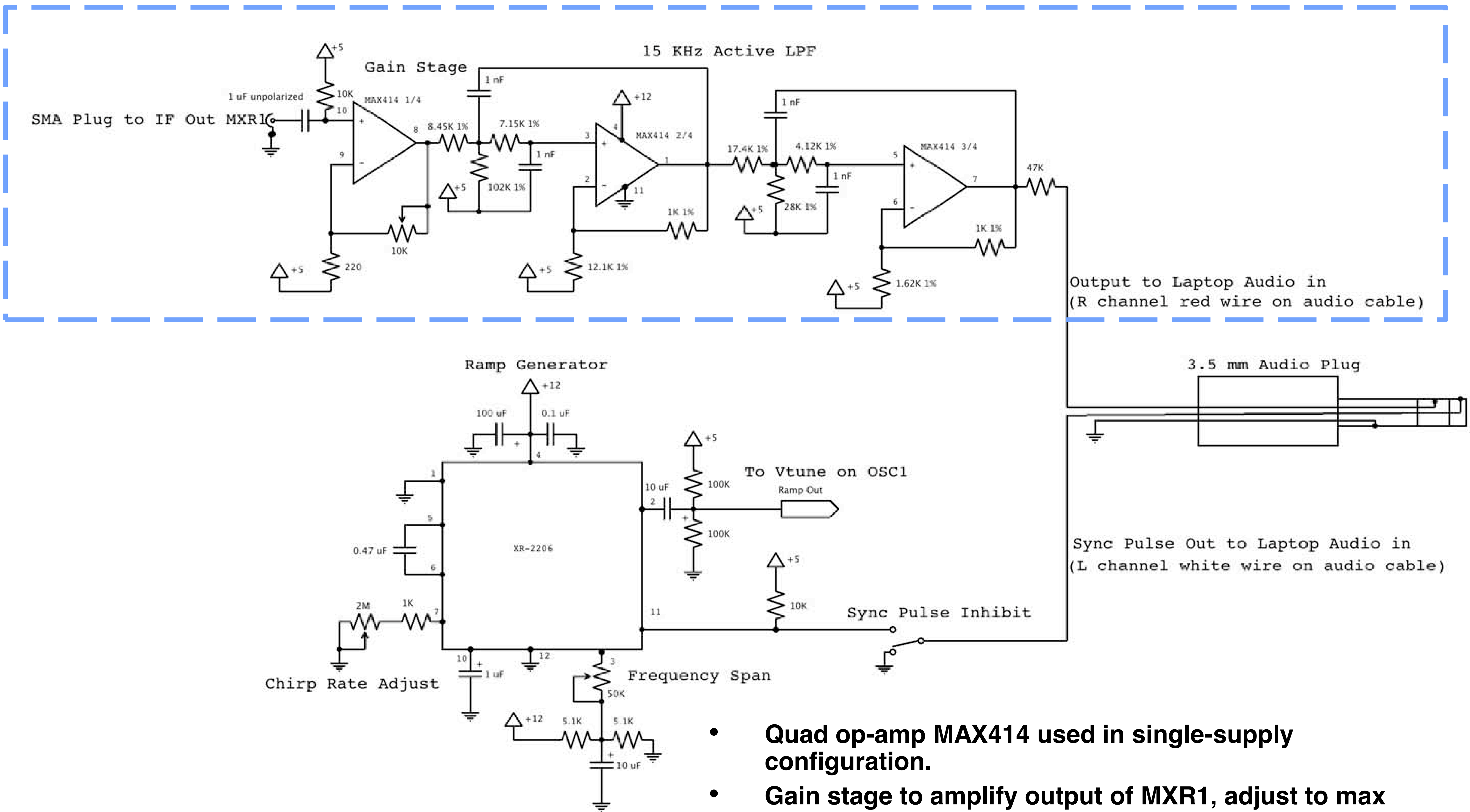
    Supporting FFT, 2-pulse canceller, SAR image

Callouts



Cantenna1
Cantenna2
OSC1
ATT1
PA1
SPLTR1
MXR1
LNA1
Modulator1
Video Amp1
Batteries 8x AA

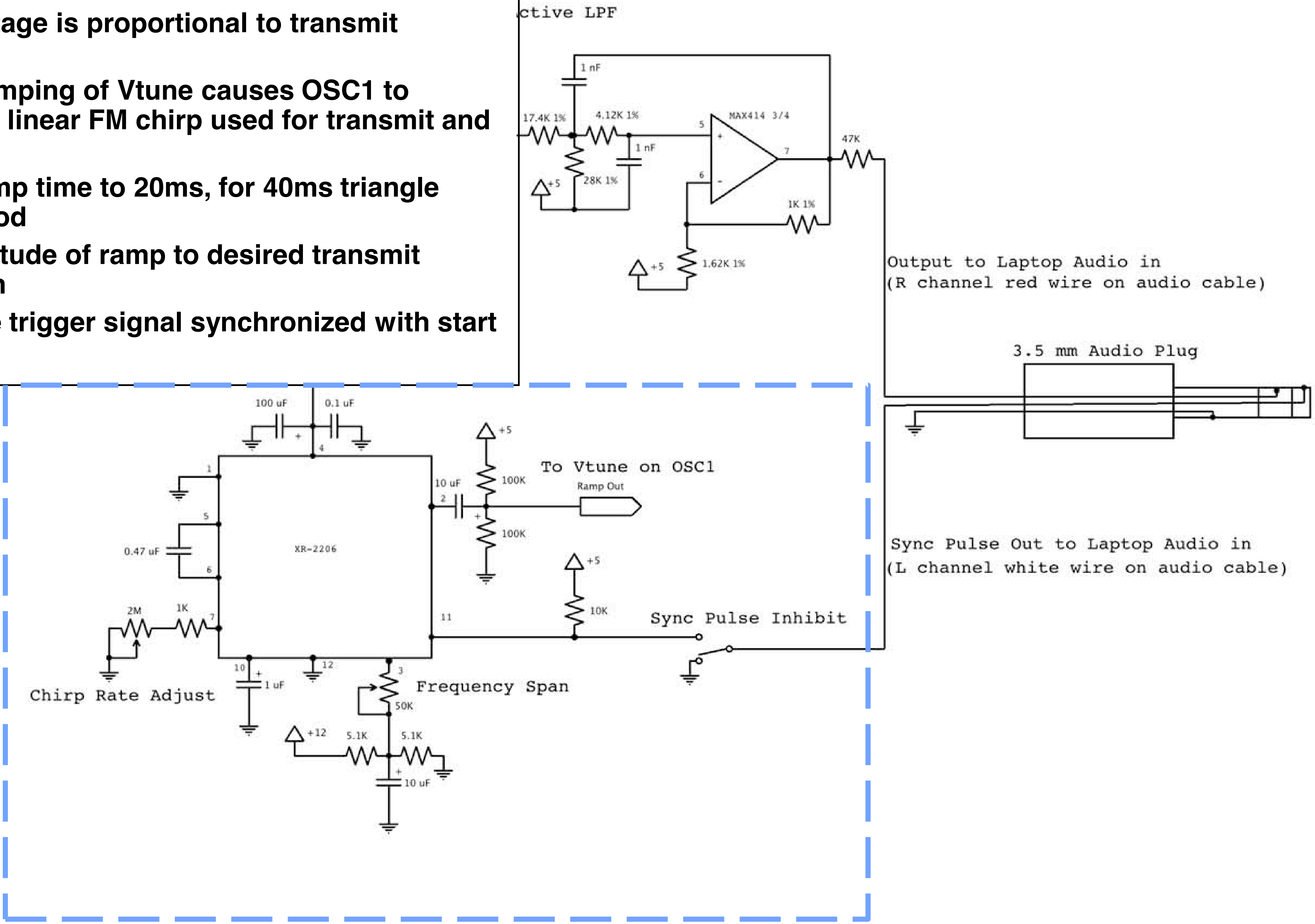
Video Amp1



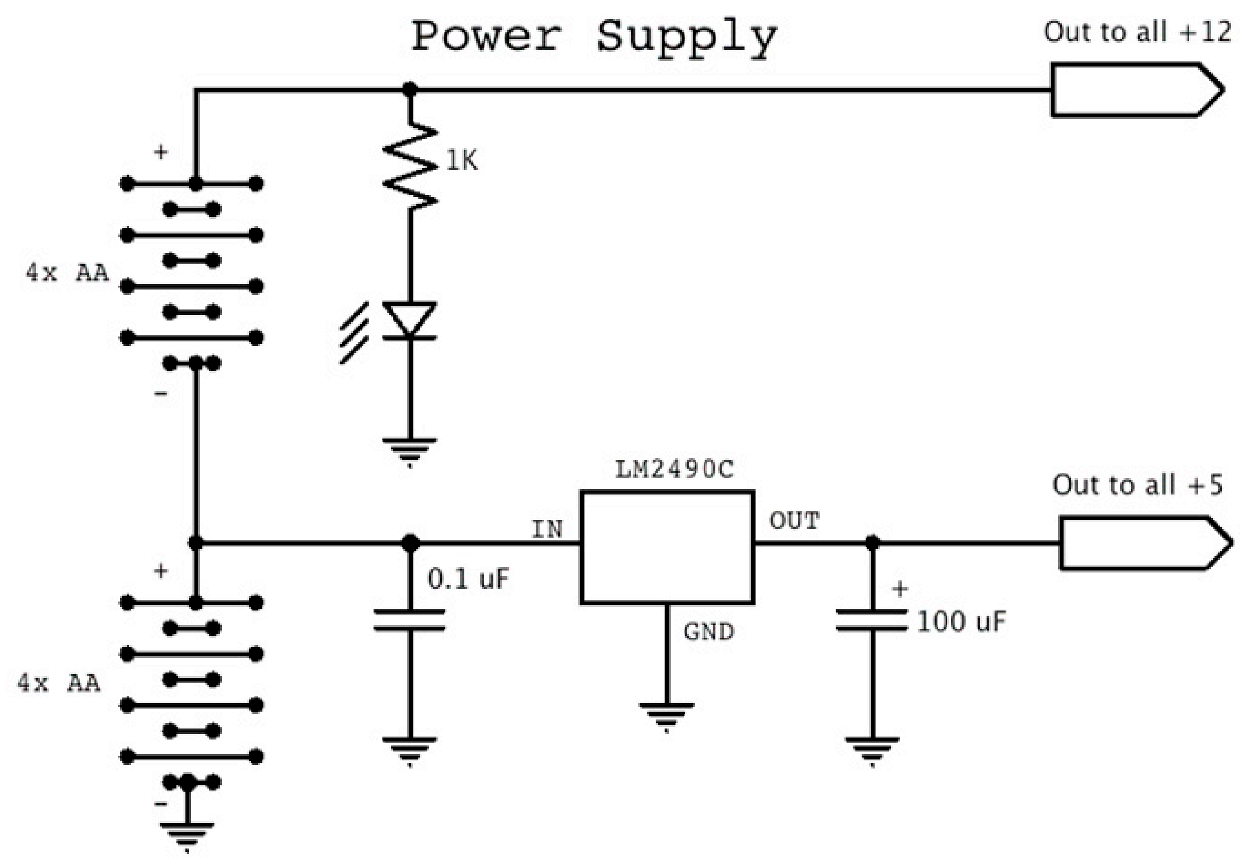
- Quad op-amp MAX414 used in single-supply configuration.
- Gain stage to amplify output of MXR1, adjust to max before op-amp clips during FMCW mode
- Followed by 15 KHz 4th order LPF
  - prevents aliasing of PC’s input audio port

Modulator1

- Produces linear ramp which modulates OSC1 Vtune input pin
  - Vtune voltage is proportional to transmit frequency
  - Linear Ramping of Vtune causes OSC1 to produce a linear FM chirp used for transmit and receive
  - Set up-ramp time to 20ms, for 40ms triangle wave period
  - Set magnitude of ramp to desired transmit bandwidth
- Produces receive trigger signal synchronized with start of linear ramp



Power Supply & Battery Pack



- 2 battery packs, 4x AA’s in each producing 6V and 12V
- 5 VDC low-dropout regulator is fed by 6V from battery packs
  - powers RF components and provides reference voltage for analog circuits which enables single supply operation
- 12 VDC powers analog circuits including Modulator1 and Video Amp1

Doppler Experiment using the MIT IAP 2011 Laptop Based Radar*

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Gregory L. Charvat, PhD
MIT Lincoln Laboratory

14 January 2011

This mode:
Constant TX frequency
(Doppler only)

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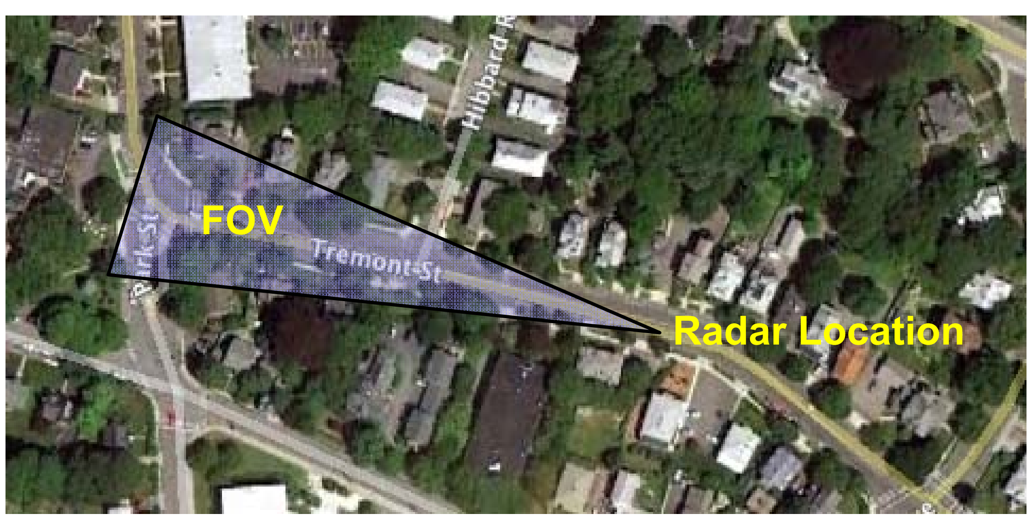
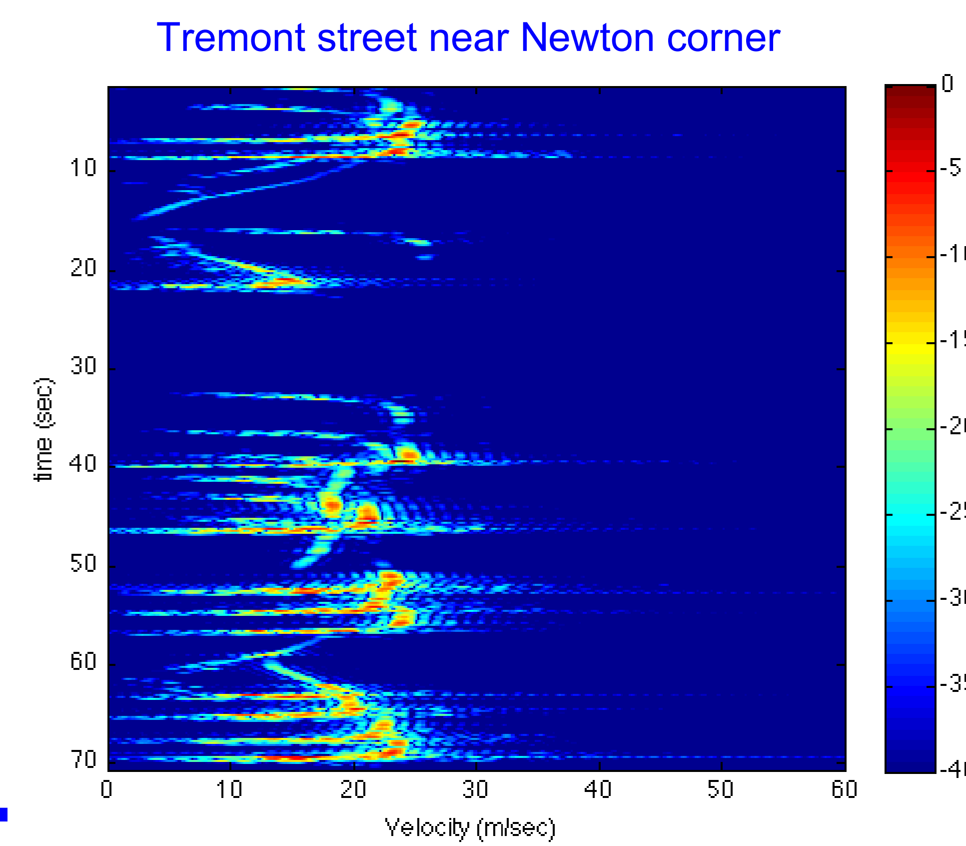
Radar Kit: Doppler vs. Time

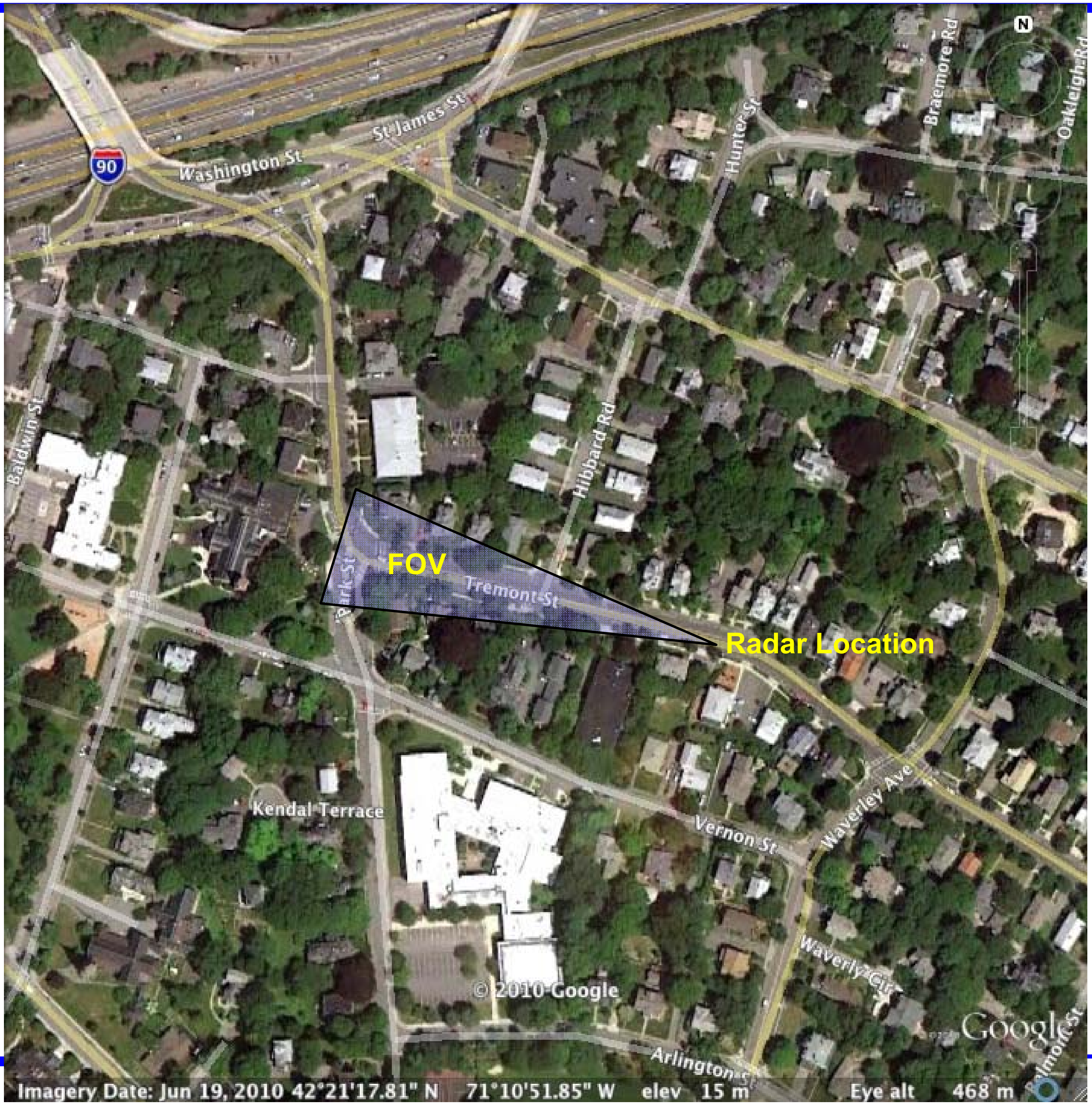
1. **Bias Vtune to CW**
2. **Connect to audio input of laptop**
3. **Open 'Sync Pulse Inhibit' switch**
4. **Deploy radar near fast moving targets**
5. **Record .wav file of input audio**
6. **Process using read_data_doppler.m**
   - **parses .wav into 4410 sample blocks**
   - **plots the log magnitude of the IDFT of each block**

This mode:
Constant TX frequency
(Doppler only)

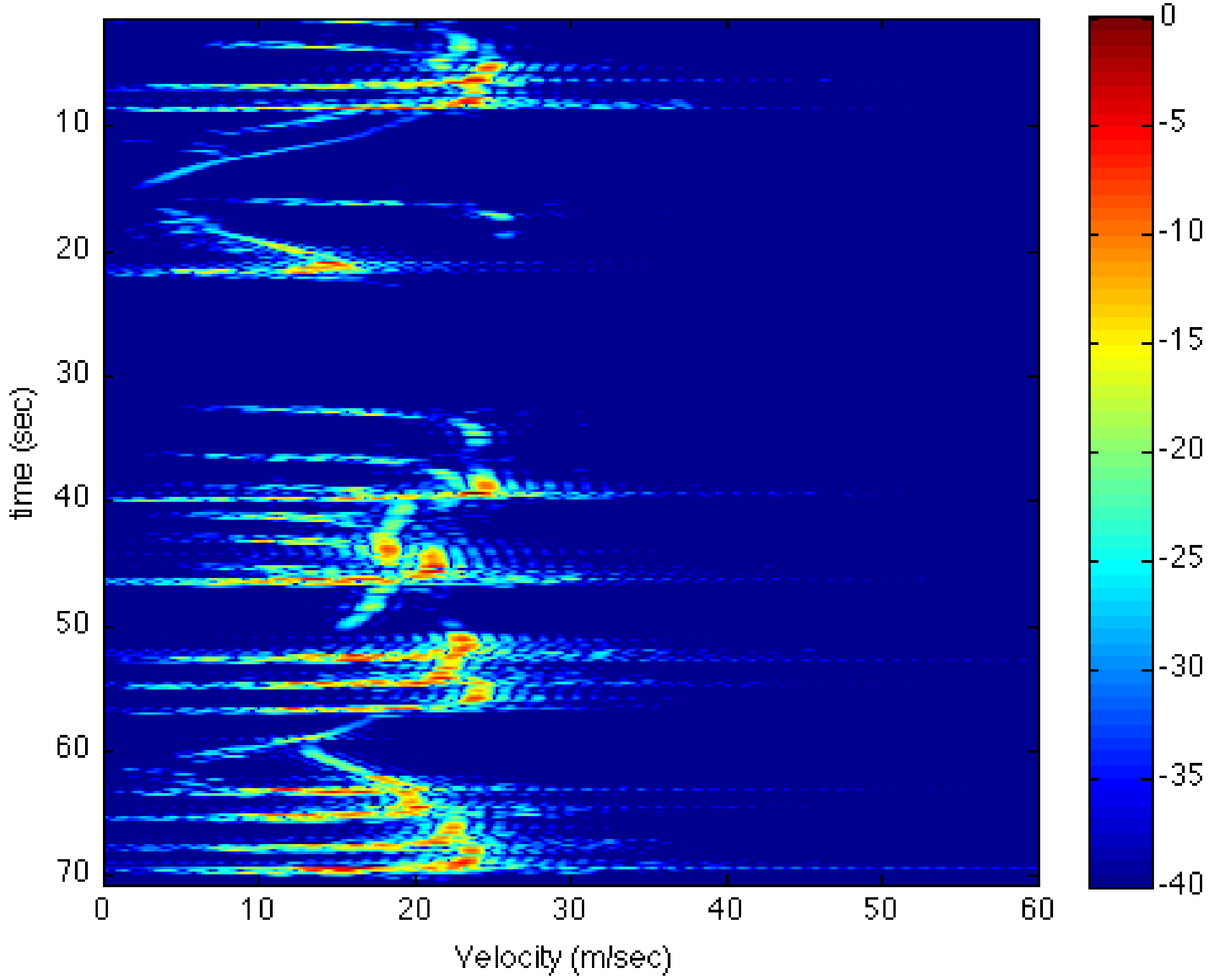




Example: Tremont Street off of Newton Corner



Example: Tremont Street off of Newton Corner



Ranging Experiment using the MIT IAP 2011 Laptop Based Radar*

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Gregory L. Charvat, PhD
MIT Lincoln Laboratory

This mode: Swept TX Frequency (Ranging)

17 January 2011

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Radar Transmissions and Pulse Compression

Range detection: revisited

$$\Delta R = \frac{c\tau}{2} = \frac{c}{2B}$$

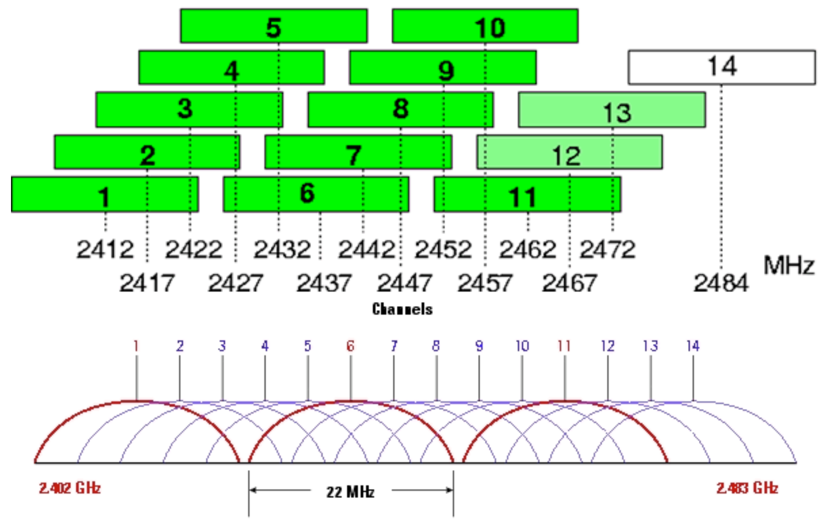
τ = Pulse length

B = Bandwidth

- **For high range resolution we want short pulse ⇔ large bandwidth**
- **For high SNR we want long pulse ⇔ small bandwidth**
- **Long pulse also uses a lot of the duty cycle, can't listen as long, affects maximum range**
- **The Goal of pulse compression is to increase the bandwidth (equivalent to increasing the range resolution) while retaining large pulse energy.**

Compression Is All Around You

http://www.air-stream.org.au/channel_802_11b



IEEE 802.11b WiFi standard

http://www.azizi.ca/gsm/modulation/index.html

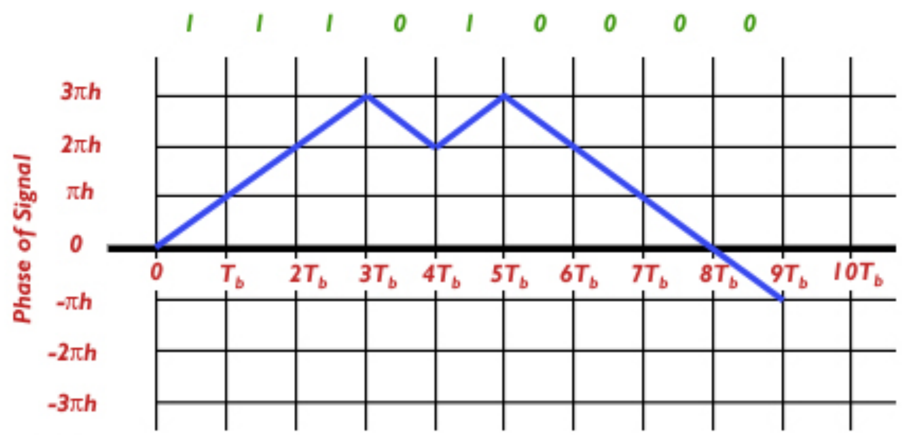


Figure 1

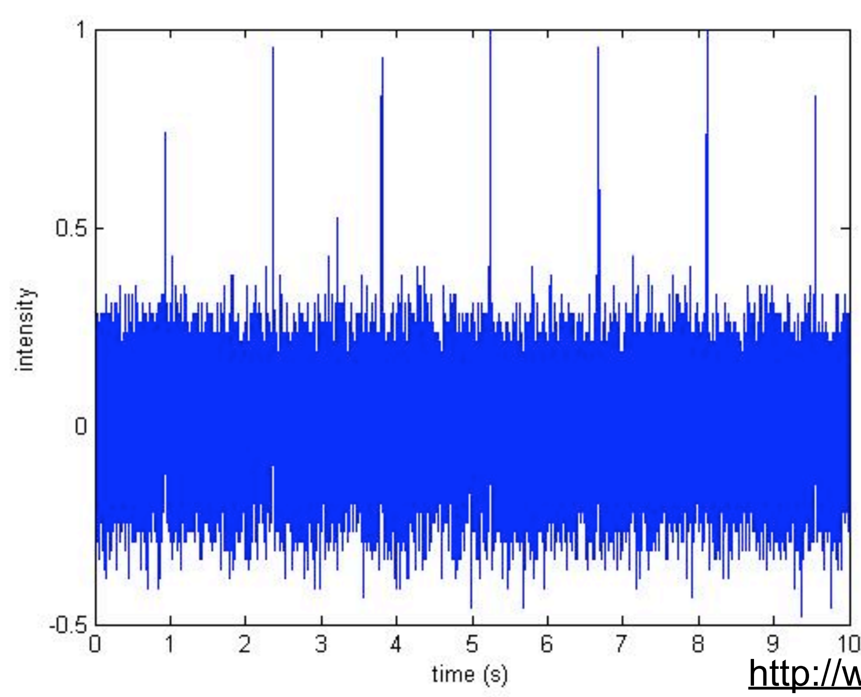
$$s(t) = \sqrt{\frac{2E_b}{T_b}}\cos(2\pi f_c t + \theta(t))$$

where

$$\theta(t) = \theta(0) + \frac{\pi h}{T_b} \quad \text{if a '1' was sent}$$

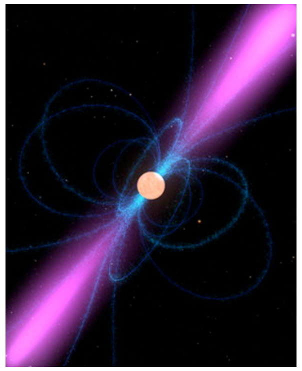
$$\theta(t) = \theta(0) - \frac{\pi h}{T_b} \quad \text{if a '0' was sent}$$

GSM mobile phone (Gaussian filtered Minimum Shift Keying)

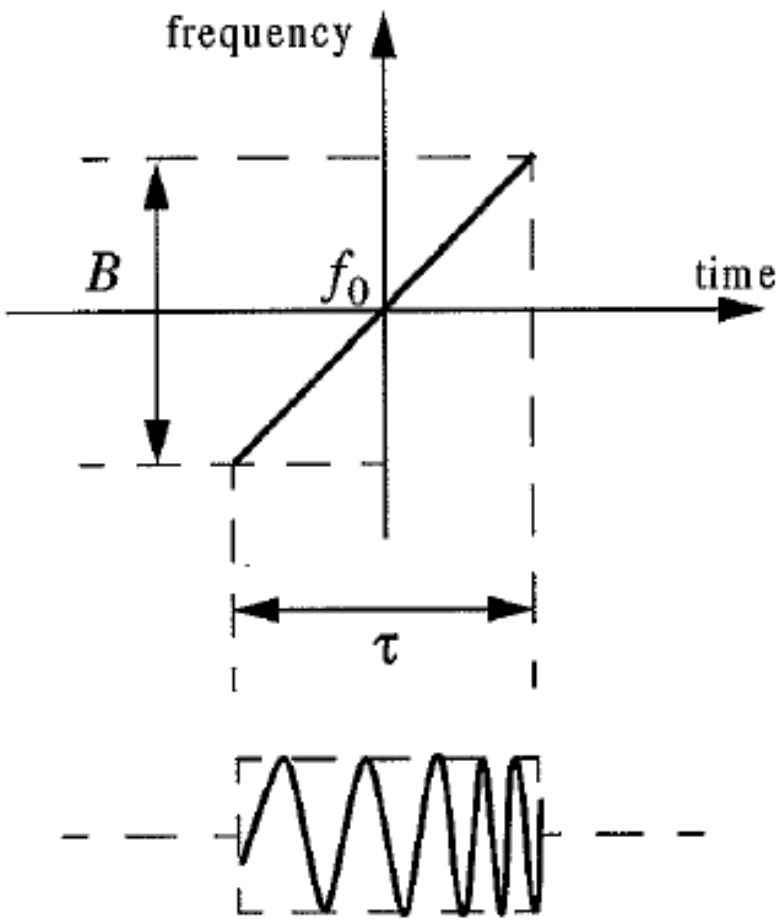


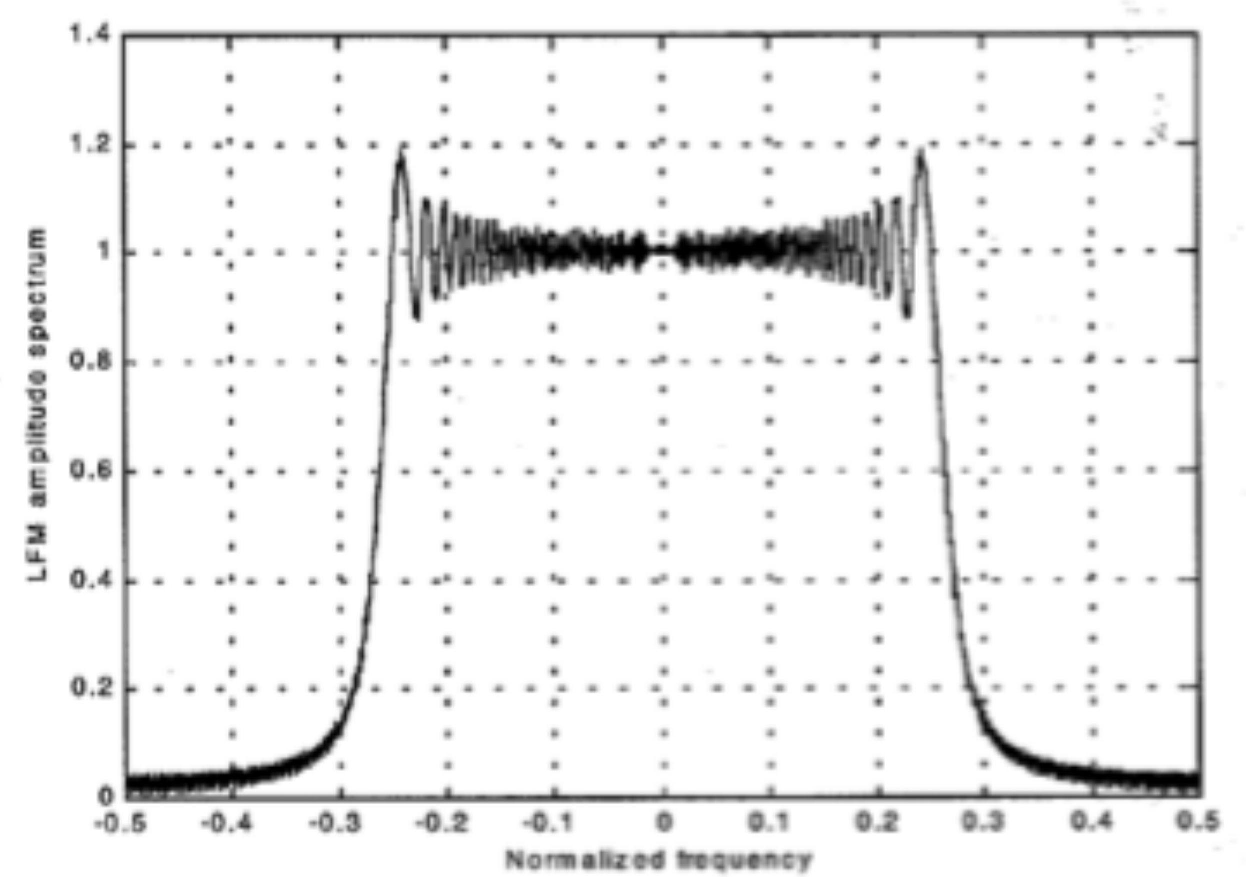
http://www.jb.man.ac.uk/~reatough/sounds.htm

Pulsar PSR B0959-54
1.668 GHz
Parkes 64m telescope
Australia
(note dispersion)



Linear Frequency Modulation (LFM or "Chirp")



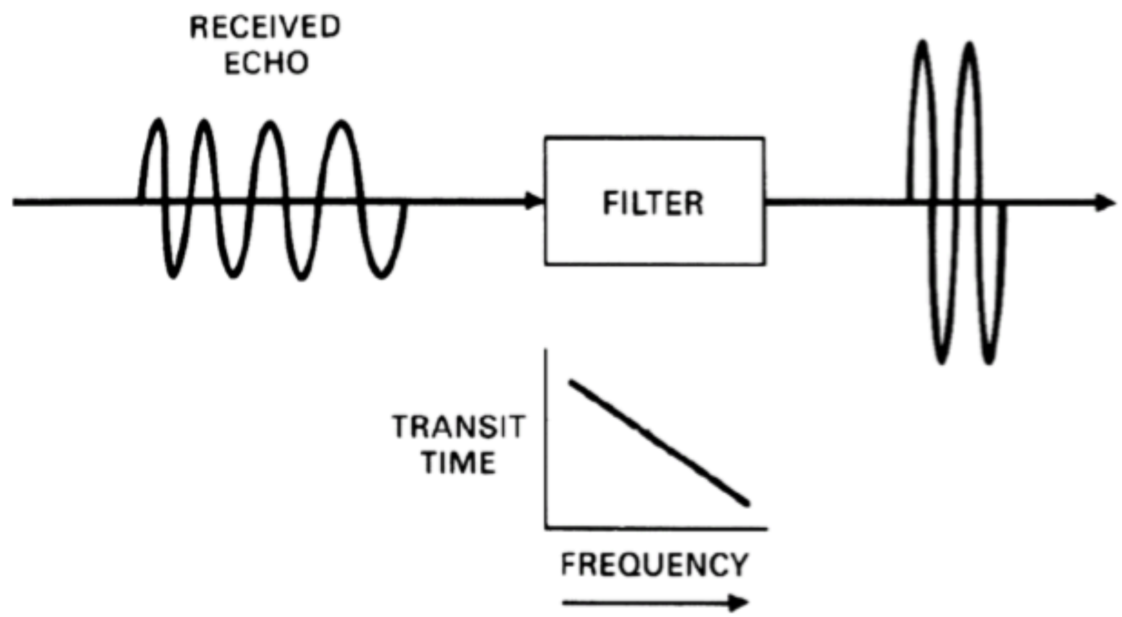


$$s_1(t) = e^{j2\pi f_0 t} s(t)$$

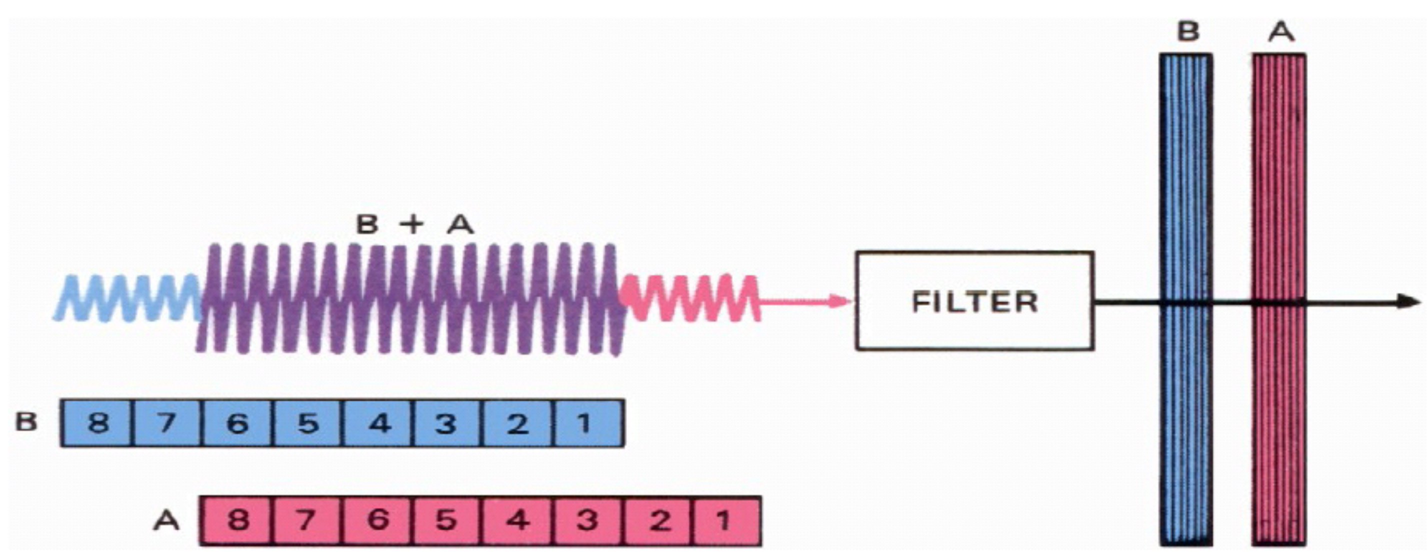
where

$$s(t) = Rect\left(\frac{t}{\tau}\right)e^{j\pi\mu t^2}$$

Matched filter detection of a chirp



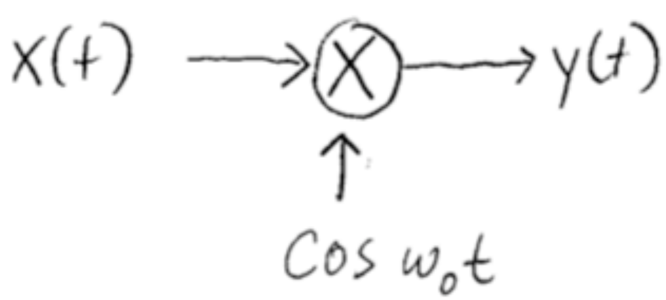
Since trailing portions of echo take less time to pass through filter, successive portions tend to bunch up: Amplitude of pulse is increased and width is decreased.



Echoes from closely spaced targets, A and B, are merged but, because of coding, separate in output of filter.

Aside: Not All Systems are LTI

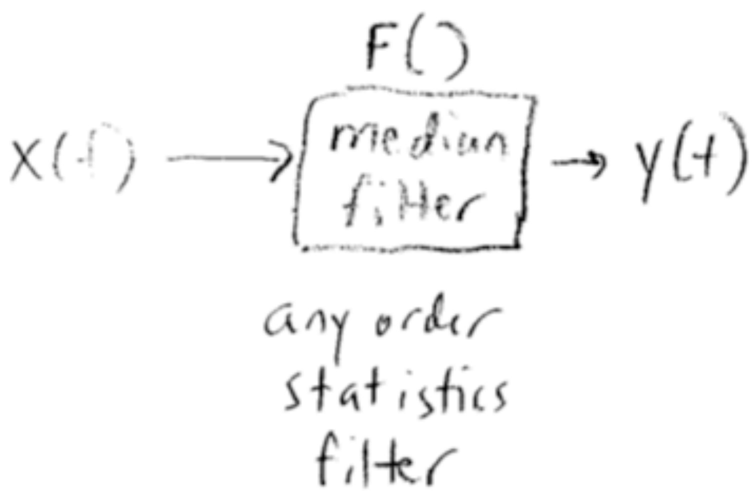
Not time invariant, but linear: Frequency mixing (Heterodyne)



$$y_1(t) = x(t)\cos(\omega_0 t)$$

$$t \rightarrow t - t_D$$

$$y_2(t) = x(t - t_D)\cos(\omega_0 t)$$



$$F(x_1(t)) + F(x_2(t)) \neq F(x_1(t) + x_2(t))$$

Not time invariant, nonlinear: Median filtering

Common systems!

LFM Decoded Waveform

τ = pulse duration B = waveform bandwidth :

$$x(t) = A \cos\left(\pi \frac{B}{\tau} t^2\right) \quad -\frac{\tau}{2} \leq t \leq \frac{\tau}{2} \quad \text{Baseband}$$

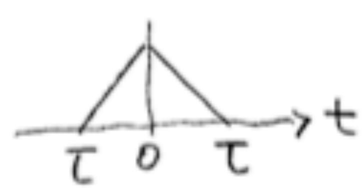
RF transmitted :

$$x_{RF}(t) = A \cos\left(2\pi f_{TX} t + \pi \frac{B}{\tau} t^2\right) \quad -\frac{\tau}{2} \leq t \leq \frac{\tau}{2}$$

After decoding, compressed response :

$$y(t) = \left(1 - \frac{|t|}{\tau}\right) \times \left(\frac{\sin A}{A}\right) \qquad A = \left(1 - \frac{|t|}{\tau}\right) \pi B t$$

triangle × sinc



Time-bandwidth product

LFM Baseband Waveform

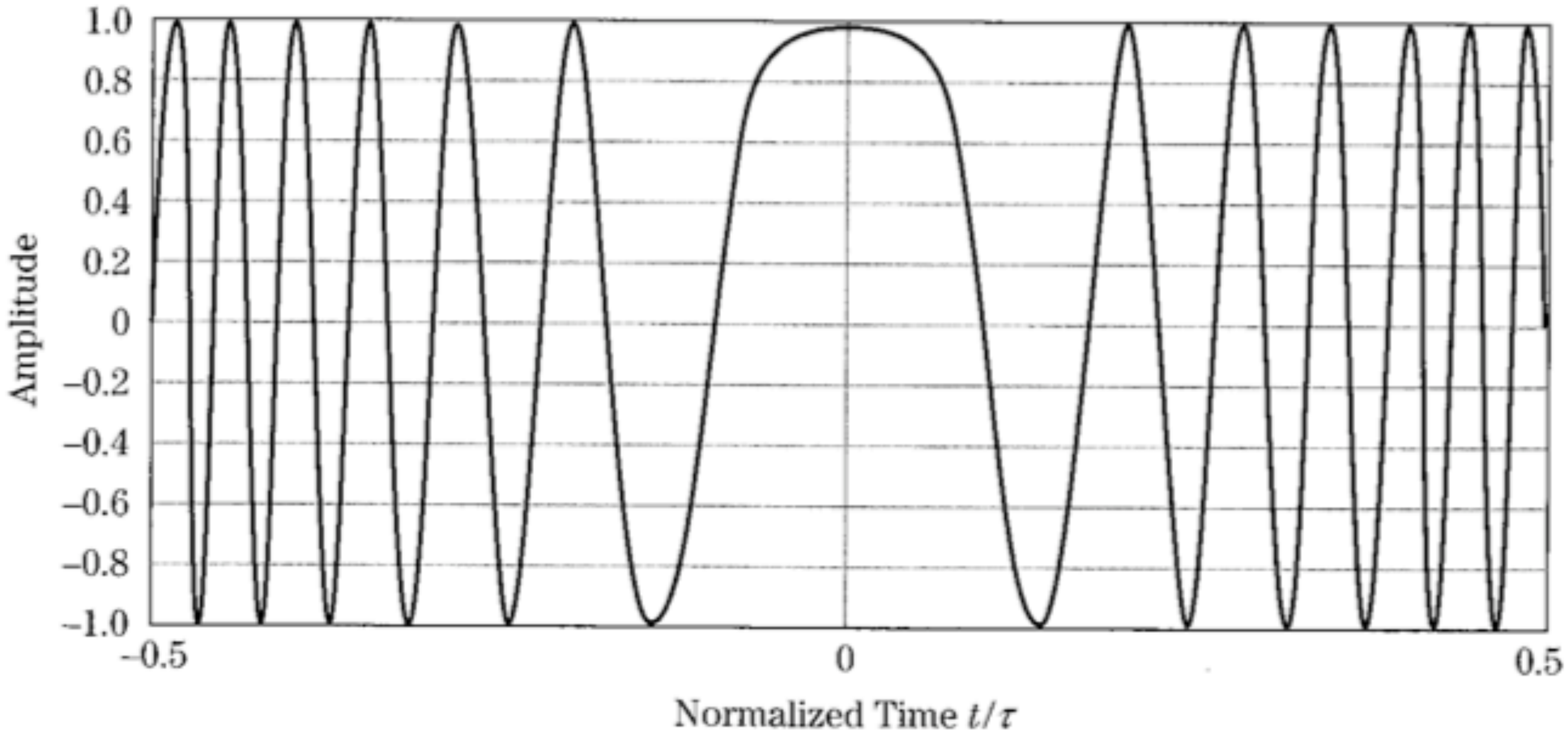
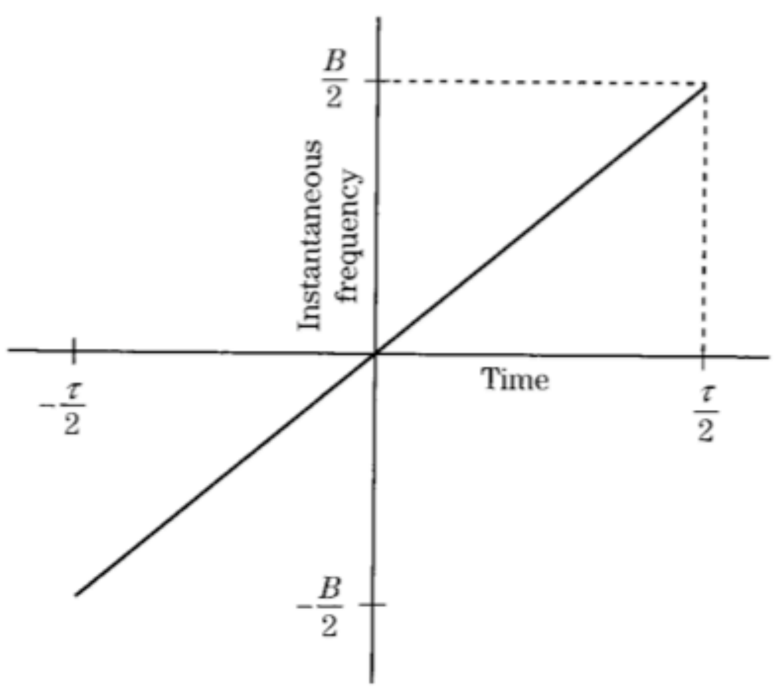


FIGURE 20-7 Time-domain response, within the pulse, of a linear frequency modulated (LFM) waveform with a time-bandwidth product equal to 50.

FIGURE 20-8 Instantaneous frequency versus time for an LFM waveform.



LFM Baseband Waveform

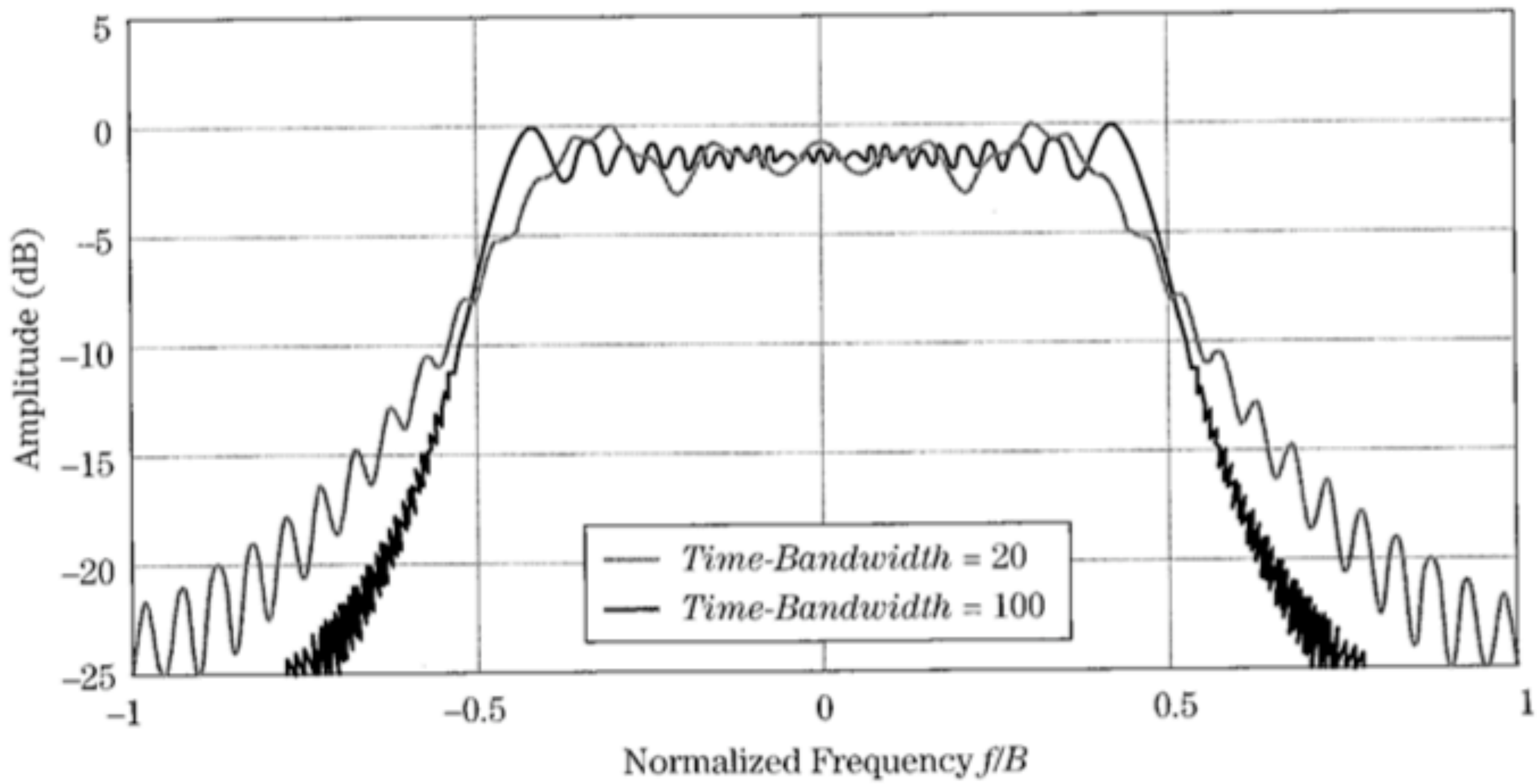


FIGURE 20-9 Comparison of the spectra of LFM waveforms with time-bandwidth products of 20 (light curve) and 100 (dark curve).

LFM Range Resolution

For $t \ll \tau$,

$$A = \left(1 - \frac{|t|}{\tau}\right)\pi B t = \pi B t - \underbrace{\frac{\pi B t^2}{\tau}}_{\text{small}}$$

looks like a sinc function,
with first lobe null
when

$$\pi B t \approx \pi$$

or $\quad Bt \approx 1 \qquad \boxed{t \approx \pm \frac{1}{B}} \qquad (\text{if } B\tau > 10)$

Rayleigh resolution:

$$\boxed{\delta R = \frac{c}{2B}}$$

For exercise data,

$$\left.\begin{aligned} \tau &= 20 \cdot 10^{-3} \text{ sec} \\ B &= 330 \cdot 10^{6} \text{ Hz} \end{aligned}\right\} \quad \underline{B\tau = 6.6 \cdot 10^{6}}$$

LFM Range Resolution: Decoded Waveform

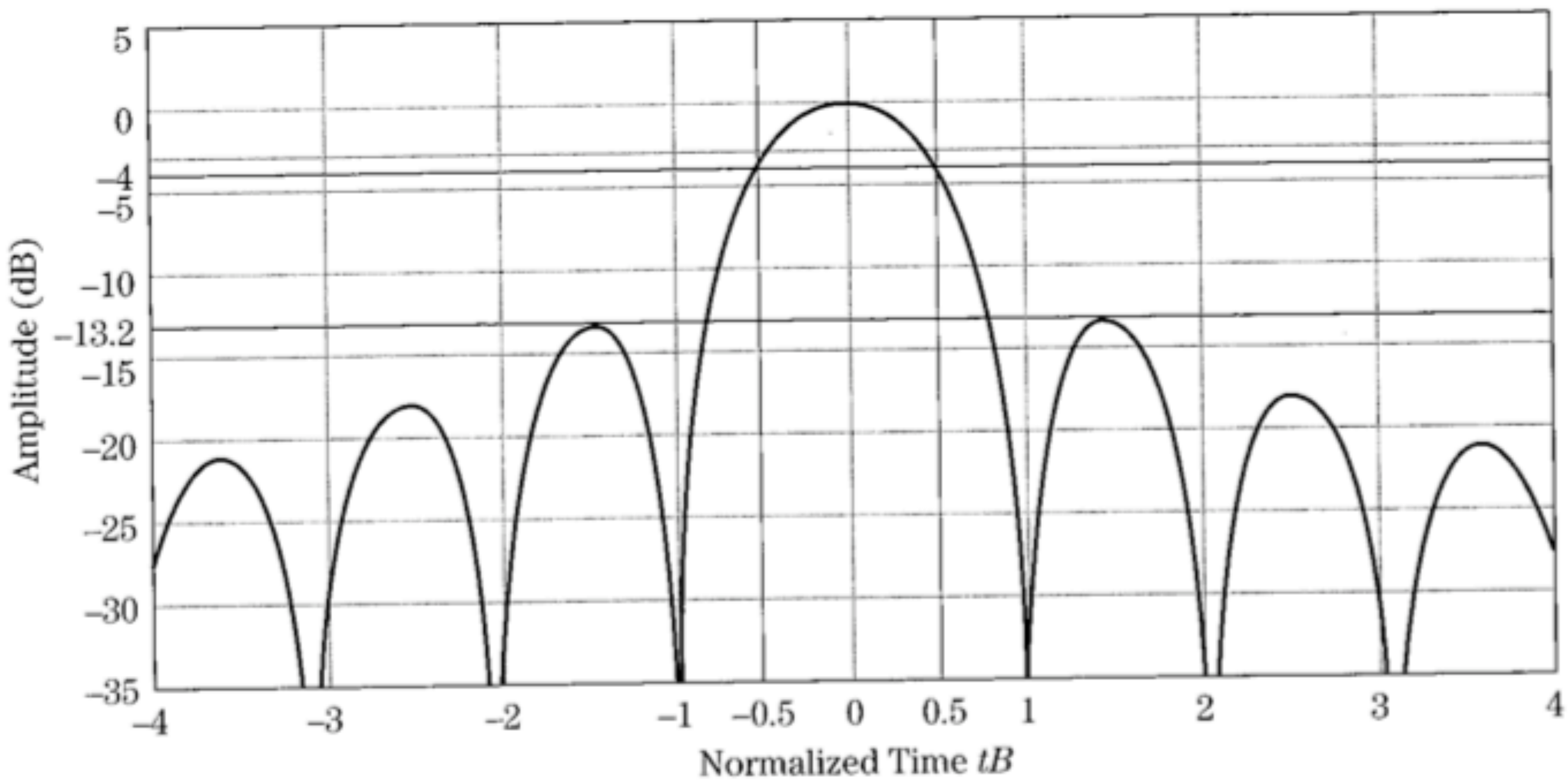


FIGURE 20-11 Mainlobe and first 3 sidelobes for the LFM waveform match filtered response with a time-bandwidth product equal to 100.

LFM Ambiguity Function

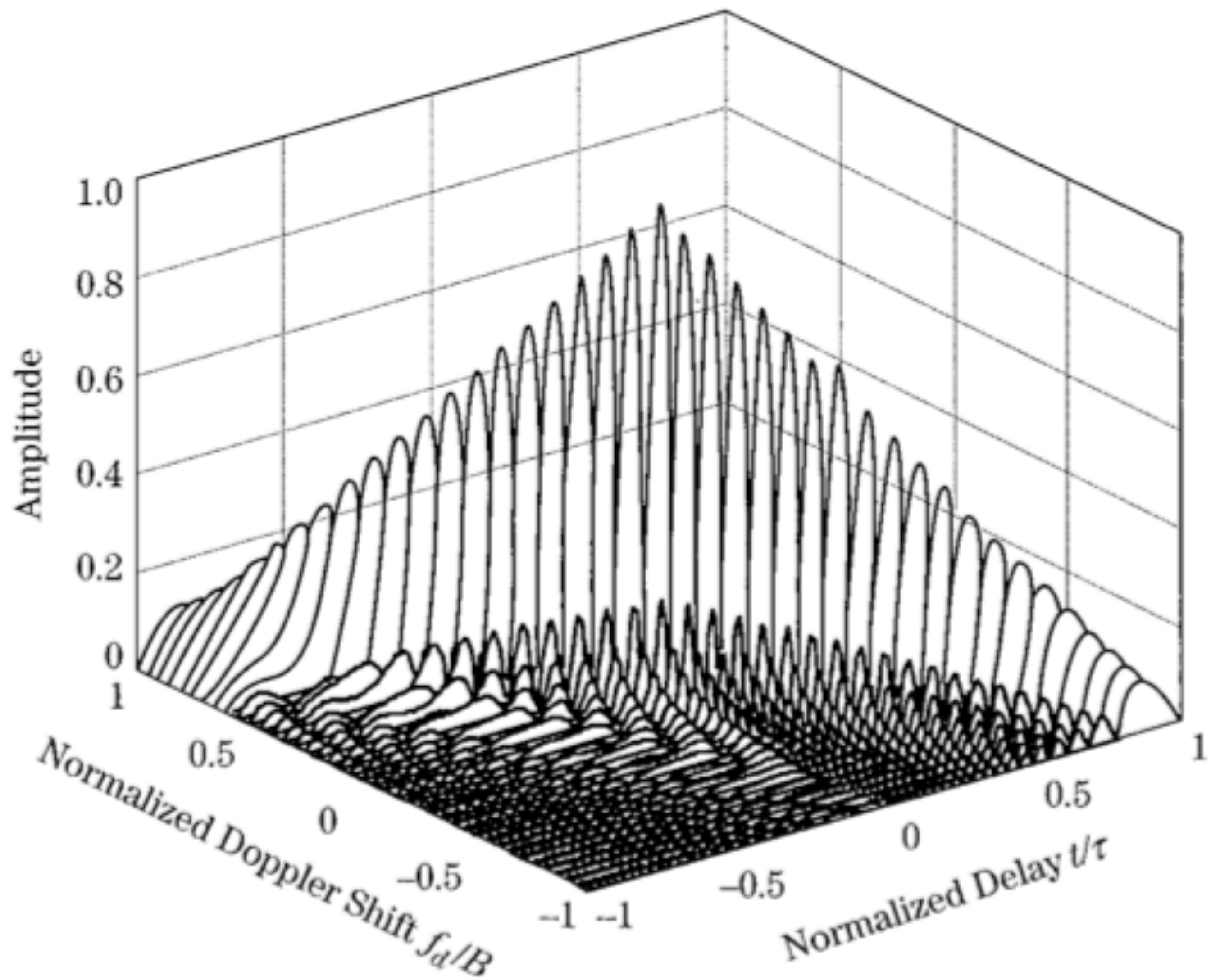


FIGURE 20-16 The ambiguity surface for an LFM waveform with $\tau B = 20$.

LFM Doppler Tolerance: Range Errors

FIGURE 20-17 Time shift in the peak of an LFM waveform's match filtered response as a function of Doppler shift.

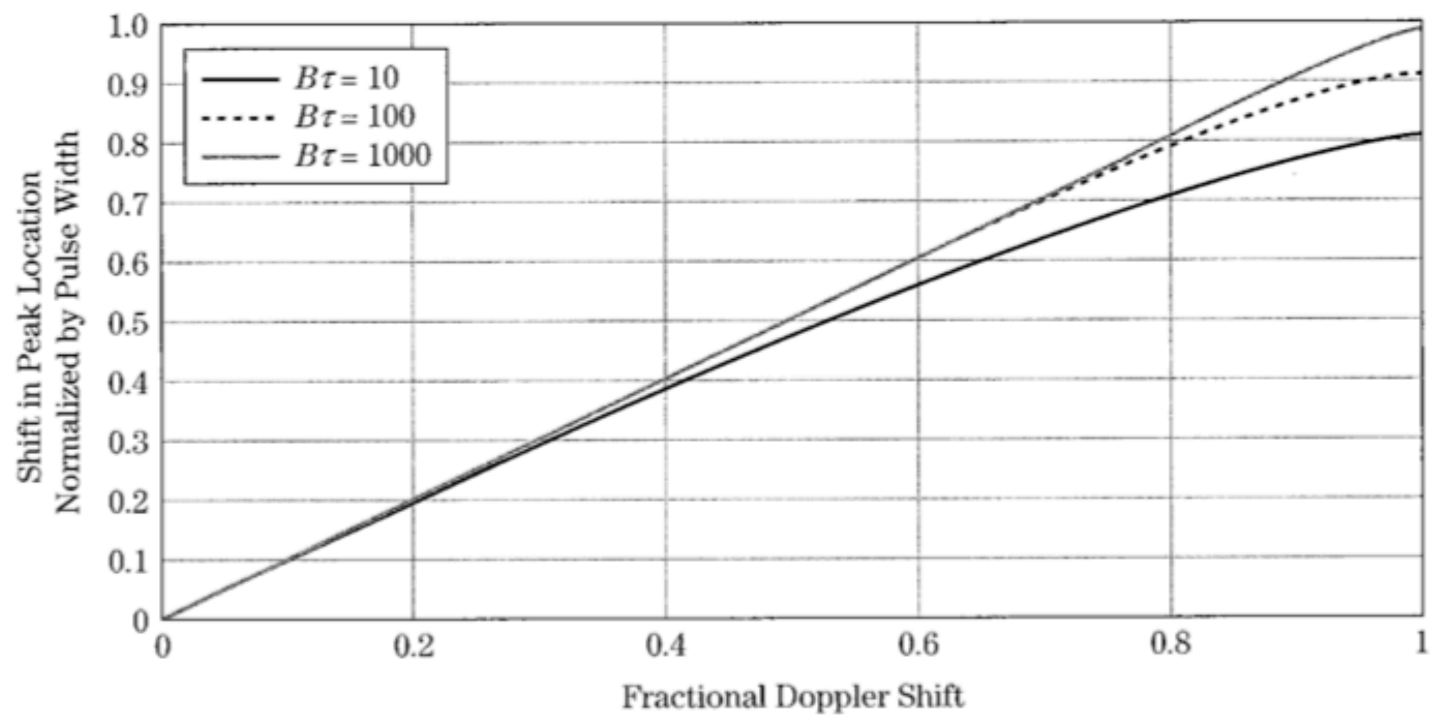
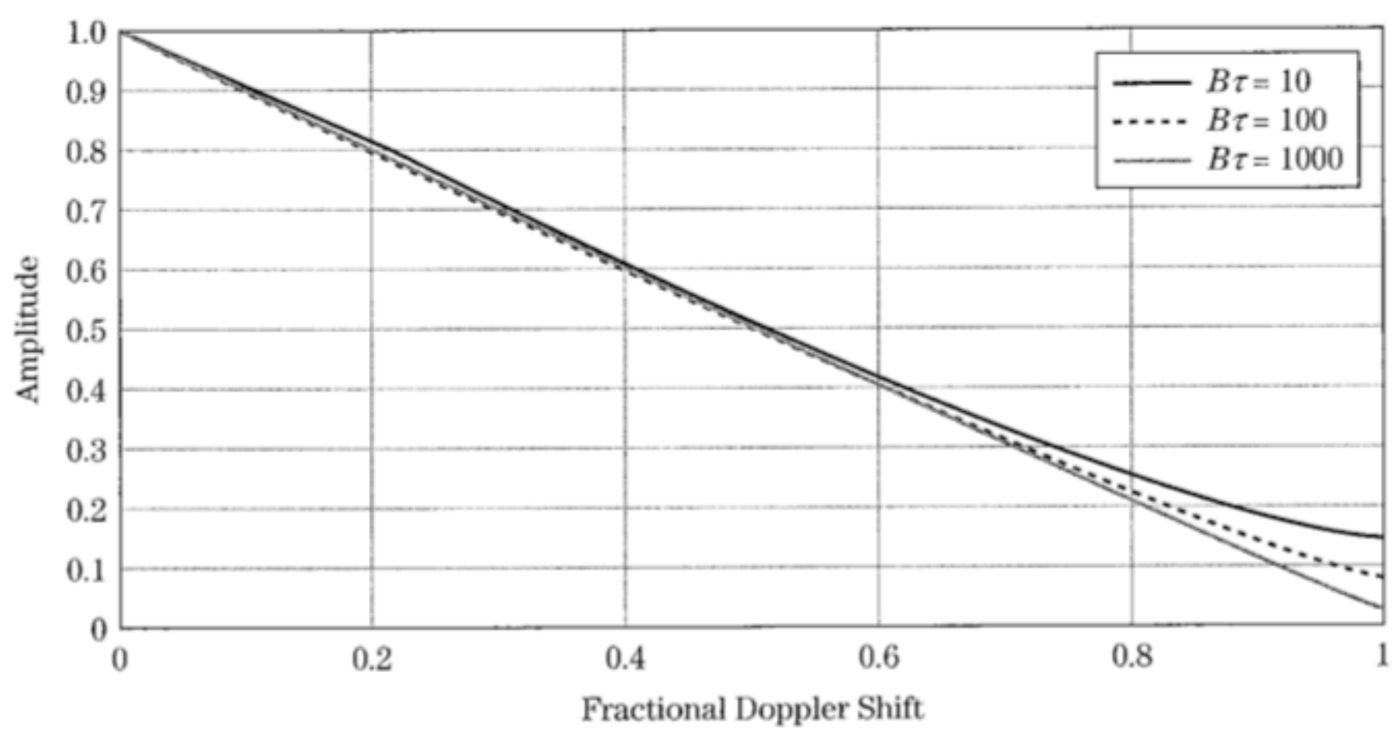
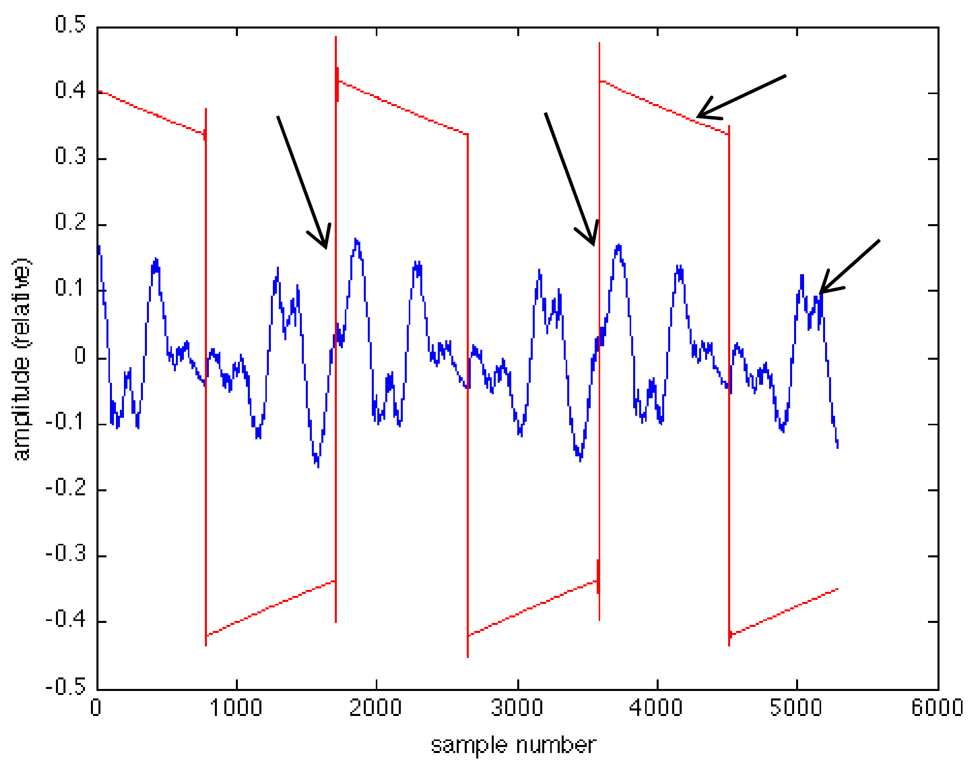


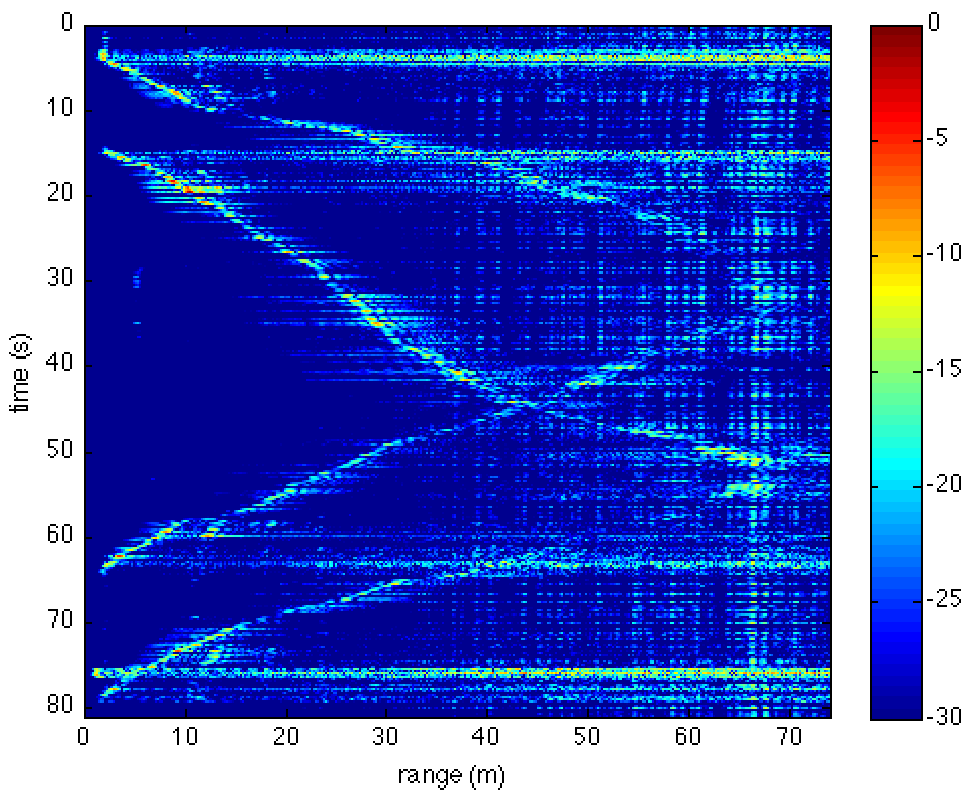
FIGURE 20-18 Reduction in peak amplitude as a function of Doppler shift.



Radar Kit: Ranging vs. Time

1. Re-connect Vtune to modulator output.
2. Set up-ramp duration to 20 ms, adjust magnitude to span desired transmit bandwidth.
3. Deploy radar where there are moving targets
4. Record a .wav file.
5. Process .wav using read_data_RTI.m
   - Looks for rising edges of sync pulse on Left channel
   - Saves 20 ms of Right channel data from rising edge, puts into array of de-chirped range profiles
   - Coherently subtracts the last range profile from the current one (2-pulse canceller)
   - Displays the log magnitude of the IDFT of the result as a range-time-indicator (RTI) plot





2 targets walking in the woods

Example: Two People Walking in the Woods