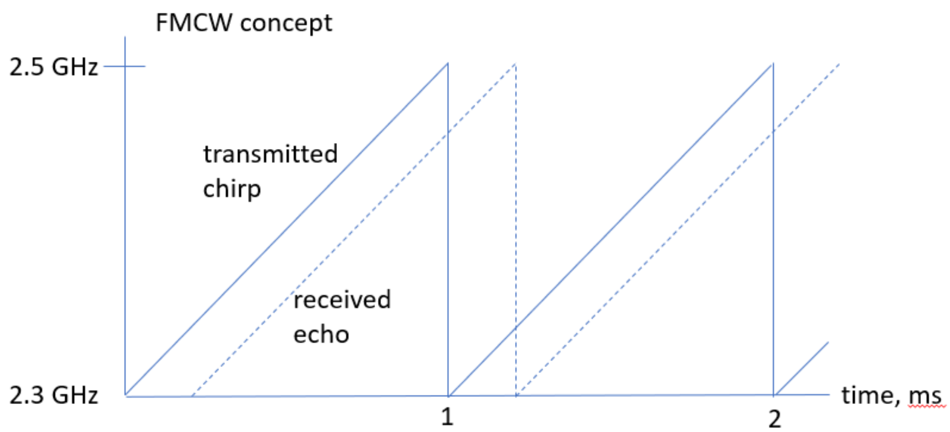
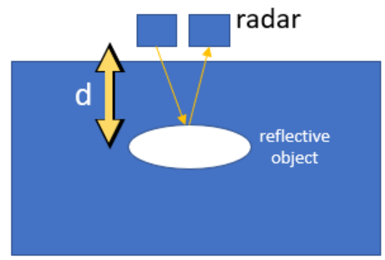
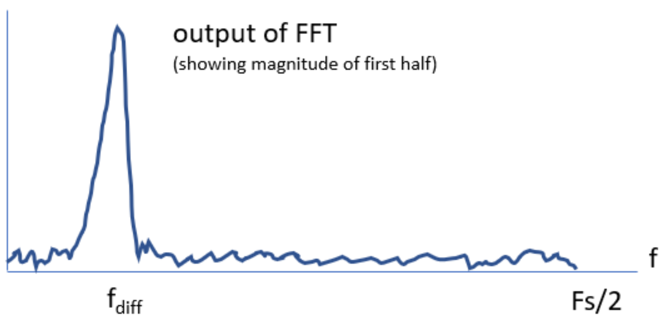
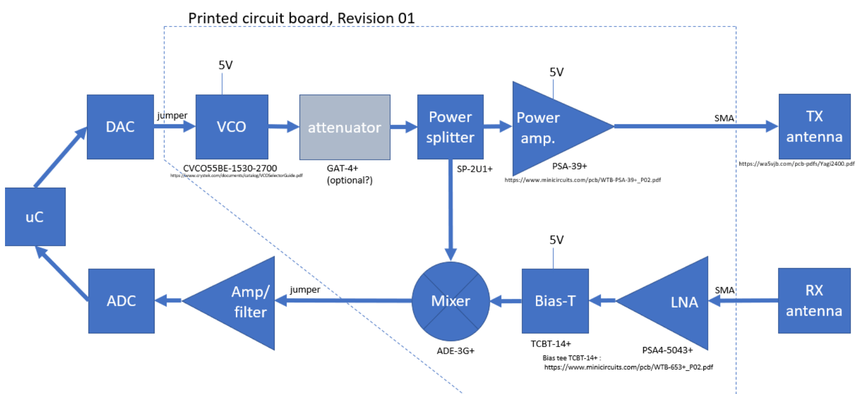








Calculations for design 1 (example numbers shown from 2023): Chirp repetition rate of 1 kHz, sweeping from 2.3 GHz to 2.5 GHz (13cm-12cm wavelength), giving sweep rate of 200 GHz/second. Also, no difference-frequencies smaller than about 2kHz could be observed, because the period would be longer than the chirp rate.

Suppose there was a target object at 10 meter distance, d = v*t, where v is the speed of light 300,000,000 m/s, so echo time t is 33 nanoseconds. Then the difference in frequency after that time would be 6.6 kHz, so that is the peak frequency that would be observed after the mixing. Using audio sampling rate of 96 kHz in Audacity, each chirp would get 96 samples, so 1 kHz/sample resolution, so the peak would show up at 6.6 samples. A 1 meter obstacle would show up at 0.6 samples (0.6 kHz), so it would basically be invisible. The resolution is basically 1.5m/sample.

Suppose we wanted better resolution. We could try to run the chirp rate higher to “zoom in” at closer distances. Suppose the new chirp rate is 10 kHz (chirps every 100 us), same VCO frequency sweep, so 2 THz/sec. Now a 1 meter obstacle would show up at 6.6 kHz and a 0.1m obstacle would show up at 0.66 kHz. However, no frequencies smaller than 10kHz could be observed because there would not be enough cycles showing up due to their period being 100 us or more (and practically, observable frequencies would be higher than 20-50 kHz to get enough cycles to get a visible spike in the FFT). So that approach doesn’t work for better resolution.

We could try higher ADC rate. If we could sample at 8 MHz, (83.33 times faster), using a 1 kHz chirp rate we would get 8000 samples/chirp. Now a 10 meter obstacle would show up at sample 550, and a 1-meter obstacle would show up at sample 55. A 0.1-meter obstacle would show up at sample 5.5. Since the wavelength is 0.125 meter (12.5 cm), the imaging at that "wavelength scale" would be very blurry/fuzzy, but there might still be some below-ground detection possible.

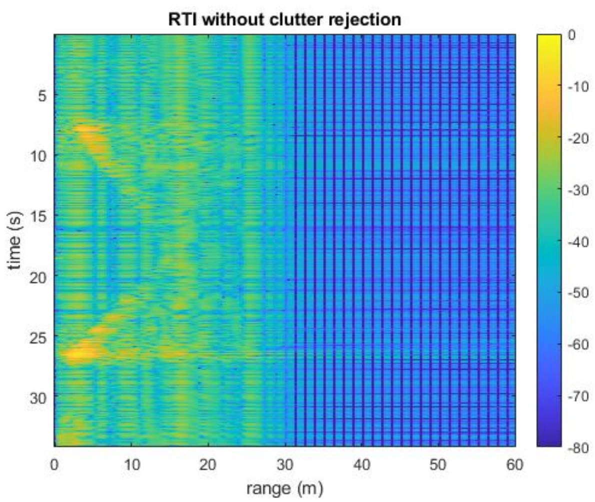
Report from summer 2023 - The radar is basically working (with the more advanced MACA-63H+ mixer module) but the sync pulse is not getting picked up in the USB audio card somehow – both L and R channels are showing only the IF mixer output regardless of what sync I try to put into it from the function generator, even tried up to 1 Vpp, both "high impedance" and "low impedance" output option.

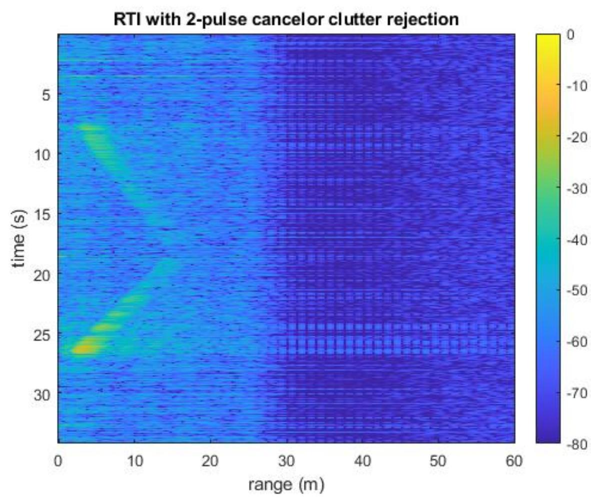
To work around this, I hard-coded a pulse length into the Matlab file and used it to generate a fake 'sync' signal, then tracked the xcorr peak to line up the "sif" matrix of pulse shapes for subsequent averaging and 2-pulse clutter rejection.

```
%MIT IAP Radar Course 2011
%Resource: Build a Small Radar System Capable of Sensing Range, Doppler,
%and Synthetic Aperture Radar Imaging
%
%Gregory L. Charvat (modified by Tim Gilmour 6/20/2023)

%Process Range vs. Time Intensity (RTI) plot

%NOTE: set up-ramp sweep from 2-3.2V to stay within ISM band
%change fstart and fstop bellow when in ISM band

clear all;
close all;

%read the raw data .wave file here
% [Y,FS,NBITS] = wavread('running_outside_20ms.wav'); % mit original
% [Y,FS] = audioread('rec4_1khzramp_weaksync.wav');
% [Y,FS] = audioread('hallway1_1khz_nosync.wav'); %WORKS, single back/forth
[Y,FS] = audioread('hallway2_1khz_weaksync.wav'); %works, multiple back/forth
% [Y,FS] = audioread('hallway3_1khz_weaksync_higain.wav'); %works, multiple back/forth

%constants
c = 3E8; %(m/s) speed of light

%radar parameters
% Tp = 20E-3; %(s) pulse time
Tp = 0.0010; %(s) pulse time
N = Tp*FS; %# of samples per pulse
% fstart = 2260E6; %(Hz) LFM start frequency for example
% fstop = 2590E6; %(Hz) LFM stop frequency for example
%fstart = 2402E6; %(Hz) LFM start frequency for ISM band
%fstop = 2495E6; %(Hz) LFM stop frequency for ISM band
fstart = 2380E6; %(Hz) LFM start frequency
fstop =  2500E6; %(Hz) LFM stop frequency
BW = fstop-fstart; %(Hz) transmit bandwidth
f = linspace(fstart, fstop, N/2); %instantaneous transmit frequency

%range resolution
rr = c/(2*BW);
max_range = rr*N/2;

%the input appears to be inverted
% trig = -1*Y(:,1);
%trig = Y(:,1) - Y(:,2);
s = -1*Y(:,2);

% this is a kludge because I can't get the trigger sync to work - estimate
% with preset hardcoded pulse time, then later below in the script, track the correlation peak to
% straighten/synchronize it
temp1 = [2.1*ones(floor(N/2),floor(length(s)/(N))); zeros(floor(N/2),floor(length(s)/(N)))] - 1.05;
trig = reshape(temp1, 1, [])';
%clear Y;

%parse the data here by triggering off rising edge of sync pulse
count = 0;
thresh = 0;
start = (trig > thresh);
for ii = 100:(size(start,1)-N)
    if start(ii) == 1 & mean(start(ii-11:ii-1)) == 0
        %start2(ii) = 1;
        count = count + 1;
```

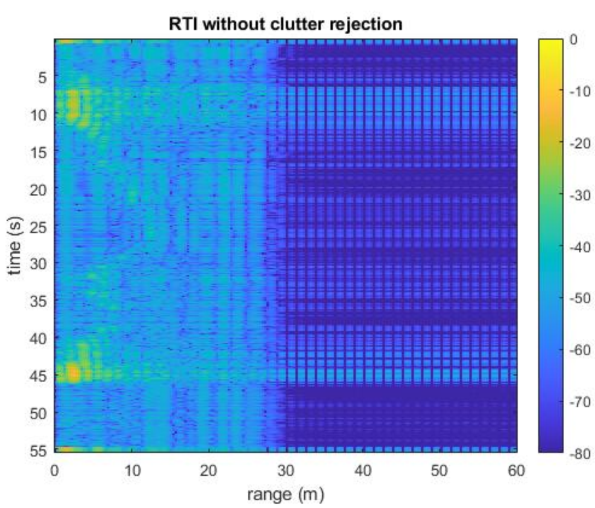
```
        sif(count,:) = s(ii:ii+N-1);
        time(count) = ii*1/FS;
    end
end
%check to see if triggering works
% plot(trig,'.b');
% hold on;si
% plot(start2,'.r');
% hold off;
% grid on;


% this is a kludge because I can't get the trigger sync to work - estimate
% with preset hardcoded pulse time, then track the correlation peak to
% straighten/synchronize it
template = sif(1.5e4,:); % hardcode a particular "pulse" template frame (adjust)
for ii = 1:size(sif,1)
    xc = xcorr(template, sif(ii,:));
    [m,peakIndex] = max(xc);
    peakIndex = peakIndex - floor(length(xc)/2);
    piSaved(ii) = peakIndex;
    sifFix(ii,:) = circshift(sif(ii,:),peakIndex);
end
% figure; plot(piSaved)
sif = sifFix;

%subtract the average
ave = mean(sif,1);
for ii = 1:size(sif,1)
    sif(ii,:) = sif(ii,:) - ave;
end

zpad = 8*N/2;

%RTI plot
figure(10);
v = dbv(ifft(sif,zpad,2));
S = v(:,1:size(v,2)/2);
m = max(max(v));
imagesc(linspace(0,max_range,zpad),time,S-m,[-80, 0]);
colorbar;
ylabel('time (s)');
xlabel('range (m)');
title('RTI without clutter rejection');

%2 pulse cancelor RTI plot
figure(20);
sif2 = sif(2:size(sif,1),:)-sif(1:size(sif,1)-1,:);
v = ifft(sif2,zpad,2);
S=v;
R = linspace(0,max_range,zpad);
for ii = 1:size(S,1)
    %S(ii,:) = S(ii,:).*R.^(3/2); %Optional: magnitude scale to range
end
S = dbv(S(:,1:size(v,2)/2));
m = max(max(S));
imagesc(R,time,S-m,[-80, 0]);
colorbar;
ylabel('time (s)');
xlabel('range (m)');
title('RTI with 2-pulse cancelor clutter rejection');

% %2 pulse mag only cancelor
% figure(30);
% clear v;
% for ii = 1:size(sif,1)-1
%     v1 = abs(ifft(sif(ii,:),zpad));
%     v2 = abs(ifft(sif(ii+1,:),zpad));
%     v(ii,:) = v2-v1;
% end
% S=v;
% R = linspace(0,max_range,zpad);
% for ii = 1:size(S,1)
%     S(ii,:) = S(ii,:).*R.^(3/2); %Optional: magnitude scale to range
% end
% S = dbv(S(:,1:size(v,2)/2));
% m = max(max(S));
% imagesc(R,time,S-m,[-20, 0]);
% colorbar;
% ylabel('time (s)');
% xlabel('range (m)');
% title('RTI with 2-pulse mag only cancelor clutter rejection');
```

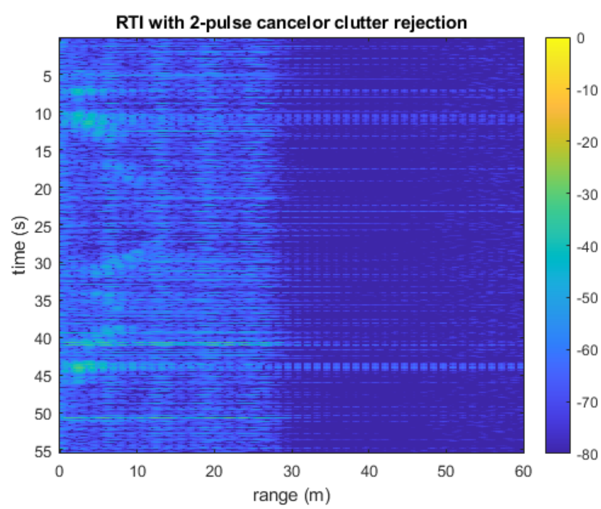
'hallway3_1khz_weaksync_higain.wav', 40dB LNA, in atrium, walking back and forth about 15meter distance, with aluminum panel on the way back, running function generator at 1 kHz ramp repeat rate (pulse rate), from VCO 6.3V to 7.3V (2.3-2.5GHz), with antennas in tin cans separated about 2 feet on table (big can had receive antenna). Digitizing in Audacity at 96kHz.





hallway2_1khz_weaksync.wav, 20dB LNA with shield can, in atrium, walking back and forth multiple times about 10 meter distance, with aluminum panel, 1kHz pulse rate, same voltage and antenna settings



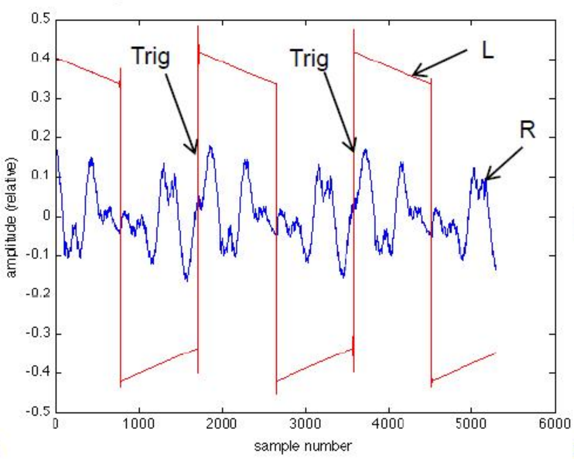


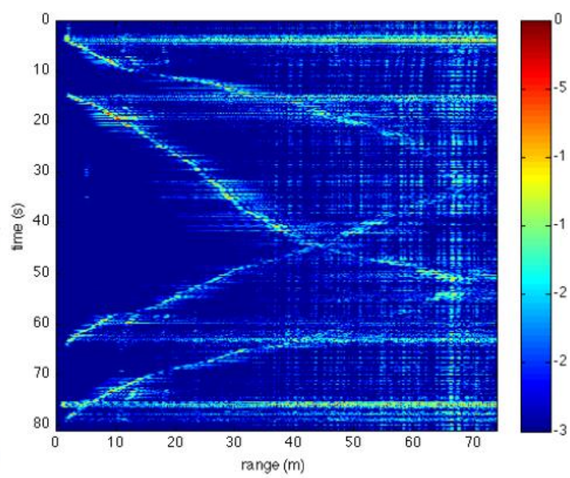
from downloaded MITRES_LL_...proj_in.pdf , and/or

https://ocw.mit.edu/courses/res-ll-003-build-a-small-radar-system-capable-of-sensing-range-doppler-and-synthetic-aperture-radar-imaging-january-iap-2011/79971a280ef1714dbff62f9cf104ee04_MITRES_LL_003IAP11_exp02.pdf

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**
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