Principles of Biomedical Ultrasound and Photoacoustics
hw04-1: Single Element Synthetic Aperture Focusing

Due on Thursday, Nov 16, 2017

106061531 Fu-En Wang

1 Introduction

In this homework, we will simulate phased array system beam forming.

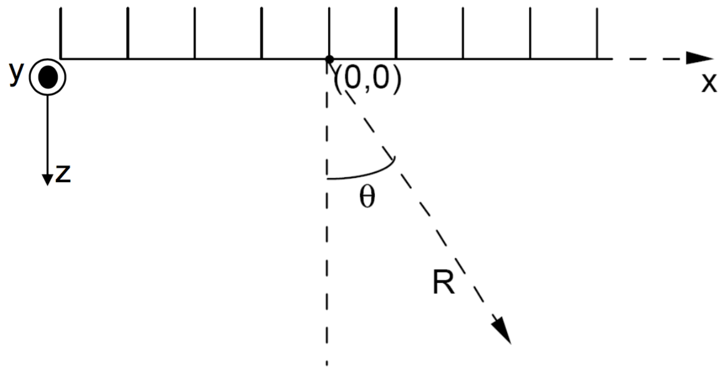

Figure 1: Phase array system

To create the channel data, we can follow the steps below.

1. The transmitter (i.e., each array element) is a perfect point source
2. The receiver (i.e., each array element) is a perfect point receiver
3. There is no attenuation. That is, the received signal does not need to be gain compensated.
4. The sound speed is 1.5 mm/us or 1500 m/s
5. The complete channel data are collected with consecutive single element transmitting and receiving.
6. The position of the 3 point targets in (x,y,z): (-5, 0, 10), (0, 0, 20), (15,0,30) in mm.
7. The initial sampling rate (i.e., fs) is set to 64*fc to emulate analog channel data
8. Perform decimation on emulated analog channel data so that the resultant sampling rate (i.e., fs) is 4*fc on sampled channel data
9. Make wavefield plots of the analog and sampled data (i.e., image of channel data). The gray scale is setup so that zero pressure is midgray, positive pressure is white, and negative pressure is black.

2 Problems

Implement RF and baseband dynamic receive beamformer to make a 120-degree sector scan image from the sampled channel data.

2.a Define beam spacing and the number of total beams

The beam space is uniformly divided in sine space.

$$\Delta \sin\theta = \frac{\lambda}{2D} = 0.0156$$

in mm. The number of beams is

$$\frac{\sqrt{3}}{\Delta \sin\theta} = 111$$

2.b RF and baseband beamforming

Now we show beamforming of RF and Baseband as shown in Figure [2 3].

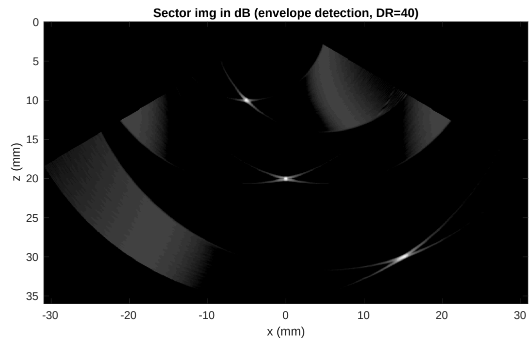

Figure 2: Sector image (RF)

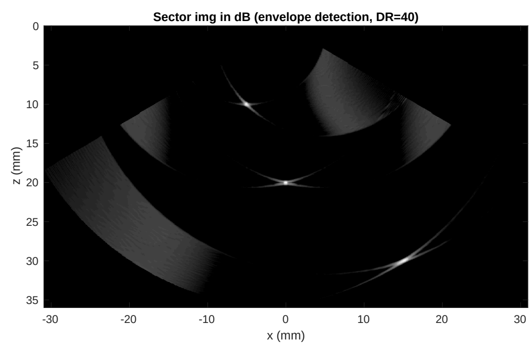

Figure 3: Sector image (Baseband)

Figure 4 show the original spectrum of center scanline for RF beamforming.

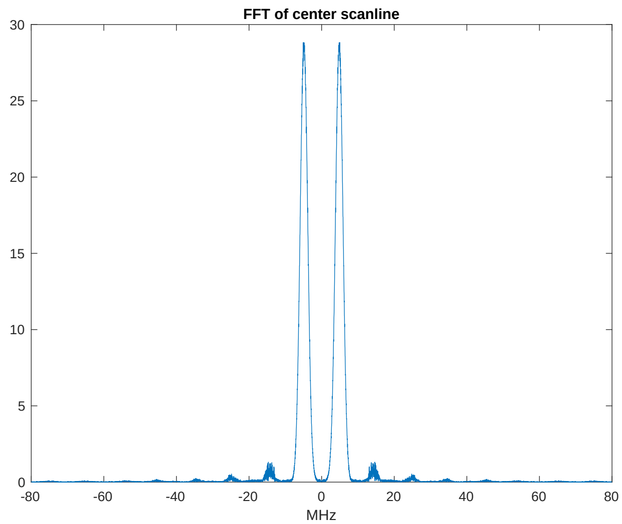

Figure 4: FFT (origin)

Now we apply demodulation with the following formula

$$BBbeam = BBbeam * \exp^{-2\pi * fc * t * j}$$

And the spectrum will shift -fc as shown in Figure 5

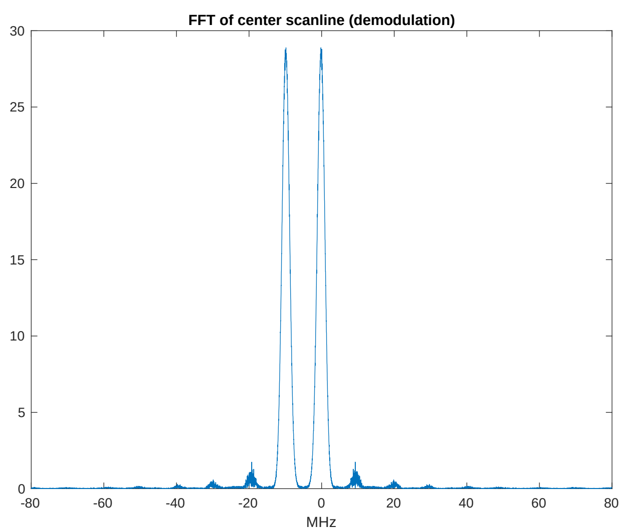

Figure 5: FFT (demodulation)

Now we apply a low pass filter with cutoff frquency fc (Figure 6) to preserve the main lobe only (Figure 7)

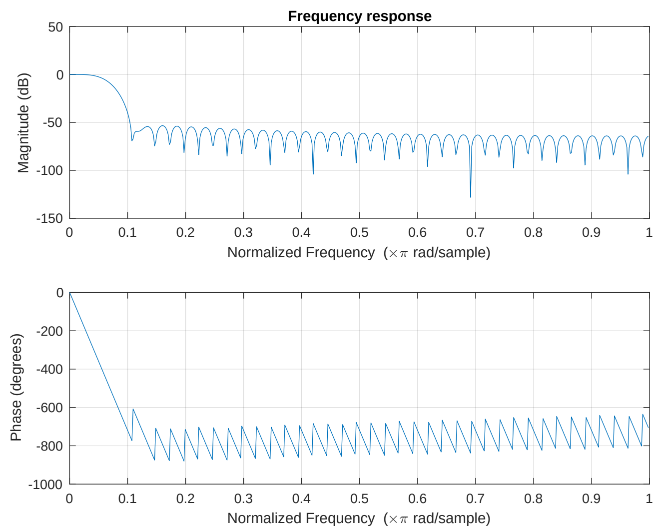

Figure 6: LPF frequency response

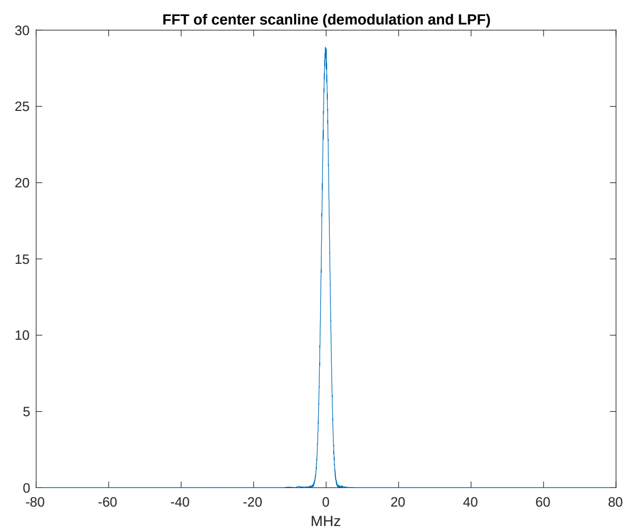

Figure 7: FFT (demodulation and LPF)

Now we finish all steps of baseband demodulation.

2.c Create baseband data (Matlab: ones())

When the **w** in source code is assigned by **ones**, the beam buffer of RF and Baseband after beamforming is shown in Figure 8 and 9, respectively.

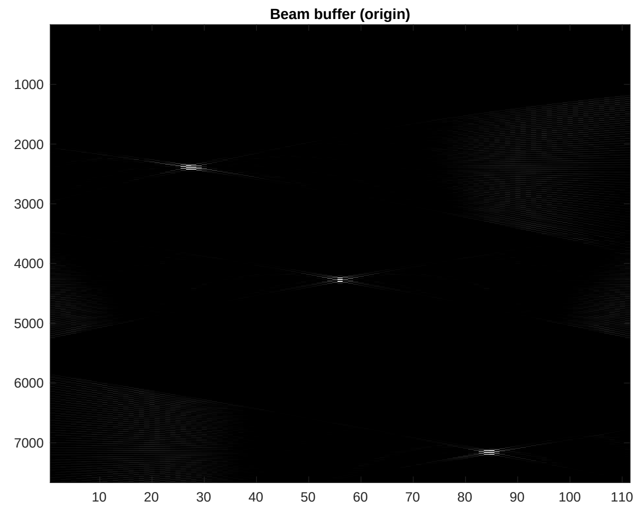

Figure 8: Beam buffer of RF(ones)

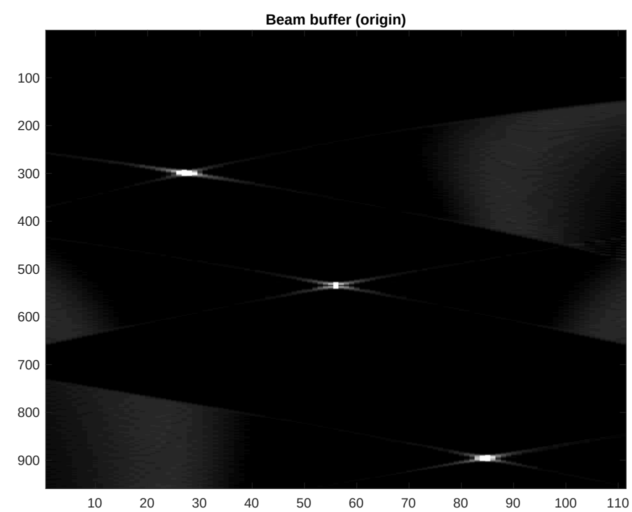

Figure 9: Beam buffer of Baseband(ones)

2.d Create baseband data (Matlab: hanning())

When the **w** in source code is assigned by **hanning**, the beam buffer of RF and Baseband after beamforming is shown in Figure 10 and 11, respectively.

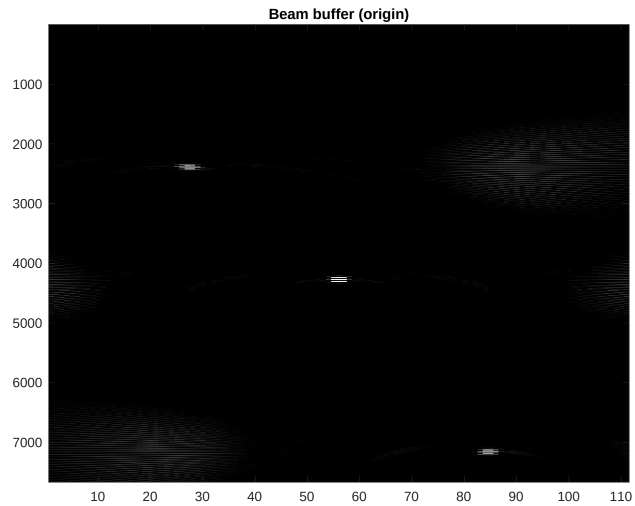

Figure 10: Beam buffer of RF (hanning)

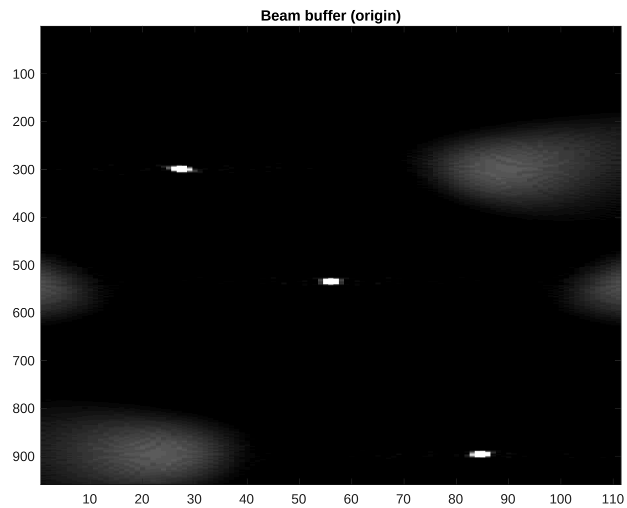

Figure 11: Beam buffer of Baseband (hanning)

2.e Create baseband data ($\Delta \sin\theta = \lambda/D$)

Figure 12 shows the result

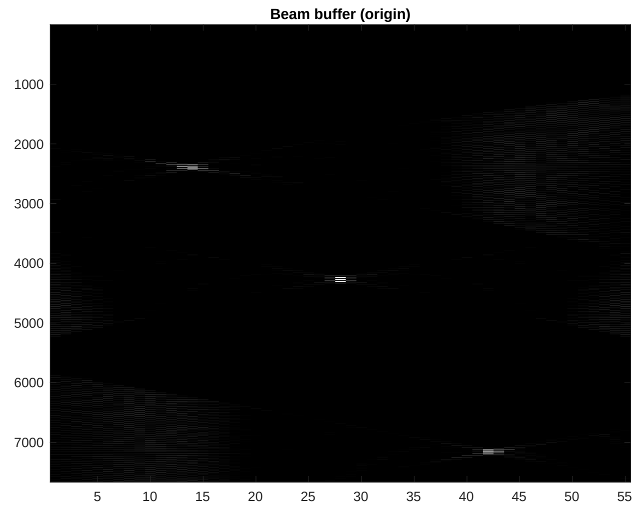

Figure 12: Beam buffer of RF ($\Delta \sin\theta = \lambda/D$)

2.f Create baseband data

Create baseband data for the R-sin beam buffer by computing the coherent sum across every other element (required for either RF or baseband beamforming only).

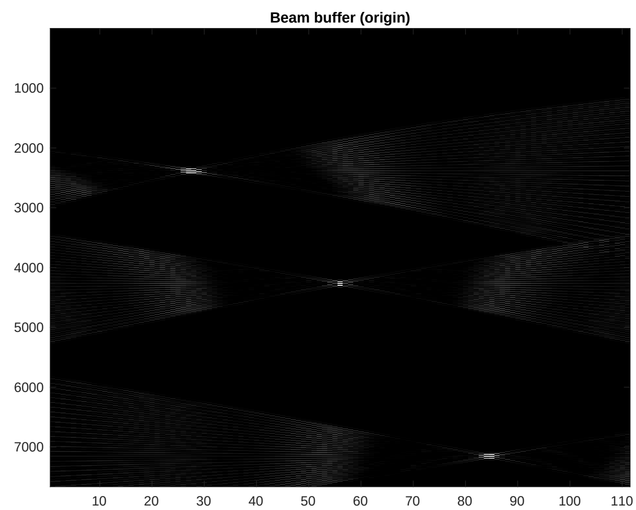

Figure 13: Beam buffer of RF (every other element)

2.g Display beam buffer with 40 dB dynamic range

Figure 14 and 15 show the result of RF and Baseband in (c), respectively.

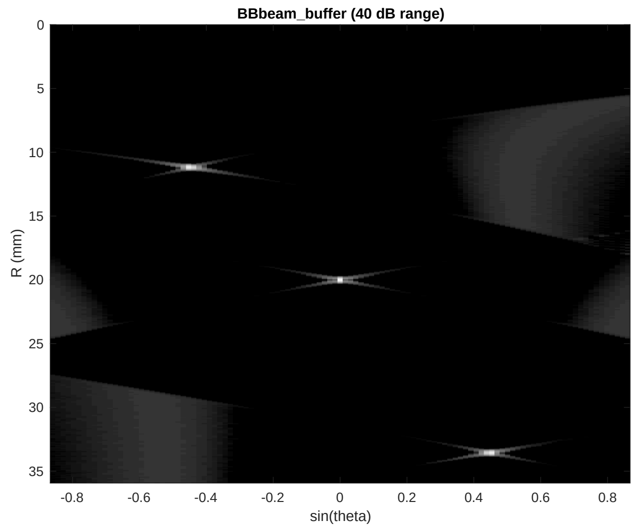

Figure 14: (c) Beam buffer of RF (40 dB dynamic range)

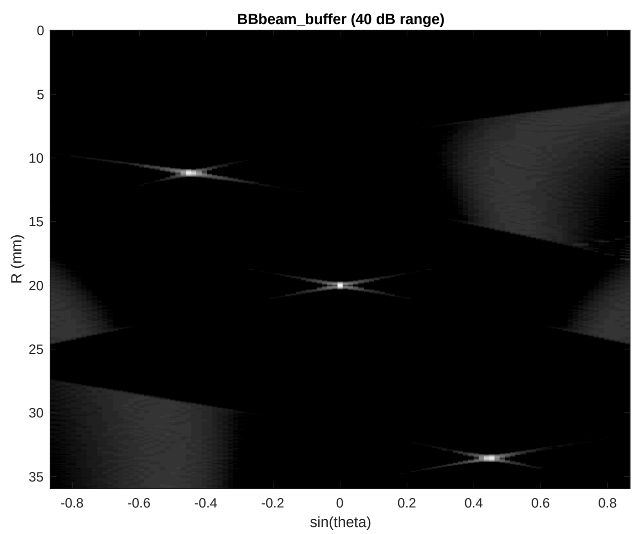

Figure 15: (c) Beam buffer of Baseband (40 dB dynamic range)

In Figure 14 and 15, the result of RF is a little smoother than that of baseband, but I think their results are such similar that I cannot tell difference from them.
Figure 16 show the 40dB result for (d).

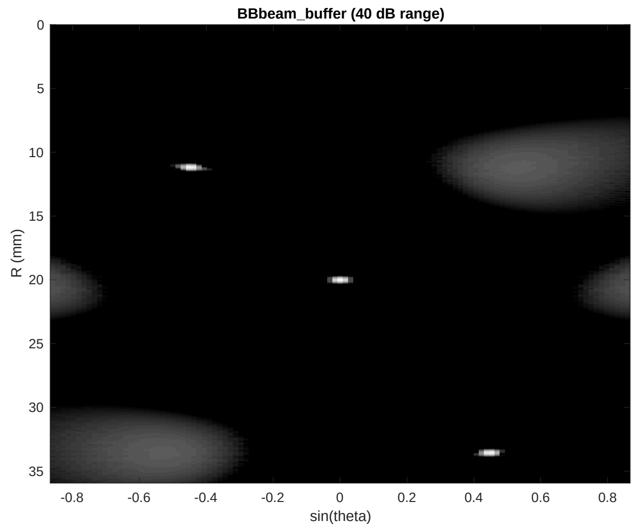

Figure 16: (d) Beam buffer of RF (40 dB dynamic range)

Compared with Figure 14, the focus points in Figure 16 are just more like a **point**. This is because the main lobe width of hanning window is wider than a rectangular window (ones()), and this can be seen as a smooth operation. So the result in figure 16 seems better.
Figure 17 show the 40dB result for (e).

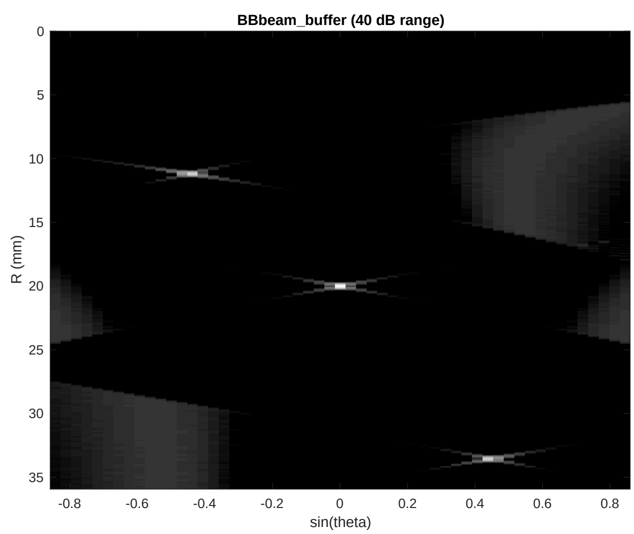

Figure 17: (e) Beam buffer of RF (40 dB dynamic range)

Because we increase the pitch (i.e distance between each $\sin\theta$ line increases), the total number of sample line decreases. As a result, we can see a poorer resolution in Figure 17 than in Figure 14.
Figure 18 show the 40dB result for (f).

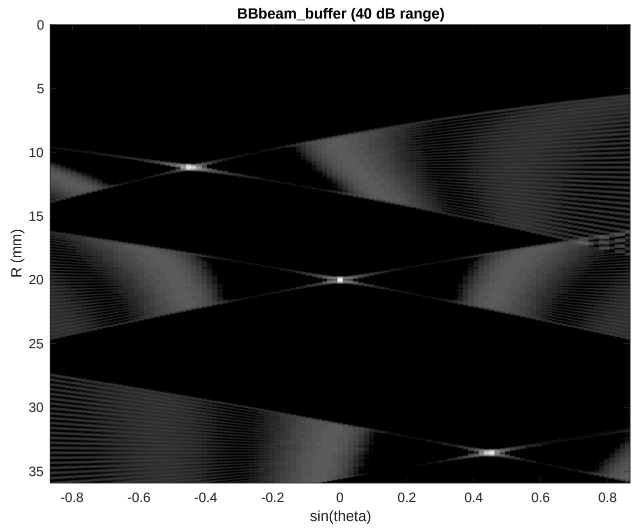

Figure 18: (f) Beam buffer of RF (40 dB dynamic range)

In Figure 18, the contrast between area around focus point and the other is much worse than Figure 14. This is because we only use data recieved from half number of elements and the energy difference of focus point area and the others will get much smaller. So the contrast becomes worse.

2.h Sector Images

Figure 19 and 20 show the sector images in (c), respectively.

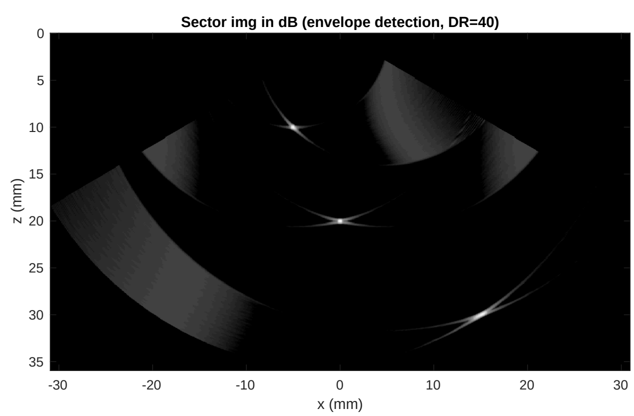

Figure 19: (c) Sector image of RF (40 dB dynamic range)

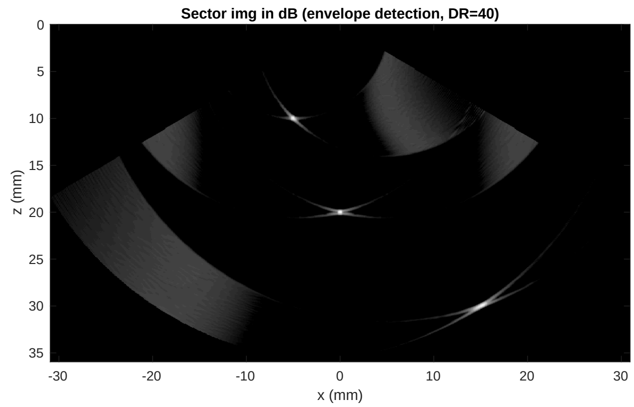

Figure 20: (c) Sector image of Baseband (40 dB dynamic range)

Figure 21 show the result of (d).

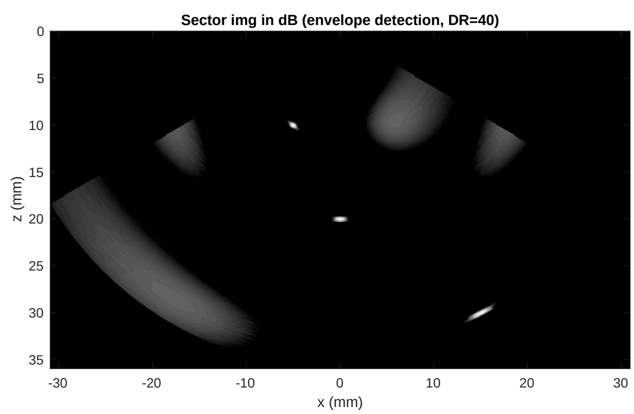

Figure 21: (d) Sector image of RF (40 dB dynamic range)

Figure 22 show the result of (e).

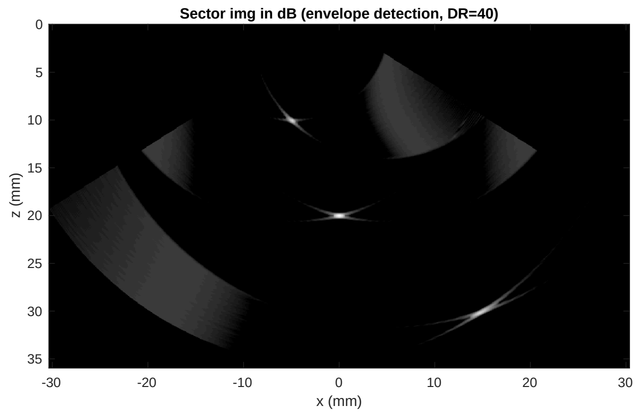

Figure 22: (e) Sector image of RF (40 dB dynamic range)

Figure 23 show the result of (f).

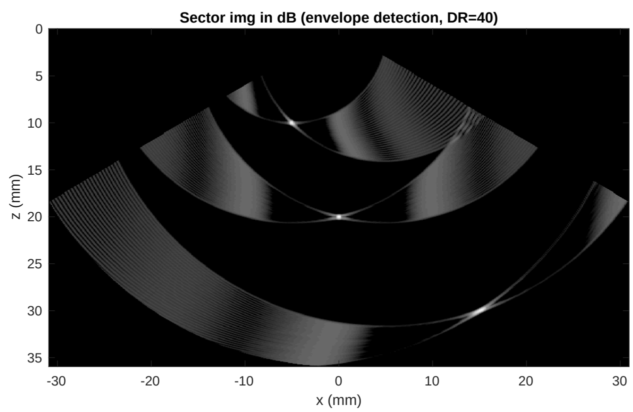

Figure 23: (f) Sector image of RF (40 dB dynamic range)