Technical Design Document

Design group: 010

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1. Subsystem Overview

Subsystem A is composed of a Radio Frequency(RF) filter and a voltage limiter, which respectively remove out-of-band RF signals and restrict the output voltage. The corresponding output, the intermediate frequency(IF) signal, is taken by the quadrature mixer in subsystem B, where it is multiplied with two oscillator signals with a phase difference of 90 degrees from Subsystem D. The two outcoming signals, IQ signals, are then processed by the IQ amplifier to receive a 30dB gain at an upper cutoff frequency of 96kHz.

2. Input/Output signals

The input of Subsystem A is an unfiltered HF RX signal (RX_SIG) within the 8-16 MHz frequency range, and the output is a filtered and limited IF signal.

Table 1: Input and output details in Subsystem A

Inputs	Outputs
Radio Frequency signal within 8-16MHz	Filtered IF signal centered at 14MHz within 8-16MHz
Power signals at either 3.3V or 5V (or both)	Limited peak-to-peak voltage at 0.7Vpp

There are three inputs, which are one IF signal from Subsystem A and two LO outputs from Subsystem D, going into Subsystem B. The output will be IQ signals composed of RX_I (in-phase) and RX_Q (quadrature) signals that are amplified to have a minimum gain and also at least first-order filtered to have a certain upper cut-off frequency.

Table 2: Input and output details in Subsystem B

<table>
<tr><th>Inputs</th><th>Outputs</th></tr>
<tr><td>IF signal centered at 14MHz within 8-16MHz</td><td rowspan="3">RX_I (in-phase) and RX_Q (quadrature) signals with a minimum 30dB gain and at least first-order filtered with a cut-off frequency at 96 kHz and baseband carrier frequency of 10 kHz</td></tr>
<tr><td>Local oscillator input with 0 degree</td></tr>
<tr><td>Local oscillator input with 90 degrees</td></tr>
</table>

3. Subsystem Design

The proposed design includes a bandpass filter and limiter for subsystem A, a Tayloe detector and its subsequent active filter and amplifier for subsystem B.

3.1 Subsystem A (bandpass filter and limiter)

The bandpass filter is implemented as a LC 3rd order bandpass filter to realize a selective pass band of 8-16MHz with minimum loss. The values are calculated by performing impedance transform and frequency transform on a normalized 3rd order bandpass filter [1]. The components chosen in the schematic are selected in ECE295 altium library. The out-of-band signals are rejected by the cascading LC components. The RF response of the filter is shown in the appendix as figure.1&2 in appendix. An approximately 3dB drop is presented at around 8-16MHz. The passband gain is mostly flat at 0dB. The limiter uses parallel 1n4001 diodes before the input of the filter and the diodes D1 and D2 clips the input voltage at the required 700mV shown in figure.3 [2].

3.2 Subsystem B (Quadrature mixer and amplifier)

A DC offset is required at the input to compensate for the limited 5V power supply of the op amp. Since a transformer can shift the AC signal to be centered at a new DC level using offset voltage without affecting the circuit, a center-tapped transformer is applied to impose a 1.41V DC offset which introduces minimal clip at the peak of the signal in simulation. Due to the low frequency (kHz) of IF signals and the advantage of producing less noise, an active filter such as the low-pass Sallen-key circuit with amplification [3] is applied to filter out high frequency signals and meet cut-off and baseband carrier frequency requirements as well as 30dB gain. We design R1, R2 to be 18kΩ and C1, C2 are set accordingly due to the 96kHz cut-off frequency [4]. We then design R13 to be 100Ω and R12 to be 56Ω [3] in order to obtain a maximally-flat response with DC gain k=1.586 [5].

A Tayloe detector is implemented to function as our quadrature mixer due to its structural simplicity and high performance. The demux routes the incoming signal to be sampled, integrated and held at each of the four capacitors in each quarter cycle. The appropriate value for the capacitors is derived by calculation [6], regarding the whole system as a RC lowpass filter. Two simplified differential op amp circuits differentially sum the outputs from the bank of capacitors to obtain the IQ signals. The value of the feedback resistors and capacitors are obtained by referring to existing designs[7,8].

Appendix:

[1] Calculation is compiled in a pdf posted on the Team wiki page.

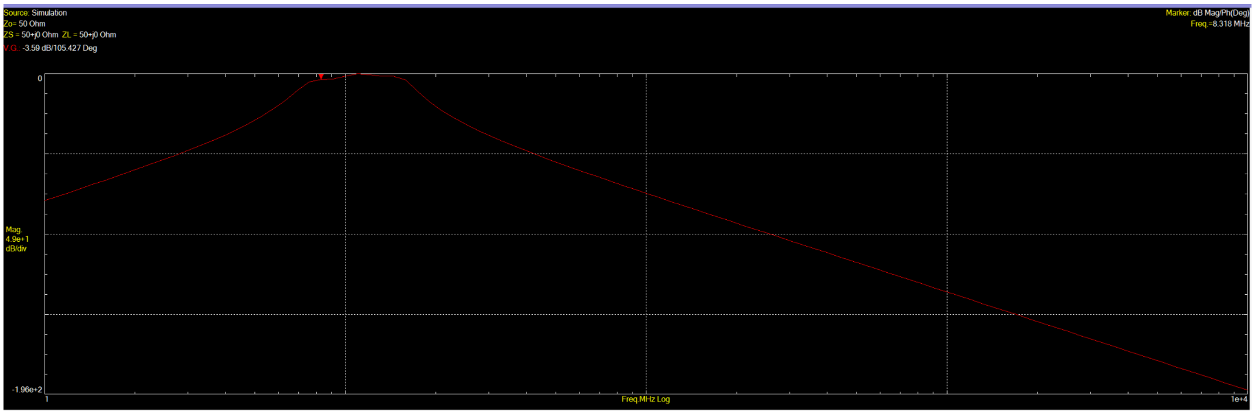


figure 1 RF response showing gain at 8MHz

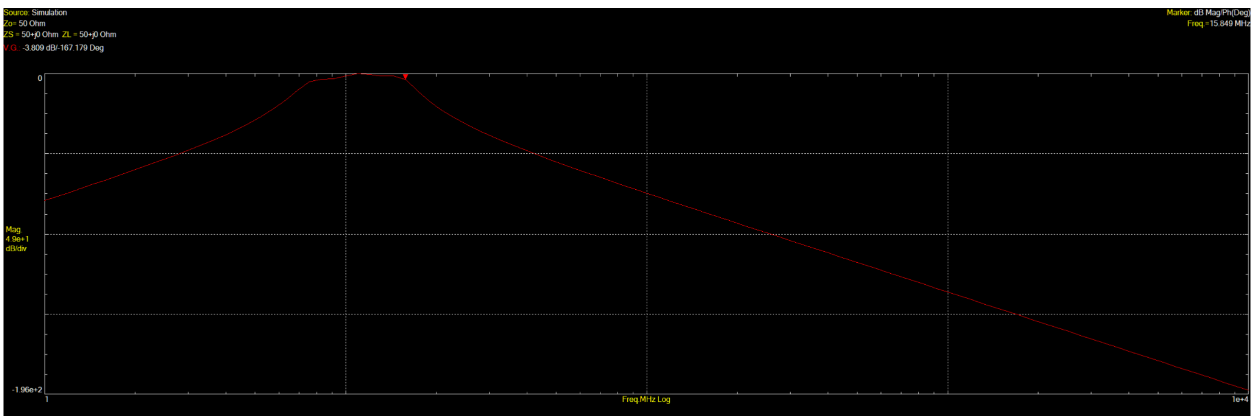


figure 2 RF response showing gain at 16MHz

[2]

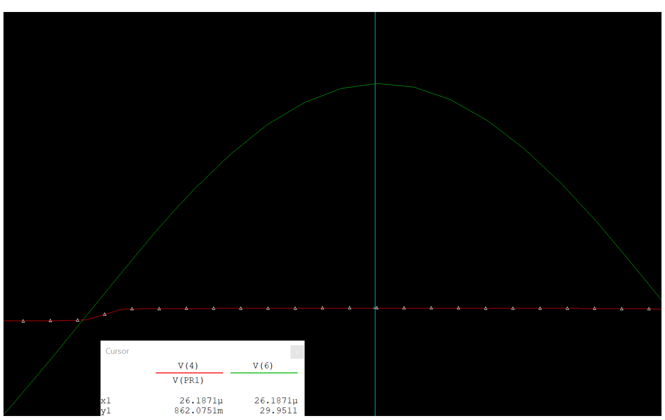


figure 3 Output voltage of limiter clipped at 862.0751mV

[3]

The IQ signals are amplified by the amplifier as configured below in figure 4. The negative feedback loop is biased to around 2.2v to compensate for the 0-5V power supply of the Op Amp. The previous low-pass filter uses an active filter with 1.41V DC offset at input with 1.56 gain. This lead to a 1.56*1.41=2.2V DC offset at its output. The 2.2V bias voltage in this configuration is to set the center of oscillation to 2.2v to prevent clip of voltage. This configuration provides an open loop gain of 101 at +5/-5V power supply and an ideal gain of 101/2 in this configuration. The amplification is found to be around 31.75dB as shown in figure 5 & 6.

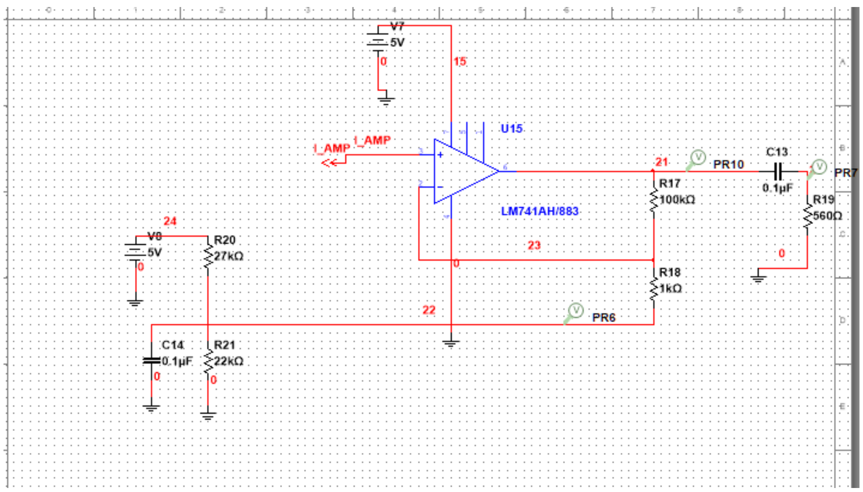


figure 4. IQ amplifier configuration

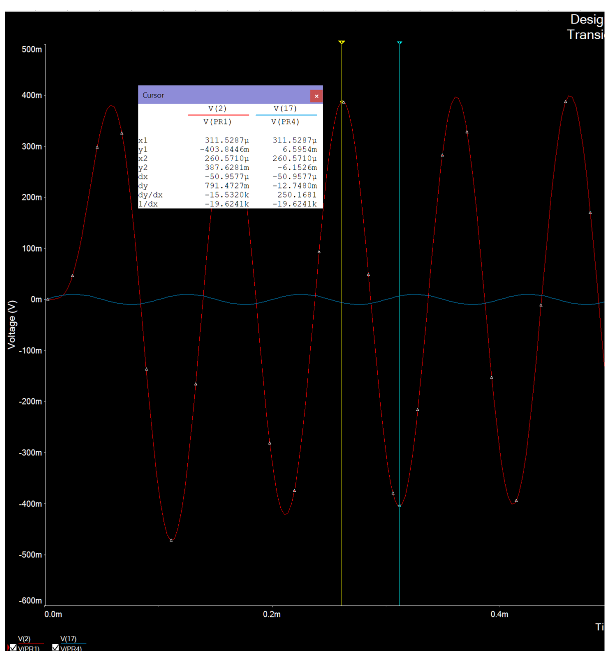


figure 5 Amplification of the output after amplifier compare to the input of the low-pass filter

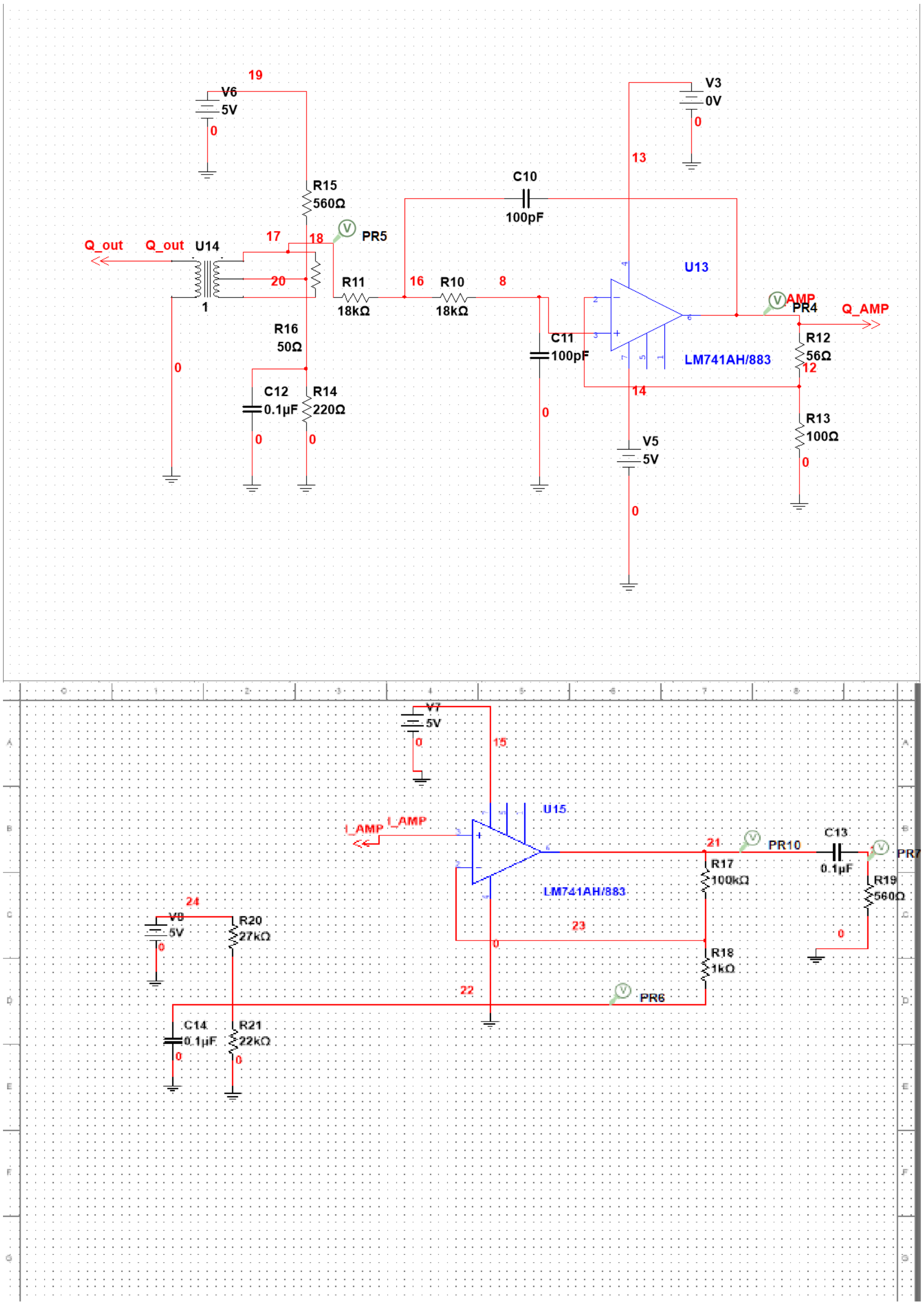
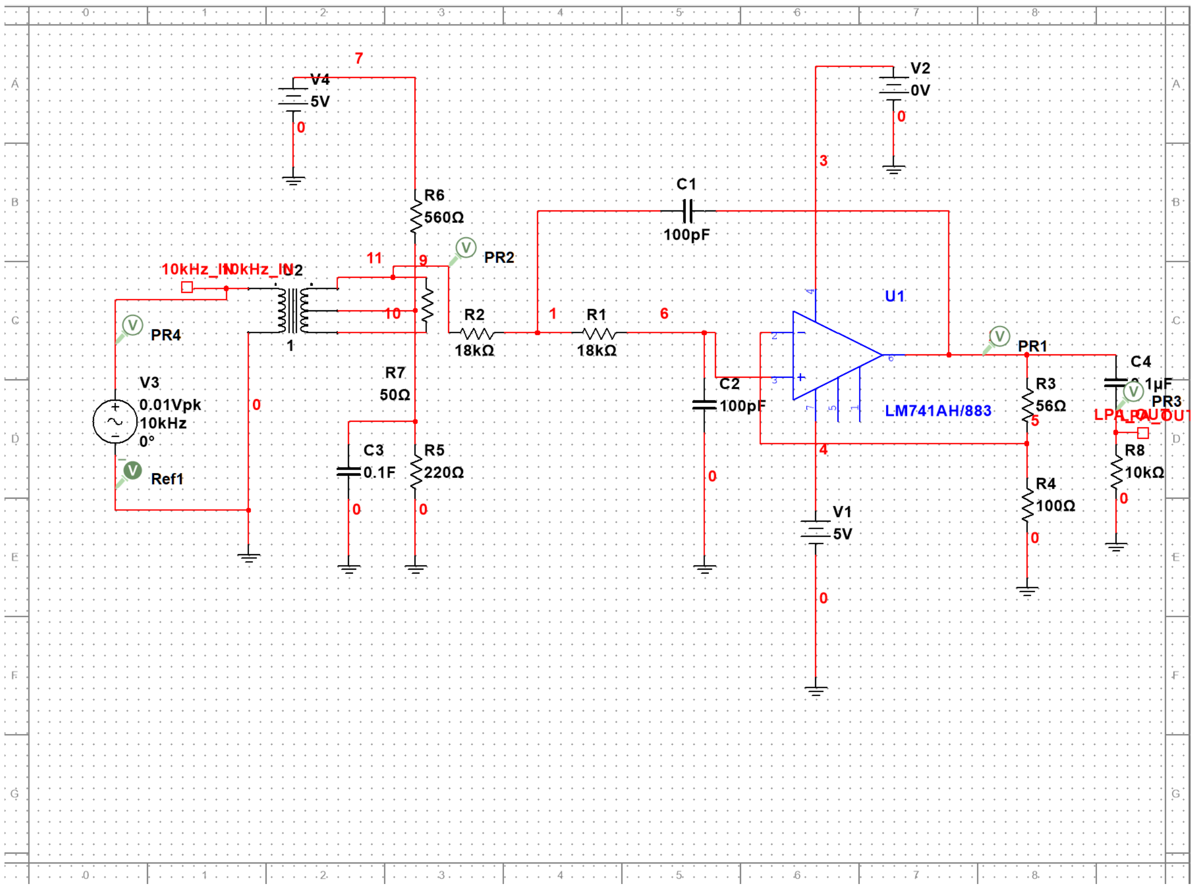


figure 6. Simulation configuration of low-pass filter connected to amplifier

[4] A schematic of center-tapped transformer and Sallen-key circuit as an active filter



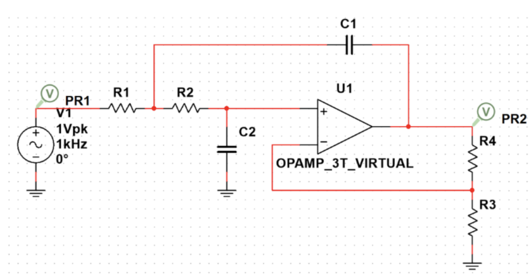
Cut-off frequency formula: fc $=\frac{1}{2\pi * R * C}$=96kHz

[5] Lecture slides about Sallen-key circuit and DC gain

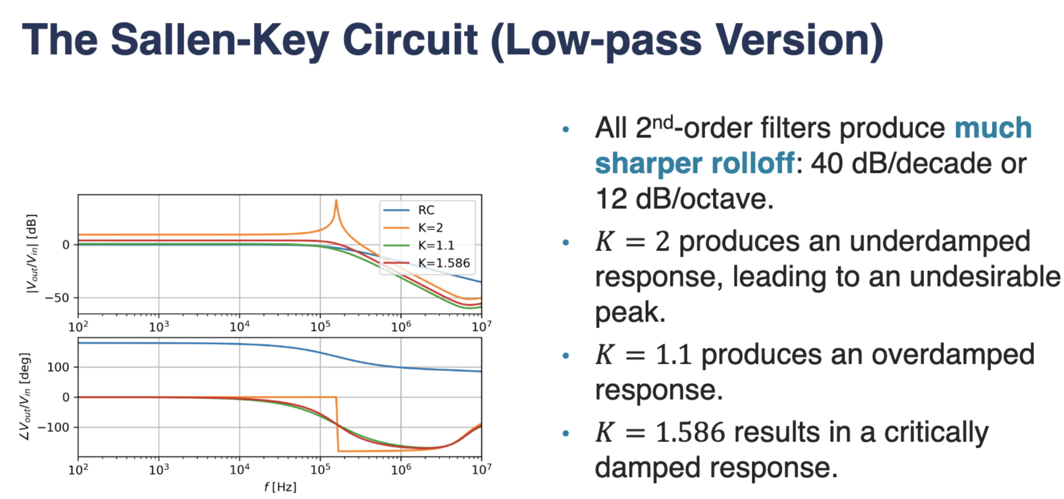
Second Order Responses

- The order of the filter can be increased by first using a Sallen-Key circuit.
- The basis of this circuit is a **non-inverting amplifier**.
- For a typical low-pass Sallen-Key circuit, we set:

$$R_1 = R_2 = R$$
$$C_1 = C_2 = C$$
$$R_3 = R_f$$
$$R_4 = (K-1)R_f$$



K is the DC gain of the non-inverting amplifier, and controls the “peakiness” of the transfer function.



We choose k = 1.586 that gives the maximum flat response, R3 (R4 in our circuit) = 100ohm, then R4 (R3 in our circuit) = 56 ohm.

[6] $Bandwidth = \frac{1}{n \times 4\pi \times RC}$, where R is the estimated system resistance of 40Ω, and n is 4 for a single balanced mixer as what we built. The bandwidth is the desired baseband frequency of 10KHz.

[7] ”TinyPico Radio”, [Online]. Available: https://www.youtube.com/watch?v=iwBk3jIxszI

[8] Zenaneh Ashebir Kebede, “Low frequency Quadrature detector design, simulation and implementation for use in underground communication”, 2014. [Online] Available: https://researchrepository.wvu.edu/cgi/viewcontent.cgi?article=1222&context=etd