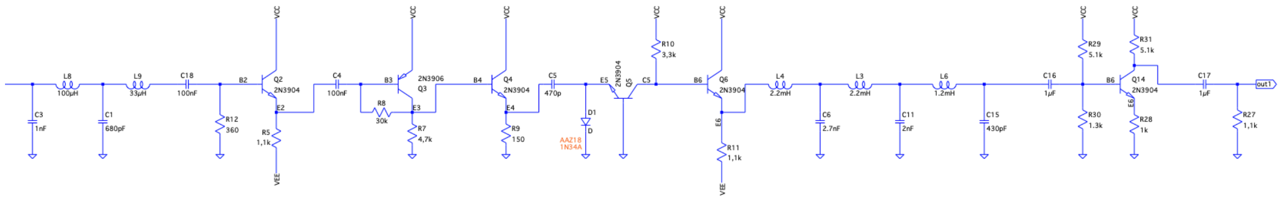
FM Detector

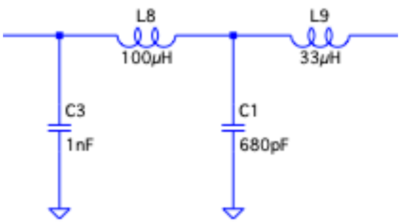
The FM detector (demodulator) demodulates the 450kHz FM signal into line level audio. The 450kHz signal is at the second intermediate frequency. The FM detector is implemented as a pulse train generator followed by a low pass filter (sometimes called a pulse count detector).

The FM detector consists of several stages:

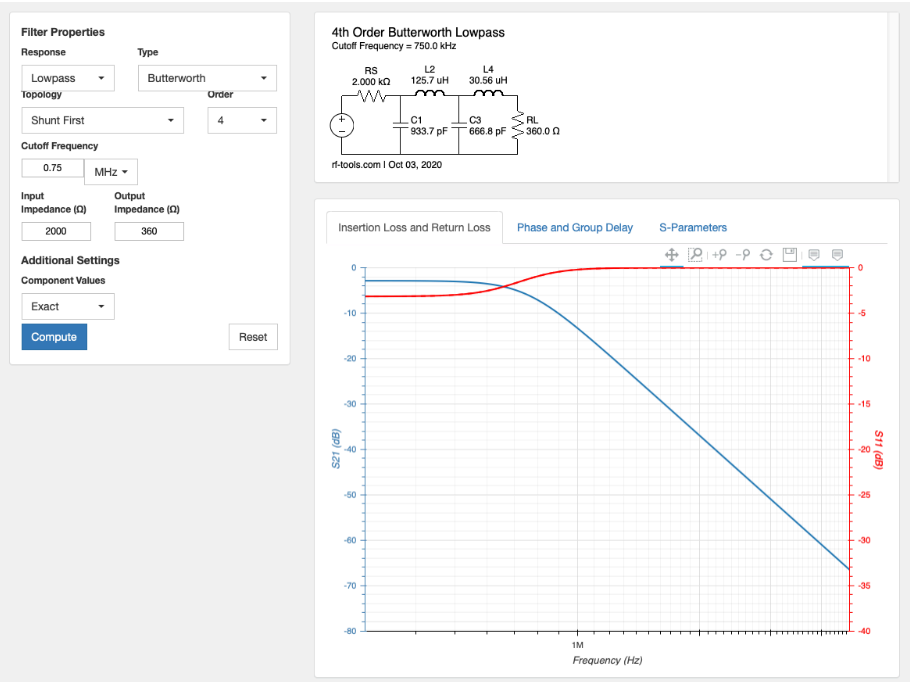
1. A 4th order 750kHz lowpass filter to filter out all mixing products except the 450kHz intermediate frequency (L_8, L_9, C_3, C_1).
2. A buffer (Q_2), to provide a constant load impedance for the preceding filter.
3. Pulse train generator (Q_3, Q_4, Q_5), which generates a constant width down-pulse for every upward slope of the input signal. With the changing frequency of the carrier, the duty cycle of the resulting pulse train varies in accordance to the carrier frequency.
4. Buffer (Q_6)
5. 6th order 100kHz lowpass filter (L_3, L_4, L_6, C_6, C_7, C_{11}) filters the pulse train with its changing duty cycle into audio and FM subcarrier signals.
6. A final amplifier Q_{14} to amplify the signal to line level.



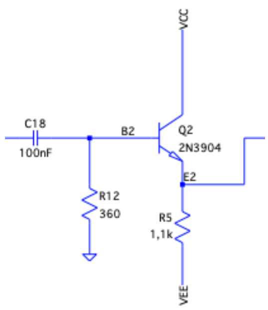
1. Lowpass input filter



A 4th order 750kHz lowpass filter to filter out all mixing products except the 450kHz intermediate frequency (L_8, L_9, C_3, C_1). Input impedance is 2kΩ, output impedance is 300Ω.

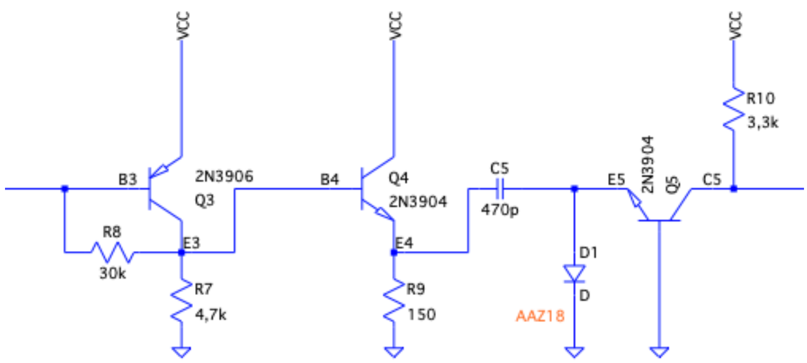


2. Buffer (Q_2)



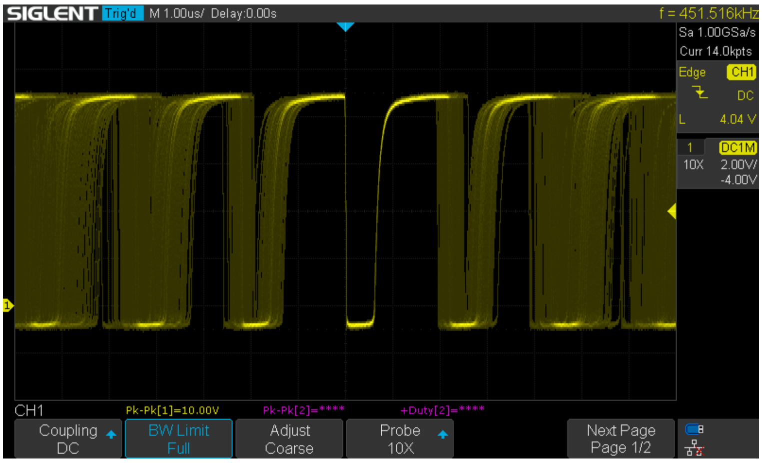
Input impedance is 360Ω. This buffer provides a frequency independent 360Ω load for the preceding filter.

4. Pulse train generator (Q_3, Q_4, Q_5)



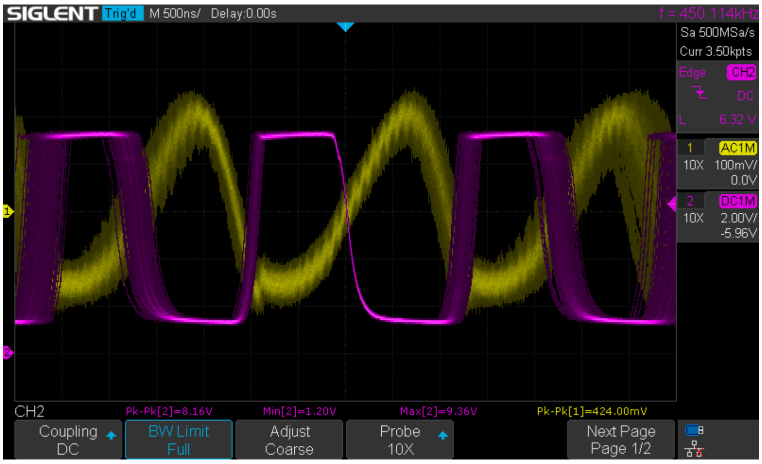
Q_3 provides basic amplification, Q_4 is a follower and Q_5 is the actual pulse train generator.

The pulse train generator generates a fixed width, down-pulse at every rising edge of the input signal. On the output is a pulse train with a duty cycle which is related to the frequency of the input signal. With an FM modulated carrier on the input, the duty cycle directly relates to the instantaneous carrier frequency. After a lowpass filter on the output (ie. taking the average), a voltage results which relates to the instantaneous carrier frequency. Because of this this voltage is directly related to the (audio) signal which was used to modulate the carrier. Net result is demodulation of the FM modulated carrier into the modulating (audio) signal.



SIGNAL ON COLLECTOR OF Q_5. IT SHOWS THE FREQUENCY-INDEPENDENT PULSE WIDTH.

Q_3 provides as much amplification as possible, to drive the circuit C_5-D_1 as hard as possible. It utilises a collector feedback biasing scheme. It has a small amount of negative feedback.



IN- AND OUTPUT OF Q_3. YELLOW = V_{B3}, PINK = V_{C3}.

The Q_3 amplifier is implemented as PNP amplifier. This produces an output signal (at E3) with a longer low period than a NPN amplifier. The longer low period allows for more choice for C_5, which is important for the duration of the output pulse. Q_3 needs to be followed by a buffer. Direct loading it with C_5-D_1 would load it too much.

Q_5 is driven over the C_5-D_1 circuit. The maximal voltage on V_{e5} is equal to the diode drop of D_1 (level 1). At that moment the diode starts to conduct and V_{e5} cannot rise any higher. Minimal voltage on V_{e5} is about -0.6V because of the base-emitter voltage drop V_{be} of Q_5 (level2). With V_{e5} at -0.6V Q_5 starts conducting, which causes the collector voltage of Q_5 to drop. R_{10} should be chosen such that it drives Q_5 into saturation. When V_{e5} is higher than $-V_{be}$, Q_5 is in cutoff, and V_{c5} is equal to V_{cc}.

Q_4 drives down its emitter voltage hard (moment A). This will drive the emitter voltage of Q_5 (V_{e5}) down as well, until it reaches its minimal voltage at the diode drop V_{be} of Q_5 (moment B, level 2). At that moment Q_5 starts to conduct and discharges C_5. Because V_{e5} is negative D_1 does not conduct; the current through Q_5 only feeds the discharge of C_5. The rate at which C_5 discharge is determined by the RC constant of R_{10} and C_5. Discharging C_5 will increase the voltage at E5 V_{e5}.

At moment C the capacitor C_5 is discharged to such a level that V_{e5} is less than the diode drop of the base-emitter junction fo Q_5, Q_5 stops conducting, which causes the voltage at its collector to rise to V_{cc}. Voltage at E5 V_{e5} will remain constant because Ve4 remains constant until moment D, and neither Q_5, nor D_1 conduct until then.

At moment D V_{e4} rises again which will drag V_{e5} with it (neither Q_5 nor D_1 conduct), until V_{e5} reaches the forward voltage of D_1 (at moment E) and will remain at that voltage until the next cycle. This causes C_5 to charge again.

STAGES IN THE PULSE TRAIN GENERATOR.
YELLOW: V_{E4}
DARK BLUE: V_{E5}
LIGHT BLUE: VOLTAGE OVER C_5
PINK: V_{C5}

V_{E4} V_{E5} V_{CAP} V_{C5}

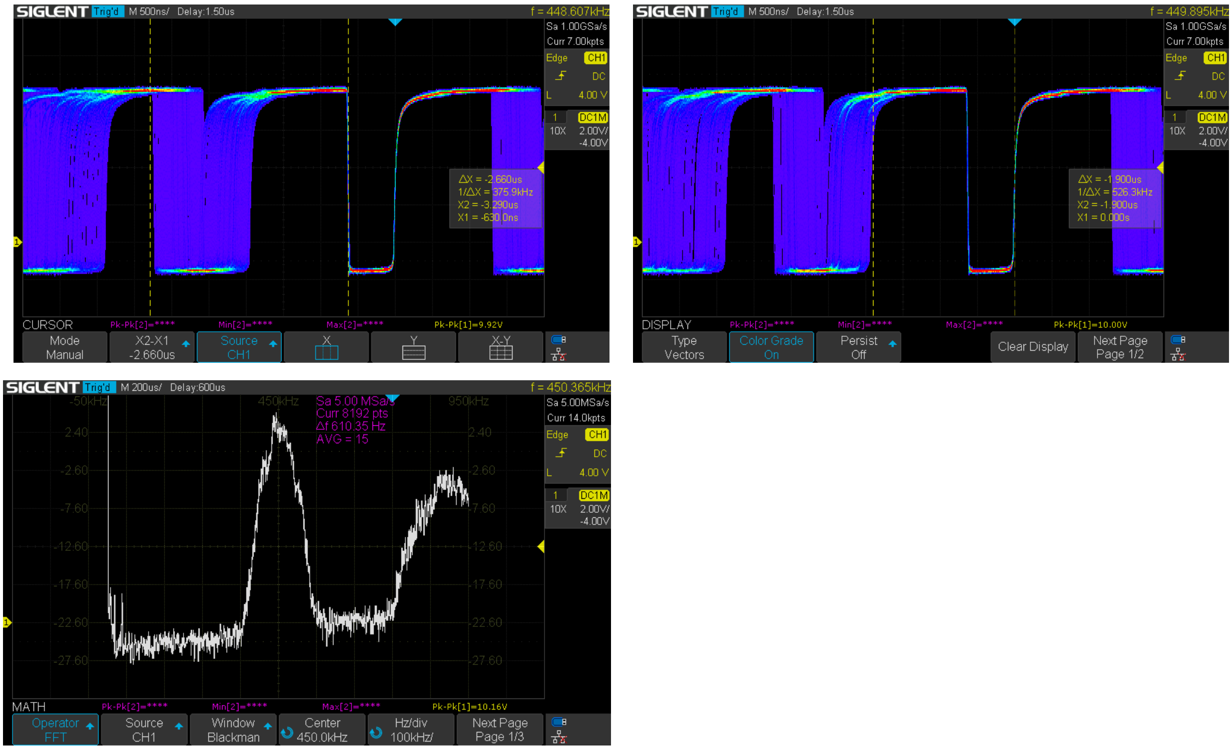
We choose R_{10} such that Q_5 is in saturation when Q_5 is conducting. Then we choose C_5 such that the the discharging time of C_5 is less than the time which V_{e4} is low.

The switching on-off of the current through Q_5 causes V_{c5} to switch between the saturation voltage (V_{C5}≈0V, current > 0) and V_{cc} (current = 0). The rate at which V_{c5} rises from the saturation voltage to V_{cc} is determined by the RC constant of R_{10} and the parasitic capacitance C_{cb} of Q_5. The charging of C_{cb} is shown by the slope of the pink line between moments C and D in the above figure.

D_1 is chosen to have a low voltage drop. By having a low voltage drop it demands less of preceding amplification stages. To have steep edges on V_{c5} we need a voltage as square as possible on V_{e5}. The falling edge on V_{e5} should be steep to get deep and steep pulses on V_{c5}.

DETERMINATION OF R_{10} AND C_5

Values of R_{10} and C_5 have been determined experimentally[1]. First R_{10} is chosen to get Q_5 into saturation. The FM signal is modulated around the IF_2, with a frequency deviation of ±75kHz.



SIGNAL AT C5 SHOWING MAXIMUM FM FREQUENCY DEVIATION OF ±75KHZ AROUND THE SECOND INTERMEDIATE FREQUENCY OF 450KHZ.

Largest audio signal is obtained when the low pulse width on C5 is $[f_{IF_2}]^{-1} / 2 \approx 1\mu s$. To account for variation in Q_5's β, and to allow Q_5's parasitic capacitance to charge through R_{10} it is better to make the pulse width on C5 somewhat smaller. Larger capacitance C_5 gives a longer low pulse on C5.

The next two figures show that the pulse width on C5 (pink) is independent of the frequency of the input signal (yellow is the signal on E4).

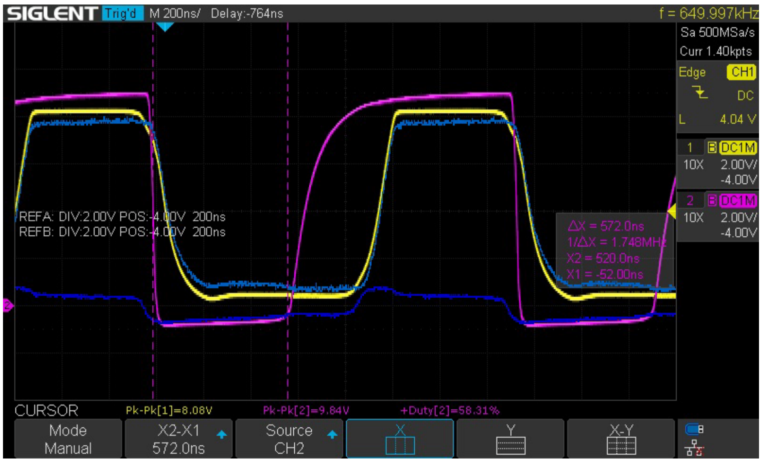
[1] It should be possible to calculate these as well. The discharge time of C_5 can be calculated with

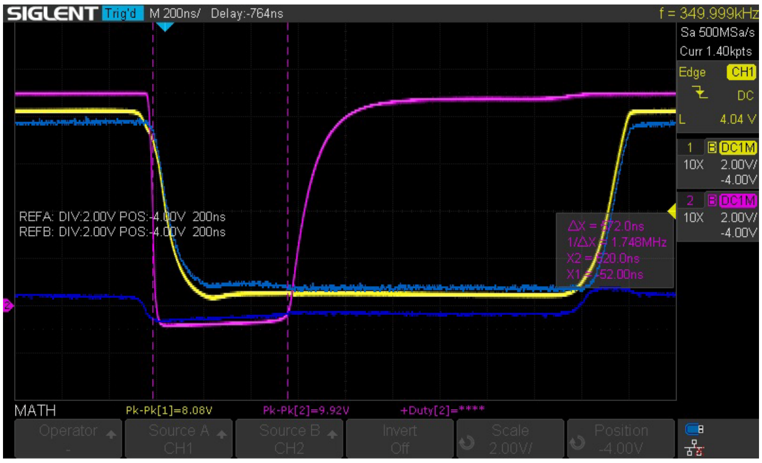
$t = Q_c / I_c = V_c * C_{C_4} * R_{10} / V_{R10}$

where

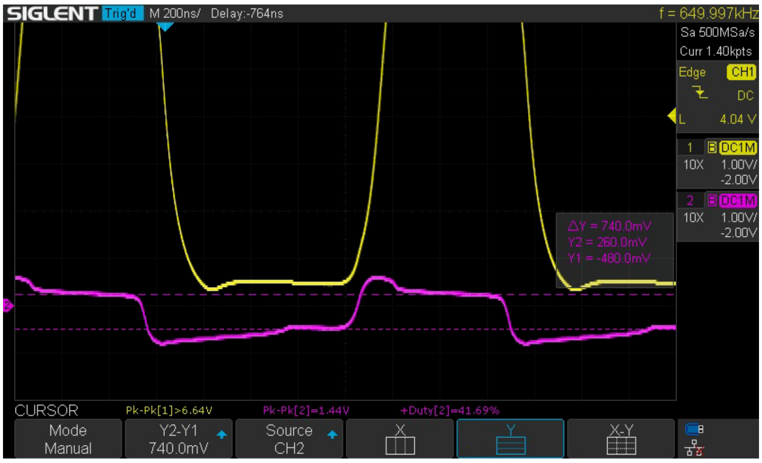
Q_c = charge on C_5
I_c = Q_5 collector current
V_c = maximum voltage over C_5 (=V_{e4}-V_{e5}, ~7V)
C_{C_5} = C_5 capacity (421pF)
R_{10} = 3275Ω
$V_{R_{10}}$ = maximum voltage over R_{10} (9.92V)

This gives $t \approx 0{,}95\mu s$, which is 170% of the measured value.

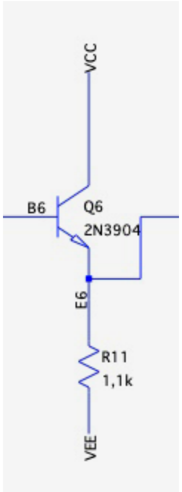




The following figure shows the signal on E5 in pink. The upper and lower voltages represent the D_1 diode drop (about 260mV), and the V_{be} of Q_5 (about 480mV). In yellow the signal on E4.

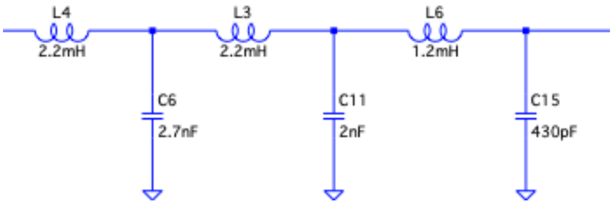


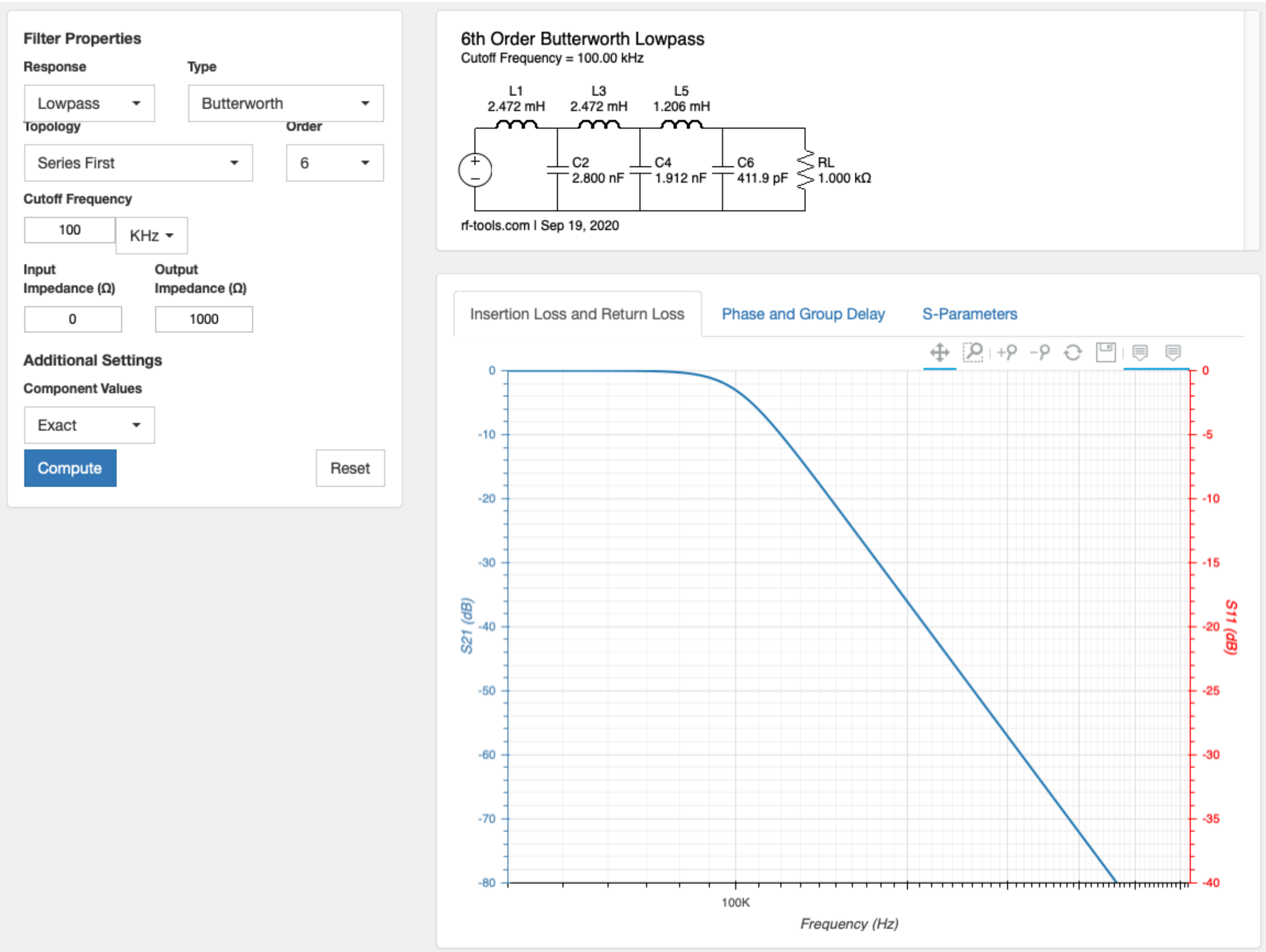
5. Buffer (Q_6)



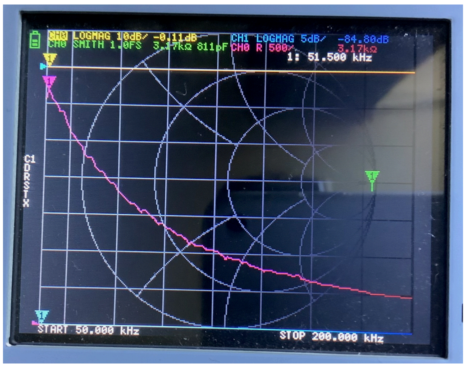
To prevent loading of Q_5 it is followed by a high impedance follower Q_6.

6. Lowpass filter (L_4, C_6, L_3, C_{11}, L_6, C_{15})



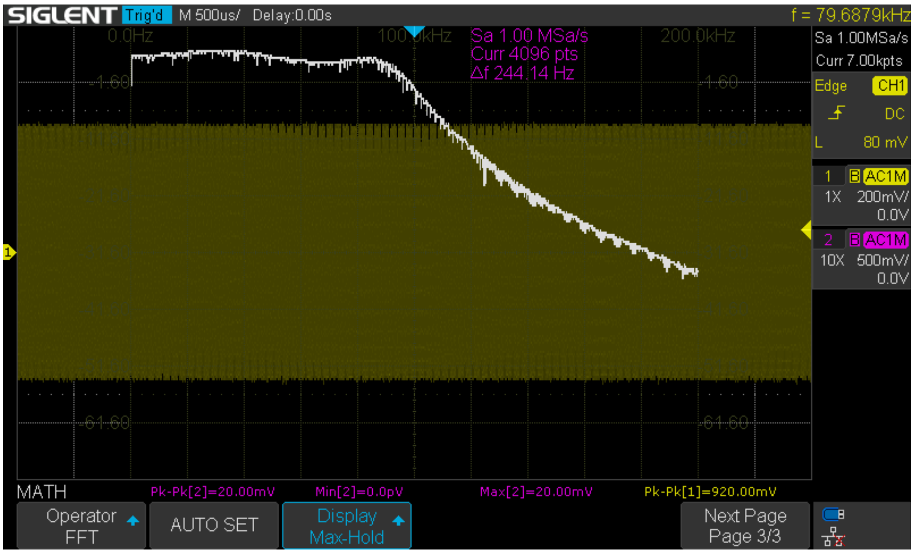


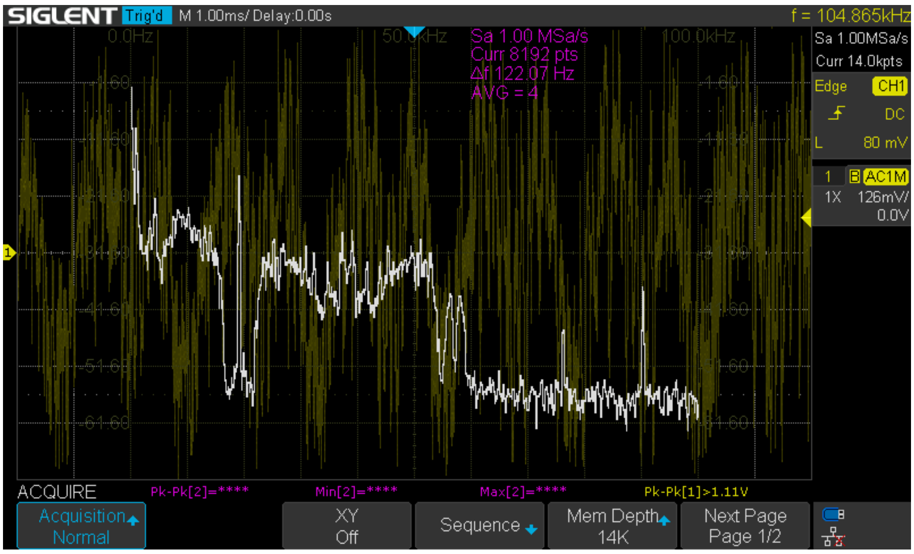
LC filters need a constant load impedance to have a flat frequency response in the passband. For this reason it is followed by a class A 1kΩ input impedance amplifier. The next stage in the lab test setup is a Behringer Xenyx 802 audio mixer which does not have a constant input impedance, see next figure.

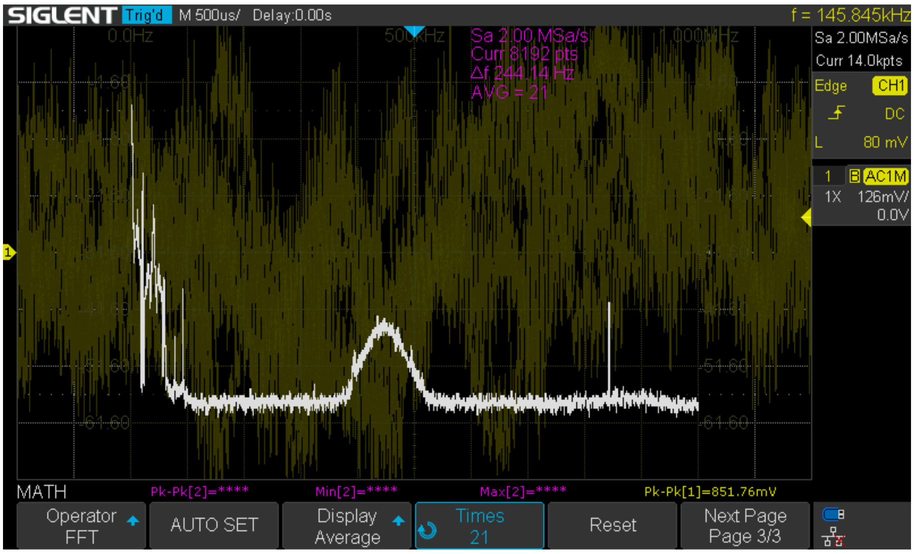


INPUT IMPEDANCE OF BEHRINGER XENYX 802
AUDIO MIXER

Actual implementation of the LC lowpass filter (including emitter follower), input AC-coupled with a 47μF capacitor:







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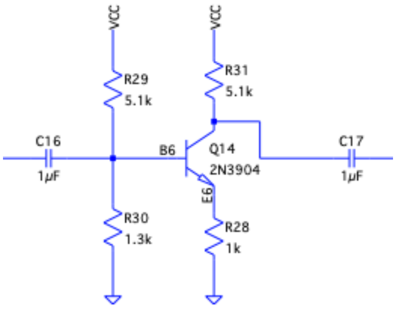
7. Line level amplifier Q14



This amplifier amplifies the audio and FM subcarrier signals to line level. It also provides a constant 1kΩ resistive load for the preceding filter. This amplifier is the last stage in (the current) setup. Next stage is a Behringer Xenyx 802 audio mixer. A stereo decoder can also be implemented after this stage. The output level seems to be right over the entire FM 75kHz bandwidth.