FM Detector Notes

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1 High Level Design

There are a few different types of fm detectors that are commonly used:

- Foster-Seeley Discriminator
- Ratio Detector
- Quadrature Discriminator

Out of all of these, the Quadrature Discriminator seems to be the best for a few reasons:

- Has a simple design only requiring a few components.
- Does not require an RF transformer, which needs to be weakly coupled in the case of the Foster-Seeley Discriminator - cannot easily find one off of digikey/mouser.
- Works with low input levels and has good linearity.

2 Principle of Operation

The original signal is

$$Acos(wt)$$

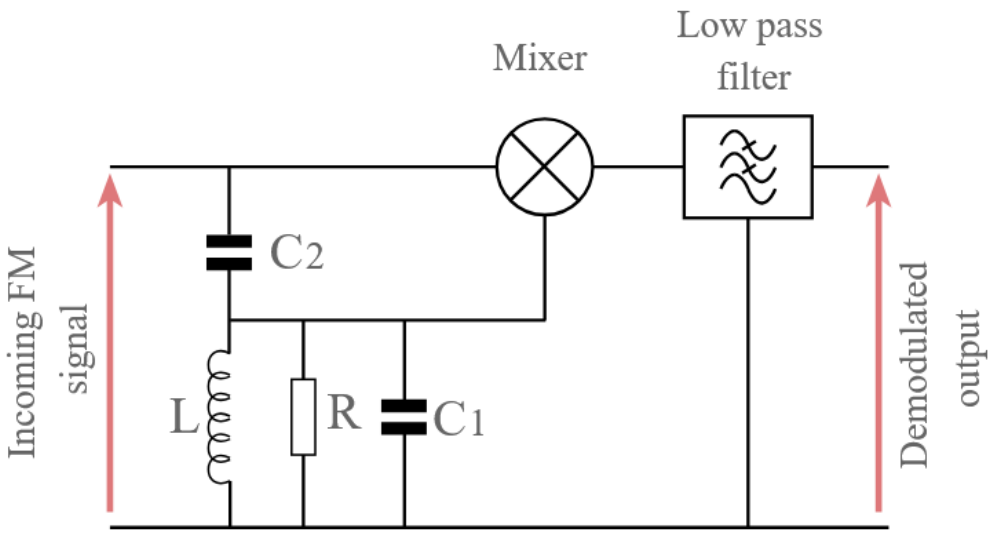
The signal after C2 is shifted by 90 degrees due to the capacitor, and additionally shifted by ϕ due to the difference between the resonant frequency of the tank circuit and the incoming FM signal. Therefore the signal after C2 is

$$Acos(wt + \frac{\pi}{2} + \phi)$$

Multiplying these two together gives

$$Acos(wt) * Acos(wt + \frac{\pi}{2} + \phi)$$

By the identity $cos(a)cos(b) = \frac{1}{2}[cos(a-b) + cos(a+b)]$,



Quadrature FM demodulator

$$= \frac{A^2}{2} cos(-\pi/2 - \phi) + cos(2wt + \frac{\pi}{2} + \phi)$$

Noting that $cos(-\pi/2 - \phi) = sin(\phi)$,

$$= \frac{A^2}{2} sin(\phi) + cos(2wt + \frac{\pi}{2} + \phi)$$

The higher frequency cosine component can be filtered out, leaving a function whose amplitude is proportional to the phase, which in turn is proportional to $sin(\phi)$. For small values of ϕ, this is approximately equal to ϕ.

3 Detailed Design

- For the tank circuit, the self resonant frequency is given by $\frac{1}{2\pi\sqrt{LC}}$. If we choose L = 0.1 uH, then for a resonant frequency of 10.7 MHz, this gives us 2.21 nF.

- For the 90 degree phase shift cap, we can use a small 10 pF cap.
- Since the inductor and capacitor values are not exact, the resonant frequency of the tank circuit will not be exactly 10.7 MHz. This will result in a phase error α. We can AC couple the output to solve this issue.
- $$out = \frac{A^2}{2} sin(\phi + \alpha)$$
- We need a mixer that can mix down to very low frequencies, since the mono baseband is typically 50 Hz to 15 kHz. We can use the same LT5600 that we used earlier for the IF, since according to `https://ez.analog.com/rf/f/q-a/165857/lt5560-low-frequency-performance`, the output goes down to DC.
- We can use an op-amp at the output and pullup resistors since transformers are impractical for DIFF to SE conversion at low frequencies, since the size of transformers is inversely proportional to their frequency for a given power transfer.

Low Frequency Applications

At low IF frequencies, where transformers can be impractical due to their large size and cost, alternate methods can be used to achieve desired differential to single-ended conversions. The examples in Figures 21 and 22 use an

Table 8. Low-Frequency Performance

f_{IN} (MHz)	f_{OUT} (MHz)	G_C (dB)	IIP3 (dBm)	DSB NF (dB)	I_{CC} (mA)
200	0.45	9	3.8	11.6	14
90	0.45	6.8	3.3	22	18

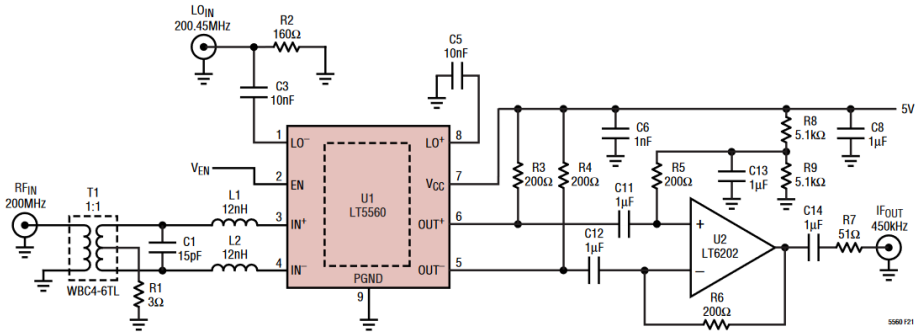


Figure 21. A 200MHz to 450KHz Downconverter with Active IF Interface

4 Mixer Impedance Matching

WAIT AT AUDIO FREQ U CANT USE 0.1 uF BYPASS CAPS! FREQ CAN BE 20 Hz!!

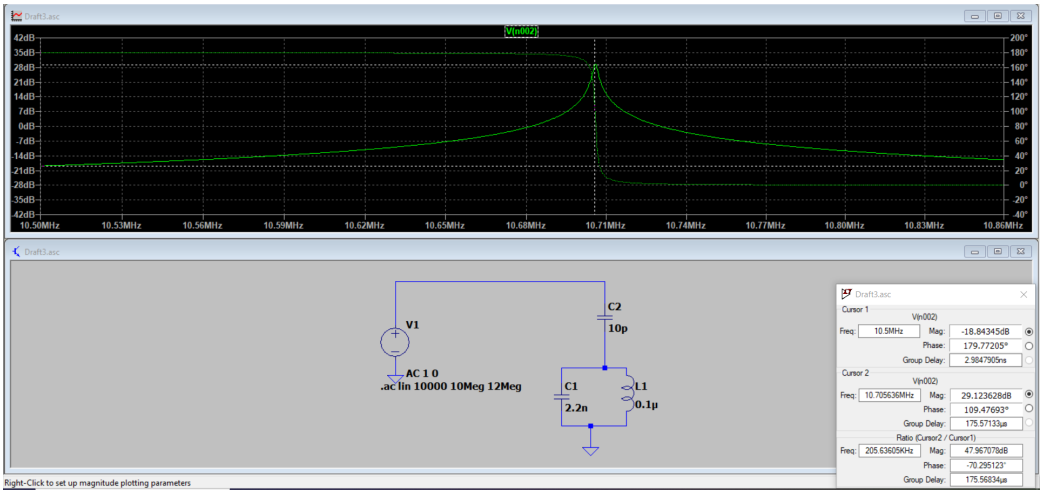
so output needs to be dc coupled to vcc. this won't work. need to choose a different mixer!

The AD831 seems like a good option - it says, "all ports can be DC coupled"!

- For the mixer, at 10.7 MHz the frequency is sufficienctly low so we can assume the input impedance is mostly low. In fact, at this frequency PCB trace length is probably not an issue so impedance matching is not necessary.

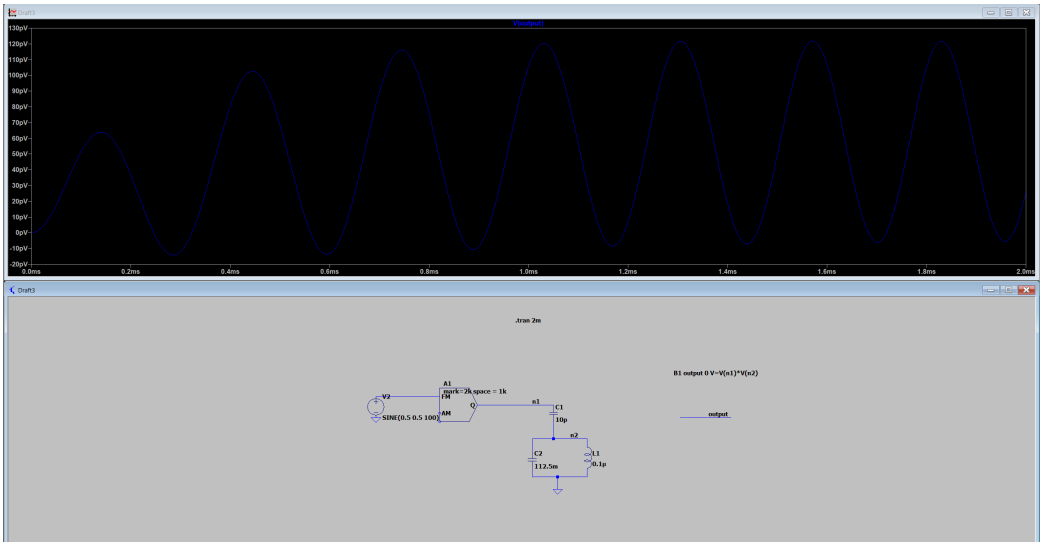
5 Simulations

Here is a simulation of the tank circuit in the discriminator:



Here's a simulation of the fm detector working at low frequencies (at high frequencies LTSpice doesn't handle it very well)

Here's a simulation of the output impedance:


V(output)
130pV
120pV
110pV
100pV
90pV
80pV
70pV
60pV
50pV
40pV
30pV
20pV
10pV
0pV
-10pV
-20pV
0.0ms
0.2ms
0.4ms
0.6ms
0.8ms
1.0ms
1.2ms
1.4ms
1.6ms
1.8ms
2.0ms
Draft3
.tran 2m
B1 output 0 V=V(n1)*V(n2)
output
A1
mark=2k space = 1k
V2
FM
AM
SINE(0.5 0.5 100)
Q
n1
C1
10p
n2
C2
112.5m
L1
0.1µ