ENEE 307
Electronic Circuit Design Laboratory
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Wireless Communications-Receivers

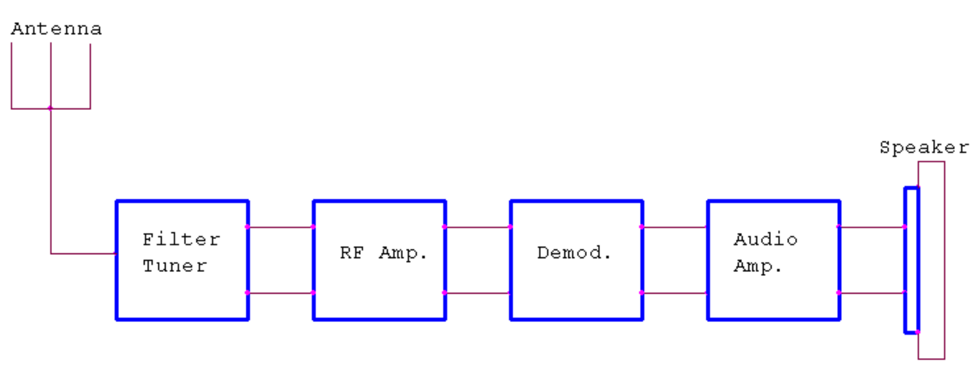
3.1. Wireless Communications: RF Receivers.

At this stage you have built and understood the amplification of signals in the Audio range and the High Frequency (RF and Video) range. For this lab project you will need to study filters and modulators-demodulators, so you can realize an RF receiver.

Before coming to this lab you should have your PSPICE design ready to show to your TA and have studied Chapter 16, band pass filters, with emphasis on LCR resonators (pp 1279-1285), and Chapter 17, signal generators, with emphasis on LC oscillators, in Sedra and Smith 6th Edition. Include your PSPICE design results in your report.

3.1.1. Receiver Lay-out.

Most common wireless communication receivers consist of the following elements shown in the block diagram of Fig. 3.1:



1. The antenna,
2. Front end band-pass filter (tuner),

3. RF amplifier,
4. Demodulator,
5. Audio amplifier,
6. Speakers.

Since the audio signal which has a frequency between 20Hz and 15KHz needs to be propagated in the atmosphere by different radio stations, i.e. different channels, the audio frequencies are incorporated into a carrier frequency in the radio frequency range with each station having its own characteristic carrier frequency. There are two ways of transmitting the signal:

1. Amplitude modulation or AM, where the carrier amplitude is modulated by the audio signal and,
2. Frequency modulation or FM, where the carrier frequency is modulated by the audio signal.

In this lab we will deal with AM reception and transmission.

3.1.2. Amplitude modulation.

The AM band of radio frequencies (RF) is from 530KHz to about 1600 KHz, and each station has a specific carrier frequency assigned 10 KHz apart from each other.

The carrier is modulated by the modulator in the transmitter and the receiver needs to demodulate the carrier using a demodulator in order for the audio to be retrieved. The modulated broadcast signal S(t) can be expressed as follows:

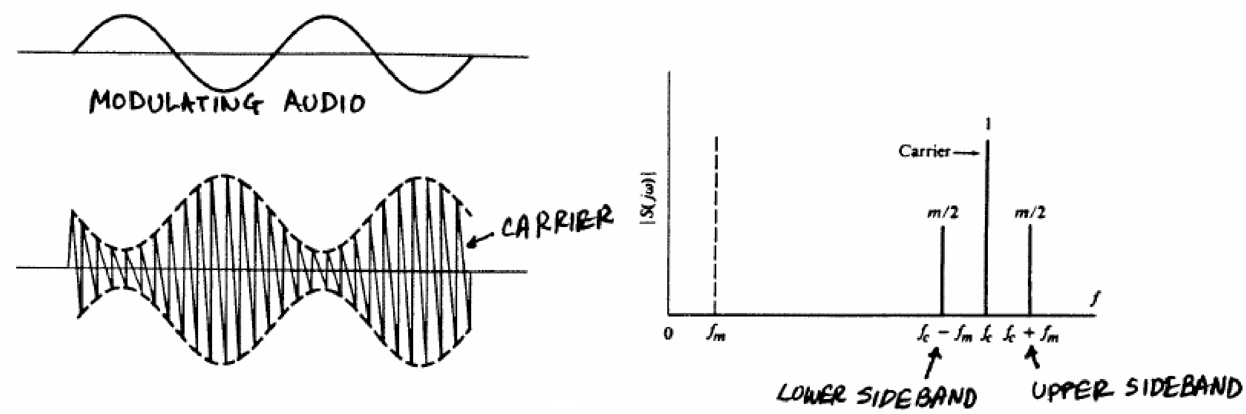
$$S(t) = A_c\,[1+ mg(t)]\sin(\omega_c t) \qquad (3.1)$$

where ω_c is the carrier frequency (angular), A_c the carrier amplitude, and m is the audio modulation index which is less than 1, indicating the level of modulation; that is if m=0.8 then we have 80% modulation of the carrier (100m=80), and g(t) is the modulating signal.

Consider a simple modulating signal $g(t)=\cos(\omega_m t)$ then eq.(3.1) becomes:

$$S(t) = A_c\,\{\sin(\omega_c t) + (m/2)\sin(\omega_c + \omega_m)t + (m/2)\sin(\omega_c - \omega_m)t\} \qquad (3.2)$$

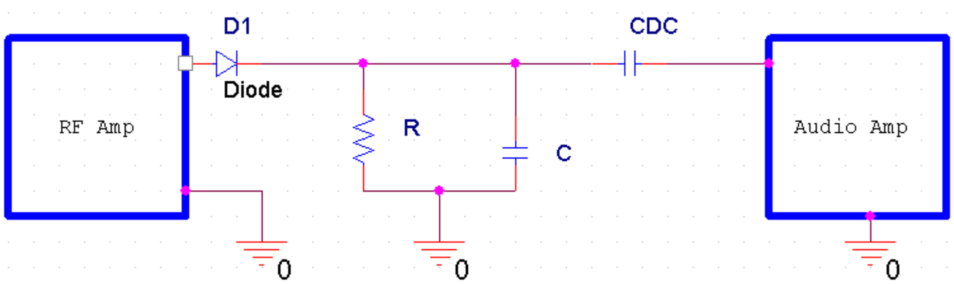
Which basically gives the center frequency of the carrier with an upper $(\omega_c+\omega_m)$ and a lower $(\omega_c-\omega_m)$ frequency side-band each with an amplitude of $A_c m/2$, as shown in Fig. 3.2.



This type of signal is usually called a full-carrier double side-band signal (DSB/FC), and the advantage is that it can be demodulated by a simple peak detector or most often by a single rectifier with an appropriate low-pass filter. The disadvantage of this type of modulation is that most of the broadcast power goes to the center carrier frequency (ω_c) that has no useful information while the two modulated side-bands that carry the information have at best (i.e. for m close to 1) only the 1/3 of the power, which makes for a very inefficient broadcasting system. Still the simplicity of the system makes it attractive enough for understanding the principles of wireless reception and transmission.

3.1.3. Demodulator.

In this lab we will use a single diode half-wave rectifier with an appropriate low pass filter as shown in Fig.3.3 to demodulate the signal.



This type of demodulator is also called an "average envelope detector", and the conditions for good demodulation are as follows:

1. If the voltage at the output of the diode is $V_d(t)$ then:

$V_d(t) = S(t)$ For $S(t) > 0$ (3.3)

$V_d(t) = 0$ For $S(t) < 0$

2. The low-pass filter is designed so that it filters out the component at ω_c and all other components higher than that, hence the output at the end of the filter will be:

$$V_o(t) = A_c[1+mg(t)]/\pi \quad (3.4)$$

3. Another condition is that the maximum modulating frequency should not exceed the half of the carrier frequency:

$$\omega_m(\max) < \omega_c/2 \quad (3.5)$$

4. Finaly for good demodulation:

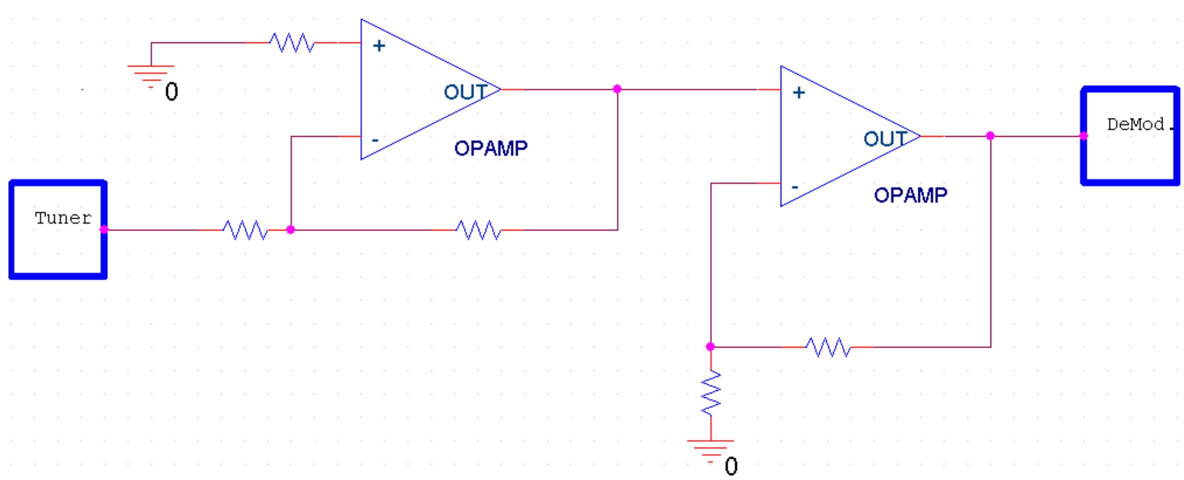
$$RC = 1/[\omega_m \, \omega_c]^{0.5} \quad (3.6)$$

These can serve as some of the design criteria for your demodulator. Points to watch out for are:

1. The diode needs 0.7 V to be "on" in the forward direction, and you would need twice or three times that at the diode input, i.e. 1.5 to 2.1V, for good demodulation. This means that a high gain RF amplifier has to be used to take the signal from the tuner output, usually between 2mV and 6mV, depending on reception and station strength, amplify it between 300 and a1000 times to provide the necessary input volts to the diode.

Your video amplifier is suitable for such a task. You can afford now to reduce its frequency response to about 1.6MHz, and increase its gain significantly.

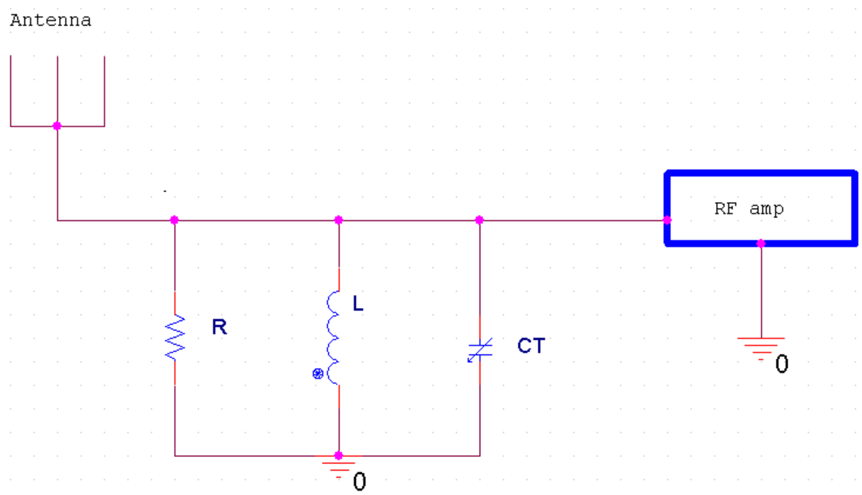
Alternatively you may use an IC amplifier, the **LF 353** (the **LF357 is not available**) op-amp in a two stage arrangement to achieve the desired gain, as shown in Fig. 3.4.



2. You must choose the RC constant to be long enough that the capacitor discharge does not follow the RF, and short enough that it captures all of the modulating signal. Use the criteria above.

3.1.4. Front-end Band-Pass Filter (Tuner).

This is an LCR filter that allows a specific frequency to go through, ω_0, which is the resonant angular frequency of the filter, as shown in Fig. 3.5 below.



The antenna absorbing the broadcasted EM radiation will generate a small current, and hence it can be modeled as a current source for the input of the filter. The output of the filter at the capacitor C, will generate a small voltage only when the filter is in resonance, otherwise the input current flows to the ground. The generated output voltage at resonance is usually around 2 to 6mV as mentioned above, which is then amplified by the RF amplifier.

The resonance frequency is given as:

$$\omega_0 = 2\pi f_0 = 1/[LC]^{0.5} \qquad (3.7)$$

The resistor values can be in the range 1 to 20K, inductor values in the range 20 to 100 μH, and capacitor values 100 to 800 pF, will get you resonances in the AM range.

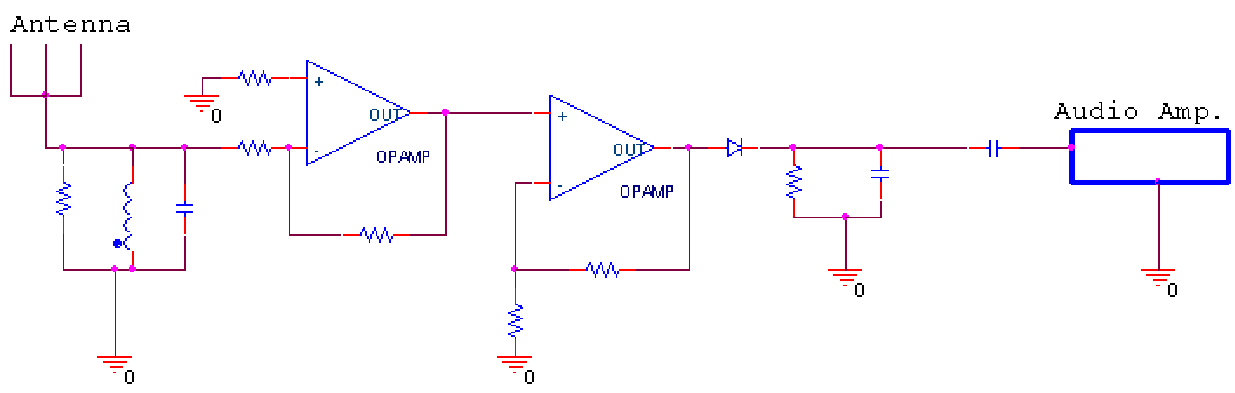
This will give you a fixed resonance frequency, which is useful for your transmitter design that is, you need to make the transmitter to emit at this same frequency.

In order however to receive more than one stations, the resonance must be changed at will, and this is done by replacing the fixed capacitor with a variable capacitor. In this case the filter becomes a tuner.

CAUTION: Due to the construction of the building, the reception is very poor in the lab, so it is unlikely that you will be able to receive a station clearly without an external or amplified active antenna. However you should optimize your tuner for one station that you know the carrier frequency of, and DO NOT DISMANTLE your circuit, so you can use it with your transmitter in the next lab project.

3.1.5. Complete receiver lay-out.

Fig. 3.6 shows the complete circuit lay-out for the receiver.



3.1.6. Lab Tasks.

1. Show complete SPICE design and SPICE characteristics for the tuner, RF amplifier input-output-gain parameters, demodulator characteristics, audio input-output-gain-power parameters. Explain the optimization of the tuner, and demodulator in terms of the relative values of the resistor-capacitor-inductor values.

2. Show measured data from your radio, such as output signal from tuner, from RF amp, from demodulator. You may not be able to distinguish voice, but you will be able to tell when you are tuning on a station so you can measure the relevant quantities.

3. If you are successful on the bread-board make your circuit permanent on the printed board and add volume knobs and an antenna input. This will give you EXTRA CREDIT.