FM Demodulation

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Objective:

To illustrate the concept of FM demodulation using a simple slope detector circuit.

Equipment:

- 15 MHz Synthesized Function and Arbitrary Waveform Generator Agilent 33120A
- 100 MHz Digital Oscilloscope Model Agilent 54600B
- two 50-ohm coaxial cables with BNC connectors
- power supply Agilent E3631A
- IF transformer, 2N3904 transistor, Ge diode
- capacitor substitution box

Prelab:

1) Read the experiment description.

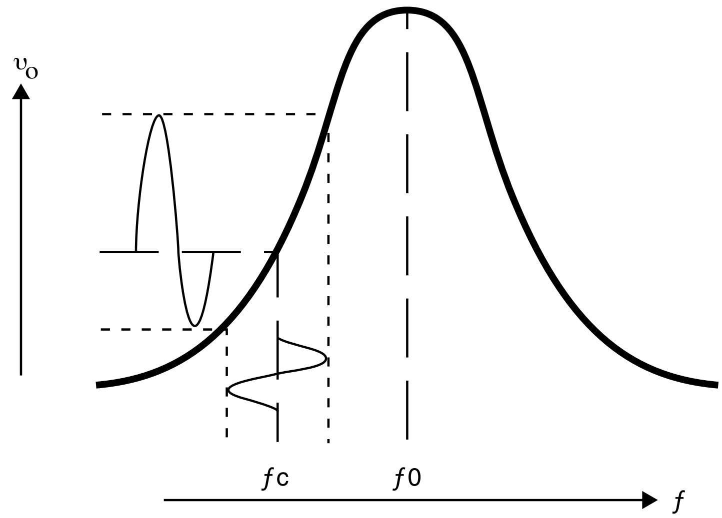
Theory:

We know that the instantaneous frequency of an FM signal is proportional to the amplitude of the modulating signal. Therefore, an FM demodulator should produce an output which is proportional to this instantaneous frequency.

There are three general categories of FM demodulator circuits, which are, "phase-locked loop demodulator," "slope detection/FM discriminator" and "quadrature detector." Although slope detection is rarely used in practice because of its nonlinearity, it is relatively simple to implement. Hence, we consider slope detection to illustrate basic concepts in this experiment.

The basic idea is to set the center frequency of a tuned circuit such that the FM carrier signal falls on the slope of the resonance curve. This way, any increase in frequency of the FM signal will result in a larger signal amplitude at the output of the tuned circuit, and any decrease will result in a smaller amplitude.

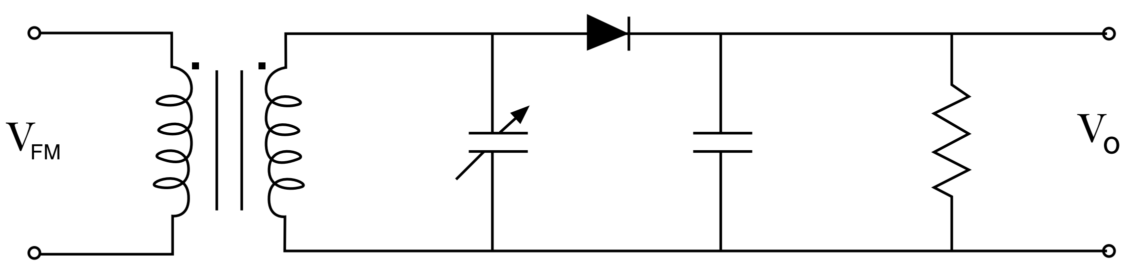
Consequently, the output of the tuned circuit becomes an amplitude-modulated signal (in addition to FM modulation). At this point, an envelope detector such as the one used for AM detection can be employed to detect the information-bearing signal.



Tuned circuit transfer characteristics

As can be seen from the figure above, frequency-to-amplitude conversion will in general be nonlinear. However, frequency deviation of FM can be kept small enough to approximate linear transfer characteristics.

A conceptual circuit for the slope detector is shown below. We will, however, use an active transistor circuit for actual implementation.



Slope detector conceptual circuit

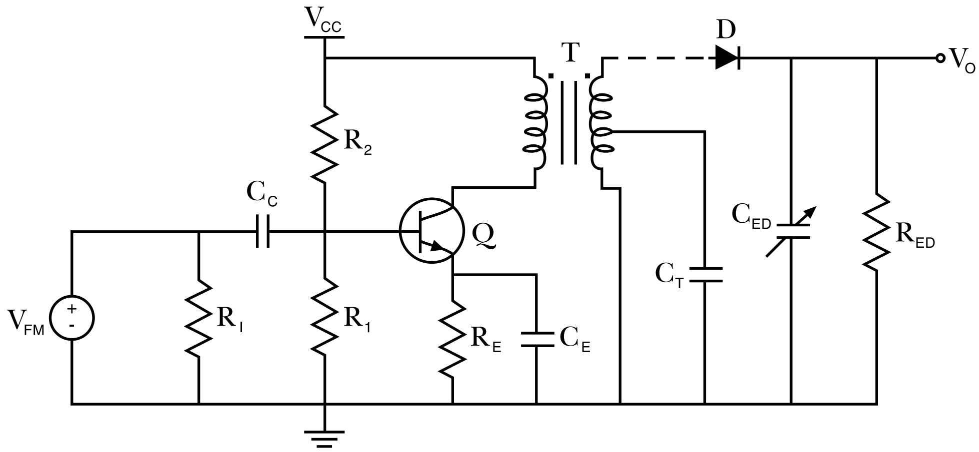
Procedure:

1) Setup: We will use internal triggering on the scope in this experiment; hence, do not connect any cable between SYNC OUT of the ARB and EXTERNAL TRIGGER of the scope. Power on the instruments and enable MAIN OUT of the ARB. The particular signals to generate will be described later.

2) Intro: In this experiment, we will consider a simple slope detector circuit for FM demodulation. A transistor amplifier is used for additional gain.

We will bias the transistor at I_C @10 mA. For this, we choose $R_1 = 10\ \text{k}\Omega$, $R_2 = 6.8\ \text{k}\Omega$, $R_E = 470\Omega$ and $V_{CC} = 10$ V. The coupling and emitter bypass capacitors are chosen as $C_C = C_E = 0.1\ \mu$ F. An input resistance $R_i = 56\Omega$ is also used to approximately match the ARB output to the circuit input.

The tuned circuit capacitor is selected to be $C_T = 500$ pF. This will provide tuning capability for the IF transformer around an IF frequency of 455 kHz.



The envelope-detector resistor is chosen as $R_{ED} = 33\ \text{k}\Omega$ so as not to extensively load the output transformer. You will use the capacitor substitution box to adjust C_{ED} for envelope detection. The resulting circuit is shown above.

3) **Initial Tuning:** We would first like to tune the circuit so that the FM carrier frequency falls on the slope of the tuned circuit response curve.

Build the circuit shown above, but keep the diode anode disconnected from the transformer secondary (the dashed line) for the time being. Verify the operating point of the transistor.

Generate a 460 kHz, 100 mV p-p *sine* waveform on the ARB and connect to the input. Verify that the arb is set for 50 ohm termination. Use the scope to observe the transformer secondary, and tune the transformer so that the secondary voltage is maximized. Record the peak-to-peak value of the transformer secondary.

Now, decrease the input signal frequency by 1 kHz down to 459 kHz and record the transformer secondary peak-to-peak. Repeat this process for all input frequencies down to 445 kHz. At this point, you should have a plot of transformer secondary vs. input frequency for the range of frequencies from 445 kHz to 460 kHz. This gives you the left side of the tuned circuit response curve.

By observing the response curve you have just obtained, decide what the carrier frequency of the FM signal, f_c, should be. Then re-tune the transformer so that the FM carrier frequency falls at 455 kHz. (*Example:* Let's assume that by looking at the transfer curve obtained, you have decided that the FM carrier should fall at 452 kHz. This means that, in order to move the FM carrier up to 455 kHz, the whole response curve should move up by 455 - 452 = 3 kHz. This, in turn, means that the tuned circuit should be tuned to 460 + 3 = 463 kHz, instead.)

Again, by observing the response curve, decide what the frequency deviation, $\Delta f_c(\text{pk})$, should be so that the frequency-to-amplitude transfer characteristic is approximately linear. It will probably be somewhere from 500 Hz to 2 kHz, but use your own judgment.

4) **FM Detection:** Now, generate an FM signal with a *center frequency* of 455 kHz, and *deviation* as determined above. Set the *mod freq* to 1 kHz and *mod signal* to *sine*. Make sure that *Vpp* is 100 mV p-p and apply the FM signal to the input of your circuit. Connect the diode anode to the transformer secondary (dashed line).

Observe V_o on the scope and adjust C_{ED} for a good compromise between ripples and diagonal clipping. Record peak-to-peak and dc values, and frequency of the displayed waveform. Does it look like the modulating signal?

Now, vary the tuning of the transformer as you observe the detected signal on the scope. Describe what happens to the output as you vary the tuning of the transformer from one end to the other, and explain why. Finally, try to tune the transformer so that it returns to the point before you started varying it (output waveform will have the same peak-to-peak and dc values as before).

We now want to observe the linearity, or lack thereof, of the slope detector. For this, set mod *signal to triangle*, and keep all other parameters of the FM waveform unchanged.

Again, observe V_o on the scope and adjust C_{ED} for a good compromise between ripples and diagonal clipping. Does the output waveform look like a perfect triangle? If not, your FM carrier frequency is probably located on a highly nonlinear section of the tuned circuit response curve. Adjust the transformer tuning until you are satisfied with the linearity and magnitude of the detected signal. Record the peak-to-peak and dc values of the signal.

Now, we want to identify this new f_0 for the tuned circuit. For this, apply a sinusoidal waveform of 100 mV p-p at approximately 460 kHz to the circuit, and disconnect the diode anode from the transformer secondary. Observe the transformer secondary on the scope while you vary the frequency of the ARB until the transformer secondary signal is maximized. Read the frequency off the ARB; this is the new center frequency of the tuned circuit.

Finally, we would like to observe the effect of increasing the frequency deviation. Generate an FM signal with a *center frequency* of 455 kHz, and *deviation* three or four times the earlier figure. Set the *mod freq* to 1 kHz and *mod signal* to *triangle*. Make sure that *Vpp* is 100 mV p-p and apply the FM signal to the input of your circuit. Reconnect the diode to the transformer and observe V_o on the scope. Does the output look like a triangle? Explain what happened.

Now, try to readjust C_{ED} for a better-looking triangular waveform. Is it possible? Finally, try to re-tune the transformer for a better triangular waveform. Are you able to get a perfect triangular waveform?

Congratulations! You have finished the lab.

Report:

Your report should include answers to the following questions:

A) *Procedure 3 questions:*

1) What is the operating point of the transistor?
2) Plot the response curve of the tuned circuit.
3) What should be the location of f_c based on the above response curve?
4) What is the new center frequency, f_0, of the tuned circuit so that f_c falls at 455 kHz?
5) What should be the deviation, Δf_c(pk), based on the tuned circuit response curve?

B) Procedure 4 questions:

6) What are the value of C_{ED}, and the resulting time constant for envelope detection of the sine waveform?
7) What are the peak-to-peak and dc voltages, and the frequency of the detected sine waveform?
8) Describe what happens to the detected signal as you vary the tuning of the transformer from one end to the other, and explain why.

9) What are the value of C_{ED}, and the resulting time constant for envelope detection of the *triangle* waveform?

10) What are the peak-to-peak and dc voltages of the detected *triangle* waveform after tuning the transformer for better linearity?

11) What is the new center frequency, f_0, of the tuned circuit after tuning the transformer for better linearity?

12) Describe and explain what happened to the detected triangle waveform when the frequency deviation of the FM signal was tripled (or quadrupled).

13) Are you able to obtain a linear triangle waveform by readjusting C_{ED} and/or re-tuning the transformer? Explain.

Reference:

Electronic Communication Techniques, by Paul H. Young, 3rd Edition, Macmillan Publishing Company, 1994: *Section 9.6*.