EM 334
COMMUNICATION SYSTEMS I
LABORATORY MANUAL

Information Signal (AF)
Angular Frequency WA

Carrier Signal (RF)
Angular Frequency WC

Amplitude modulated signal (AM)

2010-2011 SPRING
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EXPERIMENT 1: PASSIVE FILTERS

PURPOSE:
To investigate filter circuits and to understand the application sites and the aims of these circuits.

THEORY:
Filters are used frequently in communication systems. Filters, in general, allow a certain range of frequencies to be passed from input to output, while discriminating or attenuating other frequencies. Filtering occurs when the output power decreases to its half, in other words when the input voltage is 0.707 of the output voltage.

According to the type and the sensitivity of filtering, there exist various number of filter circuits. The four basic types of filters are low pass (LF), high pass (HF), band-pass (BPF), and band-rejection (BRF) filters.

Basically, a low pass filter allows lower frequencies to pass (under certain limit determined the user) while rejects the higher frequencies from this limit. This means, up to this limit input remains same, but above the limit input decreases to its 1/7. When the frequency increases this ratio also increases. But this ratio is enough. A simple low pass filter circuit and its output characteristic curve can be seen in fig.1.

A high pass filter is the inverse of a low pass filter. A high pass filter rejects frequencies up to a limit determined by the user while allows the frequencies to pass above this limit. In fig.2, a high pass filter and its output characteristic curve can be seen.

![Low pass filter circuit](image1)

**Figure 1: Low pass filter circuits and output characteristic.**
A band pass filter passes a frequency band in a certain range determined by the user while rejects the lower and upper frequencies out of this range. In this filter, inductor and capacitor are used together. The center frequency at this range is determined by the resonance frequency at this inductor and capacitor. A little amount of signal is passed below and above at this resonance frequency and the others are rejected. The wideness of this band depends on the inductor and capacitor value. A band pass filter circuit and output characteristic curve is given in fig.3.

A band reject filter is the inverse of band pass filter. It rejects a frequency band in a certain range determined by the user. Inductor and capacitor are used together in this filter. The center frequency of the selected band is determined by the resonance frequencies of the inductor and capacitor. In fig. 4, a band reject filter circuit and its output characteristic curve can be seen.
By combining these circuits, it is possible to make more sensitive decisions up on the frequencies to be allowed or rejected. The circuits given above are used experimentally, so the circuitry used in practical applications are more complicated. There exist active filters obtained by using amplifier circuits. Although the filter circuits need long calculations, the aim of this experiment is to illustrate the event basically.

**EXPERIMENTAL PROCEDURE:**

**Attention:**

A. Calibrate the oscilloscope before measurements.

B. Adjust the value of input signal after connecting the source to circuits.

1. Set the circuit given in fig.1-a. Set the oscilloscope DUAL MODE, observe the output and the input signals at the same time during the experiment. Adjust the amplitude of signal generator to $4V_{pp}$. Keep the voltage value constant due to the frequency change. Fill table 1 for the given frequency values. While calculating the cut off frequency remember that $Vo/Vi = 0.707$.

2. Repeat step 1 for fig.1-b.

<table>
<thead>
<tr>
<th>Table 1:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>F(kHz)</strong></td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>2</td>
</tr>
</tbody>
</table>

3. Repeat step 1 for the circuits in fig.2 and fill table 2 for the given frequency values.

<table>
<thead>
<tr>
<th>Table 2:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>F(kHz)</strong></td>
</tr>
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<td>2</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>2</td>
</tr>
</tbody>
</table>
4. Measure the frequency values given in table 3 for the circuits shown in the fig.3. Find the upper and the lower cut off frequencies. The most suitable way to find the resonance frequency is to find the frequency value that makes the angle zero. (use the figure of lissajous).

<table>
<thead>
<tr>
<th>F(kHz)</th>
<th>$V_{lp-p}$(Volt)</th>
<th>$V_{ot-p}$(Volt)</th>
<th>$V_o / V_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.707</td>
</tr>
<tr>
<td>$f_c=$</td>
<td>1</td>
<td>0.707</td>
<td>0.707</td>
</tr>
<tr>
<td>$f_o=$</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>$f_{(up)}=$</td>
<td>1</td>
<td>0.707</td>
<td>0.707</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.707</td>
</tr>
</tbody>
</table>

5. Repeat step 4 for the circuits shown in fig.5 with using table 4.

<table>
<thead>
<tr>
<th>F(kHz)</th>
<th>$V_{lp-p}$(Volt)</th>
<th>$V_{ot-p}$(Volt)</th>
<th>$V_o / V_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.707</td>
</tr>
<tr>
<td>$f_c=$</td>
<td>1</td>
<td>0.707</td>
<td>0.707</td>
</tr>
<tr>
<td>$f_o=$</td>
<td>1</td>
<td>1</td>
<td>0.707</td>
</tr>
<tr>
<td>$f_{(up)}=$</td>
<td>1</td>
<td>0.707</td>
<td>0.707</td>
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<tr>
<td>1</td>
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</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.707</td>
</tr>
</tbody>
</table>
EQUIPMENT LIST:

1. RF signal generator
2. Oscilloscope
3. Resistors (10Ω, 100Ω, 1KΩ, 10KΩ)
4. Capacitor (1μF)
5. Inductor (0.635mH)

QUESTIONS:

1. For each circuit, plot Vo/ Vi versus frequency.
2. For each circuit, calculate the value of inductor, used in this experiment, according to measured frequency.
EXPERIMENT 2: OSCILLATORS

PURPOSE:
To investigate different oscillator types and to compare with each other.

THEORY:
Oscillator is a circuit that produces a signal whose frequency and amplitude is defined. Oscillators can produce signals in different forms. The frequency and amplitude of these signals could have been regulated. Oscillators not only used to produce a signal but also used for different purposes (mixer, amplifier and a modulator etc.).

Normally oscillators are amplifiers. Their operating principle depends on a positive feedback and a resonant circuit at the input. There are many kinds of oscillators. All oscillators have the same operation principles. But the difference between them is the resonant circuit and the circuitry.

Generally, we should use fig.1 to explain the operation of oscillators. Think that we apply instantaneous DC voltage to (LC) resonant circuit at fig.1. When the energy is cut off, the capacitor discharges over the inductor and this creates an induced voltage on the inductor. And then the induced voltage across the inductor charges the capacitor in the reverse direction. Again the capacitor discharges current into the inductor and the induced voltage across the inductor charges the capacitor in the reverse direction. This will form an alternating voltage with positive and negative alternates.

As you know; none of the circuits are lossless. So this circuit has some losses because of the ohmic resistance of inductor. This energy loss will cause the sinusoidal oscillation to damp. To provide the continuous oscillations, we have to provide some additional energy into the circuit at each period. As a result; feedback circuit performs as an oscillator by giving the lost energy to the circuit and transistor acts as a switch.

For continuous oscillation, the amplifier gain must be greater than or equal to 1. We have to use a feedback circuit to provide losses at resonant circuit. So the input impedance and the output impedance of feedback circuit should be balanced. For this situation, generally the common-emitter amplifiers are used. Because the input and output impedance of common-emitter amplifiers are at the middle level. Oscillation frequency is adjusted by changing the value of input circuit element. We provide required amplitude value with adjusting the amplifier gain. A general oscillator circuit is shown in fig. 2.
There are many kinds of oscillators because of the changes of the resonant circuit. For example; THICKLER, COLPITS, CLAPP, PHASE-SHIFT, CRYSTAL, WIEN BRIDGE.

SERIES-HARTLEY OSCILLATOR

A transistor series Hartley oscillator is shown in the fig.3. As you seen tank circuit is connected in series between amplifier and power supply. The frequency formula of this oscillation frequency is given by

$$f = \frac{1}{2\pi \sqrt{L_1 C_t}}$$

The ratio of feedback and amplitude depends on the induced voltage ratio across $L_1$ and $L_2$. 

Figure 2: General oscillator block diagram.

Figure 3: Series Hartley oscillator.
PARALLEL HARTLEY OSCILLATOR

As you seen, in the following circuit (fig. 4); tank circuit is connecting parallel to the biasing voltage. The middle terminal of inductor is grounded so 180 degree phase shift feedback is obtained. The oscillation frequency is \( f = \frac{1}{\sqrt{2\pi (C_t L_t)^{1/2}}} \).

![Figure 4: Parallel Hartley oscillator.](image)

COLPITTS OSCILLATOR

This oscillator that in the figure(fig. 5) is shown. The frequency of this oscillation
\[ f = \frac{1}{\sqrt{2\pi (C L)^{1/2}}} \]
\[ C = C_1 \times C_2 / (C_1 + C_2) \]
Feedback depends on the value of capacitance C1 and C2. This ratio is obtained by \( n = C_1 / (C_1 + C_2) \) where \( n << 1 \). So we have to select \( C_1 << C_2 \).

![Figure 5: Colpitts oscillator](image)
CRYSTALL OSCILLATOR

We have to use crystal oscillator where the needed oscillation frequency is sensitive. In the crystal oscillator circuit; crystal act as a tank circuit. Crystal’s electric equivalent circuit is as follows. (fig. 6).

![Crystal Electric Equivalent Circuit](image)

**Figure 6: Crystal Electric Equivalent Circuit**

**EXPERIMENTAL PROCEDURE:**

**Attention:**

A. Calibrate the oscilloscope before measurements.
B. Adjust the value of input signal after connecting the source to circuits.

**Colpitts oscillator**

1. Setup the circuit shown in fig. 5.

2. Obtain AC (sine) signal from the collector by adjusting the potentiometer.

3. At the circuit, base is input an collector is output. Measure DC voltage for both input and output.

4. Set the oscilloscope to AC and DUAL mode. Obtain the feedback ratio by observing the input and output at same time.

5. Record the phase of feedback which is applied to input and output.

6. Repeat all these steps for different $R_E$ resistors and give the measurements for voltage and phase in a table.

7. Observe the changes after removing $C_C$ capacitor.

8. Measure input and output voltage and record the phase of circuit by connecting 2.7nF capacitor to 1.2nF capacitor both in series and parallel.
EQUIPMENT LIST:

1. Oscilloscope
2. DC Power Supply
3. Potentiometer (100K)
4. Resistors (10KΩ, 1KΩ, 2.2 KΩ)
5. Capacitors (1 μF, 100nF, 6.8nF, 150nF)
6. Inductor (0.635mH)
7. Transistor (BC 238)

QUESTIONS:

1. Removing the $R_E$ resistor, how does the output affected? Explain.
2. Removing the $C_C$ resistor, how does the output affected? Explain.
3. Explain why the output peak to peak voltage value more than 10 volt while supply voltage is equal to 10 volt. Explain.
PURPOSE:
To obtain the characteristics of amplitude modulator and modulated wave, by investigating amplitude modulation.

THEORY:
The operation of modulation is adding the information signal on to a carrier signal. The information signal is the voice, image etc. (audio frequency – AF), and the information frequency is radio frequency (RF). In amplitude modulation, the amplitude of the carrier wave is changed due to the change in the amplitude of the information signal. This case is shown in fig.1.

The amplitude modulator is not linear. The waveform of amplitude modulation is shown below.

Amplitude Modulation Wave Forms:

Figure 1: Amplitude Modulation

Figure 2: The Waveform of Amplitude Modulation
The modulated amplitude signal has three frequency components. These are data frequency, upper side band frequency and lower side band frequency. Amplitude modulation is given by

\[ V = (E_C + E_A \cos W_A t) \cos W_C t \]  

\( W_A \): radial frequency of modulated signal,  
\( W_C \): radial frequency of carrier signal,  
\( E_A \): amplitude of modulated signal,  
\( E_C \): amplitude of carrier signal.

\[ m = \frac{E_A}{E_C} \]  

\( m \) is called as modulation deepness or modulation index or modulation factor. From equations (1) and (2):

\[ V = E_C \cos W_C t + E_C \left( \frac{m}{2} \right) \cos (W_C + W_A) t + E_C \left( \frac{m}{2} \right) \cos (W_C - W_A) t \]

The carrier information is placed only on side bands. Side bands are formed from addition and subtraction of the frequencies of carrier and modulated signal. Relative amplitude of side bands depends on changing degree between carrier signal and modulated signal and this can be named as modulation factor. Modulation factor is given as:

\[ m = \frac{V_{\text{max}} - V_{\text{min}}}{2V_0} = \frac{V_{\text{max}} - V_{\text{min}}}{V_{\text{max}} + V_{\text{min}}} \]

Modulation factor is determined as percentage and especially it is important for determining modulation efficiency.

Modulation efficiency is defined as the ratio between the side bands’ energy and modulated waves’ energy. As the modulation factor approximates to 100%, the modulation efficiency increases. When the modulation factor is 100%, the power which transfers from input signal to modulated wave is maximum, and at that point the modulation efficiency is 33%.

The bandwidth is twice of the information signal. In general, the information signal is 4.5 kHz and so the bandwidth is formed as 9 kHz.

When the amplitude of modulator signal exceeds the amplitude of carrier (when the modulation exceeds 100%), over modulation occurs. This is not a desired position because of distortion on the transmitted information signal. In practice, the maximum modulation factor is taken as 100%.

The emitter current and so the voltage gain is changed by depending on the amplitude of modulated signal in amplitude modulator. So an output which is depending on the amplitude of modulated signal is obtained. This type of amplitude modulator is shown in fig.3.
This modulator is a normal adjustable amplifier. It is a resonance circuit which had adjusted to load carrier frequency. The output is taken with an variable inductor. Without AF input, a carrier signal is taken from output that depends on $R_{B1}, R_{B2}$ and $R_E$ resistors. With AF input; a potential is obtained due to the voltage drop across $R_E$. And that changes the emitter current by depending on the amplitude of the modulated signal. This changing affects amplifier gain directly and so the output voltage.

When the AF voltage is maximum, the emitter current is also maximum, and so the voltage gain is maximum. In this case the amplitude of RF at the output is maximum, too. When the AF voltage becomes negative, the emitter current decreases and the amplitude of RF goes down to minimum.

EXPERIMENTAL PROCEDURE:

Attention:

A. Calibrate the oscilloscope before measurements.
B. Adjust the value of input signal after connecting the source to circuits.

Procedure before Starting to Experiment:

a. Work with 1:10 probe setting because the effect of the oscilloscope probes to the circuit.
b. For triggering the modulated wave, an audio signal source can be connected to the Ext. trig input.
c. The modulator regulation, the frequency response, its linearity and over modulation will be examined. For this purpose, firstly, the modulator is adjusted to the desired frequency. Then, the sensitivity of the modulator is examined for a stable modulation factor. This sensitivity become less with the increase of frequency. This test determine the modulation band-width. The modulation is examined by changing the AF voltage, to determine the linearity. The ratio between the AF voltage and the modulation must be linear as much as possible.
1. Modulator Adjustment

1.1. Connect the oscilloscope to the modulator output
1.2. Turn on the RF signal generator by adjusting it to 455KHz and maximize the efficiency.
1.3. At this condition, measure the output and collector voltage by using an oscilloscope.

2. Modulator Characteristic

Frequency Response:

2.1. Connect the AF signal generator to the modulator input, and adjust its frequency to 1KHz.
2.2. Adjust the AF signal generator’s voltage to obtain ‘m’ value on the table-1, and fill in the table.
2.3. Repeat the same experimental procedure for 500Hz and 5 KHz frequency value at the AF signal generator.
2.4. Plot and observe the over modulation by increasing the AF voltage( for 1KHz of the AF signal generator).
2.5. Observe the effect of the RF signal to the modulated signal by changing its frequency and amplitude.

EQUIPMENT LIST:

1. Oscilloscope
2. DC power supply
3. RF and AF signal generators
4. Multimeter
5. Transistor (BC 238-B)
6. Inductor (0.635mH)
7. Modulation transformer
8. Capacitors (22nF, 10μF)
9. Potentiometer (100K)
10. Resistors (33K, 1K)

QUESTIONS:

1. Calculate the ratio of AF voltage at 1 KHz proportional to the AF voltage at different frequencies (for same ‘m’ value). As a result of this step, the response of modulator frequency will be found.
2. Plot the linearity curve of the modulator.
3. Find the side-band frequency components for 1,5MHz carrier and 150 KHz AF signal.
4. 5V_p-p carrier AF signal is modulated %60. Find the maximum amplitude of the modulated signal.
5. Explain the over-modulation, its reasons and how it can be prevent?
6. Write separately the effect of RF signals frequency and amplitude and AF signals frequency and amplitude on the modulated signal.
Table 1:

<table>
<thead>
<tr>
<th>m</th>
<th>Vmax</th>
<th>Vmin</th>
<th>$V_{AF}$</th>
<th>$V_{RF}$</th>
<th>f</th>
</tr>
</thead>
<tbody>
<tr>
<td>%20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>%20</td>
</tr>
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<td>%35</td>
<td></td>
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<td>%50</td>
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<td></td>
<td></td>
<td>%100</td>
</tr>
</tbody>
</table>
EXPERIMENT 4: AMPLITUDE DETECTOR

PURPOSE:
To learn the principles of AM amplitude detection and to obtain the characteristics of detector.

THEORY:
Detector is a circuit which subtracts the information signal on the carrier signal and converts it to the real position. Detecting is a two step operation, these are: Rectification and filtering. This is shown in fig.1.

![Detector Operation](image1)

Figure 1: Detector Operation

Operation of rectification usually designs with a diode. Because there exists same components of the carrier frequencies in the signal which is at the end of the operation of rectification, so it doesn’t give us the data signal, clearly. Because of this, information signal must selected by removing the carrier frequency. This operation can be done with filter circuit. The low-pass filter is used, because the carrier frequency is greater than the information signal frequency. A basic detector circuit is shown in fig. 2.

![Detector](image2)

Figure 2: Detector

The value of the RC time constant in the filter is very important. The RC time constant must be high enough to prevent discharging of capacitor on the negative part of modulated signal. But the
value of RC must not be very large. Otherwise the discharging of the capacitor can’t follow the changing in the envelope and the information signal form is defected on the output of filter. In fact, the circuit in fig. 2 can’t filter, well. For a good filter, it is needed to have extra RC components. Diode detector is a linear passive detector. A detector can also be formed by using a transistor. By this way, the signal can be both detected and amplified.

The circuit in fig. 2 can’t filter, well. For a good filter, it is needed to have extra RC components. Diode detector is a linear passive detector. A detector can also be formed by using a transistor. By this way, the signal can be both detected and amplified.

The one of the most important characteristic of detector is its efficiency. Detector efficiency is the ratio of the amplitude of output signal and the amplitude of input modulated signal envelope.

\[
n_D = \frac{V_{out}}{(mV_{IF})}
\]

- \(V_{out}\): Detector output voltage (Vp-p)
- \(V_{IF}\): Unmodulated carrier voltage (Vp-p)
- \(m\): Modulation factor

The linearity of detector can be described by two ways:

**A.** The modulation deepness: the output voltage degree changes linearly with the changing of modulation factor of input detector signal.

**B.** The changing of amplitude of carrier: the output voltage degree changes linearly with the changing of carrier degree of input detector.

With detector diode, the linearity can be seen for high input signals, because for low voltages, the diode curve isn’t linear.

The components of filter limit the maximum frequency. For higher frequencies, distortion occurs. For an available filter, the formula is given like that:

\[
RC[\frac{1}{mW_A}]
\]

- \(W_A\): Angular frequency of the modulated signal
- \(m\): Modulation factor

There is another distortion which is different from described as before. That distortion becomes from unlinearity of small signals of diode detector. Distortion limits the detection sensitivity. Detection sensitivity is described as the smallest signal taken and for forward stimulation; it is limited with its voltage drop in diode detector. So germanium diodes are used for this purpose.

**EXPERIMENTAL PROCEDURE:**

**Attention:**

**A.** Calibrate the oscilloscope before measurements.
**B.** Adjust the value of input signal after connecting the source to circuits.
The experiment forms from the following parts:

a. Examination of waveform,
b. Detector frequency response: examination of changes at output signal, constant modulation percentage and modulation signal frequency and calculation of the detection efficiency.
c. Detection linearity: linearity is examined by using the carrier level and the changing of modulation percentage.
d. Examination of distortion: distortions are examined which is formed from RC discord and over modulation.

1. Plotting of Waveform

1.1. Connect the AF(audio) signal generator’s outputs to the RF signal generator’s (455KHz) modulation input which is behind of the generator. At this condition, you will obtain the modulated signal from RF signal generator’s outputs.
1.2. Connect the RF signal generator’s (455 KHz) outputs to the detector input.
1.3. Adjust the amplitude of the AF (audio) signal generator (1 KHz) to obtain %50 modulations.
1.4. Observe the detector input, diode output (without a filter part, so without C) and detector output for different R values. Plot also the DC component in a scaled manner one by one, by measuring it at each part. (R=10K and R=33K)

2. Detector Frequency Response

2.1. Adjust the AF generator to 1 KHz and obtain a %50 modulation (C=5nf, R=33k)
2.2. Measure the AF voltage on the detector output.
2.3. Repeat part 2.2 for AF signal at 500Hz and 10 KHz frequencies when the modulation factor and the RF level are constants and for measurement calculate the efficiency.
2.4. Measure the unmodulated carrier voltage.

3. Detector Linearity

(By depending on the modulation deepness)
3.1. Adjust the AF generator to 1 KHz and fill in the table 1 for different modulation percentage.
3.2. Repeat the same measurement for AF at 500Hz and 10 KHz (By depending on the RF level)
3.3. Adjust the AF generator to 1 KHz and obtain %50 modulation.
3.4. At each step, measure the detector output voltage by decreasing the RF voltage and record them to the table-2 (make measurement for C=1nf, R=33K, observe the effect of RC).

4. Distortion

4.1. For different AF frequency, plot the waveform of the detector output voltage by forming a over – modulated (f=500Hz, 1 KHz, 10 KHz).
EQUIPMENT LIST:

1. RF signal generator
2. Audio signal generator
3. Oscilloscope
4. Diode
5. Resistors (10K, 33K)
6. Capacitors (1nF, 5nF)
7. Multimeter

QUESTIONS:

1. Plot the curve of the detector frequency response and calculate the detection efficiency for all values.
2. Plot the detection linearity’s curve for three- other AF generator’s frequency.
3. Plot the detection linearity for different RF voltage.
4. What does the detector linearity depend on?

<table>
<thead>
<tr>
<th>m(%)</th>
<th>$V_{out}$</th>
<th>$V_{RF}$</th>
<th>$f$(kHz)</th>
<th>m(%)</th>
<th>$V_{RF}$</th>
<th>$V_{out}$</th>
<th>$f$(kHz)</th>
</tr>
</thead>
<tbody>
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</tbody>
</table>
EXPERIMENT 5: FREQUENCY MODULATION

PURPOSE:
To investigate the frequency modulation principle and to obtain the characteristics of frequency modulator for different capacitive diodes.

THEORY:
In frequency modulation, the frequency of the carrier signal has changed due to the amplitude of the information signal.

This is the advantage of frequency modulation that signal can be transmitted without any noise and distortion. If we change the amplitude of the AF signal, the input oscillator frequency can be changeable. The waveform of the frequency modulation is shown fig. 2 with all detail.
The frequency, which is called as central frequency, is an unmodulated carrier frequency and this frequency is higher than the one that is, which is, used in amplitude modulation. The difference between modulated signal and central frequency is called instantaneous frequency deflection and the max. frequency deflection (ΔF) is obtained when AF signal has its peak value. The ratio between max. deflection frequency and max. audio frequency is defined as a modulation index.

\[ m_F = \frac{\Delta F}{f_m} \]

The equation at frequency modulation is:

\[ V = E_C \cos (W_C t + m_F \sin W_m t) \]

The mathematical expression of this equation is too complex. The graphical representation of this equation is shown in fig.3. In the figure, the correlation between the carrier and some sideband amplitude is given.

Number of the sideband is infinite, but we consider on the amplitude of first some sidebands. The amplitude of sidebands is too small at higher levels. Sideband frequency differs from carrier frequency and relates to audio frequency. This relationship can be given as:

\[ F_1 = f_C + f_m \]
\[ F_2 = f_C + 2f_m \]
\[ F_3 = f_C + 3f_m \]

Phase and amplitude of sideband change with the modulation index. Therefore the number of important sideband is a function of modulation index. Only the first sideband is important when the modulation index is less than 0.5. So for \( m_F = 0.5 \) FM is similar to AM. But, in FM the sidebands has the same phase with the carrier while has a 90° phase difference in AM.

The bandwidth of modulator determines the percent of distortion at the information. Approximate equation is usually used for bandwidth:
\[ f = 2 \left( \Delta F + f_m \right) \]

where;

\( f \): necessary bandwidth,
\( \Delta F \): max. frequency deflection,
\( f_m \): max. modulator frequency.

In fig. 4, a frequency modulator set with a variable diode having a voltage dependent capacitance can be seen. The base is grounded and resonant circuit at feeding emitter works as Hartley oscillator. The load is isolated from resonant circuit with connecting to the collector and the amplitude is less correlated with oscillation frequency. Oscillation amplitude is kept constant with emitter resistance \( R_E \).

\( C_2 \) capacitance isolates the diode from DC voltage, but does not affect frequency, because its value is higher than the diode capacitance. \( C_D \) diode is variable capacitance which changes its oscillator frequency with the audio voltage. The diode capacitance decreases when the reverse voltage increases on the diode (fig. 5).

![Figure 4: Frequency modulator with variable capacitor diode](image)

![Figure 5: Characteristics of the variable capacitance diode](image)
Resonance frequency of the circuit:

\[ f_0 = \frac{1}{2\pi \sqrt{L_0 C_D}} \]

Here;

*L₀*: constant value of inductor conductance,

*C₅*: voltage dependent diode capacitance,

As seen as fig.5, Max. capacitance change is between 0.5 and 3 V.

**EXPERIMENTAL PROCEDURE:**

**Attention:**

A. Calibrate the oscilloscope before measurements.
B. Adjust the value of input signal after connecting the source to circuits.

To define the characteristic of modulator:

1. **Modulator adjustment:**

   1.1. Adjust the RF signal generator to 455 KHz. Adjust the potentiometer and the frequency of R.F. signal to obtain the max. sinusoidal signal from the output. Record this frequency, this is central frequency. See the min. 15 cycles on the oscilloscope display and record the cycle number.

2. **Modulator output power:**

   2.1. Measure the output voltage and calculate the output power by connecting the resistances, which is given in table 1 to the modulator output. Then record these values.

**Table 1:**

<table>
<thead>
<tr>
<th>R₀ (Ω)</th>
<th>10</th>
<th>47</th>
<th>100</th>
<th>147</th>
<th>220</th>
<th>470</th>
<th>1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>V₀ (p-p)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poutput</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. **Frequency change test:**

   3.1. Connect the resistance, which gives the max. output power from the table 1, to the output.
   3.2. Measure the output voltage and frequency for the input values at table 2 by connecting DC supply to the modulator input.

**Table 2:**

<table>
<thead>
<tr>
<th>V₀ AF-IN (V)</th>
<th>-4</th>
<th>-3</th>
<th>-2</th>
<th>-1</th>
<th>0</th>
<th>1</th>
<th>1.5</th>
<th>2</th>
<th>2.5</th>
<th>3</th>
<th>3.5</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>F (KHz)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V₀ e(kHz)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>
3.3 Adjust the AF generator, to 1 kHz and connect to the modulator input. When the generator output is zero, adjust the oscilloscope to obtain 15 cycles on the display.

3.4 Carefully increase the AF signal amplitude, observe the changes on the display. Plot the output waveforms for different AF voltage.

**EQUIPMENT LIST:**

1. Oscilloscope
2. RF signal generator
3. AF signal generator
4. DC power supply
5. White inductor
6. Yellow inductor
7. Transistors (BC 238-B)
8. Varactor Diode
9. Capacitors (5nF, 22nF)
10. Resistors (39K, 10K, 560Ω, 220Ω, 10Ω, 47Ω, 57Ω, 100Ω)

**QUESTIONS:**

1. Plot the output power as a function of load resistor.
2. Plot the output voltage as a voltage of modulation frequency.
3. What is the function of the capacitor, which is, connected in series to the varactor diode? How affects the central frequency?
EXPERIMENT 6: FREQUENCY DEMODULATION

PURPOSE:
To learn the necessary measurements by analyzing the frequency modulation and obtain the discriminator characteristics.

THEORY:
FM receivers are similar to AM receivers. The main differences between them are their operating frequency and bandwidth. Analyzing operation is made different, because of the modulation difference in FM receivers. The amplitude of received signal in FM is constant and we need to obtain the amplitude change of information signal from this constant amplitude. For this purpose by using frequency change, the amplitude of the information signal is constructed. So demodulation occurs. The part used for this operation is called “discriminator”. Discriminator gives output with different amplitudes due to the signal frequency at the input. In fig.1, the discriminator characteristics, which are called “S” curves also, are shown:

Some of the important discriminator characteristics are:

Bandwidth: The interval which the variation in characteristic curve is linear.

Sensitivity: The ratio of input voltage to the variation in input frequency

\[ S = \frac{\Delta V}{\Delta F} \]  

Sensitivity is wanted to be high.

Linearity: The variation seen in characteristic curve is desired to be linear ideally. Linearity is formulated as:

\[ \text{LIN} = \left( \frac{S_{\text{max}} - S_{\text{min}}}{S_{\text{av}}} \right) \times 100 \]  

Figure 1: Characteristic of frequency discriminators
S_{\text{max}}: \text{maximum sensitivity} \\
S_{\text{min}}: \text{minimum sensitivity} \\
S_{\text{av}}: \text{average sensitivity}

**Discriminators Types:**

**Single resonant circuit:** Single resonant circuit is the simplest form of discriminators. To detect the information with this type one side at the curve is used (Fig.2).

![Discriminator with single resonant circuit](image)

This type has less sensitivity, infirm linearity and narrow bandwidth. For this reason this type doesn’t used usually.

**Travis Discriminators:** This type includes two resonance circuits. One is adjusted to f_o - f and other to f_o + f. The difference between two outputs gives response curve (Fig.3).

![Travis discriminators](image)
The disadvantage of the discriminator is the difficulty in setting two resonant circuits and adjusting them.

**Foster Seeley Discriminator:** This type is used mostly in FM receivers. The working principle of this type is to compare the 90° phase shift in secondary with the primary at resonance. At the frequencies different from resonance frequency phase shift is different from 90°. (Fig. 4)

![Foster Seeley Discriminator](image)

Figure 4: Foster Seeley Discriminator

$V_o$ voltage is connected positively to $V_1$ via $C_o$ capacitor, at this discriminator. The phase balance of $V_1$ relative to $V_o$ is dependent to the frequency. Over the resonance frequency the difference is larger than 90° and is smaller than 90° under the resonance frequency. The same rule is also true for $D_2$ diode. But this time phase shift is smaller than 90° over resonance frequency, and larger than 90° under resonance frequency. Because $V_1$ and $V_2$ has 180° phase difference in all situations. The operation of the discriminator is shown at fig.5;

![Vector Diagram](image)

Figure 5: The vector diagram of Foster Seeley Discriminator

Because of over the resonance frequency $|V_{D2}| > |V_{D1}|$, and under the resonance frequency $|V_{D2}| < |V_{D1}|$, the output curve is obtained as fig.6. This discriminator has easily adjustable and because of sensitivity and linearity properties this type is preferred, but it has AM distortion.
**Ratio detector:** It is similar to Foster Seeley Discriminators with supply and resonant circuits. But diodes are connected inversely, audio output is balanced and a larger $C_o$ capacitor is added (Fig. 7).

The $C_o$ capacitor is connected to suppress the DC variation, so the amplitude variation is prevented.

$$V_{C1}+V_{C2}=V_{CO} \quad \ldots \ldots \ldots \ldots \ldots (3)$$

At resonant frequency $|V_{D2}|=|V_{D1}|$, to get this equality $V_{C2}=V_{C1}$ is taken. The voltages on resistors are equal to each other if the resistors are identical. For $V_{RL1}=V_{RL2}$ output voltages are equal to zero.

Out of resonant frequency:

$$|V_{D1}|>|V_{D2}| \rightarrow V_{C1}>V_{C2}\quad \ldots \ldots \ldots \ldots \ldots (4)$$

Output voltage is taken as a function of input frequency between the resistors and capacitors. The detector has similar properties with Foster-Seeley discriminator and is not sensitive to AM.

**Measurement Methods:**

To plot the characteristic curve of a discriminator two methods are used:

**Static:** By changing the AF generator frequency of the discriminator’s input and by measuring output DC voltage. So values for whole curve can be taken. But the response of the discriminator to the modulated signal can not be measured.
Dynamic: The connection in fig. 8 is used for this and characteristic curve is obtained at oscilloscope.

![Dynamic discriminator test circuit.](image)

EXPERIMENTAL PROCEDURE:

Attention:

A. Calibrate the oscilloscope before measurements.
B. Adjust the value of input signal after connecting the source to circuits.

1. Static discriminator curve:

1.1. Set the circuit in fig. 2.
1.2. Adjust RF signal generators frequency and amplitude to the values given in Table 1, and then measure the output values. RF generator values at table must be measured or calculated as effective values.

1.3.

<table>
<thead>
<tr>
<th>$f_{in}$(kHz)</th>
<th>350</th>
<th>400</th>
<th>455</th>
<th>500</th>
<th>550</th>
<th>600</th>
<th>650</th>
<th>700</th>
<th>750</th>
<th>800</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{RF(in)}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Static modulation test

2.1. Adjust RF signal generator to 455 KHz and connect to discriminator input. By changing the RF signal generator frequency try to obtain zero voltage at discriminator output.
2.2. Connect DC power supply to modulator input and using the values at table 2, measure the output.

<table>
<thead>
<tr>
<th>$V_{AF(in)}$</th>
<th>-4</th>
<th>-3</th>
<th>-2</th>
<th>-1</th>
<th>0</th>
<th>1</th>
<th>1.5</th>
<th>2</th>
<th>2.5</th>
<th>3</th>
<th>3.5</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f$(KHz)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_{AF(out)}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
3. Dynamic discriminator test

3.1. Prepare the connections at fig. 8 and watch the output characteristic curve at oscilloscope.
3.2. Connect 1kΩ and 10kΩ respectively between modulator and discriminator and watch the curve.

4. Linearity test

4.1. Connect AF generator to the input of modulator and measure output for the values in table 3.

<table>
<thead>
<tr>
<th>V_{AF(in)}(V)</th>
<th>-4</th>
<th>-3</th>
<th>-2</th>
<th>-1</th>
<th>0</th>
<th>1</th>
<th>1.5</th>
<th>2</th>
<th>2.5</th>
<th>3</th>
<th>3.5</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>V_{AF(out)}(V)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

**EQUIPMENT LIST:**

1. Oscilloscope
2. RF signal generator
3. AF signal generator
4. DC power supply
5. FM modulator
6. Inductors
7. Diodes
8. Resistors (10K, 1K)
9. Capacitors (22nF, 1nF)

**QUESTIONS:**

1. Plot discriminators static “S” curve.
   1.1. Calculate discriminators sensitivity at 420, 455 and 480 KHz.
   1.2. Calculate linearity of discriminator.
   1.3. Determine the bandwidth of discriminator on the curve.
2. Plot frequency-amplitude curve for the value in table 2.
3. Plot dynamic linearity curve for values in table 3.
4. Which factors limit the bandwidth of discriminator?
5. Explain how the sensitivity of the discriminator changes as a function of RF input voltage. Does bandwidth change also?