Analog Communication Laboratory Manual

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Chapter 1

Introduction to Analog Communication

[1]Communication is the transfer of information from one place to another. A bidirectional communication system operates in opposite directions. The receiver can respond to the sender. Radio communication uses electrical energy to transmit information. Because electrical energy travels almost as fast as light, radio communication is essentially instantaneous. A radio transmitter converts audio (sound) signals to electrical signals that are sent over wires or through space. A radio receiver converts the electromagnetic waves back to sound waves so that the information can be understood.

The transmitted information is the **intelligence signal** or **message signal**. Message signals are in the **Audio Frequency (AF)** range of low frequencies from about 20 Hz to 20 kHz.

The **Radio Frequency (RF)** is the carrier signal. Carrier signals have high frequencies that range from 10 kHz up to about 1000 GHz. A radio transmitter sends the low frequency message signal at the higher carrier signal frequency by combining the message signal with the carrier signal.

Modulation is the process of changing a characteristic of the carrier signal with the message signal. In the transmitter, the message signal modulates the carrier signal. The modulated carrier signal is sent to the receiver where **demodulation** of the carrier occurs to recover the message signal.

IMPORTANT TERMS

- **Audio** - signals that a person can hear.
- **Electromagnetic waves** - the radiant energy produced by oscillation of an electric charge.
- **Intelligence signal** - any signal that contains information; it is also called the message signal.

- **Message signal** - any signal that contains information; it is also called the intelligence signal.
- **Audio Frequency (AF)** - frequencies that a person can hear. AF signals range from about 20 Hz to 20 kHz.
- **Radio Frequency (RF)** - the transmission frequency of electromagnetic (radio) signals. RF frequencies are from about 300 kHz to the 1,000,000 kHz range.
- **Carrier signal** - a single, high-frequency signal that can be modulated by a message signal and transmitted.
- **Modulation** - the process of combining the message signal with the carrier signal that causes the message signal to vary a characteristic of the carrier signal.
- **Demodulation** - the process of recovering or detecting the message signal from the modulated carrier frequency.
- **Amplitude Modulation (AM)** - the process of combining the message signal with the carrier signal and the two sidebands: the lower sideband and the upper sideband.
- **Frequency Modulation (FM)** - the process of combining the message signal with the carrier signal that causes the message signal to vary the frequency of the carrier signal.
- **Phase Modulation (PM)** - the process of combining the message signal with the carrier signal that causes the message signal to vary the phase of the carrier signal.
- **Angle modulation** - the process of combining the message signal with the carrier signal that causes the message signal to vary the frequency and/or phase of the carrier signal.
- **Balanced modulator** - an amplitude modulator that can be adjusted to control the amount of modulation.
- **Double-Sideband (DSB)** - an amplitude modulated signal in which the carrier is suppressed, leaving only the two sidebands: the lower sideband and the upper sideband.
- **Mixer**- an electronic circuit that combines two frequencies.
- **Product detector** - a detector whose audio frequency output is equal to the product of the Beat Frequency Oscillator (BFO) and the RF signal inputs.
- **Phase detector** - an electronic circuit whose output varies with the phase differential of the two input signals.

- **Envelopes**- the waveform of the amplitude variations of an amplitude modulated signal.
- **Sidebands** - the frequency bands on each side of the carrier frequency that are formed during modulation; the sideband frequencies contain the intelligence of the message signal.
- **AM** - an amplitude modulated signal that contains the carrier signal and the two sidebands: the lower sideband and the upper sideband.
- **Bandwidth** - the frequency range, in hertz (Hz), between the upper and lower frequency limits.
- **Harmonics** - signals with frequencies that are an integral multiple of the fundamental frequency.
- **Beat Frequency Oscillator (BFO)** - an oscillator whose output frequency is approximately equal to the transmitter's carrier frequency and is input to a product detector

Chapter 2

Intermediate Frequency (Tuned) Amplifier

Aim

To design and implement a tuned intermediate frequency amplifier using BJT and IFT.

Theory

Intermediate frequency amplifiers are tuned voltage amplifiers used to amplify a particular frequency. Its primary function is to amplify only the tuned frequency with maximum gain and reject all other frequencies above and below this frequency. This type of amplifiers are widely used in intermediate frequency amplifiers in AM super heterodyne receivers, where intermediate frequency is usually 455 kHz.

In common emitter voltage amplifier circuit (emitter bypassed), the voltage gain is $A_V = \frac{R_C||R_L}{r_e}$, where R_C is the collector resistance in the circuit, R_L is the load resistance and r_e is the internal emitter resistance. In tuned voltage amplifier the collector resistance is replace by a tuned load upon which the gain is dependant. For a parallel resonating circuit the impedance Z_o is maximum at resonant frequency, $f_o = \frac{2\pi}{\sqrt{LC}}$. So an amplifier with tuned load will have maximum gain at resonant frequency. In practical tuned amplifier circuits,an intermediate frequency transformer(IFT) is used as tuned load. IFT is tuned to standard 455 kHz audio frequency, (See A.3).

The quality factor of the circuit is given by $Q = \frac{f_o}{Bandwidth}$.

Design

Inorder to design a Common Emitter Intermediate frequency amplifier, use a high frequency transistor like BF194,BF195, BF494, BF495 or 2N2222.
Choose transistor BF 194/195. For its datasheet See A.1,

Let V_{CC} be 10% more than the required output amplitude,ie. 10V.

$$\therefore V_{CC} = 12\ V \tag{2.1}$$

$$I_c = 10\%\ of\ I_{Cmax} =\ 10\%\ of\ 30\ mA \approx 1\ mA \tag{2.2}$$

The current gain,

$$h_{FEmin} =\ 67 \tag{2.3}$$

Let the stability factor of the circuit be,

$$S = 10 \tag{2.4}$$

Under dc conditions, the primary dc resistance of the IFT is very small,($< 5\Omega$).
So dc volatage drop across collector circuit is very low, approximately zero.
For class A mode of operation set,

$$V_{CE} = \frac{V_{CC}}{2} = 6V \tag{2.5}$$

Design of Emitter resistance
The voltage across emitter resistance is,

$$V_{RE} = V_{CC} - V_{CE} =\ 12V -\ 6V =\ 6V \tag{2.6}$$

$$I_E \approx I_C \tag{2.7}$$

Hence

$$I_E = 1mA \tag{2.8}$$

Thus

$$R_E =\ \frac{V_{RE}}{I_E} =\ \frac{6V}{1mA} =\ 6k\Omega \tag{2.9}$$

Choose standard value of $R_E =\ 5.6\ k\Omega$.

Design of Potential divider biasing
The Stability factor S=10. Assuming R_B is the effective resistance at the base,

$$S =\ 10 =\ 1 + \frac{R_B}{R_E} \tag{2.10}$$

$$R_B =\ 9R_E =\ 50.4k\Omega \tag{2.11}$$

$$R_B =\ R_1||R_2 = \frac{R_1R_2}{R_1 + R_2} =\ 50.4k\Omega \tag{2.12}$$

The voltage at the base of the transistor is

$$V_B = V_E + V_{BE} = V_{RE} + V_{BE} = 6V + 0.6V = 6.6V \tag{2.13}$$

This is the voltage across R_1.

$$V_{R1} = VCC\frac{R_2}{R_1 + R_2} = 6.6V \tag{2.14}$$

$$\frac{R_2}{R_1 + R_2} = \frac{6.6V}{12V} = 0.55 \tag{2.15}$$

From 2.12 and 2.15,

$$R_1 = 91.4\ k\Omega \approx 82\ k\Omega\ and\ R_2 = 100\ k\Omega \tag{2.16}$$

Design of capacitors

The capacitors C_1, C_2 and C_E can be designed based on lower cut-off frequency at -3 dB point. Since this frequency is verylower than 300 kHz, Choose low values of capacitance like

$$C_1 = C_2 = C_E = 1\ \mu F \tag{2.17}$$

Circuit Diagram

See Figure 2.1 for circuit diagram.

Procedure

- Assemble the circuit as shown in the circuit diagram.
- Obtain output from terminal-1 or terminal-2 as in the circuit diagram.
- Give input signal, which is a sinewave of frequency variable from 300 kHz to 600 kHz and amplitude 50 mV_{pp}.
- Calculate gain A_V by varying V_{inpp}.

  $(A_V = \frac{V_{outpp}}{V_{inpp}})$
- Plot frequency response characteristics. Find out resonant frequency, 3-dB bandwidth and Q-factor.

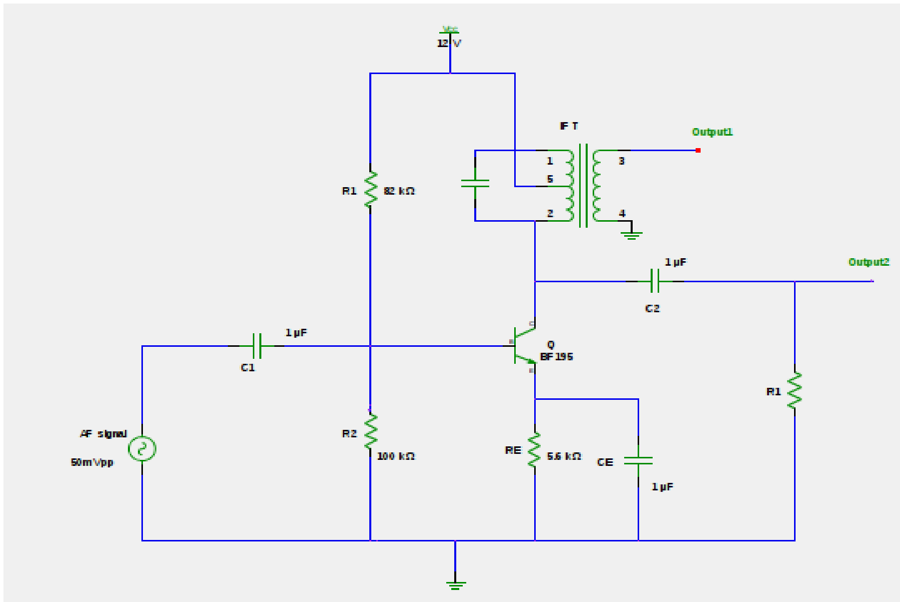

Figure 2.1: Circuit Diagram for IF Tuned Amplifier

Observation

f_{in}	V_{inpp}	V_{outpp}	A_v

TODO:frequency response curve of gain to be added.

Result

A tuned amplifier was implemented using IFT.
Its maximum gain=
Resonant frequency=
Band-width=
Q-factor=

Chapter 3

Amplitude Modulation-Generation

Aim

To design and set-up an AM generator using BJT and measure the modulation index from the observed output waveform.

Theory

The transistor T_1 is configured as a common emitter amplifier. The RF carrier wave is given at the base through a coupling capacitor C_1. The message signal used for modulation is the AF signal applied between the emitter resistance and the ground. The message signal modulates the envelope of the carrier which is obtained as output from the collector through a coupling capacitor C_3.

The ratio of the maximum amplitude of the modulating signal voltage to that of the carrier voltage is termed as modulation index. This is represented as $m = \frac{V_m}{V_c}$.

Design

Design steps need to be verified

DC Biasing conditions: Choose BF194 which is a high frequency transistor. From its datasheet (See A.1) the various parameters can be obtained as:

Let the supply voltage be 60% of the maximum V_{ce}.

$$V_{cc} = 60\% of V_{cemax} = 12V \tag{3.1}$$

Let the collector current I_c be 10% of maximum rated value.

$$I_c = \ 3\% \ of \ I_{cmax} = \ 1mA \tag{3.2}$$

In-order to fix the biasing point in the middle of load line, let V_{RC} be 40% of V_{cc}, V_{RE} be 10% of V_{cc} and V_{ce} be 50% of V_{cc}.

$$V_{RC} = \ 45\% \ of \ V_{cc} = \ 5.4V \tag{3.3}$$

$$V_{RE} = \ 5\% \ of \ V_{cc} = \ 0.6V \tag{3.4}$$

$$V_{ce} = \ 50\% \ of \ V_{cc} = \ 6V \tag{3.5}$$

Design of Resistors:

$$R_C = \frac{V_{RC}}{I_c} = \frac{5.4V}{1mA} = \ 5.4k\Omega \tag{3.6}$$

$$R_E = \frac{V_{RE}}{I_e} = \frac{0.6V}{1mA} = \ 600\Omega \tag{3.7}$$

From the datasheet, hFE has a minium value of 67.

$$I_b = \frac{I_c}{hFE} = \frac{1mA}{67} = \ 15\mu A \tag{3.8}$$

Assume the current through $R_1 = \ 10I_b$ and that through $R_2 = 9I_b$

$$V_{R2} = V_{be} + V_{RE} = 0.7 + 0.6V = 1.3V \tag{3.9}$$

Then

$$R_2 = \frac{V_{R2}}{9I_b} = \frac{1.2V}{9X15X10^{-6}} = 8.8k\Omega \tag{3.10}$$

and

$$R_1 = \frac{V_{R1}}{10I_b} = \frac{10.8V}{10X15X10-6} = 72k\Omega \tag{3.11}$$

Based on these design equations use the standard resistor values of $R_1 = 22k\Omega, \ R_2 = 10k\Omega, \ R_c = 10k\Omega, \ R_c = 560\Omega$ and a load resistance of $R_L = 1k\Omega$. Use coupling capacitors $C_1 = 0.1\mu F, \ C_2 = 0.001\mu F$ and emitter bye-pass capacitor $C_E = 0.01\mu F$.

Components and Equipments Required

Function Generators(2), CRO(2), Connection wires, Breadboard, Probes.
BF194 - High frequency bipolar junction transistor
$22k\Omega, \ 10k\Omega \ (2), \ 560\Omega, \ 1k\Omega$ - Resistors
$0.1\mu F, \ 0.01\mu F, \ 0.001\mu F$ - Capacitors

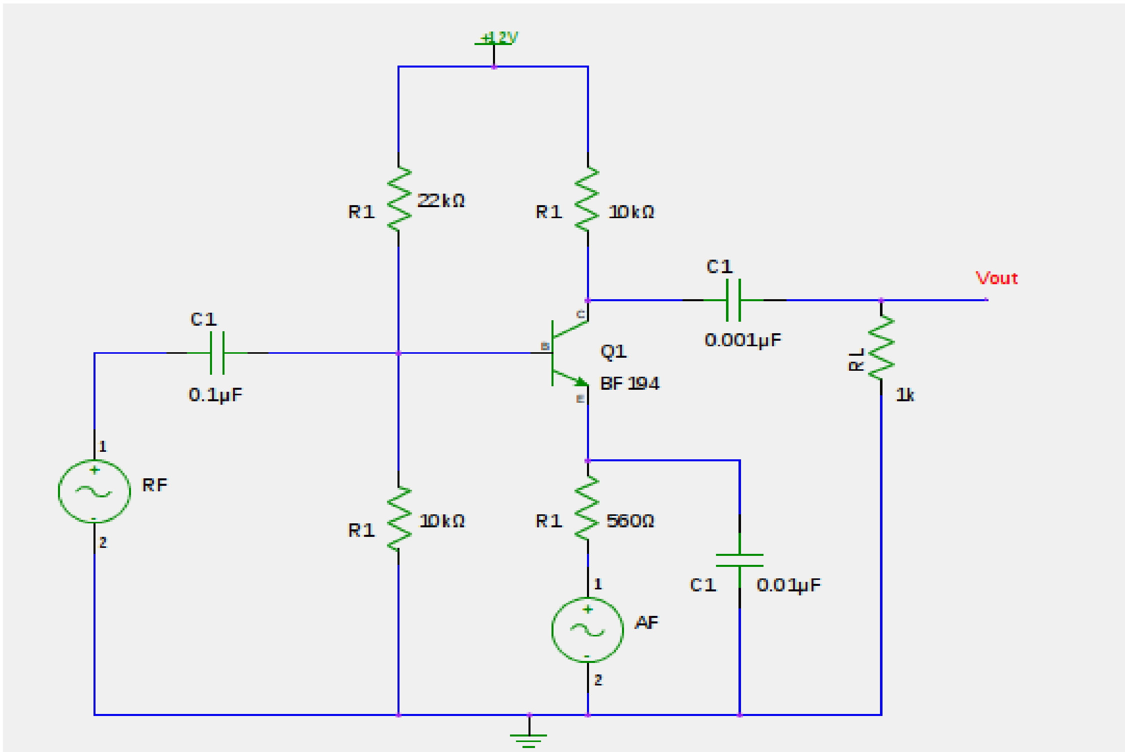

Figure 3.1: Circuit Diagram for Amplitude modulation using BJT

Circuit Diagram

Procedure

1. Set up the circuit after verifying the condition of components.
2. Feed AF modulating signal (say, $f_m = 1kHz$ and $E_m = 150mV$) and Rf carrier (say, $f_c = 70kHz$ and $E_c = 300mV$) using function generators.
3. Adjust amplitude and frequencies of the AF and RF signals and observe amplitude modulated waveform on the CRO.
4. Fix f_m and f_c. Note down E_{max} and E_{min} of the AM signal and calculate modulation index according to the formula ,

$$m = \frac{E_{max} - E_{min}}{E_{max} + E_{min}}. \tag{3.12}$$

Here E_{max} is the maximum of the positive envelope of the carrier and E_{min} is the minimum of the positivee envelope of the carrier.

5. Repeat for different values of E_m and E_c. Observe the AM waveforms for different values of m.

6. Plot the waveforms on a graph sheet.

7. Fill in the observation column

Observation

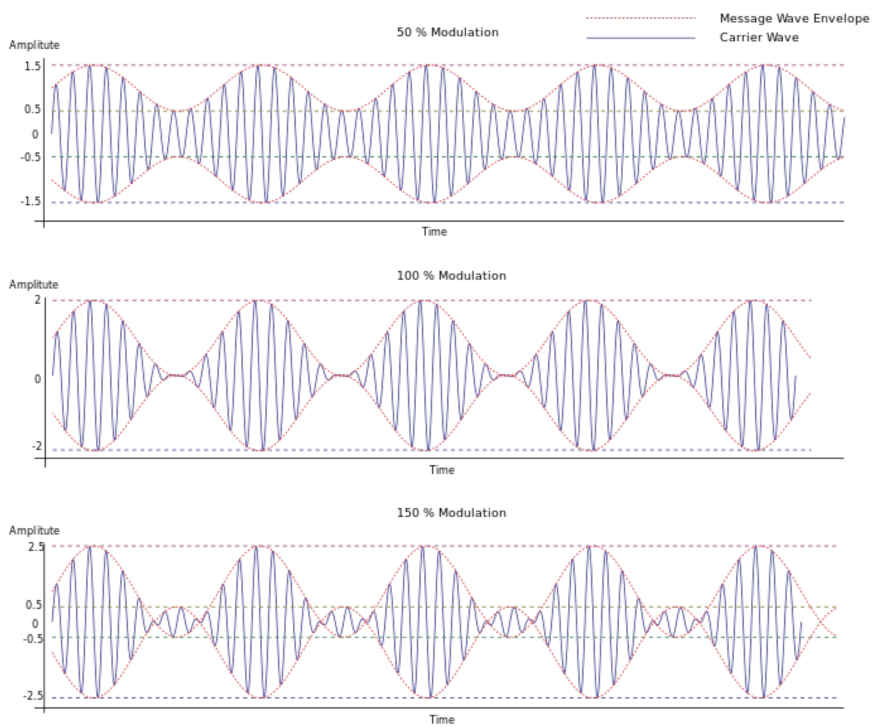

Figure 3.2: Effect of modulation index on AM

Fig 3.2 shows the effect of modulation index on the resultant AM wave[1]

[1] https://commons.wikimedia.org:/wiki/File:Amplitude_Modulated_Wave-hm-64.svg

E_{min}	E_{max}	$m = \frac{E_{max}-E_{min}}{E_{max}+E_{min}}$

Result

Implemented the AM modulation circuit using BJT. The modulation index corresponding to $E_m =$ ——and $E_c =$ ——is : m= ——.

Chapter 4

Amplitude Modulation - Detection

Aim

The experiment aims at designing an AM demodulator circuit and implementing it.

Theory

The AM signal is a high radio frequency carrier whose amplitude envelope represents a slow varying message signal, as can be seen in Fig. 3.2. The process of detecting the envelope and thus regaining the message signal from the modulated carrier wave is calledd AM demodulation.

It can be implemented by a simple diode envelope detector to eliminate the negative half of the carrier envelope followed by a simple RC filter to remove the high frequency carrier. The result will be the low frequency envelope which is the demodulated message.

A diode with low junction capacitance is used in the circuit as it is has to rectify high frequency carrier.It offers low impedence at high frequency. The **RC** circuit used at the output of the diode acts as a filter. Its time constant is chosen wisely so that it is too slow to follow the high frequency of the carrier wave at the same time its fast enough to follow the low frequency message envelope.

Design

Choose high frequency diode OA79.
The time period of the circuit must be much larger than the RF carrier frequency.

$$R_1C_1 >> T_c \tag{4.1}$$

$$R_1C_1 >> \frac{1}{f_c} = \frac{1}{2\pi\omega_c} \tag{4.2}$$

At the same time it should be smaller than the message bandwidth. ie.,

$$R_1C_1 << \frac{1}{f_m} \tag{4.3}$$

Assuming $f_c = 100kHz(T_c = .01ms)$ and $f_m = 1kHz(T_m = 1ms)$, Let

$$R_1C_1 = 10XT_c = 0.1ms \tag{4.4}$$

Let $C_1 = .01\mu F$

$$R_1 = \frac{.1ms}{C_1} \tag{4.5}$$

$$R_1 = \frac{.1ms}{0.01\mu F} = 10k\Omega. \tag{4.6}$$

Circuit Diagram

The circuit diagram for AM Demodulator using a simple diode detector is shown in Fig. 4.1.

Components and Equipments Required

CRO, Function Generators(2), Breadboard, Probes.
Diodes- OA79
Capacitor- 0.01 μF
Resistor-10kΩ

Procedure

1. Make connections on the breadboard as per the circuit diagram.
2. Supply AM signal either from the signal generator or from the circuit designed in experiment Amplitude Modulation- Generation.
3. Connect the demodulated output to one channel of CRO along with the unmodulated signal on the other channel.

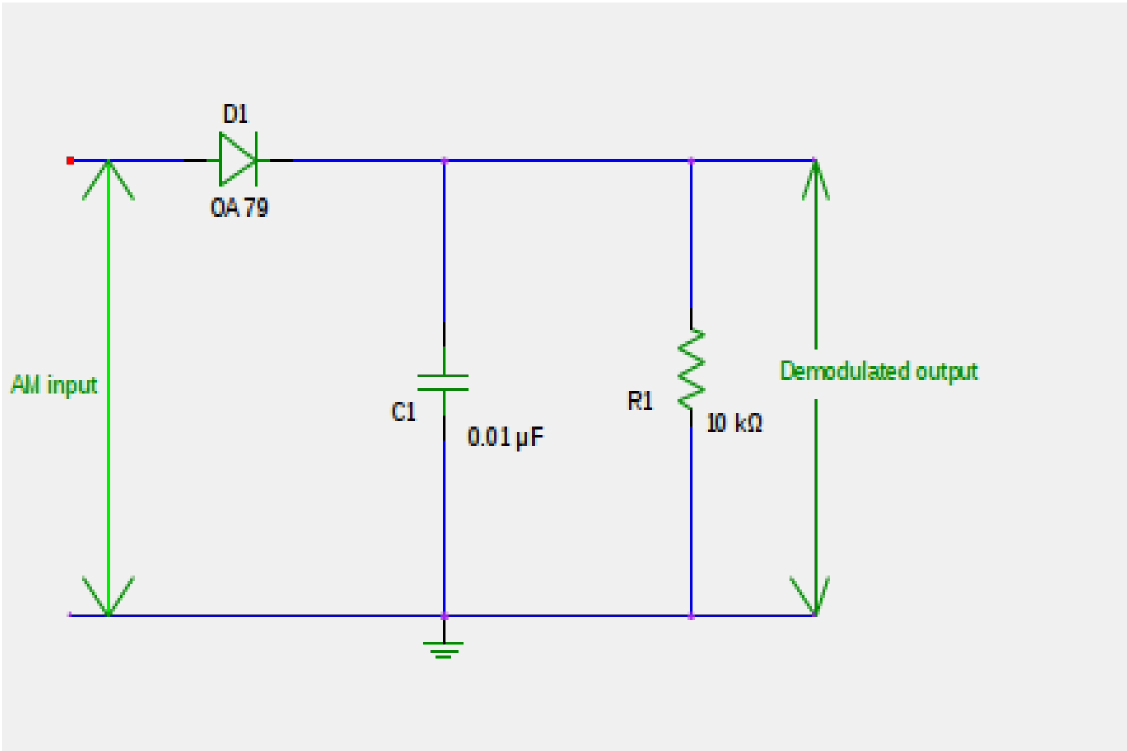

Figure 4.1: AM Demodulation-Simple Diode Detector

4. Observe the Modulated and demodulated waveforms and plot it on a graph sheet.

Observation

A model plot showing the expected result of the experiment is shown in the Fig.4.2

Result

AM demodulation circuit was implemented on breadboard and output was observed and plotted ona graph sheet.

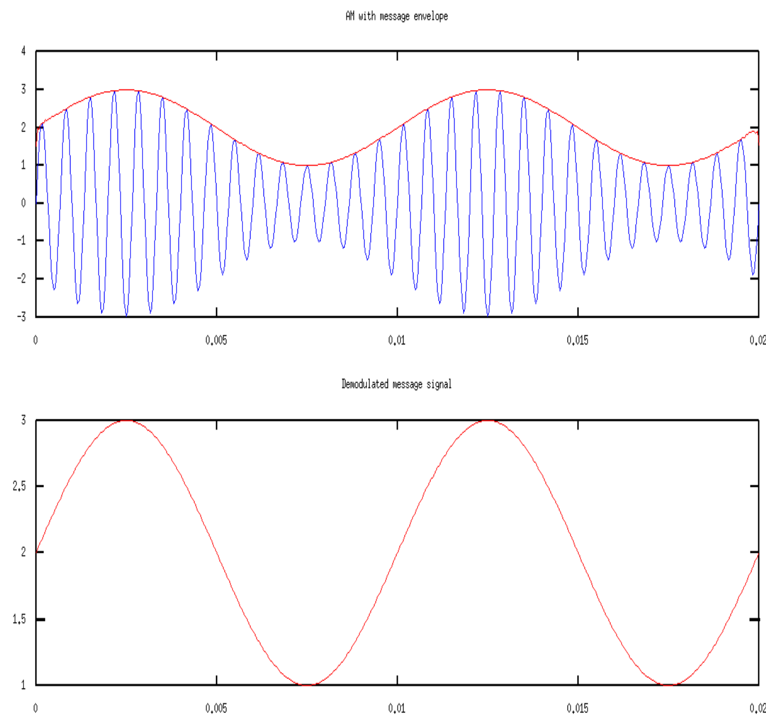

Figure 4.2: Modulated AM signal and Demodulated carrier

Chapter 5

Mixer (Frequency Converter) Circuit using BJT

Aim

To design and set up a frequency converter circuit to produce an output frequency (f_0) which is the difference frequency between the two input frequency, ($f_1 - f_2$).

Theory

A mixer or frequency mixer is a nonlinear electrical circuit that creates new frequencies from two signals applied to it. In its most common application, two signals at frequencies f_1 and f_2 are applied to a mixer, and it produces new signals at the sum $f_1 + f_2$ and difference $f_1 - f_2$ of the original frequencies. Other frequency components (like $f_1 \pm 2f_2$ may also be produced in a practical frequency mixer.[1]

The most important application of mixers are in superhetrodyne receivers where the very high carrier frequency is down converted to an intermediate frequency. This is done by mixing the carrier frequency with a locally generated oscillator frequency to get an output frequency which is the difference between local oscillator frequency and incoming signal frequency, ie the intermediate frequency. In widely used AM receivers the local oscillator frequency is so chosen with respect to carrier frequency such that their difference is a conststnt intermediate frequency of 455kHz.

$$f_{IF} = f_{oscillator} - f_{carrier} = 455kHz$$

[1] `http://en.wikipedia.org/wiki/Frequency_mixer`

The mixer output which contains all image frequencies of $f_1 \pm n f_2$ is filtered to obtain the required difference frequency $f_1 - f_2$.

Design

Choose Transistor BC107. See A.2 for details.

Components and Equipments required

Function Generators(2), CRO(1), Connection wires, Breadboard, Probes.
BC107 (1)
$47k\Omega,\ 10k\Omega\ (2),\ 560\Omega,\ \ 2.2k\Omega,\ 10k\Omega(2)$- Resistors
$1\mu F,\ 0.1\mu F,\ 0.01\mu F$ - Capacitor

Circuit Diagram

See Figure 5.1 for circuit diagram.

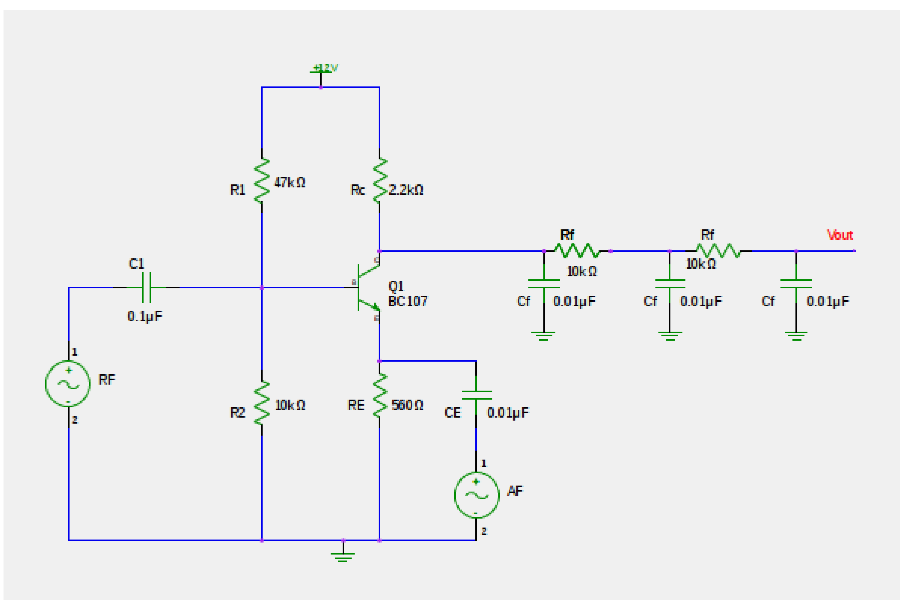

Figure 5.1: Circuit Diagram for Mixer circuit using BJT

Procedure

Observation

Result

Chapter 6

Balanced Modulator for DSB-SC

Aim

Theory

Design

Circuit Diagram

Procedure

Observation

Result

Chapter 7

FM generation - Reactance Modulator

Aim

Theory

Design

Circuit Diagram

Procedure

Observation

Result

Chapter 8

FM Demodulation

Aim

Theory

Design

Circuit Diagram

Procedure

Observation

Result

Chapter 9

PAM Generation and Demodulation

Aim

Theory

Design

Circuit Diagram

Procedure

Observation

Result

Chapter 10

Intermediate Fequency Amplifier

Aim

Theory

Design

Circuit Diagram

Procedure

Observation

Result

Chapter 11

FM Demodulation using PLL

Aim

Theory

Design

Circuit Diagram

Procedure

Observation

Result

Chapter 12

AM generation and Demodulation

Aim

Theory

Design

Circuit Diagram

Procedure

Observation

Result

Chapter 13

SSB generation and Demodulation

Aim

Theory

Design

Circuit Diagram

Procedure

Observation

Result

Appendix A

Quick Reference-Data on Components

A.1 BJT BF194/195

BF194/195 is a high frequency transistor. From its datasheet
Type Designator: BF194/BF195
Material of transistor: Si
Polarity: NPN
Maximum collector power dissipation (Pc), W: 0.25
Maximum collector-base voltage $|V_{cb}|$, V: 30
Maximum collector-emitter voltage $|V_{ce}|$, V: 20
Maximum emitter-base voltage $|V_{eb}|$, V: 5
Maximum collector current $|I_{cmax}|$, mA: 30
Forward current transfer ratio (hFE), min: 67
TODO: Pinout diagram to be added

A.2 BJT BC107

Type Designator: BC107
Material of transistor: Si
Polarity: NPN
Maximum collector power dissipation (P_c), W: 0.3
Maximum collector-base voltage $|V_{cb}|$, V: 50
Maximum collector-emitter voltage $|V_{ce}|$, V: 45
Maximum emitter-base voltage $|V_{eb}|$, V: 6
Maximum collector current $|I_{cmax}|$, A: 0.1
Forward current transfer ratio (h_{FE}), min: 110
Package of BC107 transistor: TO18

A.3 Intermediate Frequency Transformer

IFT act as parallel resonant circuits whose resonating frequency is around 455 kHz. This frequecy is adjustable by a factor of FIXME plusorminus 10%. IFT has a tappedd primary winding and a secondary winding. Primary winding has a capacitor connected in parallel internally. Its inductor value is $L_eq = 450\,muH$ and capacitance $C = 270\,pF$.
Its resonant frequency is thus $f = \frac{2\pi}{\sqrt{L_{eq}C}} \approx 455kHz$.

TODO: add schematic diagram and photo of IFT

Bibliography

[1] LABORATORY MANUAL COMMUNICATIONS LABORATORYEE 321, CALIFORNIA STATE UNIVERSITY, LOS ANGELES Lab-Volt Systems, Inc