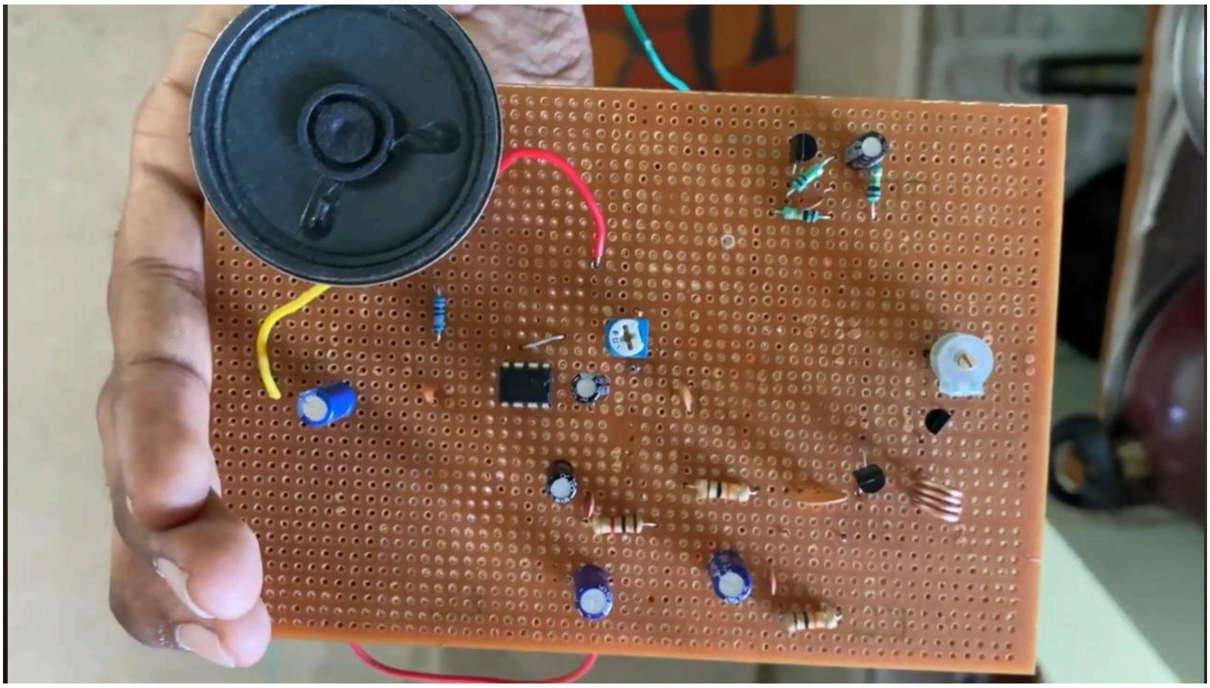

Minor Project Circuit (FM Receiver)

Abstract

An FM receiver is an essential electronic device designed to capture and demodulate frequency-modulated (FM) radio signals, converting them into high-fidelity audio output for listeners. Widely used in radio broadcasting, FM technology operates within the 88–108 MHz Very High Frequency (VHF) band, offering superior audio quality and greater resistance to noise and interference compared to amplitude modulation (AM) systems. The FM receiver’s primary function is to process electromagnetic waves transmitted through the air, select the desired station, and reproduce the embedded audio information with clarity.

The operation of an FM receiver begins with an antenna, which intercepts a broad range of radio frequency (RF) signals. These signals are first passed through an RF amplifier, often implemented with high-frequency transistors such as the BF494 and BF495, to boost their strength while minimizing noise. The amplified signal then enters a tuned circuit, composed of an inductor and a variable capacitor, which isolates the desired FM frequency by resonance. This tuning mechanism is crucial for selectivity, allowing the receiver to focus on one station while rejecting others.

Following the selection of the target frequency, the signal is processed by a mixer and oscillator stage. This stage converts the incoming RF signal to a fixed intermediate frequency (IF), typically 10.7 MHz, which simplifies further filtering and amplification. The IF amplifier enhances the signal’s strength and sharpens selectivity, ensuring that only the chosen station is processed. The next critical stage is demodulation, where the frequency variations in the FM signal are converted back into the original audio waveform. Various demodulator circuits, such as the Colpitts oscillator configuration using BF494 and BF495 transistors, are employed to achieve this.

The extracted audio signal is still relatively weak and requires further amplification. This is typically accomplished using an audio amplifier integrated circuit, such as the LM386, which boosts the signal to a level suitable for driving a speaker or headphones. The final output is clear, high-quality audio, making FM receivers popular for music and voice broadcasts.

One of the key advantages of FM receivers is their large signal-to-noise ratio, which makes them highly effective at rejecting radio frequency interference and delivering superior sound quality. The FM transmission’s wider bandwidth (200 kHz per channel) allows for the transmission of higher audio frequencies, up to 15 kHz, compared to AM’s 4.5 kHz, further enhancing the listening experience.

The design and construction of a basic FM receiver, as detailed in this project, involve careful selection and integration of components such as transistors, variable capacitors, coils, resistors, and audio amplifier ICs. The circuit is simple yet effective for local FM reception, providing an educational platform for understanding the principles of wireless communication and analog electronics. While basic FM receivers are best suited for strong, nearby stations due to their limited sensitivity and selectivity, they serve as an excellent introduction to radio technology and have applications in educational kits, hobby projects, and basic communication systems.

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Introduction

Purpose:

The primary purpose of designing the FM receiver described above is to create an electronic device capable of receiving frequency-modulated (FM) radio signals and converting them into usable audio output, such as music or voice, for listeners. This involves capturing radio waves through an antenna, filtering and amplifying the desired signal, demodulating it to extract the original audio information, and finally amplifying this audio for playback through a speaker.
The design serves several key objectives:

- **Educational Value:** It demonstrates fundamental concepts in wireless communication, including frequency modulation, signal amplification, filtering, and demodulation, making it highly valuable for learning and teaching electronics and communication principles.
- **Practical Application:** The receiver allows users to access FM radio broadcasts, which are widely used for high-fidelity audio transmission in public, educational, and entertainment contexts.
- **Noise Resistance:** FM technology is chosen for its superior signal-to-noise ratio, which provides better rejection of radio frequency interference compared to amplitude modulation (AM), resulting in clearer audio reception.
- **Component-Level Understanding:** By using discrete components like transistors (BF494, BF495) and an audio amplifier IC, the project enables a deeper understanding of circuit design, component selection, and the practical challenges of building functional electronic systems.
- **Foundation for Further Development:** The project lays the groundwork for more advanced communication systems, including the integration of digital technologies and improved receiver architecture

Background

The design of the FM receiver is rooted in the historical evolution of radio technology, which has continually advanced to meet the growing demands for clearer audio, better selectivity, and improved resistance to interference. The concept of FM (Frequency Modulation) radio was pioneered by Edwin Armstrong in the early 20th century, following his earlier invention of the superheterodyne circuit-an innovation that became the foundation for most modern radio receivers. Armstrong's work was driven by the limitations of AM (Amplitude Modulation) radio, particularly its vulnerability to static and noise, which FM technology effectively overcomes by encoding information in frequency variations rather than amplitude. Early radio receivers relied on simple tuned circuits and crystal detectors, but as radio broadcasting expanded, the need for improved selectivity and sensitivity led to the development of more complex receiver architectures. The introduction of the superheterodyne receiver by Armstrong in 1918 was a major milestone, enabling receivers to convert incoming RF signals to a fixed intermediate frequency (IF) for easier amplification and filtering. This architecture remains the standard in FM receivers, as it allows for precise tuning and strong rejection of unwanted signals.

Another key development was the use of double-tuned inductively coupled circuits, or resonant transformers, which provided sharper tuning and narrower bandwidths, essential for distinguishing closely spaced stations. These advances addressed the challenges posed by the proliferation of radio stations and the need for clear, interference-free reception.

The transition from vacuum tubes to transistors in the 1960s and the later advent of integrated circuits (ICs) in the 1970s revolutionized receiver design, making radios more compact, reliable, and energy-efficient. Today, even simple FM receivers can be constructed using a combination of high-frequency transistors, such as the BF494 and BF495, and audio amplifier ICs, providing an accessible way to demonstrate the core principles of radio communication.

The background for designing the FM receiver in this project is therefore shaped by a century of innovation aimed at improving audio quality, selectivity, and ease of use. By leveraging proven circuit techniques-such as superheterodyne conversion, selective bandpass filtering, and robust demodulation-the design offers a practical and educational solution for receiving FM broadcasts, illustrating the enduring relevance of Armstrong's foundational work and the ongoing evolution of radio receiver technology.

Scope of above project

The FM receiver project, utilizing discrete components such as BF494 and BF495 transistors along with an audio amplifier IC, offers a wide and multifaceted scope in both educational and practical domains.

Educational Scope:

This project serves as an excellent learning platform for students and electronics enthusiasts to understand the fundamental principles of radio frequency (RF) communication, analog circuit design, and frequency modulation (FM) technology. By building the receiver from scratch, learners gain hands-on experience in circuit assembly, component selection, troubleshooting, and testing. The project also introduces key concepts such as resonance, amplification, filtering, and demodulation, which are foundational in electronics and communication engineering curricula.

Technical Scope:

The project demonstrates the practical implementation of an FM receiver capable of tuning into the 88–108 MHz VHF band, which is the standard FM broadcast range. It covers the design and functioning of critical blocks such as the RF amplifier, mixer, oscillator, IF amplifier, demodulator, and audio amplifier. By using commonly available transistors and ICs, the project emphasizes cost-effective and accessible design, making it suitable for local FM reception and experimentation with various circuit topologies.

Practical Applications:

Beyond educational value, the FM receiver can be adapted for real-world uses such as wireless public address systems, especially in environments like schools, colleges, and community centers. Its ability to reject radio frequency interference and deliver high-fidelity audio makes it suitable for addressing large gatherings, conducting events, or relaying important announcements. The receiver can also be integrated into other systems, such as wireless microphones or remote-control applications, further broadening its utility.

Research and Development:

The project can serve as a foundation for further research in wireless communication. Students and researchers can experiment with enhancements like stereo reception, digital tuning, signal strength indication, or integration with microcontroller-based systems for advanced features such as automatic station scanning and display. The modular nature of the design allows for iterative improvements and adaptation to emerging technologies.

Industry Relevance:

While basic in nature, the project reflects the core architecture used in commercial FM radios and communication devices. Understanding these principles is valuable for careers in electronics, telecommunications, and embedded systems design. The skills and insights gained from this project are directly transferable to more complex radio frequency and wireless communication projects.

Theoritical Background:

FM modulation and demodulation:

FM modulation:

Frequency Modulation (FM) is a widely used technique in electronic communication for encoding information onto a carrier wave by varying its instantaneous frequency in accordance with the amplitude of the input (modulating) signal. Unlike Amplitude Modulation (AM), where the carrier's amplitude changes to reflect the input, FM keeps the amplitude constant and instead shifts the frequency up and down, proportional to the modulating signal's instantaneous value.

In FM, the process begins with a high-frequency carrier wave and a lower-frequency modulating signal, such as an audio waveform. The carrier's frequency deviates above and below its central value depending on the amplitude of the modulating signal. The maximum extent of this frequency shift is called the peak frequency deviation (Δf), and the range over which the carrier frequency swings is determined by both the amplitude and frequency of the modulating signal. The mathematical representation of an FM signal is:

$$V_{FM}(t)=V_{co}\sin(2\pi[fc+(\Delta f/V_{mo})V_m(t)]t+\phi)$$

where f_c is the carrier frequency, $V_m(t)$ is the modulating signal, Δf is the peak deviation, and V_{mo} is the maximum amplitude of the modulating signal. The modulation index (β) in FM is defined as the ratio of the frequency deviation to the modulating frequency:

$$\beta=(\Delta f/f_m)$$

FM offers several significant advantages over AM. The most notable is its superior immunity to noise and interference. Since most noise affects amplitude rather than frequency, FM signals are less susceptible to static and other forms of electromagnetic interference, resulting in a clearer and higher-fidelity audio output. This makes FM especially suitable for music and high-quality audio broadcasting, as is common in commercial radio. Additionally, FM allows for a more efficient use of transmitted power, as the power is concentrated in the sidebands that carry the actual information rather than being wasted in the carrier.

However, FM also has some drawbacks. It requires a much larger bandwidth than AM-sometimes up to 20 times more-making spectrum allocation more challenging. FM transmitters and receivers are also more complex and costly to design and implement, as they require precise frequency control and more sophisticated circuitry.

Types of FM modulation:

1) Narrow Band
2) Wide Band

Narrow Band FM:

Narrowband Frequency Modulation (NBFM) is a form of frequency modulation where the frequency deviation of the carrier signal is small compared to the modulating frequency. In NBFM, the modulation index (β)-the ratio of frequency deviation (Δf) to the maximum modulating frequency (f_m)-is less than 1. This results in a much narrower bandwidth compared to wideband FM, making NBFM ideal for applications where spectrum efficiency is important.

Key Characteristics

- **Modulation Index (β):** Less than 1, typically much less than one radian.
- **Maximum Frequency Deviation:** Restricted to about 5 kHz.
- **Bandwidth:** Much smaller than wideband FM; approximately equal to twice the maximum modulating frequency (similar to AM), i.e., $BW \approx 2f_m$.
- **Spectrum:** Consists mainly of the carrier and the first upper and lower sidebands, closely resembling the spectrum of an AM signal.
- **Noise Immunity:** Lower than wideband FM, but sufficient for voice and simple data communication6.
- **Applications:** Commonly used in two-way mobile radio communications such as police, ambulance, taxi services, and point-to-point communication systems where channel spacing is limited.

Mathematical Representation

For a single-tone modulating signal, the NBFM signal can be approximated as:

$s(t) \approx A_c \cos(\omega_c t) - A_c \beta \sin(\omega_c t) \sin(\omega_m t)$

where:

- A_c = carrier amplitude
- ω_c = carrier angular frequency
- ω_m = modulating angular frequency
- β = modulation index ($\Delta f / f_m$)

This simplified expression shows that NBFM contains the carrier and just one pair of sidebands, similar to AM, but with a phase difference.

Bandwidth Calculation

The bandwidth of an NBFM signal can be estimated using Carson's Rule:

$BW = 2(\Delta f + f_m)$

For NBFM, since Δf is small and β < 1, the bandwidth is typically close to $2f_m$

<u>Wide Band FM</u>

Wideband Frequency Modulation (WBFM) is a form of frequency modulation where the frequency deviation of the carrier is large relative to the modulating frequency, resulting in a high modulation index (typically much greater than 1). This leads to a much wider signal bandwidth compared to narrowband FM, enabling the transmission of high-quality audio and additional services.

Key Characteristics

- **Frequency Deviation:** In WBFM, the maximum frequency deviation is large-up to ±75 kHz for FM broadcasting.
- **Bandwidth:** The total bandwidth required is much greater, typically around 200 kHz per FM broadcast channel.
- **Modulation Index:** The modulation index (ratio of frequency deviation to modulating frequency) is much greater than 1, often reaching values of 10 or higher.
- **Spectrum:** WBFM signals contain the carrier and a large number of sidebands, with power distributed among many spectral components according to Bessel functions.
- **Signal Quality:** WBFM provides excellent noise immunity and high-fidelity audio, making it ideal for music and entertainment broadcasting.

Mathematical Representation

The WBFM signal can be represented as:

$s(t)=A_C\cos(2\pi f_c t+\beta\sin(2\pi f_m t))$

where:

- A_C = carrier amplitude
- f_c = carrier frequency
- f_m = modulating frequency
- β = modulation index (very large for WBFM)

Bandwidth Calculation

The bandwidth of WBFM is estimated using Carson's Rule:

$BW=2(\Delta f+f_m)$

where:

- Δf = maximum frequency deviation (e.g., 75 kHz)
- f_m = maximum modulating frequency (e.g., 15 kHz for audio)
- For FM broadcasting, this results in a bandwidth of approximately 180–200 kHz

<u>FM demodulation:</u>

FM demodulation is the process of extracting the original information (such as audio or data) from a frequency-modulated carrier signal. In FM, information is encoded by varying the instantaneous frequency of the carrier wave. The demodulator's job is to recover this information by detecting these frequency variations and converting them back into the original baseband signal.

Methods of FM Demodulation:

1. Slope Detector (FM-to-AM Conversion)

- A slope detector uses a tuned circuit slightly offset from the carrier frequency. As the FM signal's frequency shifts, the amplitude response of the circuit changes, effectively converting frequency changes into amplitude changes. These amplitude variations can then be detected using a standard AM demodulator.
- While simple, slope detection is not very efficient or linear, and is rarely used in modern FM receivers except for demonstration purposes.

2. Foster–Seeley Discriminator and Ratio Detector

- These are classic analog circuits specifically designed for FM demodulation. They use phase and amplitude relationships in tuned circuits to produce an output voltage proportional to the instantaneous frequency deviation of the FM signal.
- The Foster–Seeley discriminator is sensitive to amplitude variations, so it is usually preceded by a limiter stage to remove amplitude noise.

3. Phase-Locked Loop (PLL)

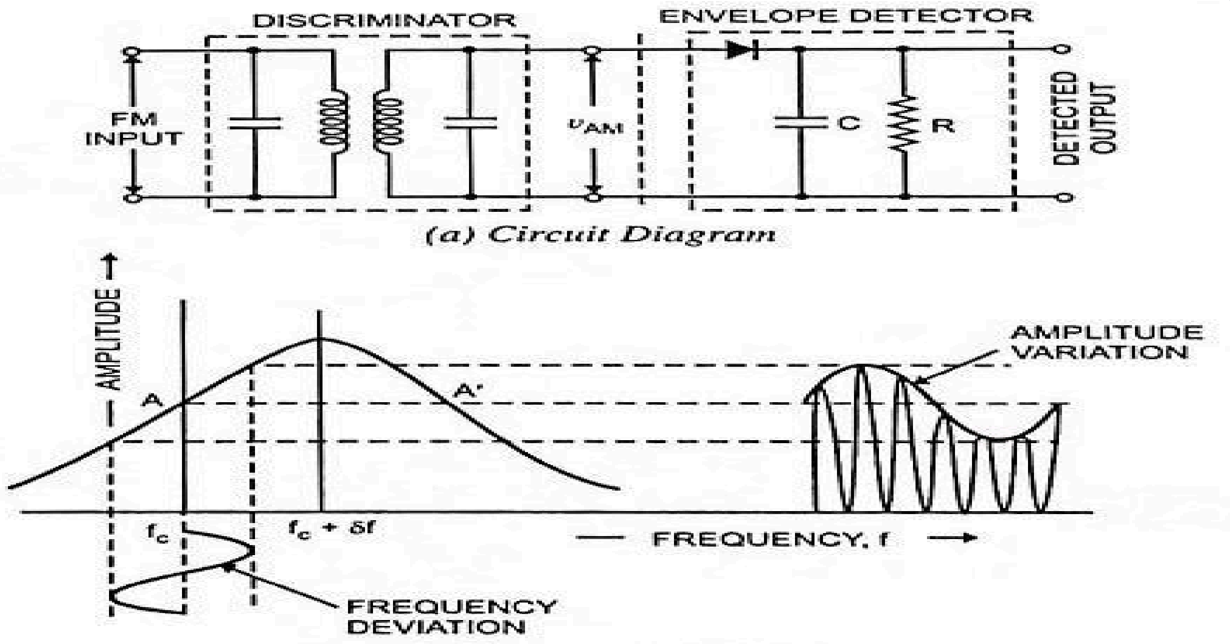
- A PLL is a highly effective and widely used FM demodulator. It locks onto the frequency of the incoming FM signal and tracks its variations. The error voltage generated by the PLL (which keeps the VCO in sync with the input) is proportional to the original modulating signal.
- PLL demodulators offer excellent linearity and noise performance and are common in both analog and digital FM receivers.

1)**Slope Detection in FM Demodulation:**

Slope detection is one of the simplest and earliest methods used for demodulating frequency-modulated (FM) signals. The core idea is to convert the frequency variations in the FM signal into amplitude variations using a tuned circuit, and then recover the original modulating signal by detecting these amplitude changes.

How Slope Detection Works

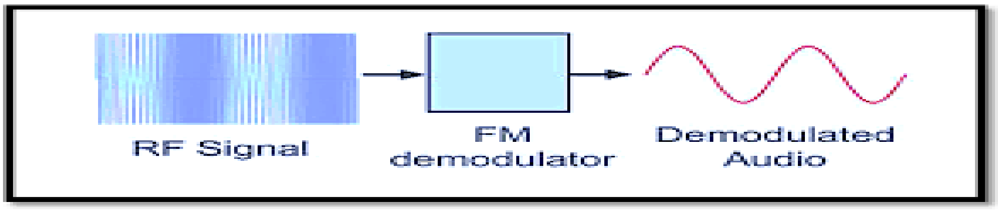
1. **Tuned Circuit Offset:**
   A slope detector uses a resonant LC (inductor-capacitor) circuit that is intentionally tuned slightly off (either above or below) the carrier frequency of the incoming FM signal. This offset places the FM signal on the sloping part of the circuit's frequency response curve.
2. **Frequency-to-Amplitude Conversion:**
   As the frequency of the FM signal varies (due to modulation), it moves up and down the slope of the tuned circuit's response. This causes the output amplitude of the circuit to increase or decrease in proportion to the frequency deviation from the resonance point. Essentially, frequency changes are translated into amplitude changes.
3. **Amplitude Detection:**
   The output of the tuned circuit, now an amplitude-modulated (AM) signal, is fed into a simple envelope detector (typically a diode followed by an RC filter). This stage extracts the amplitude variations, which correspond to the original audio or data signal that modulated the FM carrier.



(a) Circuit Diagram

(b) Characteristic Curve

Fig. 22.52 Slope Detector



Circuit Structure

- **Single-Ended Slope Detector:**
  Consists of one tuned LC circuit and a diode detector.
- **Balanced Slope Detector (Frequency Discriminator):**
  Uses two slope detectors, one tuned above and one below the carrier frequency, with their outputs combined to improve linearity and cancel out common-mode errors, such as those caused by amplitude noise.

<u>2)Foster Seeley Discriminator:</u>

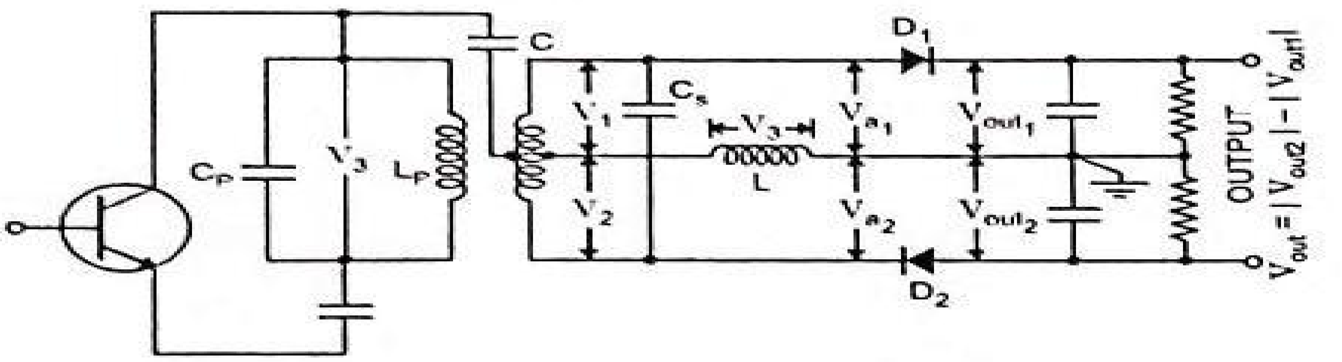


Fig. 22.54 *Circuit Diagram of Foster-Seeley Detector*

The centre of the secondary coil is connected to the top of the primary (collector end) through a capacitor C. This capacitor C performs the following functions:

1. It blocks the dc from primary to secondary.
2. It couples the signal frequency from primary to centre tapping of secondary.

The primary voltage V_3 (i.e., the signal voltage) thus appears across the inductor L. Nearly entire voltage V_3 appears across inductor L except a small drop across the capacitor C. However, by a suitable choice of C and L, the voltage drop across the capacitor C can be made negligible

The centre tapping of the secondary coil has an equal and opposite voltage across each half winding. Hence V_1 and V_2 are equal in magnitude but opposite in phase. The radio frequency voltages V_{a1} and V_{a2} applied to the diodes D_1 and D_2 are expressed as

$$V_{a_1} = V_3 + V_1 \text{ and } V_{a_2} = V_3 + V_2$$

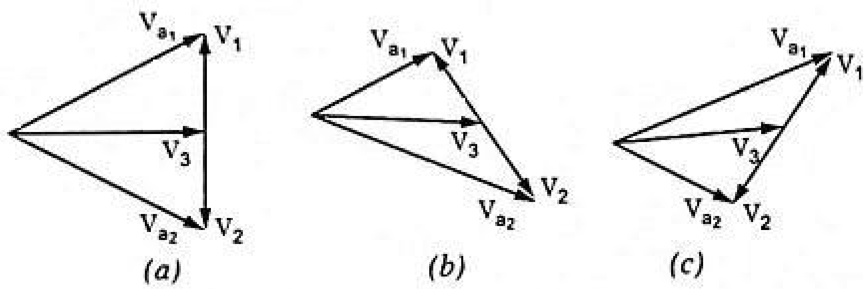


Fig. 22.55 *Phasor Diagram*

Voltage V_{a1} and V_{a2} depend upon the phase relations between V_1, V_2 and V_3. The phasor diagrams of Foster Seeley Detector for different frequencies have been shown in Fig. 22.55. The phasors V_1 and V_2 are always equal in magnitude but in phase opposition. However, the phase position of V_1 and V_2 relative to V_3 would depend upon the tuned secondary coil at the resonance or off the resonance as discussed below:

1. At Resonance: When an input voltage has a frequency equal to the resonant frequency f_{if} of the tuned secondary, V_3 is in phase quadrature (90° out of phase) with V_1 and V_2. This has been indicated in Fig. 22.55 (a). The resultant voltages V_{a1} and V_{a2} are equal in magnitude.

2. Off Resonance: When the input voltage is off the resonant frequency f_{if} of the tuned secondary, the phase position of V_1 and V_2 relative to V_3 will be different from 90°. Let Q_s be the quality factor of tuned secondary coil. When an input signal frequency exceeds the resonant frequency f_{if} by an amount $f_{if}/2Q_s$ the phase difference between V_3 and V_1 is 45° as shown in Fig. 22.55 (b). Because V_2 is in phase opposition of V_1, the phase difference between V_3 and V_2 is 135°. The phasor diagram shown in Fig. 22.55 (b) reveals that V_{a1} is reduced whereas V_{a2} is increased. The situation is reversed when the input voltage has a frequency below f_{if} which is evident from the phasor diagram shown in Fig. 22.55 (c). Thus the magnitude of the voltages V_{a1} and V_{a2} will vary with the instantaneous frequency f in the manner shown in Fig.

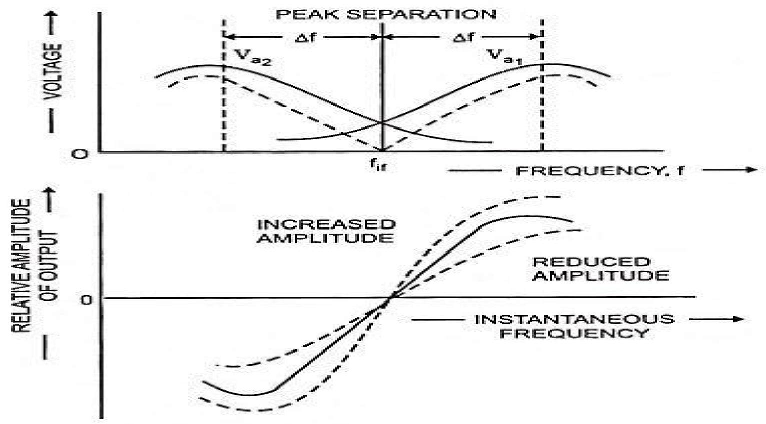


Fig. 22.56 *Discriminator Characteristics*

The RF voltages V_{a1} and V_{a2} are separately rectified by the diodes D_1 and D_2 respectively to provide voltages V_{out1} and V_{out2}. The RF components are bypassed by the capacitors leaving only modulating frequency component and a dc term. The voltages V_{out1} and V_{out2} then represent the amplitude variations of voltages V_{a1} and V_{a2} respectively. The diodes are so arranged that the output voltage V_{out} is equal to the arithmetic difference $|V_{out2}| - |V_{out1}|$.

i.e., $V_{out} = |V_{out_2}| - |V_{out_1}|$

Thus, the output voltage V_{out} will vary with instantaneous frequency in accordance with the difference $|V_{out2}| - |V_{out1}|$, as shown by the dotted curve in Fig. 22.56 (b). This allotted curve is known as **discriminator characteristic** in Fig

3)PLL FM Detector or Demodulator:

When the PLL is locked in on the FM signal, the VCO frequency follows the instantaneous frequency of the FM signal, and the error voltage or VCO control voltage is proportional to the deviation of the input frequency from the centre frequency.

Therefore, the a-c component of error voltage or control voltage of VCO will represent a true replica of the modulating voltage that is applied to the FM carrier at the transmitter.

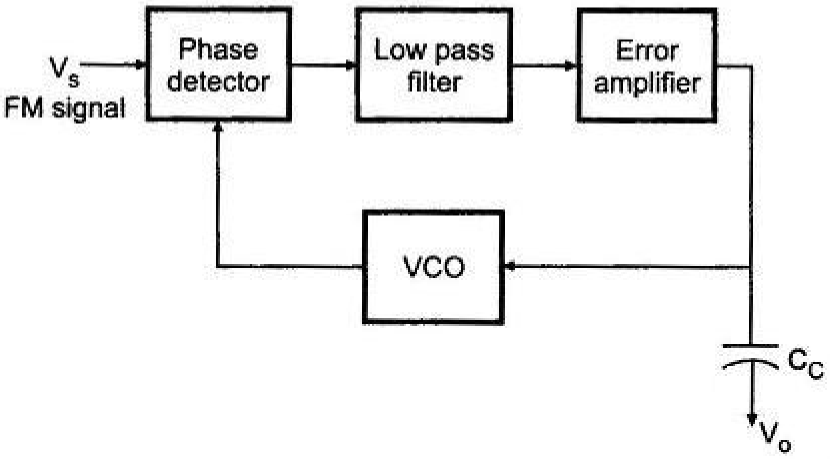


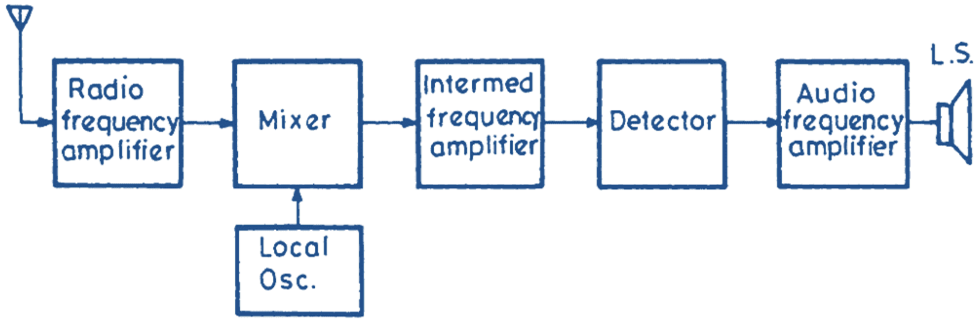
Fig. 2.131 PLL as a FM detector

The faithful reproduction of modulating voltage depends on the linearity between the instantaneous frequency deviation and the control voltage of VCO. It is also important to note that the FM frequency deviation and the modulating frequency should remain in the locking range of PLL to get the faithful replica of the modulating signal.

If the product of the modulation frequency f_m and the frequency deviation exceeds the $(\Delta f_c)^2$, the VCO will not be able to follow the instantaneous frequency variations of the FM signal**.**

Block Diagram of an FM receiver:

A **super heterodyne FM receiver** is designed to efficiently receive, select, and demodulate frequency-modulated signals by converting the received radio frequency (RF) signal to a fixed, lower intermediate frequency (IF) for easier filtering and amplification. The block diagram consists of several key stages, each with a specific function in the signal processing chain.



Block Descriptions

- **Antenna:** Captures incoming FM radio signals from the air.
- **RF Amplifier:** Amplifies the weak received RF signals and provides initial selectivity, helping to suppress unwanted frequencies and image signals.
- **Mixer:** Combines the amplified RF signal with a signal from the local oscillator to produce a fixed intermediate frequency (IF), typically 10.7 MHz for FM receivers.
- **Local Oscillator:** Generates a tunable frequency that mixes with the incoming RF to produce the IF. The tuning of the local oscillator determines which station is received.
- **IF Amplifier & Filter:** Amplifies and sharply filters the IF signal, providing most of the receiver’s gain and selectivity. Because the IF is fixed, high-performance filters (like ceramic or crystal filters) can be used.
- **Limiter:** Removes amplitude variations (noise spikes) from the IF signal, ensuring that only frequency variations remain, which is essential for FM demodulation.
- **FM Demodulator (Detector):** Extracts the original audio signal from the frequency-modulated IF signal.
- **Audio Amplifier:** Boosts the recovered audio signal to a level suitable for driving a speaker or headphones.
- **Speaker:** Converts the electrical audio signal into sound waves for the listener.

Component and their function:

1. **Antenna**

- **Function:** Captures electromagnetic FM radio signals from the air.
- **Explanation:** The antenna is the first point of contact for the incoming RF signals. Its efficiency affects the overall sensitivity of the receiver.

2. **RF Amplifier (Tuned Circuit)**

- **Function:** Amplifies weak RF signals and provides initial selectivity.
- **Explanation:** The RF amplifier boosts the strength of the received signal and helps reject unwanted frequencies, reducing noise and improving the signal-to-noise ratio.

3. **Mixer**

Function: Combines the amplified RF signal with the local oscillator signal to produce the intermediate frequency (IF).

- **Explanation:** The mixer's output is the difference between the RF and local oscillator frequencies, allowing the desired signal to be shifted to a fixed IF (commonly 10.7 MHz for FM).

4. **Local Oscillator**

- **Function:** Generates a tunable frequency that determines which station is received.
- **Explanation:** By adjusting the local oscillator, the receiver can select different FM stations. The oscillator frequency is set so that the difference between it and the incoming RF signal equals the IF.

5. **IF Amplifier & Filter**

- **Function:** Amplifies and filters the IF signal.
- **Explanation:** Most of the receiver's gain and selectivity are achieved here. Because the IF is fixed, highly selective filters (like ceramic or crystal filters) can be used to reject adjacent channel interference and improve audio quality.

6. **Limiter**

- **Function:** Removes amplitude variations from the IF signal.
- **Explanation:** Since FM signals carry information in frequency, not amplitude, the limiter eliminates any amplitude noise or spikes, ensuring only frequency variations reach the demodulator.

7. **FM Demodulator (Detector)**

- **Function:** Recovers the original audio signal from the frequency-modulated IF signal.
- **Explanation:** The demodulator converts frequency changes back into voltage variations corresponding to the original audio or data signal. Common FM demodulators include the Foster-Seeley discriminator, ratio detector, and phase-locked loop (PLL).

8. **Audio Amplifier**

- **Function:** Amplifies the recovered audio signal.
- **Explanation:** The audio amplifier boosts the low-level output from the demodulator to a level suitable for driving a speaker or headphones.

9. **Speaker**

- **Function:** Converts the amplified electrical audio signal into sound waves.
- **Explanation:** The speaker provides the final output, making the received audio audible to the listener.

Colpitts oscillator:

Colpitts oscillator is an electronic circuit that generates sinusoidal oscillations, typically in the radio frequency (RF) range, using a combination of inductors and capacitors to form a resonant "tank" circuit. It is widely used for its ability to produce stable and pure sine wave signals.

Circuit Configuration and Working Principle

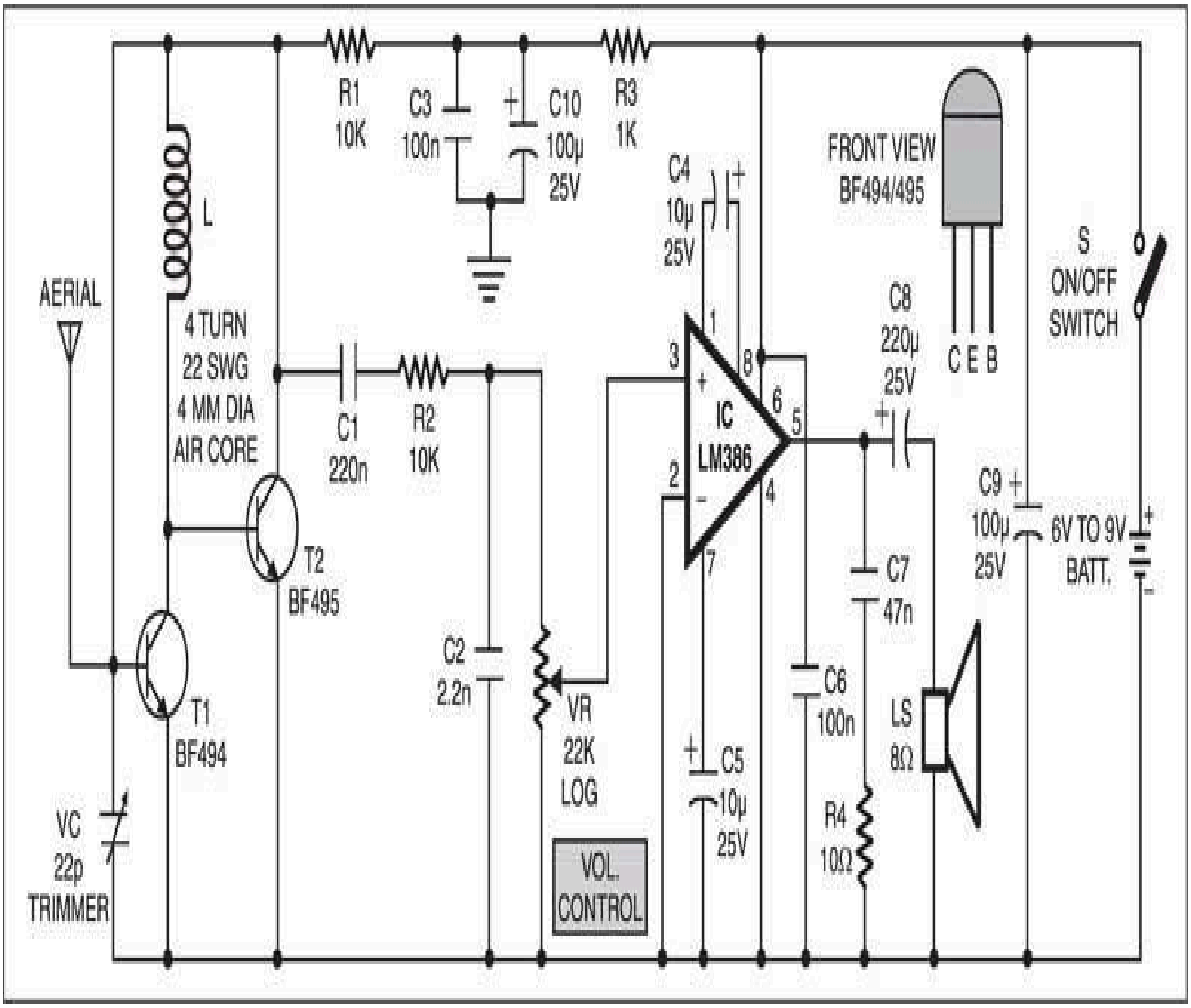
- The core of the Colpitts oscillator is a parallel LC (inductor-capacitor) tank circuit, but unlike the Hartley oscillator (which uses a tapped inductor), the Colpitts uses two capacitors (C1 and C2) in series and an inductor (L) in parallel.
- The junction of the two capacitors forms a capacitive voltage divider, which provides the required feedback for sustained oscillations.
- The feedback signal is taken from the center point between C1 and C2 and fed back to the active device (such as a transistor or op-amp) to satisfy the Barkhausen criterion for oscillation (total phase shift of 360° or 0° and loop gain ≥ 1).
- The frequency of oscillation is determined by the values of the inductance (L) and the series combination of the two capacitances (C1 and C2), given by:

$f=(1/L\cdot C_{eq})^{1/2}/2\pi$

where $C_{eq}= C1\cdot C2/(C1+C2)$

Design and Implementation:

Circuit Diagram:



Componenet selection:

- **L (Aerial Coil):**

This is an inductor that, along with VC, forms the tuning circuit to select the desired radio frequency. It's specified as a 4-turn coil of 22 SWG wire with a 4mm diameter air core.

- **VC (Variable Capacitor/Trimmer):**

  This is a variable capacitor used to fine-tune the receiver to the desired radio station. Its value is 22pF (picofarads).

- **T1, T2 (Transistors BF494/BF495):**

  These transistors are used in the RF amplifier stage to amplify the weak radio signals received by the antenna.

- **R1, R2, R3, R4 (Resistors):**

  These resistors are used for biasing the transistors and setting the gain of the amplifier stages. Their values are 10kΩ (kiloohms), 10kΩ, 1kΩ, and 100Ω respectively.

- **C1, C2, C3, C4, C5, C6, C7, C8, C9, C10 (Capacitors):**

  These capacitors are used for filtering, coupling, and bypassing signals in the circuit. Their values range from 2.2nF (nanofarads) to 100µF (microfarads).

- **IC (LM386):**

  This is an audio amplifier integrated circuit that amplifies the demodulated audio signal to drive the speaker.

- **VR (Variable Resistor/Potentiometer):**

  This is a variable resistor used as a volume control to adjust the loudness of the audio output. It's a 22kΩ logarithmic potentiometer.

- **LS (Loudspeaker):**

  This is the speaker that converts the amplified audio signal into sound waves. It has an impedance of 8Ω (ohms).

- **S (Switch):**

  This is a simple on/off switch to control the power supply to the circuit.

- **BATT (Battery):**

  This is the power source for the circuit, providing a voltage between 6V and 9V.

  This circuit works by receiving radio waves through the aerial, tuning to a specific frequency using the variable capacitor, amplifying the signal with transistors, demodulating the audio signal, amplifying the audio signal with the LM386, and finally outputting the sound through the speaker.

Generation of FM receiver:

Inductor:

An **inductor**-also known as a *coil*, *choke*, or *reactor*-is a passive two-terminal electrical component that stores energy in a magnetic field when electric current flows through it. It typically consists of an insulated wire wound into a coil, often around a core made of air, iron, or ferrite to enhance its properties.

Calculate the **inductance** for an air-core inductor made with **22 SWG wire**, a **4 mm diameter**, and **4 turns**.

1. **Given Data**

- **Wire Gauge:** 22 SWG (diameter ≈ 0.711 mm)
- **Coil Diameter:** 4 mm (radius = 2 mm = 0.2 cm)
- **Number of Turns:** 4
- **Coil Length:** For a single-layer coil, length ≈ number of turns × wire diameter
  = 4 × 0.711 mm = 2.844 mm = 0.2844 cm

2. **Inductance Formula (Wheeler's Formula for Air-Core Solenoid)**

For a single-layer air-core coil:
$L=[(r^2)\cdot N^2]/[9r+10l]$
Where:

- L = inductance in micro henries (µH)
- r = radius of coil in centimeters (cm)
- l = length of coil in centimeters (cm)
- N = number of turns

3. **Plug in the Values**

- r=0.2 cm
- N=4
- l=0.2844 cm

$L=[(0.2^2)\times 4^2]/[9\times 0.2+10\times 0.2844]$

$L=[0.04\times 16]/[1.8+2.844]$

$L=0.64/4.644$

$L\approx 0.138$ µH

<u>Trimmer(22pF):</u>

A **22pF trimmer capacitor** is a small, adjustable capacitor designed for precise tuning in electronic circuits, especially in radio frequency (RF) and high-frequency applications.

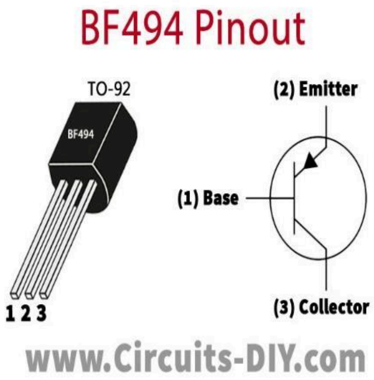
Key Features:

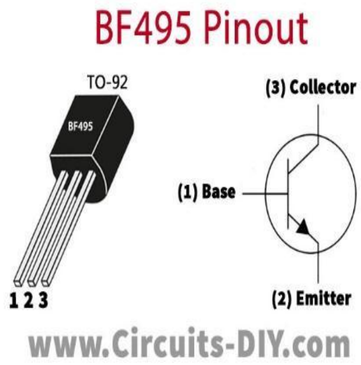
- **Capacitance Range:** Typically adjustable from about 2pF up to 22pF, with some models starting at 2.5pF.
- **Voltage Rating:** Commonly rated for 50V to 250V, depending on the specific model.
- **Mounting Type:** Usually through-hole, but surface-mount versions are also available.
- **Adjustment:** Capacitance is adjusted using a small screw or similar mechanism, allowing fine-tuning during circuit calibration.
- **Size:** Compact, suitable for PCB mounting and space-constrained designs.
- **Temperature Range:** Operating temperature typically from -40°C to +85°C.

Typical Applications

- **RF & Wireless Communication Circuits:** Used for impedance matching and frequency tuning.
- **Oscillators & Crystal Circuits:** Fine-tunes clock signals and frequency stability.
- **Antenna Matching & Filters:** Optimizes performance in radios, TVs, and communication equipment.
- **Tuning Circuits for Audio & Sensors:** Ensures optimal signal processing.

Transistor(BF494, BF495):





BF494 and **BF495** are NPN silicon planar epitaxial transistors designed for medium-frequency applications, especially in radio and television receivers, FM tuners, AM mixer-oscillators, and IF amplifiers.

- The main difference between BF494 and BF495 is the DC current gain (hFE): BF494 offers higher gain (67–220) compared to BF495 (35–125), making BF494 preferable where higher amplification is needed.

These transistors are widely used in RF and IF stages due to their frequency response and low noise characteristics.

<u>Resistor(R1,R2,R3,R4):</u>

A resistor is a passive two-terminal electronic component designed to introduce electrical resistance into a circuit, thereby limiting or regulating the flow of electric current

Capacitors(C1,C2,C3,C4,C5,C6,C7,C8,C9,C10):

A capacitor is a passive electronic component that stores electrical energy in an electric field, created by accumulating electric charges on two closely spaced conductors (plates) separated by an insulating material called a dielectric. When a voltage is applied across its terminals, one plate gathers positive charge while the other accumulates negative charge, allowing the capacitor to store energy temporarily and release it when needed.

Variable Resistance(22kOhm):

A potentiometer of 22k ohm is a variable resistor with a total resistance of 22,000 ohms. It allows you to adjust the resistance manually, making it useful for controlling voltage, current, or signal levels in electronic circuits.
Key Features

- **Resistance:** 22k ohm (22,000 ohms)
- **Type:** Available as single-turn rotary, dual-gang rotary, and trimmer/preset versions
- **Adjustment:** Typically adjusted by rotating a shaft or screw
- **Terminals:** Usually 3 pins (for use as a variable resistor or voltage divider)
- **Tolerance:** Commonly ±20%
- **Power Rating:** Varies by model (e.g., 0.5W to 3W)
- **Mounting:** Panel mount or PCB mount options available

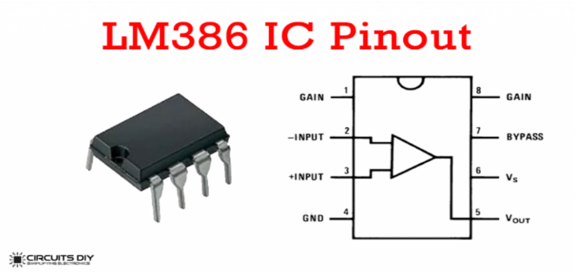
Loud speaker (8Ohm):

An 8 ohm speaker is a widely used audio component characterized by its impedance of 8 ohms, making it compatible with most audio amplifiers and systems. The 8 ohm rating indicates the speaker's resistance to electrical current, which is important for matching with amplifiers to ensure optimal performance and prevent damage.

Key Specifications (Typical)

- **Impedance:** 8 ohms (±10–15%)
- **Power Handling:** Available in various ratings such as 1W, 2W, 5W, 20W, etc.
- **Frequency Response:** Commonly ranges from around 95 Hz to 10 kHz for small speakers, and up to 20 kHz for larger or higher-end models.
- **Sensitivity:** Typically around 85–98 dB depending on the model and size.
- **Size:** Available in compact sizes (e.g., 20 mm, 36 mm, 78 mm) for embedded and portable projects, as well as larger sizes for more powerful audio systems

LM386 IC:



The LM386 (sometimes written as IClm386 or IC LM386) is a popular low-voltage audio power amplifier integrated circuit designed for use in battery-powered consumer applications and small audio projects.

Key Features

- **Operating Voltage:** 4V to 12V (some variants up to 18V)
- **Output Power:**
- 325 mW at 6V supply into 8Ω load (LM386N-1)
- Up to 700 mW at 9V supply into 8Ω load (LM386N-3)
- Up to 1W at 16V supply into 32Ω load (LM386N-4)
- **Speaker Compatibility:** Can drive loads from 4Ω to 32Ω
- **Voltage Gain:** Internally set to 20 (26 dB); adjustable up to 200 (46 dB) by adding a capacitor and resistor between pins 1 and 8
- **Low Quiescent Current:** Typical 4 mA, making it ideal for battery operation
- **Low Distortion:** 0.2% at 125 mW, 1 kHz, 8Ω load
- **Package:** 8-pin DIP or surface-mount

Bluetooth Speaker DIY Combo Kit – Upgraded TG 113 PCB Module with inbuilt Amplifier FM MP3 SD Card USB Slot 3.5 MM Audio Jack, 5W Mini Speaker, 2500mAH Li-ion Battery, Single Cell Holder

The **Bluetooth Speaker DIY Combo Kit** featuring the upgraded TG113 PCB module is a versatile and compact solution for building your own portable Bluetooth speaker system. Here's a detailed breakdown of the components and features based on your query and the available specifications:

TG113 PCB Module Features

- **Bluetooth Connectivity:** Supports wireless streaming from smartphones, tablets, and laptops.
- **Audio Inputs:** Multiple input options including Bluetooth, FM radio, MP3 (via USB/SD card), USB slot, 3.5mm audio jack (AUX), and FM tuner.
- **Inbuilt Amplifier:** Contains a small onboard amplifier suitable for driving speakers rated from 0.2W to 5W, making it compatible with your 5W mini speaker.
- **Microphone:** Integrated sound sensor/mic for recording or hands-free calling.
- **Power Supply:** Operates on 3.7V–5V DC, suitable for direct connection to a 2500mAh Li-ion battery (single cell).
- **Controls:** Push buttons for volume, play/pause, track navigation, and mode selection.
- **Additional Features:** Voltage regulator, LED indicators, and support for MP3/WMA/WAV formats.
- **Physical Size:** Compact, typically around 43mm x 38mm x 11.5mm.

Included Components in the DIY Combo Kit

- **TG113 Bluetooth Speaker Circuit Board Module** (with all-in-one amplifier, FM, MP3, USB, SD, AUX, and mic)
- **5W Mini Speaker:** Suitable for direct connection to the TG113 module.
- **2500mAh Li-ion Battery:** Provides long-lasting portable power.
- **Single Cell Holder:** For secure battery mounting and connection.
- **USB Charging Support:** The module can be powered and charged via USB

Result:

The result of an FM amplifier project-such as one built using an LM386 audio amplifier IC or similar module-typically includes successful amplification of weak FM audio signals to a level suitable for driving a small speaker (e.g., 8-ohm, 1-watt), making the audio output louder and clearer for listening.

Key outcomes and observations from such projects:

- **Amplification:** The circuit reliably increases the volume of FM audio signals, making them audible through a connected speaker.
- **Testing:** A common test is to touch the amplifier's input with a screwdriver, resulting in a humming sound from the speaker, confirming the circuit's functionality.
- **Volume Control:** Incorporating a potentiometer allows for easy adjustment of output volume.
- **Power Supply:** The amplifier operates effectively on low voltage (typically 6V or a single-cell Li-ion battery), making it suitable for portable FM radios and DIY projects.
- **Applications:** The amplified output is suitable for use in FM radios, portable music players, and similar low-power audio devices.
- **Performance:** The LM386 and similar circuits can provide a gain of up to 200 with external components, ensuring sufficient amplification for most FM audio applications

Conclusion:

Summary of finding:

- **Amplification Achieved:**
  The project successfully amplified weak FM audio signals, making them clearly audible through an 8-ohm speaker.
- **Circuit Functionality:**
  The amplifier circuit (e.g., using LM386) operated as expected, with input signals producing a strong output and a test hum confirming proper operation.
- **Volume Control:**
  The inclusion of a potentiometer allowed for smooth and effective volume adjustment.
- **Power Efficiency:**
  The amplifier worked reliably with a low-voltage power source (such as a single Li-ion cell), confirming suitability for portable applications.
- **Output Quality:**
  The amplified audio was clear and sufficiently loud for typical FM radio listening, with minimal distortion.
- **Practical Application:**
  The project demonstrated that a simple, low-cost amplifier circuit can significantly enhance the usability of FM receivers in DIY and educational settings.

Limitation:

While the FM amplifier project using the LM386 or similar low-voltage audio amplifier IC can deliver effective audio amplification for small speakers, several limitations are commonly observed:

- **Noise and Interference:**
The LM386 is prone to picking up noise, especially if power supply decoupling is inadequate or if the circuit layout is not optimal. Users often report background hiss, hum, or high-frequency whine, particularly when adjusting the volume or when the circuit is built on a breadboard.
- **Limited Output Power:**
The LM386 can only deliver modest output power (typically up to 700 mW to 1W, depending on the variant and supply voltage), making it suitable only for small speakers and low-volume applications. It is not appropriate for driving large speakers or for high-fidelity audio systems.
- **Crossover Distortion:**
As a simple push-pull amplifier, the LM386 can exhibit crossover distortion, which may affect audio quality, especially at low output levels.
- **Gain and Stability Constraints:**
While the gain can be increased up to 200 by adding external components, the amplifier is only compensated for closed-loop gains above 9. Using very low resistance values for feedback may cause instability or oscillation.
- **Sensitivity to Power Supply Quality:**
The circuit's performance is sensitive to power supply fluctuations and noise. Poor quality or unregulated power supplies can introduce additional noise or even damage the IC if voltage exceeds recommended limits.
- **Bass Response and Frequency Shaping:**
The bass response of small speakers and the LM386 circuit may be poor. External components can help shape the frequency response, but only to a limited extent[1].
- **Input Biasing Issues:**
If the input is not properly biased or capacitively coupled, DC offsets and additional noise may appear at the output.
- **Thermal and Overload Risks:**
Prolonged operation at high output or with mismatched loads can cause the IC to overheat, potentially leading to failure

Sugession for future:

Enhancing Circuit Performance

- **Add a Voltage Regulator:** Incorporate a voltage regulator to ensure tuning stability, especially when powering the receiver with a battery. This helps maintain consistent performance even as the battery voltage drops1.
- **Improve Sensitivity and Selectivity:** Upgrade the RF front-end with better filtering and amplification stages to improve the receiver's ability to pick up weak or distant stations1.
- **Implement Proper FM Demodulation:** Ensure the circuit includes a dedicated FM demodulator (such as a phase-locked loop or a quadrature detector) for accurate audio recovery, as some basic designs may lack this essential stage.

Advanced Design Approaches

- **Superheterodyne Architecture:** Move from a simple direct-conversion design to a superheterodyne receiver with an intermediate frequency (IF) stage (commonly 10.7 MHz for FM). This enhances selectivity and image rejection, making the receiver more robust and professional.
- **PLL-based Synthesizer:** Integrate a phase-locked loop (PLL) for local oscillator generation, which allows for precise and stable tuning across the FM band.
- **Digital Signal Processing (DSP):** Explore using software-defined radio (SDR) techniques or microcontrollers for digital demodulation and signal processing, which can open up features like RDS decoding or digital audio output.

User Interface and Features

- **Digital Tuning and Display:** Add a digital frequency display and push-button tuning for user convenience, possibly using microcontrollers and LCDs8.
- **Stereo Reception:** Upgrade the audio section to support stereo FM, which requires a stereo decoder circuit.
- **Signal Strength Indicator:** Include an RSSI (Received Signal Strength Indicator) or simple LED bar graph to visually indicate signal quality.

Exploring Modern Technologies

- **Hybrid Digital/Analog Reception:** Investigate integrating HD Radio or DAB (Digital Audio Broadcasting) capabilities for future-proofing your project.
- **Cognitive and Software-Defined Radio:** Experiment with cognitive radio or SDR platforms, allowing dynamic adaptation to the radio environment and supporting multiple modulation schemes.

Documentation and Learning

- **Detailed Project Documentation:** Maintain comprehensive documentation-including schematics, PCB layouts, and troubleshooting notes-to aid future improvements and help others replicate your work.
- **Educational Kits:** Consider building or modifying educational kits (like the Elenco FM-88K) to deepen your understanding of FM receiver design principles.

List of resources:

1)Communication Systems: Analog and Digital , by RP Singh, S. Sapre

2)Electronics for you: https://www.electronicsforu.com/electronics-projects/simple-fm-receiver

3)Tutorialpoint:https://www.tutorialspoint.com/principles_of_communication/principles_of_communication_fm_radio.htm

4) Communication Systems (Analog and Digital) by Dr. Sanjay Sharma

5) Communication System engineering book by John G Proakis and Masood Salehi

PCB Design of FM Receiver :