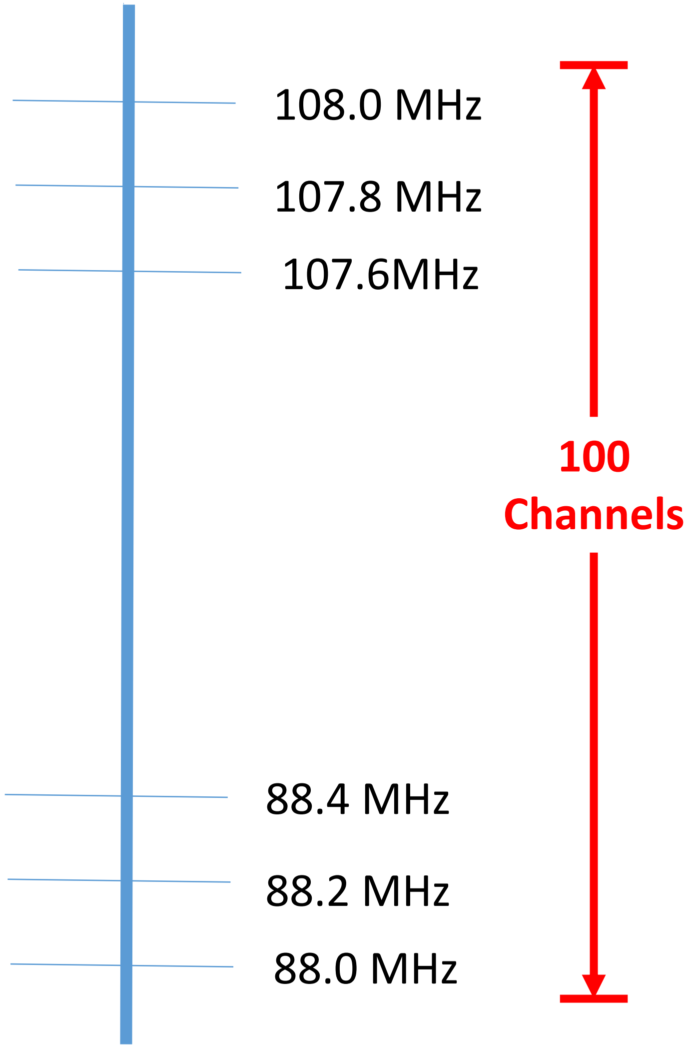
FREQUENCY MODULATION

EEN 462 – ANALOGUE COMMUNICATION SYSTEMS

Tuesday, 03 June 2025

HISTORY OF FREQUENCY MODULATION (FM)

1. **Edwin H. Armstrong**, known as one of the founding fathers of radio technology, invented the superheterodyne radio receiver in 1918 and frequency modulation (FM) in 1933.
2. FM radio was first deployed in **monaural form in 1940**.
3. **FM stereo was introduced in 1960**.
4. **These two concepts**, along with his regenerative circuit technique developed in 1912, formed the basis of radio frequency electronics as we know it today.
5. In Kenya (ITU region 1) FM radio stations broadcast between radio frequencies of 87.5 MHz to 108 MHz with a channel bandwidth of 200 kHz.



PRINCIPLE OF ANALOGUE MODULATION

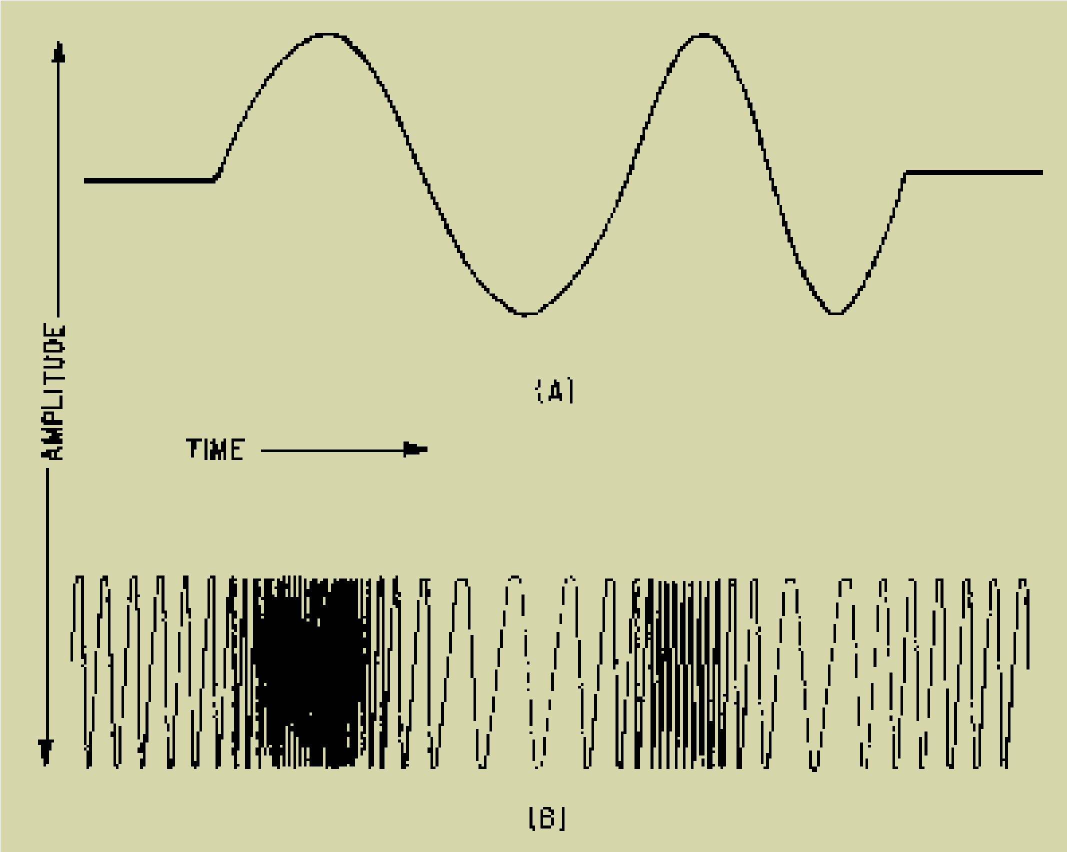
1. Consider the signal below

$$x(t) = A_c sin(2\pi f_c t + \theta)$$

2. This signal can be modulated to carry an information-bearing signal by varying:
   a) **Amplitude, A_c** : Amplitude modulation(AM)
   b) **Frequency, f_c** : Frequency Modulation (FM)
   c) **Phase, θ** : Phase modulation (PM)

3. **Frequency modulation and phase modulations are collectively referred to as angle modulation**.

BASIC RULES OF FREQUENCY MODULATION



1. **Amount of Frequency Shift** is Proportional to the Amplitude of the Modulating Signal

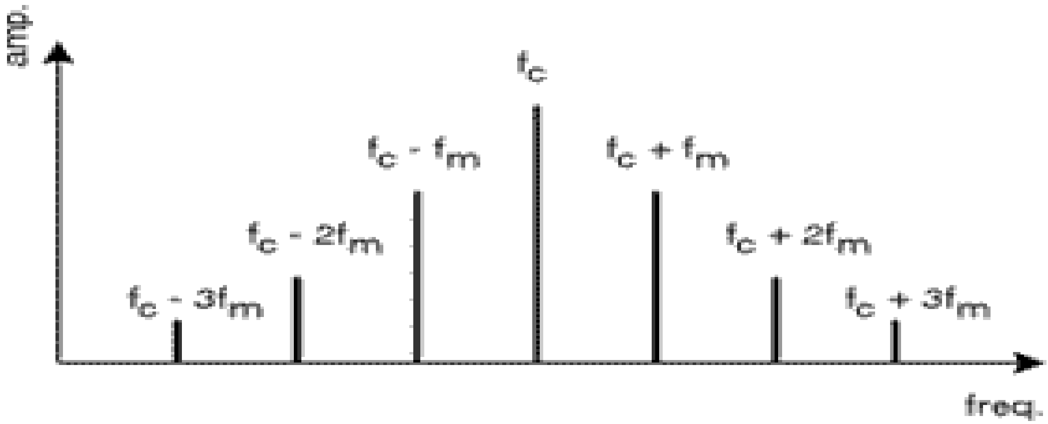
(This Rule Simply Means That If 10-Volt Signal Causes Frequency Shift of 20 Kilohertz, Then a 20-Volt Signal Will Cause a Frequency Shift Of 40 Kilohertz.)

2. **Rate of Frequency Shift** Is Proportional to the Frequency of the Modulating Signal

(This Rule Means That If The Carrier Is Modulated With 1-Kilohertz Tone, Then The Carrier Is changing frequency 1,000 Times each second.)

SIDEBANDS IN FREQUENCY MODULATION (FM)

1. **Frequency Modulation (FM)** produces a set of sidebands around the carrier C, equally spaced at a distance equal to the modulating frequency M.
2. The sidebands are referred to in pairs as: 1st, 2nd, 3rd, and so on.
3. **Number of sidebands in FM** would be infinite as the modulation index increases and hence the theoretical BW of FM would be infinite.
4. In practice, **only significant side frequencies** are considered for calculating the BW.



FM MODULATION INDEX

1. **FM transmissions are governed by a modulation index, β,** which controls
2. the dynamic range of the information being carried in the transmission.
3. The modulation index is defined as:

$$\beta = \frac{f_d}{f_m}$$

   where f_d is the frequency deviation and f_m is the modulating frequency.

4. FM modulated signal can be written as

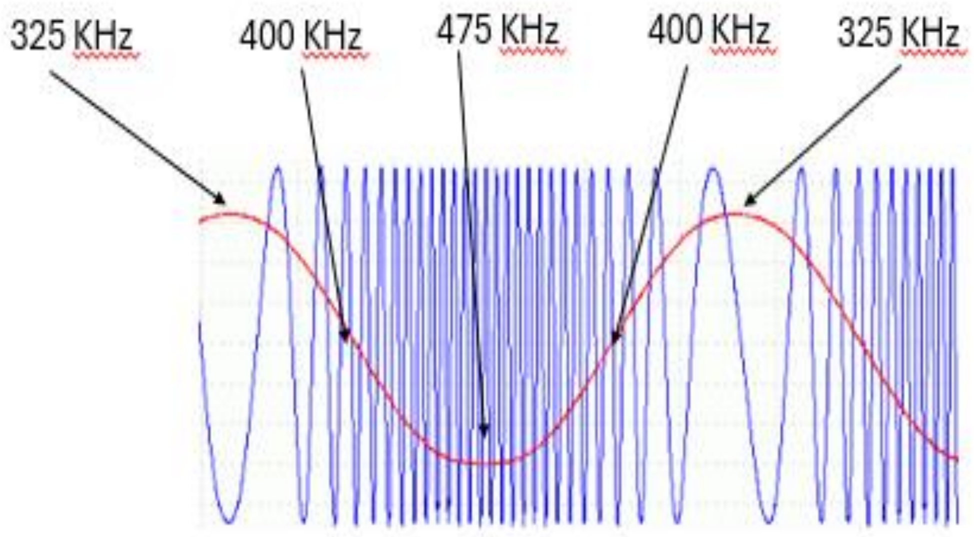
$$v(t) = A_c \sin(2\pi f_c t + \beta \sin(2\pi f_m t))$$

5. The index determines the number and spacing of the sidebands of the transmitted signal.

WORKED EXAMPLE 1

- A 400kHz sinusoidal carrier of amplitude 5V is frequency modulated by a 3kHz sinusoidal information signal of amplitude 3V. The frequency deviation per volt and for this system is 25kHz per volt. Describe how the resulting FM signal changes with time.

Solution:
The FM carrier will change in frequency from 400 kHz to 475 kHz to 400 kHz to 325 kHz and back to 400 kHz, 3000 times per second. This is because the frequency deviation f_d= 3 x 25 kHz = 75 kHz. The amplitude of the carrier will remain fixed at 5 V.



CARSON'S RULE

1. FM creates modulation sidebands that in theory extend to infinite bandwidth. These sidebands consist of Bessel Functions of any order.
2. However, practically the band occupancy of an FM-modulated carrier solely needs to count the Bessel Function sidebands of necessary amplitude.
3. Carson's Bandwidth Rule is used for the calculation of FM modulation bandwidth or occupancy for the FM signal. It is written as:

$$BW = 2(f_d + f_m)$$

where,

B is the bandwidth

f_m is the highest modulating frequency

f_d is the maximum frequency deviation

We can write the equation in terms of the modulation index m since

$$m = \frac{f_d}{f_m}$$

Then, the equation becomes

$$BW = 2f_m(1 + m)$$

NARROWBAND FM

In narrowband FM,

$f_d \ll f_m$ which means m $\ll$1

The bandwidth by the carson's rule is given as
$BW = 2f_m(1 + m) \approx 2f_m$

WORKED EXAMPLE 2

- A broadcasting station has a highest modulating frequency f_m = 10kHz and a maximum frequency deviation f_d =4 kHz. Calculate the bandwidth required using Carson's Rule.

MODEL ANS

Using Carson's Rule formula:

$BW = 2(f_m + f_d)$

$= 2(10+4)$

$= 2\times14$

$= 28kHz$

WORKED EXAMPLE 3

1. In national radio broadcasts using FM, the frequency deviation of the carrier , f_d is chosen to be 75 kHz, and the information baseband is the high-fidelity range 20 Hz to 15 kHz. Find

   (a) The modulation index

   (b) The bandwidth required to broadcast the FM signal

SOLUTION

(a) Modulation index, $\beta = \frac{f_d}{f_m} = \frac{75}{15} = 5$

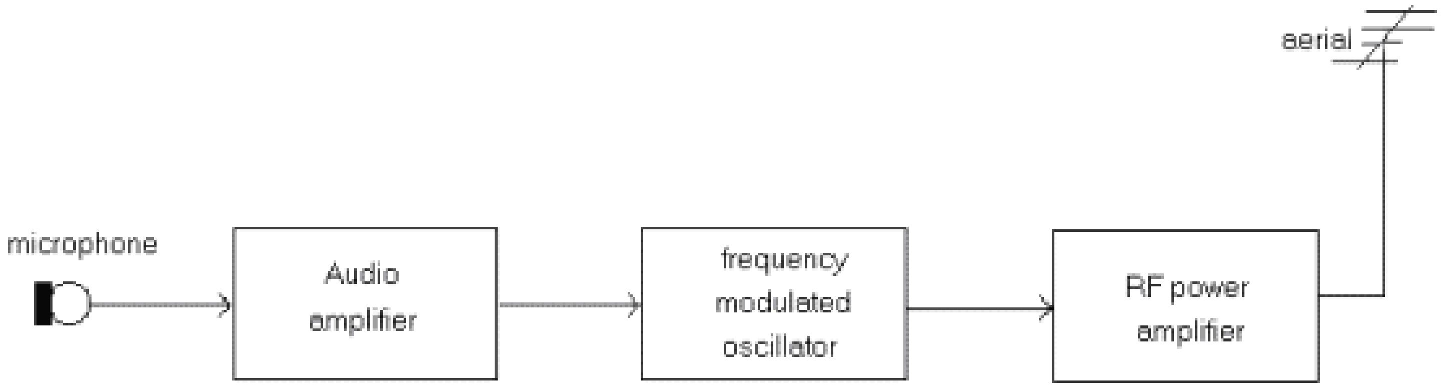
(b) Bandwidth according to Carson's law is given by

$$BW = 2(f_m + f_d) = 2(75 + 15) = 180\ MHz$$

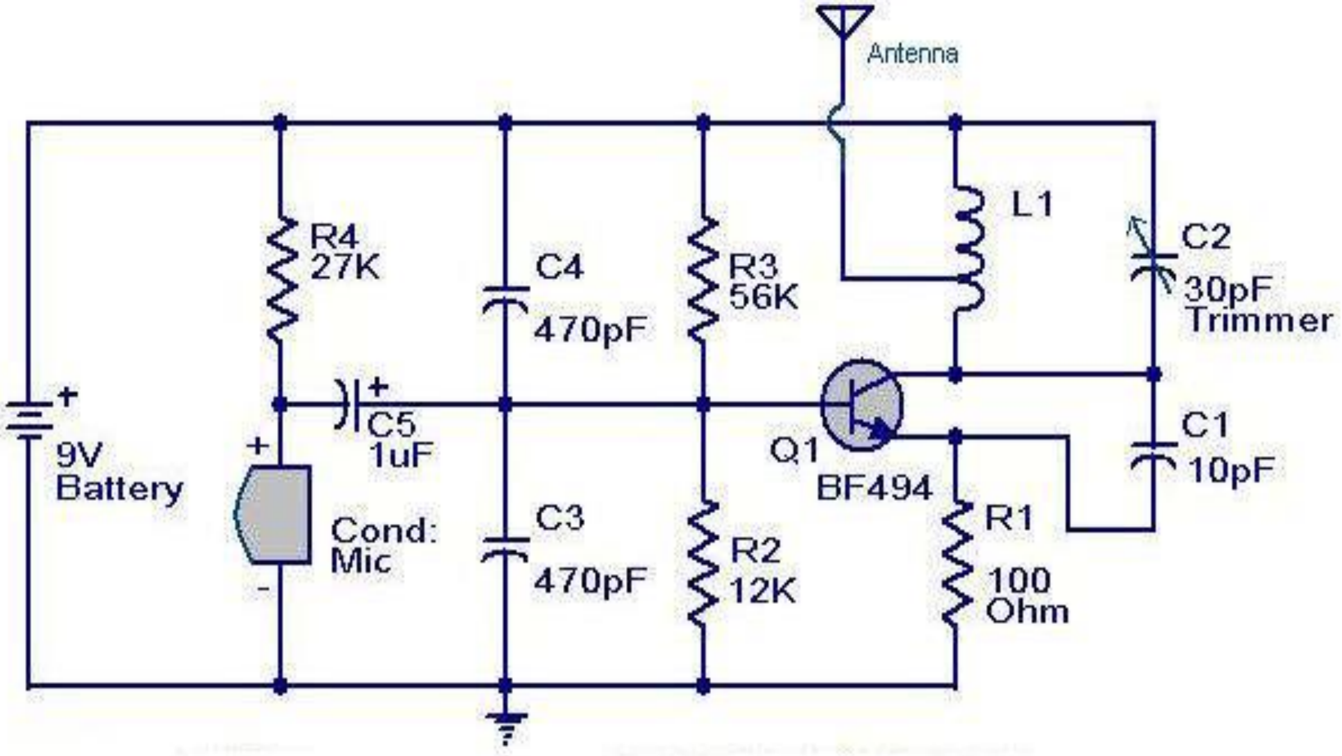
FM BROADCASTING IN KENYA

1. Frequency range: 88.0 - 108.0 MHz
2. Channel width: 200 KHz (100 channels)
3. Channel center frequencies: 88.1, 88.3, 88.5….
4. Frequency deviation: $\pm$75 KHz
5. Stereo uses sum and difference of L/R audio channels

BLOCK DIAGRAM OF A FM TRANSMITTER



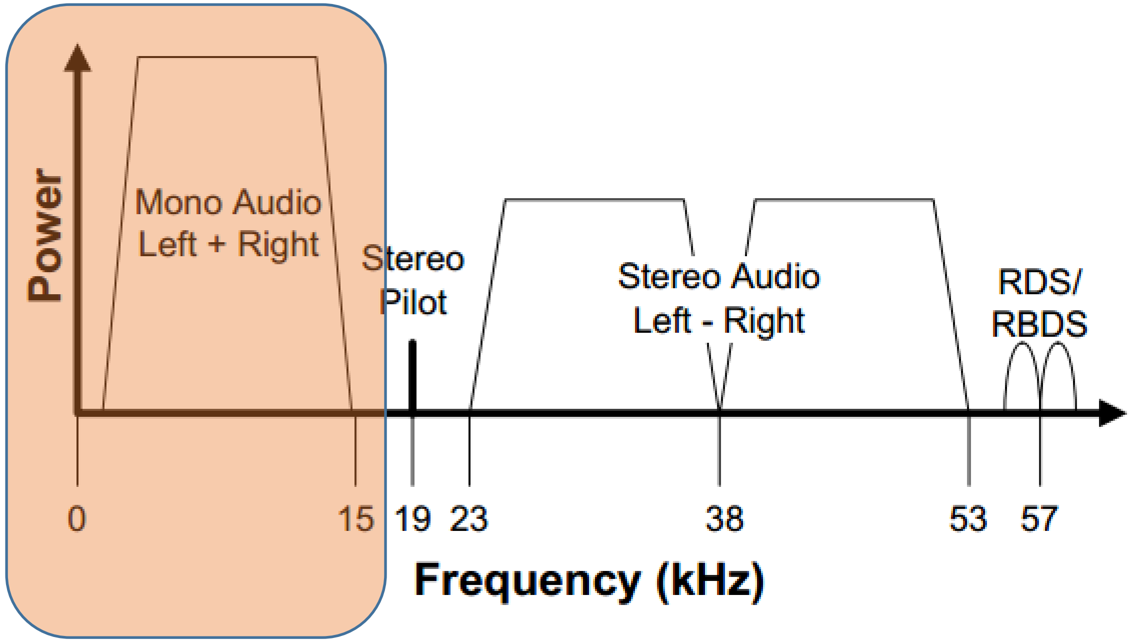
SIMPLE TRANSISTOR FM MODULATOR



1. The condenser microphone serves as our transducer converting sound to electrical signal which is fed to the base of Q1.
2. Transistor Q1 performs the amplification as well as modulation.
3. The capacitor C2 and L1 determines the frequency of transmission.

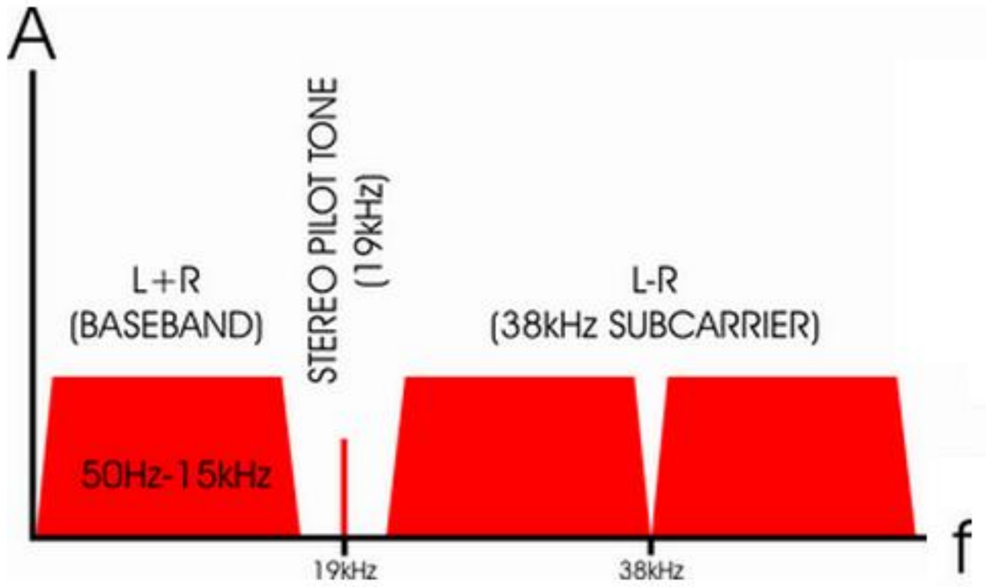
FM STEREO TRASMITTER (1)

1. **Prior to 1961**, monaural broadcasting of audio signals was the standard for AM, FM and TV.
2. **In 1961**, the Federal Communications Commission (FCC) approved the transmission of stereophonic sound, which extends the idea of multiplexing signals to generate stereo audio.
3. One of the key requirements of the stereo multiplex signal was to be backwards compatible with the large existing base of FM monophonic receivers.
4. To accomplish this goal, the 0 to 15 kHz baseband part of the multiplex (MPX) signal had to contain the left (L) and right (R) channel information (L+R) for monophonic reception.



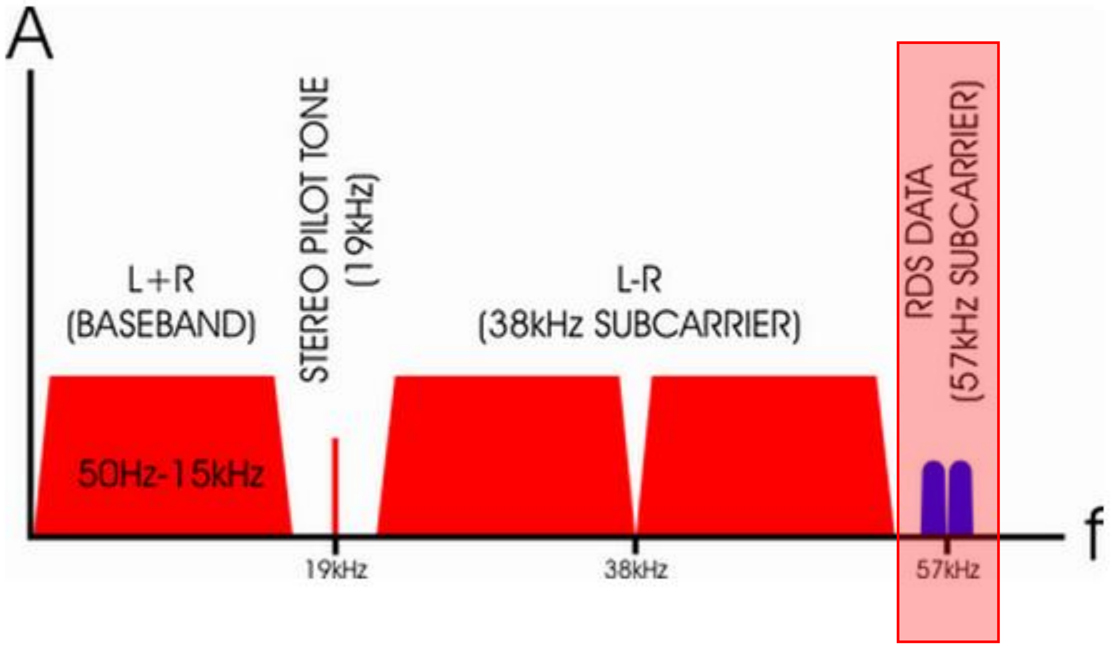
FM STEREO TRASMITTER (2)

1. **Stereophonic sound** is achieved by amplitude modulating the (L-R) information onto a suppressed 38 kHz subcarrier in the 23 to 53 kHz region of the baseband spectrum.
2. **19 kHz pilot tone** is added to the multiplex signal to enable FM stereo receivers to detect and decode the stereo left and right channels.
3. **The composite baseband signal** format meets the backwards compatibility needed for FM mono receivers while simultaneously providing enough information for FM stereo receivers to decode the left and right stereo channel outputs.



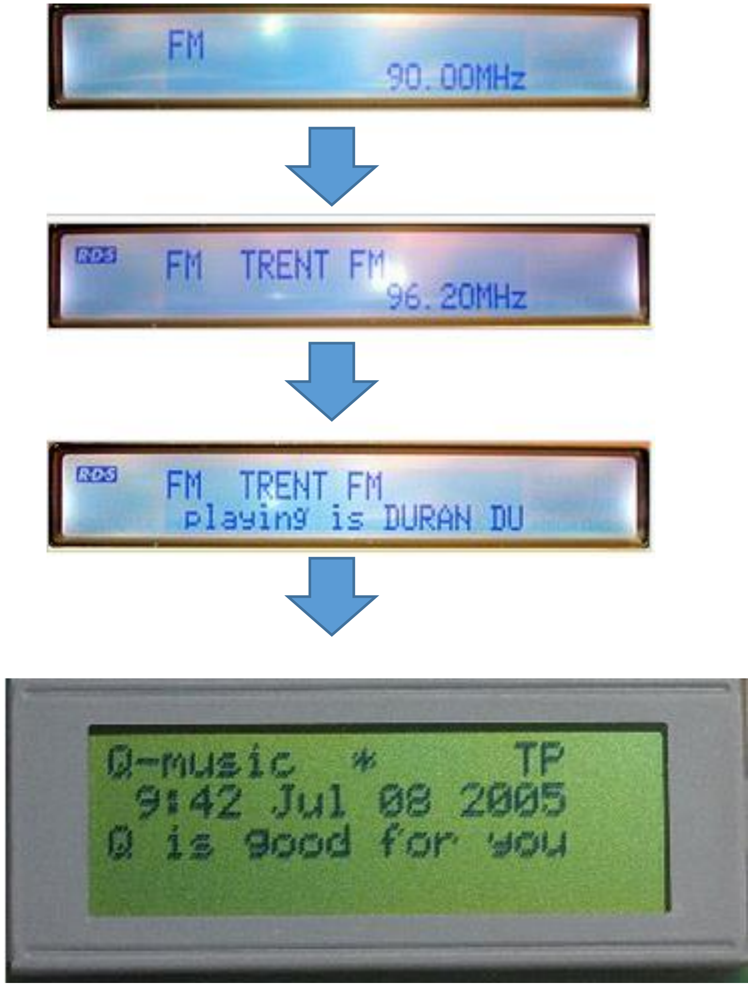
RADIO DATA SYSTEM (RDS)

1. **Today's FM signal includes a 57 kHz subcarrier** that carries RDS (RBDS) signals.
2. **Radio Data System (RDS)** is a communications protocol standard for embedding small amounts of digital information in conventional FM radio broadcasts.
3. **RDS carries several types of information** including time, station identification and programme information.
4. **RDS standard began as a project of the European Broadcasting Union (EBU),** but has since become an international standard of the International Electrotechnical Commission (IEC).
5. **RDS carries data at 1,187.5 bits per second** on a 57-kHz subcarrier, so there are exactly 48 cycles of subcarrier during every data bit.
6. **RBDS/RDS subcarrier was set to the third harmonic of the 19-kHz FM stereo pilot tone to minimize interference and intermodulation** between the data signal and the stereo pilot and the 38-kHz DSB-SC stereo difference signal. (The stereo difference signal extends up to 38 kHz + 15 kHz = 53 kHz, leaving 4 kHz for the lower sideband of the RDS signal.)

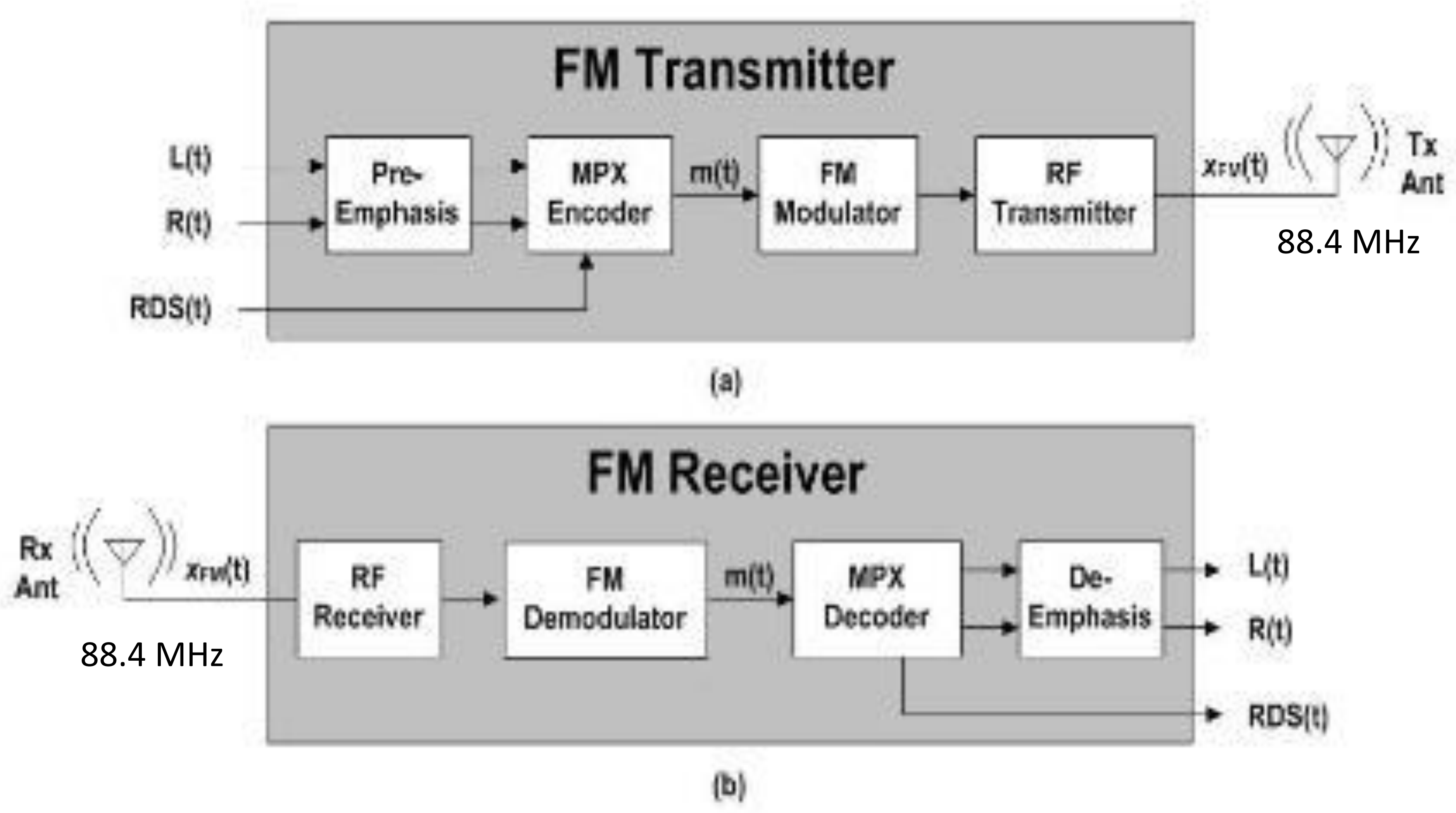


INFORMATION FIELDS IN RDS

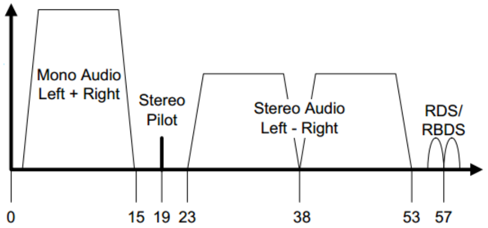
AF (alternative frequencies)	Allows a receiver to re-tune to a different frequency providing the same station when the first signal becomes too weak (e.g., when moving out of range).
CT (clock time)	Can synchronize a clock in the receiver or the main clock in a car. Due to transmission vagaries, CT can only be accurate to within 100 ms of UTC.
EON (Enhanced Other Networks)	Allows the receiver to monitor other networks or stations for traffic programmes, and automatically temporarily tune into that station.
PI (programme identification)	This is the unique code that identifies the station. Every station has a specific code with a country prefix.
PS (programme service)	This is simply an eight-character static display that represents the call letters or station identity name.
PTY (programme type)	Codes up to 31 pre-defined programme types (e.g., in Europe: PTY1 News, PTY6 Drama, PTY11 Rock music) allows users to find similar programming by genre.



BLOCK DIAGRAM OF FM TRANSMITTER WITH RDS



FREQUENCY PLANNING FOR FM TRANSMISSION



$$f_m = 60\ KHz$$
$$f_c = 88.2$$

ONE CHIP FM TRANSMITTER

1. **MAX2606 is a compact, high-performance intermediate frequency VCO** specially designed for wireless communication circuits.
2. **It has on-chip varicap diode** and feedback capacitances that avoid the need for external tuning components.
3. Only an external inductor is needed to set the oscillation frequency.
4. The nominal frequency is set to 100 Mhz by inductor L1, (390nH).
5. R1 can be used to select a channel of transmission between 88Mhz and 108Mhz