Radio Broadcast Technology

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This article traces the history of radio broadcasting beginning with the experiments of Heinrich Hertz and the successful transatlantic transmission of wireless signals by Marconi to the current satellite based radio broadcasting.

Introduction

The radio as we know today had its beginning when Heinrich Hertz (in whose honour is named the unit of frequency, namely, Hertz abbreviated Hz) experimentally produced electromagnetic waves in 1888 by inducing a spark between two electrodes. These waves were detected by him a few metres away. These waves were called Hertzian waves and remained a laboratory curiosity. Hertz's motivation for his experiments was the work of James Clerk Maxwell who had derived his famous equations and predicted that a variable current in a conductor would produce electromagnetic waves in space and that these waves will travel with the velocity of light.

Guglielmo Marconi got interested in Hertzian waves and started experimenting in his father's villa near Bologna. He transmitted wireless signals over tens of kilometres in 1895, seven years after the first demonstration of electromagnetic waves in space by Hertz. In the meanwhile several other inventions were being made which ultimately led Marconi to develop long distance wireless telegraphy. It was the forerunner of radio and Marconi is wrongly called the 'inventor of radio'. Radio as we know it today, that is, audio broadcast by wireless was the culmination of many other inventions starting with the work of Thomas Alva Edison. Edison observed that if plates sealed in an incandescent lamp, which he himself had developed, were connected to the positive end of the filament through a galvanometer, current would flow. If the galvanometer lead was connected to the

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negative end of the filament, no current flowed. This phenomenon was known as the Edison effect (1883). J J Thompson showed that this current was due to the travel of electrons from the filament to the plate (1899). Later J A Fleming patented two electrode vacuum tube as a detector of high frequency oscillations through the rectifying action of the device. These discoveries laid the foundation of telecommunication and broadcasting.

Marconi was not only a good scientist and inventor but was also good at exploiting the business potential of telecommunication. At the turn of the nineteenth century Marconi conceived the idea of wireless telegraphy and formed in 1897, the Wireless Telegraph and Signal Company for manufacturing wireless apparatus. Marconi's system was adopted for ship to shore communication after he was successful in receiving a prearranged Morse code signal, which was sent from the far side of Atlantic in December 1901. The year 2001 was celebrated as the centenary of the first transatlantic wireless transmission.

Marconi type of 'transmitters' used a spark between two electrodes, which produced a small-scale discharge of energy resulting in crackles in headphones of a distant receiver. The spark between the electrodes was produced by a telegrapher's key making it possible to communicate by a code. The transmitters were called the 'spark transmitters'.

Around the same time R A Fessenden devised another type of wireless transmitter equipment employing 'alternator' – an electromechanical device which produced continuous waves (CW) of a single frequency rather than burst of energy as in the case of Marconi type of transmitters. The 'CW transmitters' could cover longer distances with lesser power. They could transmit and receive Morse code better. The first ever 1 KW continuous wave transmitter operating at 42 KHz was amplitude modulated with the Morse code signal in 1902. J A Fleming's invention of two element vacuum tube with rectifying properties in 1904 and the development of three element vacuum tube triode by Lee De Forest which could perform the function of an amplifier, sounded the death-knell of the 'spark gap' and the 'alternator' type of transmitters. David Sarnoff – a visionary at the American Marconi Company was instrumental in giving a push to radio broadcasting. Voice was broadcast in the real sense of the word for the first time in 1915 in USA. World's first radio broadcasting station was set up in USA followed by the second one in UK in 1922.

Radio Wave Propagation

The long distance transmission of electromagnetic waves (popularly known as radio waves) was explained by the discovery of ionized layers in the upper atmosphere which could serve as a reflecting surface for radio waves and confine the radiation to Earth. It was also established that the radio waves entering the ionized medium were bent. The amount of bending depended upon the degree of ionization and its gradient as well as upon the frequency of the incident waves. It could also be established that the intensity of electromagnetic waves emanating from a vertical quarter wave radiator and travelling along the surface of the Earth (ground waves) were attenuated which increased with the frequency of the wave and the electrical conductivity of the soil through which these waves travel. Long waves or LF (153-279 KHz) which are not used for the purpose of broadcasting in the tropical region, do not suffer diurnal and seasonal variations. The difference between day and night field strengths becomes quite marked for medium waves or MF (531-1602 KHz). The return of the sky wave to Earth at night produces serious fading at nominal distances where these two waves are of comparable intensities. Short waves or HF (3-27 MHz) are eminently suited for long distance broadcasting within the country as well as overseas. Propagation of HF is dependent on the vagaries of the ionized layers, which sends them back to Earth and they are therefore unsuitable for listening pleasure. One of the reasons why the advantages of HF transmissions remained undiscovered until about 1922 was that extensive investigations which had been made on long distance transmission all showed that the attenuation of the signals increased rapidly as the frequency

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was raised. It may be pointed out that the choice of frequency for communication over a given distance depends upon a number of factors. Radio waves with higher frequencies penetrate through ionosphere and escape from Earth. VHF/UHF or the space waves (30-300 MHz) travel as the crow flies and behave like a beam of light. VHF/UHF waves are used extensively for communication purposes over distances up to 60 km. SHF or the millimeter waves (1-10 GHz) are considered best for communication from and to geostationary communication satellites. EHF (10-100 GHz), though used for satellite communication, are attenuated due to water vapour in the atmosphere.

The Radio Transmitter

Antennas help to radiate radio frequency energy (electromagnetic waves) into space. They can be designed to radiate energy in all directions or in a particular direction. Radio wave at a constant frequency (called base band) has to be suitably modified to carry a message signal. Any one of the three characteristics of the varying sinusoidal wave (amplitude, frequency or phase) may be modified to carry the programme (voice or music) signals. The process of changing the characteristics of the radio wave is called 'modulation'. The radio transmitter generates the radio frequency energy on which the voice or music rides 'piggyback'. The main components of the transmitter are the oscillator; the modulator and the power amplifier. The oscillator generates the continuous waves, one of the three characteristics (amplitude, frequency and phase) of which is changed by the modulator. The energy level of the modulated continuous wave is raised to the desired level by the power amplifier which pumps its output into the antenna which radiates the radio frequency energy into space.

At the receiving end, the signal is 'demodulated' and the original voice or music signal is obtained. The earliest receivers called crystal receiving sets were based on the discovery that if certain kind of crystals were touched in the right place with a fine wire called 'cat-whiskers' they could detect radio waves and transform them into electric current. The radio waves were captured by a receiving antenna. The listening was via a pair of headphones. The crystal receiving sets were replaced in 1923 by the 'valve wireless' with improved reception and listening via a loudspeaker. The radio set of the1940s and 1950s vintage appeared to be a jumble of wires and components such as vacuum tubes, capacitors, resistors and inductors and were indeed a fashionable piece of furniture in the household.

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The Technology Push

The entire foundation of electronics, which had been so carefully built upon triode and other vacuum tubes was shaken in 1947 by the technical innovation called the transistor – a tiny semiconductor device. The new transistor radios could make use of dry cells since they consumed much less power, were more reliable and inexpensive, much lighter and smaller than the old wireless sets so that people could easily carry them around. Transistor radios were first marketed in USA (1953). By the end of 1970s, 70% of the radio receivers were either portable or mobile. The transistor caused a revolution in the way radio broadcasting could be used. But what followed the invention of transistor was even more amazing. Several transistors, diodes, resistors, and capacitors were combined to form a complete circuit on a single germanium chip, which came to be known as integrated circuit (IC). IC chips brought about a major conceptual change in the design of electronic systems. Attempts to make electronics systems failsafe and foolproof resulted in the development of printed circuit boards (PCB) and the concept of modular construction of electronic systems.

Application of frequency modulation technique for superimposing audio signals on the VHF carrier was a notable development in radio broadcasting in 1950. 88-108MHz frequency band is reserved for FM Broadcast Service. The major advantage of FM broadcasting is its better noise tolerance and higher fidelity compared to AM broadcasting. The major disadvantage of FM is its short range, only tens of kilometres. VHF/FM

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technology has since been extensively used for broadcasting in India.

The advent of man-made geostationary communication satellites in 1960s, which in effect are 'radio repeaters' in the sky, was indeed an innovation in radio technology. The idea of communication through a satellite was conceived by a British scientist Arthur C Clarke. He had pointed out that a satellite in the circular equatorial orbit with a radius of 42, 242 km would have an angular velocity equal to that of the Earth. Thus, such a satellite would always remain above the same spot on ground and it could receive and relay signals from most of the country. He had also stated that the electrical power for the satellite would be obtained from conversion of the Sun's radiation by means of solar cells. However, it was AT&T of the USA which established the modern technique of communication satellite thereby ushering in a new era of broadcasting.

An innovation in sound broadcasting called *stereophony* was developed in the late 1950s and used in the UK in 1966. In this system sound is split into parts and reproduced by two separate channels in order to create spatial effect. Currently FM broadcasting in India uses stereo sound.

Digital Audio and Radio

Analogue audio signal is continuous in time. In other words, at each instant the signal has an instantaneous level, which can assume any value within the permissible dynamic range of the analogue system. On the contrary, digital audio signal is binary. In other words it can assume any one of the two levels namely 0 or 1. Audio signal in digital form is mere numbers.

Samuel F Morse, without being aware of it, established the foundation of electrical digital signalling in 1944. In his telegraph the electrical signal had only two options. Either some current flowing through the circuit or no current at all. Most telegraph systems used a special code to represent the characters of the alphabet. He used a short duration electrical pulse known as a 'dot' and a long duration pulse known as 'dash' with gaps of no voltage in between. He combined these dots and dashes into a pattern known as the Morse code to send text messages over long conducting wires. When automation came along in the field of communication, Morse code gave way to newer binary codes.

Audio broadcasting in the digital era has indeed become multimedia broadcasting.

A method of digitizing audio was first proposed by Alec Reeves of England and is known as pulse code modulation (PCM). In PCM, the analogue signal is sampled at a rate slightly greater than twice the highest frequency contained in it. Each sample is then converted into a code of binary bits. In professional audio systems 16-bit PCM is used. In order to eliminate the bit error in the digital audio code upon reproduction, additional data bits are encoded along with the digital audio data. All these result in incredibly large number of bits, the bandwidth of which is at least 25 times that of the analogue audio signal, and requirement of enormous amount of storage space. It is thus necessary to compress the signal without sacrificing quality. The audio compression system depends on the fact that human ear perceives good quality sound despite data compression. The basic principle of the psycho-acoustic model of audio bit reduction is to reduce redundancy and irrelevance in source signal thus significantly lowering the requirement of bandwidth for transmission and storage space. The foremost requirement of any real time compression system is to achieve a low bit rate with minimum delay and perceived loss of quality from either small signal distortion or injected noise. The art of compressing the data stream into narrower and narrower pipes continues. The current standard is MP3 (see *Resonance*, Vol.6, No.8, p.25, 2001.)

As a result of the cost-effective digitalization of analogue audio signal, additional data could now be broadcast giving added values to traditional voice and music. Audio broadcasting in the digital era has indeed become multimedia broadcasting. Multimedia broadcasting means use of existing broadcast infrastructure to a variety of devices such as PC, Smart TV receiver and personal digital assistant. Digital technology is breaking down

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the barriers that separate the technologies and service characteristics which exist between broadcasting, telecommunication and computers.

Digital Audio Broadcasting (DAB) System

Simple digital broadcasting results in the impairment of the signal due to selective fading, production of echoes (multipath propagation), and Doppler frequency drift when addressing a mobile receiver. A digital audio broadcasting system, which can overcome these limitations, has been developed under the European EUREKA Project 147. DAB system developed by this group is capable of navigating through all types of propagation channels while maintaining CD quality audio without any blemish.

Eureka 147 digital radio ensures reliable reception on fixed, portable and mobile receivers even under adverse conditions. Single frequency networks are possible thus resulting in the efficient use of the radio frequency spectrum. Besides compact disk quality audio, this system provides choice of more programmes, text and still pictures. This radio system has been specifically designed to work in the multipath reflection conditions commonly experienced by mobile and portable receivers.

The key to digital radio's robustness lies in the use of a modulation system called orthogonal frequency division multiplexing (OFDM) which provides noise immunity to such systems. OFDM uses a large number of closely spaced carriers, each modulated with a subset of the total data being broadcast. As a result, the data rate associated with each carrier is low and much less sensitive to multipath signals. Any reflections, although of course delayed with reference to the direct signal, are still sufficiently 'in phase' to avoid destructive interference. The tolerable delay is further increased by the introduction of guard band at the beginning of each symbol. Arranged in this way, reception is also immune to signals from out-of-area digital transmitters operating in the same spectrum and carrying the same programs. As a consequence, single frequency networks can be established throughout an area in which a common multiplex of digital services are to be delivered. In practice, far from causing interference, any out-of-area signal augments that from the local transmitter enhancing overall coverage.

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In addition to this very effective modulation system and flexible multiplex composition, DAB uses base band audio compression techniques. This typically reduces the amount of data needed with an inaudible impact on quality. This ensures a high overall spectrum efficiency, enabling wider range of programme services to be offered. In practice, the equivalent of six high quality stereo service can be accommodated in a single multiplex occupying about 1.55 MHz. The capacity allocated to data is generally kept low with a view of maintaining the unique quality of audio in radio. Program associated data e.g. artist's name, music title and phone-in numbers could constitute the 'data' for enriching the listening experience. Other possible data sources could be provision of travel information, and radio texts, etc. The spectrum allocated for DAB in many countries in 217.5 to 230 MHz in band III and 1452-1492 MHz in L band. The radio receivers for DAB system have been designed to exhibit good radio frequency performance and audio quality at each of the bit rate allowed in the range of 32 Kbps to 256 Kbps at both full and half bit rate sampling.

The World Space Satellite to Radio Multimedia Broadcast System

A full century after Marconi and half a century after Arthur C Clarke, the WorldSpace system has indeed ushered in a revival of the good old radio through the satellite medium. It is a global information and entertainment service covering the remotest corner of the developing world. In essence, it is a worldwide satellite digital audio system and multimedia system using communication satellites to deliver signals directly into home to portable hand held receivers. The primary aims of WorldSpace is to provide live access to news, educational material and entertainment from around the world through unique global relay capability of this integrated system. Satellite radio is discussed in detail in the article by S Rangarajan in this issue.

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Digital Radio Mondiale (DRM)

A recent worldwide standard for digital broadcasting called DRM has been designed to use frequency bands below 30 MHz. This system will be able to use existing AM transmitters and antennas together with low cost digital exciter and sound coding and multiplexing equipment. This system will provide better audio quality, text messages and data applications. DRM too uses OFDM and MP3 audio bit rate reduction as the core technologies. DRM is designed to occupy 9 or 10 KHz channel and consequently has a capacity of only about 25 Kbps and will deliver audio quality comparable to mono FM. Field trials for this system have been successfully completed in October 2000. It is also possible to transmit audio signals on the internet (see Napster Story in *Resonance*, Vol.6, No.8, p.26, 2001). In theory it is thus possible to broadcast audio over internet by any one, provided reasonable bandwidth is available.

Conclusion

The objective of radio broadcasting is to entertain, inform and educate people. The developments in radio technology are aimed at providing reliable, interference free and high quality voice and music to the listener at home or those moving in as wide area as possible. Rapid technological developments in the areas of digital signal processing and transmission, global cable networks and satellite technology have made their way into radio broadcasting. These factors have resulted in the conver-

Suggested Reading

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gence of computing, telecommunication and broadcasting. Voice and music can now be combined with data and text for broadcasting. The listener can also be provided with interactivity using the return channel. Way has been paved for high quality broadcasts directly to the listeners from space. Internet too is fast emerging as a means of delivering programs. Radio broadcasting has indeed become multimedia broadcasting and the world truly a global village.

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First transatlantic message to:

His Majesty, Edward VII, London, England.

In taking advantage of the wonderful triumph of scientific research and ingenuity which has been achieved in perfecting a system of wireless telegraphy, I extend on behalf of the American people most cordial greetings and good wishes to you and all the people of the British Empire.

Theodore Roosevelt

South Wellfleet, Massachusetts, Jan. 19, 1903

The Answer came back:

The President, White House, Wash., America.

I thank you most sincerely for the kind message which I have just received from you through Marconi's transatlantic wireless telegraph. I sincerely reciprocate in the name of the people of the British Empire the cordial greetings and friendly sentiment expressed by you on behalf of the American nation, and I heartily wish you and your country every possible prosperity.

Edward R. and I.

Sandringham, Jan. 19, 1903