EIE312 COMMUNICATIONS PRINCIPLES

Outline:

Principles of communications:

1. An elementary account of the types of transmission (Analogue signal transmission and digital signal transmission). Block diagram of a communication system.
2. Brief Historical development on communications:
    a. Telegraph
    b. Telephony
    c. Radio
    d. Satellite
    e. Data
    f. Optical and mobile communications
    g. Facsimile
3. The frequency Spectrum
4. Signals and vectors, orthogonal functions.
5. Fourier series, Fourier integral, signal spectrum, convolution, power and energy correlation.
6. Modulation, reasons for modulation, types of modulation.
7. Amplitude modulation systems:
    a. Comparison of amplitude modulation systems.
    b. Methods of generating and detecting AM, DBS and SSB signals.
    c. Vestigial sideband
    d. Frequency mixing and multiplexing, frequency division multiplexing
    e. Applications of AM systems.
8. Frequency modulation systems:

   a. Instantaneous frequency, frequency deviation, modulation index, Bessel coefficients, significant sideband criteria

   b. Bandwidth of a sinusoidally modulated FM signal, power of an FM signal, direct and indirect FM generation,

   c. Various methods of FM demodulation, discriminator, phase-lock loop, limiter, pre-emphasis and de-emphasis, Stereophonic FM broadcasting

9. Noise waveforms and characteristics. Thermal noise, shot noise, noise figure and noise temperature. Cascade network, experimental determination of noise figure. Effects of noise on AM and FM systems.

10. Block diagram of a superheterodyne AM radio receiver, AM broadcast mixer, local oscillator design, intermodulation interference, adjacent channel interference, ganging, tracking error, intermediate frequency, automatic gain control (AGC), delay AGC, diode detector, volume control.

11. FM broadcast band and specification, Image frequency, block diagram of a FM radio receiver, limiter and ratio detectors, automatic frequency control, squelch circuit, FM mono and FM stereo receivers.

12. AM broadcast band and specification.

13. TV broadcast band and specification. Signal format, transmitter and receiver block diagrams of black and white TV and colour TV.

WHAT IS COMMUNICATION?

Communication is the transfer of information from a source to a receiver through a medium. Communication can be unidirectional or bidirectional.

In bidirectional communication, one is able to get a feedback from the distant end in other to know what to say next. Examples of bidirectional communication include chatting on the internet, communicating through the mobile phone or Landline, telex or telegraph, peer to peer computer network, etc.

In unidirectional communication information is transferred from the source to the receiver without the provision of receiving a feedback from the distant end. Examples of unidirectional communication include using public address systems to address a crowd, Radio/Television systems to transmit information to the public, etc.

Outlines of a Telecommunication System

In practice, telecommunications involve the conversion of messages which may be in the form of words, text or coded symbols into electrical voltage or current which varies with time and is used to carry information from one point to another. Such electrical quantities are termed as signals. These signals are then transmitted over a communication system to the receiver where they are converted back to the original form. Figure1 shows the outline of a telecommunications system.

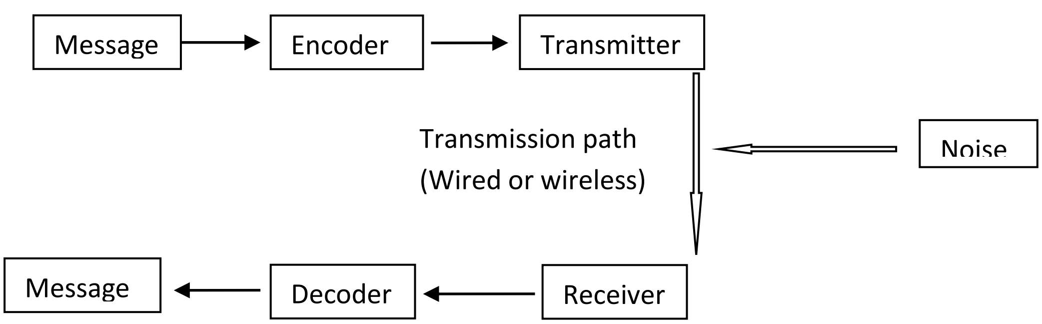


Fig.1. Outlines of a Telecommunication System

The encoder converts the message into electrical signals using appropriate transducers and feeds them to the transmitter. The signals are processed (e.g, amplified) at the transmitter and then transmitted to the receiver through a channel or transmission path which is either wireless (free space) or wired (cables). The word transmission media (medium, singular) is used to describe what is transporting telecommunication signals. There are however five basic types of medium: wire pair, coaxial cable, fiber optics, waveguides and radio. Wired communication is usually referred to as Line communication whereas wireless communication is usually referred to as Radio communication.

At the receiving end, the receiver is designed to select the desired signal, process it (demodulate it, etc,) and then deliver to the decoder an electrical signal which in all aspects resembles the signal produced by the encoder. The decoder then converts the signal into the form of the original message.

Assignment: Write out your own summary of the history of communications and submit before the next class.

Brief Historical Developments on Telecommunications

The history of telecommunications began with the use of smoke signals and drums in Africa, the Americas and parts of Asia. In the 1790s, the first fixed semaphore systems emerged in Europe; however it was not until the 1830s that electrical telecommunication systems started to appear.

This article details the history of telecommunication and the individuals who helped make telecommunication systems what they are today. The history of telecommunication is an important part of the larger history of communication.

Information transmission evolved in a series of dramatic sub-revolutions and with most of them the innovations arose in many places. Sometimes, as with the telegraph, the advent was rather sudden, other times as with Computer software, it was confused and drawn out.

Present day telecommunications arose over the last two centuries because of four great trends. These were:

1. The invention of electric signalling technology (telegraph, telephone, radio, etc.).
2. Scientific and mathematical understanding of these signalling technologies.
3. The advent of micro circuits (or micro-chips) which made the equipment small fast, reliable and very cheap.
4. The software concepts which makes possible complex algorithms.

It is interesting to observe that telecommunications from telegraphs up to television was based on science known in the 1800s. Only with data networking and the internet did communication make use of technology of the mid 1900s, namely computer software and micro circuitry.

We will now take a look at the revolutions of information transmission in the order they occurred: telegraph, telephone, radio, television, cable TV, mobility and the internet.

The Telegraph (Beacon and Optical Telegraphy)

Early telecommunications included smoke signals and drums. Talking drums were used by natives in Africa, New Guinea and South America, and smoke signals in North America and China.

Contrary to what one might think, these systems were often used to do more than merely announce the presence of a camp.

In 1792, a French engineer, Claude Chappe built the first visual telegraphy (or semaphore) system between Lille and Paris. A Semaphore line is a system of long-distance communication based on towers with moving arms (e.g Flag *semaphore system*; Railway semaphore signals for railway, etc.). It was built to transmit messages by optical signal over a distance of hundreds of kilometres without physical transport of written letters. The semaphore telegraph line usually comprised several stations each furnished with a signal mast with six cable-operated arms. The stations were equipped with telescopes that operators used to copy coded messages and forward them to the next station.

This was followed by a line from Strasbourg to Paris. In 1794, a Swedish engineer, Abraham Edelcrantz built a quite different semaphore telegraph system from Stockholm to Drottningholm. As opposed to Chappe's system which involved pulleys rotating beams of wood, Edelcrantz's system relied only upon shutters and was therefore faster. However semaphore as a communication system suffered from the need for skilled operators and expensive towers often at intervals of only ten to thirty kilometres (six to nineteen miles). As a result, the last commercial line was abandoned in 1880.

The Telegraph (Electrical Telegraphy)

A very early experiment in electrical telegraphy was an 'electrochemical' telegraph created by the German physician, anatomist and inventor Samuel Thomas von Sömmering in 1809, based on an earlier, less robust design of 1804 by Catalan polymath and scientist Francisco Salva Campillo. Both their designs employed multiple wires (up to 35) in order to visually represent almost all Latin letters and numerals. Thus, messages could be conveyed electrically up to a few kilometers (in von Sömmering's design), with each of the telegraph receiver's wires immersed in a separate glass tube of acid. An electrical current was sequentially applied by the sender through the various wires representing each digit of a message; at the recipient's end the currents electrolysed the acid in the tubes in sequence, releasing streams of hydrogen bubbles next to each associated letter or numeral. The telegraph receiver's operator would visually observe the bubbles and could then record the transmitted message, albeit at a very low baud rate. The principal disadvantage to the system was its prohibitive cost, due to having to manufacture and string-up the multiple wire circuits it employed, as opposed to the single wire (with ground return) used by later telegraphs.

The first commercial electrical telegraph was constructed in England by Sir Charles Wheatstone and Sir William Fothergill Cooke. It used the deflection of needles to represent messages and started operating over twenty-one kilometres of the Great Western Railway on 9 April 1839. Both Wheatstone and Cooke viewed their device as "an improvement to the [existing] electromagnetic telegraph" not as a new device.

On the other side of the Atlantic Ocean, Samuel Morse independently developed a version of the electrical telegraph that he unsuccessfully demonstrated on 2 September 1837. Soon after he was joined by Alfred Vail who developed the register — a telegraph terminal that integrated a logging device for recording messages to paper tape. This was demonstrated successfully over three miles (five kilometres) on 6 January 1838 and eventually over forty miles (sixty-four kilometres) between Washington, DC and Baltimore on 24th May 1844. The patented invention proved lucrative and by 1851 telegraph lines in the United States spanned over 20,000 miles (32,000 kilometres).

The first successful transatlantic telegraph cable was completed on 27th July 1866, allowing transatlantic telecommunication for the first time. Earlier transatlantic cables installed in 1857 and 1858 only operated for a few days or weeks before they failed. The international use of the telegraph has sometimes been dubbed the "Victorian Internet".

The telegraph is hardly present today but its chief significance is in how it led to other technologies and ways of social organisations.

Telephone

As with the telegraph, the scientific effect that underlay the telephone was simply the fact that electricity propagated down a wire. There was no theory of charged particle flow and no one had ideas about whether brute electricity could carry what we call a waveform today.

The electric telephone was invented in the 1870s, based on earlier work with harmonic (multi-signal) telegraphs. The first commercial telephone services were set up in 1878 and 1879 on both sides of the Atlantic in the cities of New Haven and London. Alexander Graham Bell, a Scot, held the master patent for the telephone that was needed for such services in both countries. His first demonstration of the telephone which comprises a microphone, electricity carrying a waveform and a reproducer was in Boston in 1876. He was not trying to demonstrate voice transmission but was trying to send several telegraph signals down the same wire line by interrupting different frequency tones and he noticed that something resembling a voice could be transmitted.

The first demonstration was only between two rooms after which demonstrated telephone calls over several kilometres at Brantford, Canada. The first telephone exchange was in Hamilton Canada in 1878. As early as 1878, Alexander Graham Bell was the first to conceive of a central office where wires could be connected together as desired to establish direct communication between any two places in the city which he claimed will be the outcome of the introduction of the telephone to the public.

The concept of message based charging was also developed with the commercialisation of the telephone., in which users paid for each call and was not forced to pay all at once for installation of expensive lines.

Telephone was fundamentally different from the telegraph in the following ways:

1. It carried voice instead of letters
2. It served almost everyone directly
3. Connections were set up and taken down in a switched way.

In 1880, Bell and co-inventor Charles Sumner Tainter conducted the world's first wireless telephone call via modulated lightbeams projected by photophones. The scientific principles of their invention would not be utilized for several decades, when they were first deployed in military and fiber-optic communications.

The telephone technology grew quickly from this point, with inter-city lines being built and telephone exchanges in every major city of the United States by the mid-1880s. Despite this, transatlantic voice communication remained impossible for customers until January 7, 1927 when a connection was established using radio. However no cable connection existed until TAT-1 was inaugurated on September 25, 1956 providing 36 telephone circuits.

In summary, the scientific basis of the telephone was electricity and the inventions that made it practical were simple: just an earphone, a microphone and the switching concept.

Radio

James Clerk Maxwell, the Scottish physicist, was very interested in Michael Faraday's work on electromagnetism. Faraday explained that electric and magnetic effects result from lines of force that surround conductors and magnets. Maxwell drew an analogy between the behaviour of the lines of force and the flow of a liquid, deriving equations that represent electric and magnetic effects. In 1855 he produced a paper which built on Faraday's ideas, and in 1861 developed a model for a hypothetical medium, that consisted of a fluid which could carry electric and magnetic effects. He also considered what would happen if the fluid became elastic and a charge was applied to it. This would set up a disturbance in the fluid, which would produce waves that would travel through the medium. The German physicists Friedrich Kohlrausch and Wilhelm Weber calculated that these waves would travel at the speed of light. Maxwell finally published this work in his 'Treatise on Electricity and Magnetism' in 1873.

In 1888 German physicist Heinrich Hertz made the sensational discovery of radio waves, a form of electromagnetic radiation with wavelengths too long for our eyes to see, confirming Maxwell's ideas. He devised a transmitting oscillator, which radiated radio waves, and detected them using a metal loop with a gap at one side. When the loop was placed within the transmitter's electromagnetic field, sparks were produced across the gap. This proved that electromagnetic waves could be sent out into space, and be remotely detected. These waves were known as 'Hertzian Waves' and Hertz managed to detect them across the length of his laboratory.

Italian born Guglielmo Marconi was fascinated by Hertz's discovery, and realised that if radio waves could be transmitted and detected over long distances, wireless telegraphy could be developed. He started experimenting in 1894 and set up rough aerials on opposite sides of the family garden. He managed to receive signals over a distance of 100 metres, and by the end of 1895 had extended the distance to over a mile. He approached the Italian Ministry of Posts and Telegraphs, informing them of his experiments. The Ministry was not interested and so his cousin, Henry Jameson-Davis arranged an interview with Nyilliam Preece, who was Engineer-in-Chief to the British Post Office.

Fig. Guglielmo Marconi and his family in 1933

He came to England in February 1896 and gave demonstrations in London at the General Post Office Building. His transmissions were detected 1.5 miles away, and on 2nd September at Salisbury plain the range was increased to 8 miles. In 1897 he obtained a patent for wireless telegraphy, and established the Wireless Telegraph and Signal Company at Chelmsford. The world's first radio factory was opened there in 1898. On 11th May 1897 tests were carried out to establish that contacts were possible over water. A transmitter was set up at Lavernock Point, near Penarth and the transmissions were received on the other side of the Bristol Channel at the Island of Holm, a distance of 3.5 miles. The Daily Express was the first newspaper to obtain news by wireless telegraphy in August 1898, and in December of that year communication was set up between Queen Victoria's Royal yacht, off Cowes and Osborne House. The Queen received regular bulletins on the Prince of Wales' health, by radio, from the yacht, where he was convalescing.

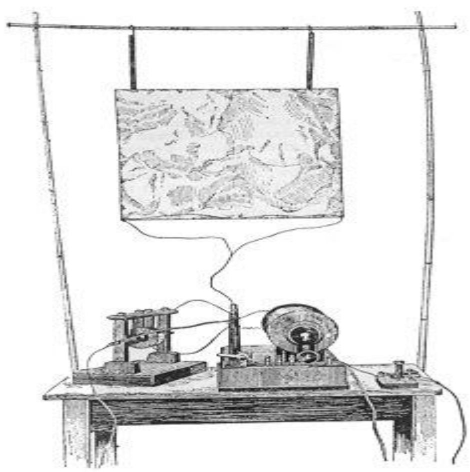
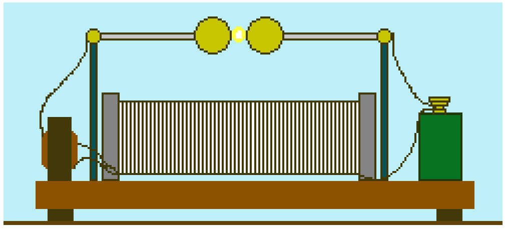


Fig. An early Marconi transmitter

Also in December of that year, wireless communication was set up between the East Goodwin light ship and the South Foeland lighthouse. On 3rd March 1899 Marconi obtained a lot of publicity when the first life was saved by wireless telegraphy, which was used to save a ship in distress in the North Sea. By the summer cross channel communication had been established and the first ocean newspaper published bulletins sent by wireless.



About this time Marconi began to develop tuned circuits for wireless transmission, so that a wireless can be tuned to a particular frequency, to remove all other transmissions except the one of interest. He patented this on 26th April 1900, under the name of ‘Tuned Syntonic Telegraphy’. On Thursday 12th December 1901, Marconi and his associates succeeded in transmitting a signal across the Atlantic Ocean. He sailed to Newfoundland with G.S. Kemp and P.W. Paget, and received a transmission from Poldhu, Cornwall. The transmission was received at Signal Hill using a kite aerial. The British government and admiralty were greatly impressed and many people wanted to invest in the new technology.

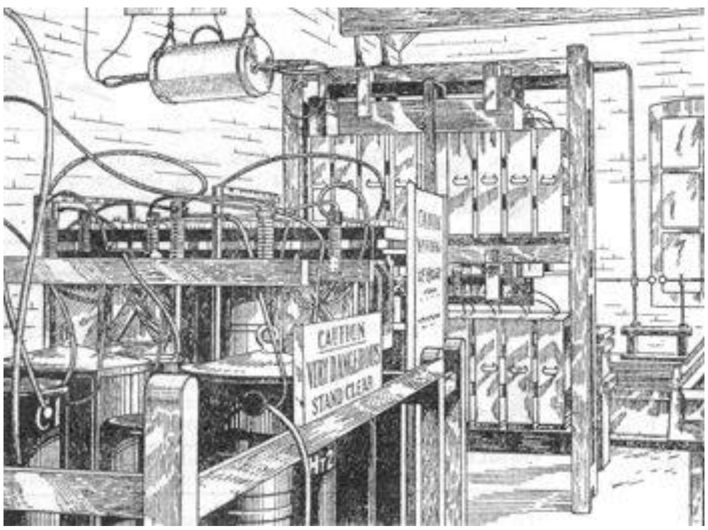


Fig. The transmitter at Poldhu

Demand grew and large numbers of ships carried the new apparatus, which saved many lives at sea. One of the most famous occasions was when the Titanic sank. Signals transmitted by its Marconi wireless summoned help and saved many lives.

Receivers at this time were mainly crystal sets, which were extremely insensitive and unselective. They were connected to a pair of headphones and required a long aerial.

In addition to Marconi, two of his contemporaries Nikola Tesla and Nathan Stufflefield took out patents for wireless radio transmitters. Nikola Tesla is now credited with being the first person to patent radio technology; the Supreme Court overturned Marconi's patent in 1943 in favor of Tesla.

Television

Television was not invented by a single inventor, instead many people working together and alone over the years, contributed to the evolution of television.

Broadcasting Pioneers: The Many Innovators Behind Television History
At the dawn of television history there were two distinct paths of technology experimented with by researchers.

Early inventors attempted to either build a mechanical television system based on the technology of Paul Nipkow's rotating disks; or they attempted to build an electronic television system using a cathode ray tube developed independently in 1907 by English inventor A.A. Campbell-Swinton and Russian scientist Boris Rosing.

Electronic television systems worked better and eventual replaced mechanical systems.

Mechanical TV systems
German, Paul Nipkow developed a rotating-disc technology to transmit pictures over wire in 1884 called the Nipkow disk. Paul Nipkow was the first person to discover television's scanning principle, in which the light intensities of small portions of an image are successively analyzed and transmitted.

John Logie Baird switched from mechanical television and became a pioneer of colour television using cathode-ray tubes. In the 1920's, John Logie Baird patented the idea of using arrays of transparent rods to transmit images for television. Baird's 30 line images were the first demonstrations of television by reflected light rather than back-lit silhouettes. John Logie Baird based his technology on Paul Nipkow's scanning disc idea and later developments in electronics. It was a system which scanned images using a rotating disk with holes arranged in a spiral pattern and were demonstrated by John Logie Baird in England and Charles Francis Jenkins in the United States in the 1920s.

Charles Jenkins invented a mechanical television system called radiovision and claimed to have transmitted the earliest moving silhouette images on June 14, 1923.

Cathode Ray Tube - Electronic Television History
Electronic television is based on the development of the cathode ray tube, which is the picture tube found in some modern TV sets. German scientist, Karl Braun invented the cathode ray tube oscilloscope (CRT) in 1897.

Russian inventor, Vladimir Zworykin invented an improved cathode-ray tube called the kinescope in 1929. The kinescope tube was sorely needed for television. Zworykin was one of the first to demonstrate a television system with all the features of modern picture tubes.

Electronic television was first successfully demonstrated in San Francisco on Sept. 7, 1927. The system was designed by Philo Taylor Farnsworth, a 21-year-old inventor who had lived in a house without electricity until he was 14. While still in high school, Farnsworth had begun to conceive of a system that could capture moving images in a form that could be coded onto radio waves and then transformed back into a picture on a screen. Boris Rosing in Russia had conducted some crude experiments in transmitting images 16 years before Farnsworth's first success.

However, Farnsworth's invention, which scanned images with a beam of electrons, is the direct ancestor of modern television. The first image he transmitted on it was a simple line. Soon he aimed his primitive camera at a dollar sign because an investor had asked, "When are we going to see some dollars in this thing, Farnsworth?"

Early television was quite primitive. All the action at that first televised baseball game had to be captured by a single camera, and the limitations of early cameras forced actors in dramas to work under impossibly hot lights, wearing black lipstick and green makeup (the cameras had trouble with the color white). The early newscasts on CBS were "chalk talks," with a newsman moving a pointer across a map of Europe, then consumed by war. The poor quality of the picture made it difficult to make out the newsman, let alone the map. World War II slowed the development of television, as companies like RCA turned their attention to military production. Television's progress was further slowed by a struggle over wavelength allocations with the new FM radio and a battle over government regulation.

It was in June of 1956, that the TV remote controller first entered the American home. The first TV remote control called "Lazy Bones," was developed in 1950 by Zenith Electronics Corporation (then known as Zenith Radio Corporation). The very first prototype for a plasma display monitor was invented in 1964 by Donald Bitzer, Gene Slottow, and Robert Willson. After mid-century the spread of coaxial cable and microwave radio relay allowed television networks to spread across even large countries.

By the 1980s politicians and government leaders were familiar enough with the workings of television to be able to exploit the medium to their own ends. This seemed particularly apparent during the presidency of Ronald Reagan, himself formerly the host of a television show (*General Electric Theater*, 1954Ð62). Reagan's skilled advisors were masters of the art of arranging flags and releasing balloons to place him in the most attractive settings. They also knew how to craft and release messages to maximize positive coverage on television newscasts. The Persian Gulf War in 1991 provided further proof of the power of television, with pictures of U.S. bombs falling on the Iraqi capital broadcast live in the United States. Both Iraqi and U.S. leaders admitted to monitoring CNN to help keep up with news of the war. However, the U.S. Defense Department, armed with lessons learned in Vietnam, succeeded in keeping most reporters well away from the action and the bloodshed. Instead, pictures were provided to television by the military of "smart" bombs deftly hitting their targets.

In the 1980s, home videocassette recorders became widely available. Viewers gained the ability to record and replay programs and, more significantly, to rent and watch movies at times of their own choosing in their own homes. Video games also became popular during this decade, particularly with the young, and the television, formally just the site of passive entertainment, became an intricate, moving, computerized game board. The number of cable networks grew throughout the 1980s and then exploded in the 1990s as improved cable technology and direct-broadcast satellite television multiplied the channels available to viewers. The number of broadcast networks increased also, with the success of the Fox network and then the arrival of the UPN and WB networks.

In 1997 the federal government gave each U.S. television broadcaster an additional channel on which to introduce high definition television, or HDTV. Initial transmissions of this high-resolution form of television, in which images appear much sharper and clearer, began in 1998. Standard television sets cannot pick up HDTV and will presumably have to be replaced or modified by 2006, when traditional, low-definition television broadcasts are scheduled to end and broadcasters are scheduled to return their original, non-HDTV channel to the government. The HDTV format approved in the United States calls for television signals to be transmitted digitally. This will allow for further convergence between computers, the Internet, and television.

Web TV

Web TV was rolled out in 1996. In 1998 it was already possible to view video on the World Wide Web and to see and search television broadcasts on a computer. As computers become more powerful, they should be able to handle video as easily as they now handle text. The television schedule may eventually be replaced by a system in which viewers are able to watch digitally stored and distributed programs or segments of programs whenever they want. Such technological changes, including the spread of new cable networks, have been arriving slower in most other countries than in the United States. Indeed, according to one survey, it was only in the 1990s that the spread of television transmitters, television sets, and electricity made it possible for half of the individuals in the world to watch television. However, television's attraction globally is strong. Those human beings who have a television set watch it, by one estimate, for an average of two-and-a-half hours a day.

Mobility

There is nothing new about mobile Radio. Radio at its beginning was a wireless radio service. By 1922, there were experiments with fire and police mobile radio. By the mid 1930s, mobile radio broadcast receivers were appearing in cars.

Mobile telephony for the general public slowly grew and became less expensive and clumsy to use. Eventually a service emerged that would be recognisable today, except that the handheld telephone was considerably larger. These service used analogue frequency modulation worked at either 400 or 800MHz and were cellular meaning that many transmitters covered small patches of land and the user was handed off from one to the other as he moved around.

In the US, the system was called Advanced mobile phone system (AMPS) and it was one of the last contributions of the old Bell System. Very similar systems referred to as the first Generation of mobile systems appeared in the rest of the world at the same time.

The explosion of the public interest in mobile telephony came with the digital second generation systems. The cutting edge was in Europe and the system was the Global system for Mobile (GSM) that we still use today. First test were carried out in 1986 and GSM began to be installed in the mid 1990s. Public use of mobile telephony grew rapidly and dramatically with the introduction of GSM for several reasons:

1. In part, digital telephony was inherently more efficient.
2. It adapted easily to other services such as e-mail.
3. High frequency radio and digital circuitry were dropping rapidly in price and size in any case.
4. It offered for the first time a more subtle advantage called roaming because it was unified over many countries and now over much of the world. Its software procedures also made identification of visiting telephones easy thus people could roam over much of the earth and still use the same mobile phone.

All these factors combined to make a very attractive product and public use of the mobile phone doubled in the first years of the second generation technologies. Today in some countries such as Nigeria, there are more mobile users than fixed users.

Today, mobile phone based technologies have progressed to third generations having higher bandwidth (so that it can handle music with video) and a combining of mobility with internet access. The third generation is thus a fusion of a data base (The Internet) with communication to it.

Fourth generation technologies are already appearing in the market. They offer even higher bandwidths than 3rd Generation technologies thus they are excellently for live video streaming applications.

Communications Satellites: Making the Global Village Possible

In 500 years, when humankind looks back at the dawn of space travel, Apollo's landing on the Moon in 1969 may be the only event remembered. At the same time, however, Lyndon B. Johnson, himself an avid promoter of the space program, felt that reconnaissance satellites alone justified every penny spent on space. Weather forecasting has undergone a revolution because of the availability of pictures from geostationary meteorological satellites--pictures we see every day on television. All of these are important aspects of the space age, but satellite communications has probably had more effect than any of the rest on the average person. Satellite communications is also the only truly commercial space technology- -generating billions of dollars annually in sales of products and services.

The Billion Dollar Technology

In fall of 1945 an RAF electronics officer and member of the British Interplanetary Society, Arthur C. Clarke, wrote a short article in *Wireless World* that described the use of manned satellites in 24-hour orbits high above the world's land masses to distribute television programs. His article apparently had little lasting effect in spite of Clarke's repeating the story in his 1951/52 *The Exploration of Space*. Perhaps the first person to carefully evaluate the various technical options in satellite communications *and* evaluate the financial prospects was John R. Pierce of AT&T's Bell Telephone Laboratories who, in a 1954 speech and 1955 article, elaborated the utility of a communications "mirror" in space, a medium-orbit "repeater" and a 24-hour-orbit "repeater." In comparing the communications capacity of a satellite, which he estimated at 1,000 simultaneous telephone calls, and the communications capacity of the first trans-atlantic telephone cable (TAT-1), which could carry 36 simultaneous telephone calls at a cost of 30-50 million dollars, Pierce wondered if a satellite would be worth a billion dollars.

After the 1957 launch of Sputnik I, many considered the benefits, profits, and prestige associated with satellite communications. Because of Congressional fears of "duplication," NASA confined itself to experiments with "mirrors" or "passive" communications satellites (ECHO), while the Department of Defense was responsible for "repeater" or "active" satellites which amplify the received signal at the satellite--providing much higher quality communications. In 1960 AT&T filed with the Federal Communications Commission (FCC) for permission to launch an experimental communications satellite with a view to rapidly implementing an operational system. The U.S. government reacted with surprise-- there was no policy in place to help execute the many decisions related to the AT&T proposal. By the middle of 1961, NASA had awarded a competitive contract to RCA to build a medium-orbit (4,000 miles high) active communication satellite (RELAY); AT&T was building its own medium-orbit satellite (TELSTAR) which NASA would launch on a cost-reimbursable basis; and NASA had awarded a sole- source contract to Hughes Aircraft Company to build a 24-hour (20,000 mile high) satellite (SYNCOM). The military program, ADVENT, was cancelled a year later due to complexity of the spacecraft, delay in launcher availability, and cost over-runs.

By 1964, two TELSTARs, two RELAYs, and two SYNCOMs had operated successfully in space. This timing was fortunate because the Communications Satellite Corporation (COMSAT), formed as a result of the Communications Satellite Act of 1962, was in the process of contracting for their first satellite. COMSAT's initial capitalization of 200 million dollars was considered sufficient to build a system of dozens of medium-orbit satellites. For a variety of reasons, including costs, COMSAT ultimately chose to reject the joint AT&T/RCA offer of a medium-orbit satellite incorporating the best of TELSTAR and RELAY. They chose the 24-hour-orbit (geosynchronous) satellite offered by Hughes Aircraft Company for their first two systems and a TRW geosynchronous satellite for their third system. On April 6, 1965 COMSAT's first satellite, EARLY BIRD, was launched from Cape Canaveral. Global satellite communications had begun.

The Global Village: International Communications

Some glimpses of the Global Village had already been provided during experiments with TELSTAR, RELAY, and SYNCOM. These had included televising parts of the 1964 Tokyo Olympics. Although COMSAT and the initial launch vehicles and satellites were American, other countries had been involved from the beginning. AT&T had initially negotiated with its European telephone cable "partners" to build earth stations for TELSTAR experimentation. NASA had expanded these negotiations to include RELAY and SYNCOM experimentation. By the time

EARLY BIRD was launched, communications earth stations already existed in the United Kingdom, France, Germany, Italy, Brazil, and Japan. Further negotiations in 1963 and 1964 resulted in a new international organization, which would ultimately assume ownership of the satellites and responsibility for management of the global system. On August 20, 1964, agreements were signed which created the International Telecommunications Satellite Organization (INTELSAT).

By the end of 1965, EARLY BIRD had provided 150 telephone "half- circuits" and 80 hours of television service. The INTELSAT II series was a slightly more capable and longer-lived version of EARLY BIRD. Much of the early use of the COMSAT/INTELSAT system was to provide circuits for the NASA Communications Network (NASCOM). The INTELSAT III series was the first to provide Indian Ocean coverage to complete the global network. This coverage was completed just days before one half billion people watched APOLLO 11 land on the moon on July 20, 1969.

From a few hundred telephone circuits and a handful of members in 1965, INTELSAT has grown to a present-day system with more members than the United Nations and the capability of providing hundreds of thousands of telephone circuits. Cost to carriers per circuit has gone from almost $100,000 to a few thousand dollars. Cost to consumers has gone from over $10 per minute to less than $1 per minute. If the effects of inflation are included, this is a tremendous decrease! INTELSAT provides services to the entire globe, not just the industrialized nations.

Hello Guam: Domestic Communications

In 1965, ABC proposed a domestic satellite system to distribute television signals. The proposal sank into temporary oblivion, but in 1972 TELESAT CANADA launched the first domestic communications satellite, ANIK, to serve the vast Canadian continental area. RCA promptly leased circuits on the Canadian satellite until they could launch their own satellite. The first U.S. domestic communications satellite was Western Union's WESTAR I, launched on April 13, 1974. In December of the following year RCA launched their RCA SATCOM F- 1. In early 1976 AT&T and COMSAT launched the first of the COMSTAR series. These satellites were used for voice and data, but very quickly television became a major user. By the end of 1976 there were 120 transponders available over the U.S., each capable of providing 1500 telephone channels or one TV channel. Very quickly the "movie channels" and "super stations" were available to most Americans. The dramatic growth in cable TV would not have been possible without an inexpensive method of distributing video.

The ensuing two decades have seen some changes: Western Union is no more; Hughes is now a satellite operator as well as a manufacturer; AT&T is still a satellite operator, but no longer in partnership with COMSAT; GTE, originally teaming with Hughes in the early 1960s to build and operate a global system is now a major domestic satellite operator. Television still dominates domestic satellite communications, but data has grown tremendously with the advent of very small aperture terminals (VSATs). Small antennas, whether TV-Receive Only (TVRO) or VSAT are common-place sight all over the country.

New Technology

The first major geosynchronous satellite project was the Defense Department's ADVENT communications satellite. It was three-axis stabilized rather than spinning. It had an antenna that directed its radio energy at the earth. It was rather sophisticated and heavy. At 500-1000 pounds it could only be launched by the ATLAS- CENTAUR launch vehicle. ADVENT never flew, primarily because the CENTAUR stage was not fully reliable until 1968, but also because of problems with the satellite. When the program was cancelled in 1962 it was seen as the death knell for geosynchronous satellites, three-axis stabilization, the ATLAS-CENTAUR, and complex communications satellites generally. Geosynchronous satellites became a reality in 1963, and became the only choice in 1965. The other ADVENT characteristics also became commonplace in the years to follow.

In the early 1960s, converted intercontinental ballistic missiles (ICBMs) and intermediate range ballistic missiles (IRBMs) were used as launch vehicles. These all had a common problem: they were designed to deliver an object to the earth's surface, not to place an object in orbit. Upper stages had to be designed to provide a delta-Vee (velocity change) at apogee to circularize the orbit. The DELTA launch vehicles, which placed all of the early communications satellites in orbit, were THOR IRBMs that used the VANGUARD upper stage to provide this delta-Vee. It was recognized that the DELTA was relatively small and a project to develop CENTAUR, a high-energy upper stage for the ATLAS ICBM, was begun. ATLAS-CENTAUR became reliable in 1968 and the fourth generation of INTELSAT satellites used this launch vehicle. The fifth generation used ATLAS-CENTAUR and a new launch-vehicle, the European ARIANE. Since that time other entries, including the Russian PROTON launch vehicle and the Chinese LONG MARCH have entered the market. All are capable of launching satellites almost thirty times the weight of EARLY BIRD.

In the mid-1970s several satellites were built using three-axis stabilization. They were more complex than the spinners, but they provided more despun surface to mount antennas and they made it possible to deploy very large solar arrays. The greater the mass and power, the greater the advantage of three-axis stabilization appears to be. Perhaps the surest indication of the success of this form of stabilization was the switch of Hughes, closely identified with spinning satellites, to this form of stabilization in the early 1990s. The latest products from the manufacturers of SYNCOM look quite similar to the discredited ADVENT design of the late 1950s.

Much of the technology for communications satellites existed in 1960, but would be improved with time. The basic communications component of the satellite was the traveling-wave-tube (TWT). These had been invented in England by Rudoph Kompfner, but they had been perfected at Bell Labs by Kompfner and J. R. Pierce. All three early satellites used TWTs built by a Bell Labs alumnus. These early tubes had power outputs as low as 1 watt. Higher- power (50-300 watts) TWTs are available today for standard satellite services and for direct-broadcast applications. An even more important improvement was the use of high-gain antennas. Focusing the energy from a 1-watt transmitter on the surface of the earth is equivalent to having a 100-watt transmitter radiating in all directions. Focusing this energy on the Eastern U.S. is like having a 1000-watt transmitter radiating in all directions. The principal effect of this increase in actual and effective power is that earth stations are no longer 100-foot dish reflectors with cryogenically-cooled maser amplifiers costing as much as $10 million (1960 dollars) to build. Antennas for normal satellite services are typically 15-foot dish reflectors costing $30,000 (1990 dollars). Direct-broadcast antennas will be only a foot in diameter and cost a few hundred dollars.

Mobile Services

In February of 1976 COMSAT launched a new kind of satellite, MARISAT, to provide mobile services to the United States Navy and other maritime customers. In the early 1980s the Europeans launched the MARECS series to provide the same services. In 1979 the UN International Maritime Organization sponsored the establishment of the International Maritime Satellite Organization (INMARSAT) in a manner similar to INTELSAT. INMARSAT initially leased the MARISAT and MARECS satellite transponders, but in October of 1990 it launched the first of its own satellites, INMARSAT II F-1. The third generation, INMARSAT III, has already been launched.

An aeronautical satellite was proposed in the mid-1970s. A contract was awarded to General Electric to build the satellite, but it was cancelled--INMARSAT now provides this service. Although INMARSAT was initially conceived as a method of providing telephone service and traffic-monitoring services on ships at sea, it has provided much more. The journalist with a briefcase phone has been ubiquitous for some time, but the Gulf War brought this technology to the public eye.

The United States and Canada discussed a North American Mobile Satellite for some time. Later the first MSAT satellite, in which AMSC (U.S.) and TMI (Canada) cooperate, would be launched providing mobile telephone service via satellite to all of North America.

Competition

In 1965, when EARLY BIRD was launched, the satellite provided almost 10 times the capacity of the submarine telephone cables for almost 1/10th the price. This price-differential was maintained until the laying of TAT-8 in the late 1980s. TAT-8 was the first fiber-optic cable laid across the Atlantic. Satellites are still competitive with cable for point-to-point communications, but the future advantage may lie with fiber-optic cable. Satellites still maintain two advantages over cable: they are more reliable and they can be used point-to-multi-point (broadcasting).

Cellular telphone systems have risen as challenges to all other types of telephony. It is possible to place a cellular system in a developing country at a very reasonable price. Long-distance calls require some other technology, but this can be either satellites or fiber-optic cable.

The LEO Systems

Cellular telephony has brought us a new technological "system"-- the personal communications system (PCS). In the fully developed PCS, the individual would carry his telephone with him. This telephone could be used for voice or data and would be usable anywhere. Several companies have committed themselves to providing a version of this system using satellites in low earth orbits

(LEO). These orbits are significantly lower than the TELSTAR/RELAY orbits of the early 1960s. The early "low-orbit" satellites were in elliptical orbits that took them through the lower van Allen radiation belt. The new systems will be in orbits at about 500 miles, below the belt.

The most ambitious of these LEO systems is Iridium, sponsored by Motorola. Iridium plans to launch 66 satellite into polar orbit at altitudes of about 400 miles. Each of six orbital planes, separated by 30 degrees around the equator, will contain eleven satellites. Iridium originally planned to have 77 satellites-- hence its name. Element 66 has the less pleasant name Dysprosium. Iridium expects to be providing communications services to hand- held telephones in 1998. The total cost of the Iridium system is well in excess of three billion dollars.

In addition to the "Big LEOS" such as Iridium and Globalstar, there are several "little LEOs." These companies plan to offer more limited services, typically data and radio determination. Typical of these is ORBCOM which has already launched an experimental satellite and expects to offer limited service in the very near future.

A Selective Communications Satellite Chronology

- 1945 Arthur C. Clarke Article: "Extra-Terrestrial Relays"
- 1955 John R. Pierce Article: "Orbital Radio Relays"
- 1956 First Trans-Atlantic Telephone Cable: TAT-1
- 1957 Sputnik: Russia launches the first earth satellite.
- 1960 1st Successful DELTA Launch Vehicle
- 1960 AT&T applies to FCC for experimental satellite communications license
- 1961 Formal start of TELSTAR, RELAY, and SYNCOM Programs
- 1962 TELSTAR and RELAY launched
- 1962 Communications Satellite Act (U.S.)
- 1963 SYNCOM launched
- 1964 INTELSAT formed
- 1965 COMSAT's EARLY BIRD: 1st commercial communications satellite
- 1969 INTELSAT-III series provides global coverage
- 1972 ANIK: 1st Domestic Communications Satellite (Canada)
- 1974 WESTAR: 1st U.S. Domestic Communications Satellite
- 1975 INTELSAT-IVA: 1st use of dual-polarization
- 1975 RCA SATCOM: 1st operational body-stabilized comm. satellite
- 1976 MARISAT: 1st mobile communications satellite
- 1976 PALAPA: 3rd country (Indonesia) to launch domestic comm. satellite
- 1979 INMARSAT formed.
- 1988 TAT-8: 1st Fiber-Optic Trans-Atlantic telephone cable

Facsimile (FAX)?

It refers to the transmission of photographs, drawings, maps, and written or printed words by electric signals. Facsimile (Fax) is a method of encoding data, transmitting it over the telephone lines or radio broadcast, and receiving hard (text) copy, line drawings, or photographs. Light waves reflected from an image are converted into electric signals, transmitted by wire or radio to a distant receiver, and reconstituted on paper or film into a copy of the original.

Facsimile is used by news services to send news and photos to newspapers and television stations, by banks, airlines, and railroads to transmit the content of documents, and by many other businesses as an aid in data handling and record keeping.

Facsimile systems involve optical scanning, signal encoding, modulation, signal transmission, demodulation, decoding, and copy making.

Scanning

Scanning is done in a manner similar to that used in television. An original, a photo for example, is illuminated and systematically examined in small adjacent areas called pixels (picture elements). Light reflected from each pixel is converted into electric current by an electronic device, a photocell, photodiode, or charge-coupled device (CCD).

A single such device may be used to cover one pixel after another in a row, row after row from top to bottom until the entire image has been translated into electric impulses. This is rectilinear scanning. Scanning may also be done a row at a time by a battery of devices; this is array scanning.

We owe development of fax to a Scottish inventor, Alexander Bain, who was granted a patent for his creation back in 1843. Bain's original concept is still the basis for modern facsimile machines.

Fax was invented in 1842 by Alexander Bain, a Scottish clockmaker, who used clock mechanisms to transfer an image from one sheet of electrically conductive paper to another. He invented a machine capable of receiving signals from a telegraph wire and translating them into images on paper.

Bain's fax transmitter was designed to scan a two-dimensional surface (Bain proposed metal type as the surface) by means of a stylus mounted on a pendulum.

Analog Telephone Facsimile - Digital Facsimile

Between 1920 and 1923 the American Telephone & Telegraph Company (AT&T) worked on telephone facsimile technology, and in 1924 the telephotography machine was used to send pictures from political conventions in Cleveland, Ohio, and Chicago to New York City for publication in newspapers.

Computer Networks and the Internet

On September 11, 1940, George Stibitz was able to transmit problems using teletype to his Complex Number Calculator in New York and receive the computed results back at Dartmouth

College in New Hampshire. This configuration of a centralized computer or mainframe with remote dumb terminals remained popular throughout the 1950s. However it was not until the 1960s that researchers started to investigate packet switching — a technology that would allow chunks of data to be sent to different computers without first passing through a centralized mainframe. A four-node network emerged on December 5, 1969 between the University of California, Los Angeles, the Stanford Research Institute, the University of Utah and the University of California, Santa Barbara. This network would become ARPANET, which by 1981 would consist of 213 nodes. In June 1973, the first non-US node was added to the network belonging to Norway's NORSAR project. This was shortly followed by a node in London.

ARPANET's development centred around the Request for Comment process and on April 7, 1969, RFC 1 was published. This process is important because ARPANET would eventually merge with other networks to form the Internet and many of the protocols the Internet relies upon today were specified through this process. In September 1981, RFC 791 introduced the Internet Protocol v4 (IPv4) and RFC 793 introduced the Transmission Control Protocol (TCP) — thus creating the TCP/IP protocol that much of the Internet relies upon today. A more relaxed transport protocol that, unlike TCP, did not guarantee the orderly delivery of packets called the User Datagram Protocol (UDP) was submitted on 28 August 1980 as RFC 768. An e-mail protocol, SMTP, was introduced in August 1982 by RFC 821 and http://1.0 a protocol that would make the hyperlinked Internet possible was introduced on May 1996 by RFC 1945.

However not all important developments were made through the Request for Comment process. Two popular link protocols for local area networks (LANs) also appeared in the 1970s. A patent for the Token Ring protocol was filed by Olof Söderblom on October 29, 1974 and a paper on the Ethernet protocol was published by Robert Metcalfe and David Boggs in the July 1976 issue of *Communications of the ACM*.

Internet access became widespread late in the 19th century, using the old telephone and television networks.