1 Introduction

1.1 Introduction

Communication has always been important, and lack of communication in the past has resulted in terrible wars and tragedies. It could be said that the reason that we have had world peace for so long is more to do with global communications, than with diplomacy. The great growth of communications has revolved around three main technologies: the telephone, television and radio. All three initially involved the transmission of analogue signals over wires or with radio waves. On an analogue telephone system, the voltage level from the telephone varies with the voice signal. Unwanted signals from external sources easily corrupt these signals. In a digital communication system, a series of digital codes represents the analogue signal, which are then transmitted as 1's and 0's. These digit forms are less likely to be affected by noise and thus, have become the predominant form of communications.

Digital communication also offers a greater number of services, greater traffic rates and allows for high-speed communications between digital equipment. The usage of digital communications includes cable television, computer networks, facsimile, mobile digital radio, digital FM radio, and so on.

1.2 History

Communications, whether from smoke signals, pictures or the written word, is as old as mankind. Before electrical communications, man used fire, smoke and light to transmit messages over long distances. For example, Claude Chappe developed the semaphore system in 1792, which has since been used to transmit messages with flags and light.

The history of communication can be traced to four main stages:

- **Foundation**. This was the foundation of electrical engineering and radio wave transmission, and owes a great deal to the founding fathers of electrical engineering such as Coulomb, Ampère, Ohm, Gauss, Faraday, Henry and Maxwell, who laid down the basic principles of electrical engineering.
- **Electronics revolution**. This brought increased reliability, improved operations, improved sensitization and increased miniaturization.
- **Desktop computer revolution**. This accelerated the usage of digital communication and has finally integrated all forms of electronic communications: text, speech, images and video.
- **Modern communication**. This increased the ways of connections, and has steadily increased the speed of the connection, such as from satellite communications, local area networks and digital networks. Along with the integration of text, speech, images and video has came the integration of different type's carriers.

1.2.1 History of electrical engineering

The Greek philosopher Thales appears to have been the first to observe electrical force. From this, he noted that rubbing a piece of amber with fur caused it to attract feathers. It is interesting that the Greek name for amber was *elektron* and the name has since been used in electrical engineering.

An important concept in electrical systems is that electrical energy is undoubtedly tied to magnetic energy. Thus when there is an electric force, there is an associated magnetic force. The growth in understanding of electrics and magnetics began during the 1600s when the court physician of Queen Elizabeth I, William Gilbert, investigated magnets and found that the Earth had a magnetic field. From this he found that a freely suspended magnet tends to align itself with the magnetic field lines of the Earth. From then on, travelers around the world could easily plot their course because they knew which way was North.

Much of the early research in magnetics and electrics was conducted in the Old World, mainly in England, France and Germany. However, in 1752, Benjamin Franklin put the USA on the scientific map when he flew a kite in an electrical storm and discovered the flow of electrical current. This experiment is not recommended and resulted in the premature deaths of several scientists.

In 1785, the French scientist Charles Coulomb showed that the force of attraction and repulsion of electrical charges varied inversely with the square of the distance between them. He also went on to show that two similar charges repel each other, while two dissimilar charges attract.

Two scientists who were commemorated by giving their name to electrical units, made most of their findings in the 1820s. The French scientist André Ampère studied electrical current in wires and the forces between them, and then, in 1827, the German scientist Georg Ohm studied the resistance to electrical flow. From this, he determined that resistance in a conductor was equal to the voltage across the material divided by the current through it. Soon after this, English scientist Michael Faraday produced an electric generator when he found that the motion of a wire through an electric field generated electricity, and mathematically expressed the link between magnetism and electricity.

The root of modern communication can be traced back to the work of Henry, Maxwell, Hertz, Bell, Marconi and Watt. American Joseph Henry produced the first electromagnet when he wrapped a coil of insulated electrical wire around a metal inner. Henry, unfortunately, like many other great scientists, did not patent his discovery. If he had done, he would have enjoyed his retirement years as a very wealthy man, rather than on his poor pension. The first application of the electromagnet was in telegraphy, which was the beginning of the communications industry. Henry sent coded electrical pulses over telegraph wires to an electromagnet at the other end. It was a great success, but it was left to the artist Samuel Morse to take much of the credit. Morse, of course, developed Morse code, which is a code of dots and dashes. He used Henry's system and installed it in a telegraph system from Washington to Baltimore. The first transmitted message was 'What hath God wrought'. It received excellent publicity and after eight years, there were over 23, 000 miles (37, 000 km) of telegraph wires in the USA. Several of the first companies to develop telegraph systems went on to become very large corporations, such as the Mississippi Valley Printing Telegraph Company, which later became the Western Union. One of the first non-commercial uses of telegraph was in the Crimean War and the American Civil War, where a communications line from New York to San Francisco was an important mechanism for communicating with troops.

Other important developers of telegraph systems around the world were P.L. Shilling in Russia, Gauss and Weber in Germany, and Cooke and Wheatstone in Britain. In 1839, Cooke and Wheatstone opened a telegraph system alongside the main railway route running west from London.

One of the all-time greats was James Clerk Maxwell, who was born in Edinburgh in 1831. His contribution to science puts him on par with Isaac Newton, Albert Einstein, James Watt and Michael Faraday. Maxwell's most famous formulation was a set of four equations that define the basic laws of electricity and magnetism (Maxwell's equations). Before Maxwell's work, many scientists had observed the relationship between electricity and magnetism. However, it was Maxwell, who finally derived the mathematical link between these forces. His four short equations described exactly the behaviour and interaction of electric and magnetic fields. From this work, he also proved that all electromagnetic waves, in a vacuum, travel at 300,000 km per second (or 186,000 miles per second). This, Maxwell recognized, was equal to the speed of light and from this, he deduced that light was also an electromagnetic wave. He then reasoned that the electromagnetic wave spectrum must contain many invisible waves, each with its own wavelength and characteristic. Other practical scientists, such as Hertz and Marconi, soon discovered these *unseen* waves. The electromagnetic spectrum was soon filled with infrared waves, ultraviolet, gamma ray, X-rays and radio waves (and some even proposed waves which did not even exist).

While Maxwell would provide a foundation for the transmission of electrical signals, another Scot, Alexander Graham Bell, would provide a mechanism for the transmission and reception of sound: the telephone. From his time in Scotland, he had always had a great interest in the study of speech and elocution. In the USA, he fully developed his interest and opened the Boston School for the Deaf. His other interest was in multiple telegraphy and he worked on a device which he called a harmonic telegraph, which he used to aid the teaching of speech to deaf people. In 1876, from this research he produced the first telephone with an electromagnet for the mouthpiece and the receiver. Alexander Graham Bell actually made the first telephone call to his assistant with the words '*Mr Watson, come here, I want you*.' Unlike many other great inventions, it attracted great press coverage. 'It talks' was one of the headlines (it has not stopped since). Even the great Maxwell was amazed that anything so simple could reproduce the human voice, and, in 1877, Queen Victoria acquired a telephone. Edison then enhanced it by using carbon powder in the diaphragm, to create a basic microphone. This produced an increased amount of electrical current. To fully commercialize his invention, Bell along with several others formed the Bell Telephone Company which fully developed the telephone, so that, by 1915, long-distance telephone calls were possible. Bell's patent number 174 465 is the most lucrative ever issued. At the time, a reporter wrote, about the telephone, '*It is an interesting toy … but it can never be of any practical value*.'

Around 1851, the brothers Jacob and John Watkins Brett laid a cable across the English Channel between Dover and Cape Griz Nez. It was the first use of electrical communications between England and France (unfortunately, a French fisherman mistook it for a sea monster and trawled it up). The British maintained a monopoly on submarine cables and laid cables across the Thames, from Scotland to Ireland, and from England to Holland, as well as cables under the Black Sea, the Mississippi River and the Gulf of St Lawrence. Submarine cables have since been placed under most of the major seas and oceans around the world.

Around 1888, German Heinrich Hertz detected radio waves (as predicted by Maxwell) when he found that a spark produced an electrical current in a wire on the other side of the room. Then, Guglielmo Marconi, in 1896, succeeded in transmitting radio waves over a distance of two miles. From this humble start, he soon managed to transmit a radio wave across the Atlantic Ocean.

Scot Robert Watson-Watt made RADAR (Radio Detection and Ranging) practicable in 1935, by transmitting high frequency electromagnetic pulses which were reflected by metal objects (normally planes or ships) and were detected by a receiver. Today it is used in many applications from detecting missiles and planes, to detecting rain clouds and the speed of motor cars. Microwave signals, which are used in RADAR, have been important in the development of satellite communications.

1.2.2 History of modern communications

The main developments of modern communications have been:

- **Automated telephone switching**. After the telephone's initial development, call switching was achieved by using operators. Unfortunately, call switching tended to limit the range of the calls, and was particularly unreliable (and not very secure, as operators would often listen to the telephone conversation). However, in 1889, Almon Strowger, a Kansas City undertaker, patented an automatic switching system. In one of the least catchy advertising slogans, it was advertised as a *girl-less, cuss-less, out-of-orderless, wait-less telephone system.* His motivation for the invention was to prevent his calls being diverted to a business competitor by his local operator. It used a pawl-and-ratchet system to move a wiper over a set of electrical contacts. This led to the development of the Strowger exchange, which was used extensively until the 1970s. Another important improvement came with the crossbar, which allowed many inputs to connect to many outputs, simply by addressing the required connection. The first inventor is claimed to be J.N Reynolds of Bell Systems, but it is normally given to G.A. Betulander.
- **Radio transmission**. One of the few benefits of war (whether it be a real war or a cold war) is the rapid development of science and technology. Radio transmission benefited from this over World War I. A by-product of this work was frequency modulation (FM) and amplitude modulation (AM). In these, signals were carried on (modulated) high frequency carrier waves which travelled through the air better than unmodulated waves. Another by-product of the war effort was frequency division multiplexing (FDM) which allowed many signals to be transmitted over the same channel, but with a different carrier frequency.
- **Trans-continental cables**. After World War II, the first telephone cable across the Atlantic was laid from Oban, in Scotland to Clarenville in Newfoundland. Previously, in 1902, the first Pacific Ocean cable was laid. A cable, laid in 1963, stretches from Australia to Canada. These trans-continental cables are now important trunk routes for the global Internet. Their capacity has increased over the years, especially with the introduction of fiber-optic cables.
- **Satellites**. The first artificial satellite was Sputnik 1, which was launched by the USSR in 1957. This was closely followed in the following year by the US satellite, Explorer 1. A great revolution occurred when the ATT-owned Telstar satellite started communicating over large distances using microwave signals. It used microwave signals as these could propagate through rain and clouds and bounce off the satellite. The amount of information that can be transmitted varies with the bandwidth of the system, and is normally limited by the transmission system. A satellite system can typically carry as much as 10 times the amount of information that a radio wave can carry. This allows many TV channels to be transmitted simultaneously and/or thousands of telephone calls. Satellite TV stations are popular in transmitting TV stations over large areas, especially in areas where the use of transmission cables is restricted.
- **Digital transmission and coding**. Most information transmitted is now transmitted in

the form of digital pulses. A standard code for this transmission, called pulse code modulation (PCM), was invented by A.H. Reeves in the 1930s, but was not used until the 1960s. A major problem, in the past, with computer systems was that they used different codes to transmit text. To overcome this Baudot developed a 5-unit standard code for telegraph systems. Unfortunately, used a limited alphabet of upper-case letters and had only a few punctuation symbols. In 1966, ANSI defined a new standard code called ASCII. This has since become the standard coding system for text-based communications. It has only recently been upgraded with Unicode (which uses 16 bits). In its standard form ASCII uses 7 bits and can thus only represent 128 characters. It has since been modified to support an 8-bit code (called Extended ASCII), which includes

- **Fiber-optic transmissions.** Satellite communications increased the amount of data that could be transmitted over a channel, however, in 1965, Charles Kao laid down the future of high-capacity communication with the proof that data could be carried using optical fibers. Optical fibers now provide the backbone to many networks, including the Internet. Satellites supported the transmission of many hundreds of bits per second, but fibre optics could support billions of bits per second over a single fiber. They are also reliable, and have excellent capacity for future upgrading with higher transfer rates.

1.3 Bit rate

The communications industry has moved from transmitting a single character every second, to the transmission of many billions of characters every second. The great breakthrough was to communicate faster than someone could type, thus, one of the most basic communications rate is actually based on the speed of a typist. For this, a good typist will type at around 75 words per minute. If we assume that there are five characters on average in every word (with an extra character for a space), thus, the typist will type, on average, 450 characters per minute. This will give 7.5 characters ever second. Thus, as each character is represented, in ASCII, with 8 bits. The maximum transfer rate will be:

Transfer rate = 7.5 (characters per second) x 8 (bits per character) = **60 bps**

This was the basic bit rate that a communications link would have to support if it were to receive the speed of a fast typist. When a faster rate was required, the basic rate was doubled to 120 bps (although the standard rate was typically set at 110 bps). The speed then jumped to 300 bps, and multiples of this followed with 1200 bps, 2400 bps, 9600 bps, 19,200 bps (19 bkps), 38,400 bps (37 kbps), 57,600 bps (56 kbps), 115,200 bps (112 kbps), and so on. Most serial communications ports for computers and modems support many of these rates.

From the starting rate of 60 bps, the rates have increased over the years, as more people have used communications links, and backbone data traffic can have a capacity of tens of billions of bits per second (a 166,666,667 fold increase). For example, this chapter contains over 84,000 characters. With a 60 bps transfer rate it would take over three hours to transmit it, while at 10 billion bits per second it would be transmitted in less than 100 millionth of a second (assuming a transfer rate of 10,000,000,000 bps for 672,000 bits). The basic bit rate of transmission will increase over the years as the demand for data communications increases, and the number of applications for it increases.

The growth in data communications is creating one of the largest and most important industries in the world. It is a technology that brings benefits to virtually everyone. Without it, many organizations could not work efficiently. They are also creating industries that never existed before, such as digital TV, electronic commerce, electronic delivery of video and music, and, best of them all, electronic mail. The trend for transmitting data is to transmit digital information, thus if the original information is in the form of an analogue signal, it must first be converted into a digital form. This can then be transmitted over a digital network. At one time computer type data was sent over a network which was matched to transmitting this type of data, such as Ethernet and Token Ring, and speech was sent over a telephone-type network. The future will see the total integration of both real time (such as speech) and non-real time (such as computer-type data) into a single integrated digital network (IDN), as illustrated in Figure 1.1. The true integrator is ATM, which is covered in one of the WWW-based chapters. Networking technologies such as Ethernet are likely to remain a standard network connection onto a network, as they have become de facto standards.

The communications channel normally provides the main limitation on the amount of data that can be transmitted. This normally relates to its bandwidth, which can either be dedicated to the transmission of data from one source to a destination, or can be shared between more than one source, to more than one destination. Communications systems vary a great deal in the way they setup a connection, such as:

- **Bandwidth contention, bandwidth sharing or reserved bandwidth.** Some communication systems reserve bandwidth for a connection (such as ISDN and ATM), while others allow systems to contend for it (such as Ethernet). Normally the most efficient scheme is to allow systems to share the bandwidth. In this, some nodes can have more of the available bandwidth, if they require, while others can have a lesser share.
- **Virtual path, dedicated line or datagram.** Some communication systems allow a virtual path to be setup between the two connected systems, while others support a dedicated line between the two systems. A dedicated line provides a guaranteed bandwidth for the length of the conversation, while a virtual path should support a certain amount of bandwidth, as a connection has been setup to support the data being transmitted. In a datagram-based system, there is no setup for the route and all of the transmitted datagrams (data packets) take an independent path from the source to the destination.
- **Global addressing, local addressing or no addressing.** An addressing structure provides for individual data packets to have an associated destination address. Each of the devices involved in the routing of the data read this address and send the data packet off on the optimal path. This type of addressed system normally uses datagrams. A typical global addressing structure is IP addressing, which is the standard addressing scheme for the Internet. In a non-addressed system, the data is not tagged with the destination address, and only contains enough information to get it from one device to another. This technique is typically used in setting up a virtual path. No addressing is used when circuit connection is setup, as all the data takes the same route.

Most communication channels are sequential in their nature, where the data from one connection goes straight into another channel. Each of the channels has their own bandwidth limitation, thus the bandwidth of a complete system is limited to the bandwidth of the element of the system which has the least bandwidth (unless there are parallel paths around this element).

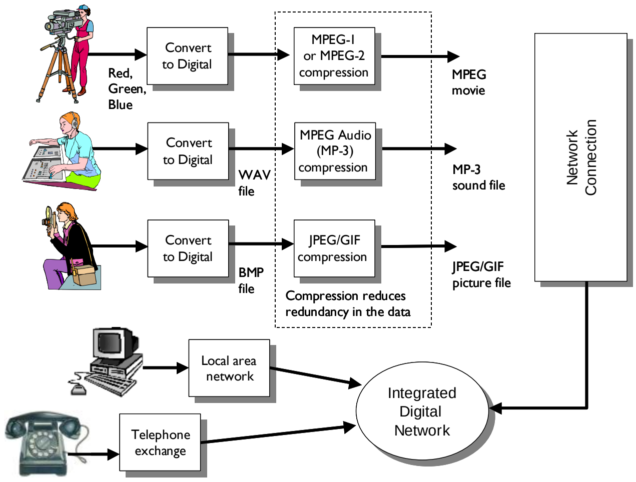

Figure 1.1 Conversion of information into an integrated digital network

1.4 Data transfer

Data is transferred from the source to the destination through a data path. This data can either be passed in a serial manner (one bit at a time) or in parallel (several bits at a time). In a parallel system, the bits are normally passed in a multiple of eight bits at a time. Typical parallel data transmissions are 8 bits, 16 bits, 32 bits, 64 bits or 128 bits wide.

Parallel transmission is normally faster than serial transmission (as it can transmit more bits in a single operation), but requires many more lines (thus requiring more wires in the cable). A parallel data transmission system normally requires extra data handshaking lines to synchronise the flow of data between devices. Serial data transmission normally uses a start and end bit sequence to define the start and end of transmission, as illustrated in Figure 1.2.

Parallel busses are typically used for local transmission systems, or where there are no problems with cables with a relatively large number of wires. Typical parallel communication systems are SCSI and the IEEE1284 parallel port, and typical serial transmission systems are RS-232, Ethernet, and most communication systems.

Serial communications can operate at very high transmission rates, where the main limiting factors are the transmission channel and the transmitter/receiver electronics. Gigabit Ethernet, for example, uses a transmission rate of 1 Gbps (125 MB/s) over high-quality twisted-pair copper cables, or over fiber-optic cables (although this is a theoretical rate as more than one bit is sent at a time). For a 32-bit parallel communication system, this would require a clocking rate of only 31.25 MHz (which requires much lower quality connectors and cables than the equivalent serial interface).

The main types of communication are:

- **Simplex communication.** Only one device can communicate with the other, and thus only requires handshaking lines for one direction.
- **Half-duplex communication.** This allows communications from one device to the other, in any direction, and thus requires handshaking for either direction.

- **Full-duplex communications.** This allows communication from one device to another, in either direction, at the same time. A good example of this is in a telephone system, where a caller can send and receive at the same time. This requires separate transmit and receive data lines, and separate handshaking for either direction.

Often the transmitter and receiver operate at different speeds, where the transmitter can send faster than the receiver can receive the data, or vice-versa. To stop too much data being transmitted before it can be processed, there must be an orderly transfer of data. This is normally achieved with handshaking, either with special handshaking lines, or by using software methods (such as sending special data characters to start and stop the flow of data).

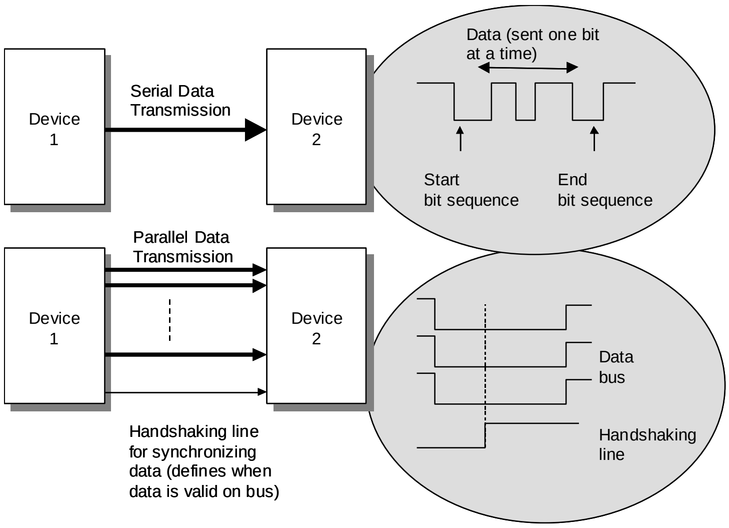

Figure 1.2 Serial and parallel data transmission

1.5 Data transfer rates

The amount of data that a system can transfer at a time is normally defined either in bits per second (bps) or bytes per second (B/s). The more bytes (or bits) that can be transferred the faster the transfer will be. Typically, serial busses are defined in bps, whereas parallel busses use B/s.

The transfer of the data occurs at regular intervals, which are defined by the period of the transfer clock. This period is either defined as a time interval (in seconds), or as a frequency (in Hz). For example, if a clock operates at a rate of 1 000 000 cycles per second, its frequency is 1 MHz, and its time interval will be one millionth of a second (1×10^{-6} s).

In general, if f is the clock frequency (in Hz), then the clock period (in seconds) will be:

$$T = \frac{1}{f} \text{ sec}$$

Conversion from clock frequency to clock time interval

For example, if the clock frequency is 8 MHz, the clock period will be:

$$T = \frac{1}{8\times10^6} = 0.000000125 \text{ sec}$$
$$= 0.125 \mu\text{s}$$

Example of a calculation of clock time interval from clock frequency

The data transfer rate (in bits/second) is defined as:

$$\text{Data transfer rate (bps)} = \frac{\text{Number of bits transmitted per operation (bits)}}{\text{Transfer time per operation (s)}}$$

If operated with a fixed clock frequency for each operation then the data transfer rate (in bits/second) will be:

$$\text{Data transfer rate (bps)} = \text{Number of bits transmitted per operation (bits)} \times \text{Clocking rate (Hz)}$$

For example, the ISA bus uses an 8 MHz (8×10^6 Hz) clocking frequency and can transfer 16 bits at a time. Thus, the maximum data transfer rate (in bps) will be:

$$\text{Data transfer rate} = 16\times8\times10^6 = 128\times10^6 \text{ bps} = 128 \text{ Mbps}$$

Often it is required that the data rate is given in B/s, rather than bps. To convert from bps to B/s, the bps value is divided by eight. Thus to convert 128 Mbps to B/s:

$$\text{Data transfer rate} = 128 \text{ Mbps}$$
$$= \frac{128}{8} \text{ Mbps} = 16 \text{ MB/s}$$

Example conversion from bps to B/s

For serial communication, if the time to transmit a single bit is 104.167 µs then the maximum data rate will be

$$\text{Data transfer rate} = \frac{1}{104.167\times10^{-6}} = 9600 \text{ bps}$$

Example conversion to bps for a serial transmission with a given transfer time interval

1.6 Data representations

Computers only understand binary. We thus often need methods to convert values into binary. The main representations for integers and binary, hexadecimal and octal. For binary we represent in powers of 2, in hexadecimal it is in powers of 16 and for octal it is in powers of 8. With binary we add the bits in powers of 2:

	128	64	32	16	8	4	2	1	Decimal
	b_7	b_6	b_5	b_4	b_3	b_2	b_1	b_0	
Val1	0	0	1	1	0	1	0	1	53
Val2	0	1	1	0	1	0	1	0	106
Val3	0	0	0	1	1	0	1	0	26

In Python, binary values are represented with 0xb leading characters. For example:

Value: 43 Decimal form: 0b101011

With hexadecimal we take four bits at a time and convert them into a hexadecimal value, and normally we show that we are using hexadecimal with leader characters. The table we use is:

Val	Hex		Val	Hex
0000	0		1000	8
0001	1		1001	9
0010	2		1010	A
0011	3		1011	B
0100	4		1100	C
0101	5		1101	D
0110	6		1110	E
0111	7		1111	F

An example is 42 which is “0010 1011”, and where we can represent this with 0x2B. With octal we take three bits at a time, and represent them with a value from 0 to 7.

1.7 Logic operations

The telecommunications we have eight main bit operations that are often used. These are: AND (&), OR (|), NOT (!), XOR (^), Shift Left (<<), Shift Right (>>), Rotate-left and Rotate-right. The operations are:

AND			OR			X-OR		
A	**B**	**Z**	**A**	**B**	**Z**	**A**	**B**	**Z**
0	0	0	0	0	0	0	0	0
0	1	0	0	1	1	0	1	1
1	0	0	1	0	1	1	0	1
1	1	1	1	1	1	1	1	0

The NOT operator basically inverts the bit, while shift-left moves the bits by a number of places to the left, and shift-right moves them to the right. For example if we have a binary value of “00110101”, the decimal equivalent is 53 (0×128 + 0×64 + 1×32 + 1×16 + 0×8 + 1×4 + 2×0 + 1×1). If we shift the bits by one position, we get “01101010”, where a zero is inserted into the least significant bit. This gives us a decimal equivalent of 106. If we move the value to the right, we get "00011010", where a zero is inserted in the most significant bit value.

	128	64	32	16	8	4	2	1	Decimal
	b_7	b_6	b_5	b_4	b_3	b_2	b_1	b_0	
Val	0	0	1	1	0	1	0	1	53
Val << 1	0	1	1	0	1	0	1	0	106
Val >> 1	0	0	0	1	1	0	1	0	26

In Python we can use the shift operators (<< and >>). In the following, we have erase the first to characters of the binary value (as Python represents a binary value with 0bxxxxxxx). This is achieved with the [2:] operation on the string. The rjust(8,'0') method pads '0's from the right-hand side:

```
val1="00110101"
print "Binary form:\t",val1
dec=int(val1,2)
print "Decimal form:\t",dec,"\t",bin(dec)[2:].rjust(8,'0')
res=dec << 1
print "Shift left:\t",res,"\t",bin(res)[2:].rjust(8,'0')
res=dec >> 1
print "Shift right:\t",res,"\t",bin(res)[2:].rjust(8,'0')
```

A sample run is:

```
Binary form:    00110101
Decimal form:   53      00110101
Shift left:     106     01101010
Shift right:    26      00011010
```

1.7.1 Bit masking

We often use the AND bitwise operation to mask off some bits, as a 0 in a certain bit position will make the result '0', while a '1' at this position will preserve the value of the bit. For example the following are bit masks for 1, 2 and 3:

	128	64	32	16	8	4	2	1	Decimal
	b_7	b_6	b_5	b_4	b_3	b_2	b_1	b_0	
Val	0	0	1	1	0	1	0	1	53
Val & 0x1	0	0	0	0	0	0	0	1	1
Val & 0x2	0	0	0	0	0	0	1	0	2
Val & 0x3	0	0	0	0	0	0	0	1	1

The operations are defined here:

http://www.asecuritysite.com/calculators/bitmask

Important masks as 0x1 (0000 0001), 0xf (0000 1111), 0xff (1111 1111), which mask of the bottom 1, 4 and 8 bits, respectively.

Often we have to test for a single bit. With this we mask with a single '1' in the position that we want to test, and then bitwise AND, and test the result. If it is zero, the bit at that position is a '0', else it is a '1'. For example to test the 4th bit (b_3), we would use:

```
result = (val & 0x80)
```

which will set all the bits other than b_3 to zero. An example is at

http://asecuritysite.com/calculators/bits

and then can operate on a number of bit with:

http://asecuritysite.com/calculators/bitops

In telecommunications we also use binary gates, such as for AND, OR, NAND, NOR and X-OR (Figure 1.6).

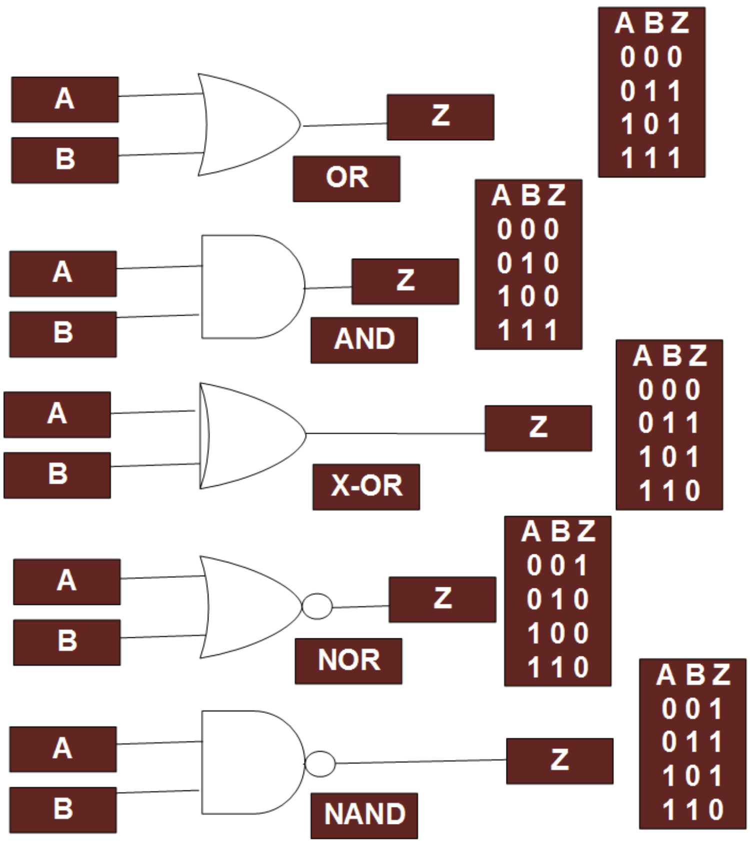

Figure 1.6 Electronic gates

Some basic operations are at:

http://asecuritysite.com/calculators/bitops2

1.8 Matrix operations

Matrix operations are often used within transformations of bits within communications systems. We can either have a single row with *m* columns (1 x *m*):

$$A = \begin{bmatrix} 5 & 7 & 8 \end{bmatrix}$$

or a single column with *n* rows (*n* x 1):

$$A = \begin{bmatrix} 5 \\ 7 \\ 8 \end{bmatrix}$$

or an *n* by *m* matrix (*n* rows and *m* columns – *n* by *m*):

$$B = \begin{bmatrix} 6 & 2 & 3 \\ 1 & 3 & 5 \\ 5 & 3 & 8 \end{bmatrix}$$

If we multiply A by B we get:

$$B = \begin{bmatrix} 5 & 7 & 8 \end{bmatrix} \times \begin{bmatrix} 6 & 2 & 3 \\ 1 & 3 & 5 \\ 5 & 3 & 8 \end{bmatrix} = \begin{bmatrix} 5\times 6 & 7\times 2 & 8\times 3 \\ 5\times 1 & 7\times 3 & 8\times 5 \\ 5\times 5 & 7\times 3 & 8\times 8 \end{bmatrix} = \begin{bmatrix} 30 & 14 & 24 \\ 5 & 21 & 40 \\ 25 & 21 & 64 \end{bmatrix}$$

The Dot product determines the magnitude of a multiplication:

$$B = \begin{bmatrix} 5 & 7 & 8 \end{bmatrix} \bullet \begin{bmatrix} 6 & 2 & 3 \\ 1 & 3 & 5 \\ 5 & 3 & 8 \end{bmatrix} = \begin{bmatrix} 5\times 6+7\times 1+8\times 5 & 5\times 2+7\times 3+8\times 3 & 5\times 3+7\times 5+8\times 8 \end{bmatrix} = \begin{bmatrix} 77 & 55 & 114 \end{bmatrix}$$

The addition and subtraction of matrices requires two matrices of the same dimensions. In Python we can use the numpy library, such as:

```
import numpy
def multi(m, g):
    en = numpy.multiply(m, g)
    return en

def dot(m, g):
    en = numpy.dot(m, g)
    return en

def multi(m, g):
    en = numpy.multiply(m, g)
    return en

g =  numpy.array([5,7,8])
h = numpy.array([[6,2,3],[1,3,5],[5,3,8]])

res=multi(g,h)
print "Multiply:"
print res

res=dot(g,h)
print "\nDot product:"
print res
```

A sample run is:

```
Multiply:
[[30 14 24]
 [ 5 21 40]
 [25 21 64]]

Dot product:
[ 77  55 114]
```