

1

A Communications Revolution

1.1 Leaving basic POTS behind

In almost every respect the telecommunications scene repeatedly experiences revolutionary change. Many people are too young to remember Strowger exchanges, regularly crossed lines, and calls often failing to connect. Yet this was the case as recently as the 1980s even in many developed countries. For anyone living in an early-stage developing economy the introduction of the basic telephone and plain old telephone service (or POTS) is, of course, a major event which promises to transform lives and businesses.

The introduction of digital electronic exchanges, fiber-optic transmission, and satellite communications changed the scene radically. By the late twentieth century crossed lines had become a rare event in advanced economies and all callers expected their connections to be made the first time and to stay connected until hanging up—even at three cents per minute. Mobile phone use had grown almost exponentially and some

people sported “dummy phones” so they would look really streetwise in spite of the fact they could not afford to use the real thing!

Total global telecommunications industry revenues, services, and equipment broke through the trillion dollar level in 1998 and (even allowing for the modest amount of Y2K disruption in year 2000) will approach \$3.2 trillion by 2010. The overall trend is shown in Figure 1.1. Service revenues are always well ahead of equipment sales—witness the fact that mobile phones and PCs are often offered free of charge because the payback from the service side dominates so greatly.

As the world progresses through the early years of the third millennium so the fabric of national and global telecommunications becomes transformed. This transformation enables broadband fixed and mobile facilities to become a reality for rapidly increasing numbers of subscribers everywhere. In the United States alone broadband revenues are expected to reach \$50 billion by 2005. Intelligent lightwave networks using dense-wavelength division multiplexing (DWDM), broadband satellite constellations, and seamlessly interconnecting wireless systems will all be linked into the self-healing and automatically rerouting global information superhighway—or “the supernet.” Such networks are forming the principal on-ramps for this superhighway.

The original Internet—the darling of late twentieth-century communications—threatened the earlier preeminence of speech telephony traffic. The great popularity of e-mail and Web surfing meant that data traffic began to outstrip talking—certainly in the developed world. From

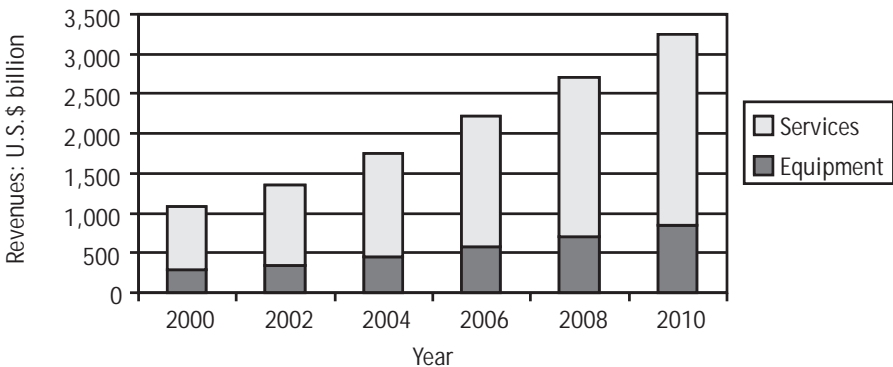


Figure 1.1 Global telecommunications revenues.

the old slogan, “it’s good to talk,” the transition was leading more toward, “it’s good to net.”

The growth of the Internet backbone market, on a global basis, is indicated in Figure 1.2. The basic technologies supporting this gigahertz and terahertz backbone include fiber optics, terrestrial millimeter-wave, and satellite communications systems.

People are, however, for the most part naturally social at all levels and this extends throughout personal, business, and professional life. This fact is likely to ensure that telephony has a highly significant future alongside the ever-expanding data needs.

Many industry analysts consider that the trend towards ever-increasing mobility will last “forever.” According to data provided by the *Financial Times* (FT) of London, England, in 1997 mobile communications still only accounted for 19% of the total telecommunications market, the bulk (60%) being taken up by telephone services. The same source gave forecasts for the years 2001 and 2005, predicting that by 2005 34% of total revenues would be accredited to mobile. With some medical concerns surrounding mobile phone use, modest Y2K disruption, and likely stabilization instead of continuous growth in vehicular transportation, this may now be considered rather unlikely, and it is more probable that mobile use will only be proportionately somewhat higher than in 1997. On the other hand, advanced fixed services including broadband applications are likely to considerably increase their share. The substantially adjusted 2005 forecasts are shown in Figure 1.3.

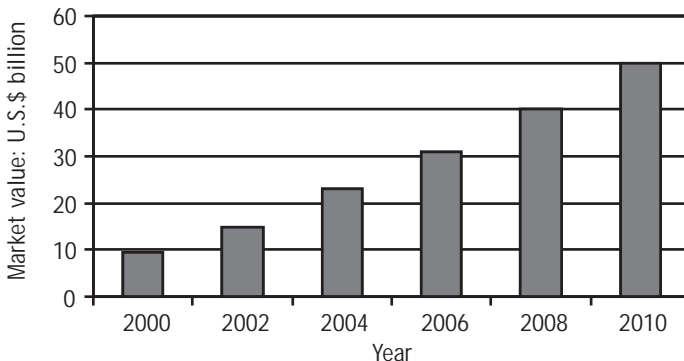


Figure 1.2 Global Internet backbone market.

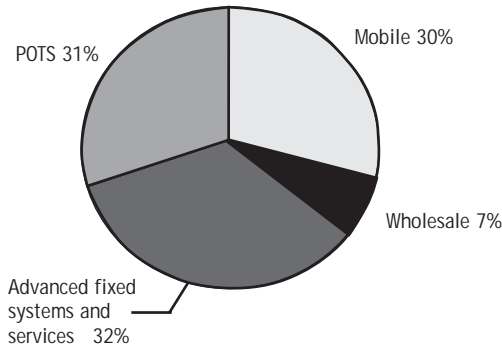


Figure 1.3 Telecommunications revenue breakdown for the year 2005.

In common with most advances in technology, the communications revolution all began with scientific and mathematical discoveries (see Table 1.1). We can usefully trace the developments back to Michael Faraday and James Clerk Maxwell of the nineteenth century.

In the “time travels” throughout the nineteenth and twentieth centuries presented in the table, the key people who match the key technological events are identified.

Well before the close of the twentieth century, true and complete convergence had been achieved between the computer and the telecommunications industries. Computer management and control were already ubiquitous in the following systems:

- Telephone services;
- Cable television (CATV—in most of the developed countries often including telephony and high-speed Internet access);
- Satellite [satellite TV—i. e., direct broadcast by satellite (DBS) and trunk satellite telecoms];
- High-speed fiber-optic connections—local and global;
- Broadband terrestrial wireless (LMDS, MVDS).

LMDS and MVDS stand for local multipoint distribution services and microwave video distribution services, respectively. These are described in Chapter 8.

Table 1.1
Key People and Key Technological Events

Some key people:		
1800s	1900s	2000s
Faraday, Maxwell, Morse	Alexander Graham Bell, Rainey (1926), Reeves (1939), Marconi, Arthur C. Clarke, Shockley et al. (1947), Kilby, Noyce (1958), Kao and Hockham (1966), Tim Berners-Lee (late 1980s)	Mainly teams rather than individual inventors
Some key events:		
1800s	1900s	2000s
Electricity Electromagnetic wave theory Transatlantic Telegraph	Telephone Pulse code modulation Practical radio Geostationary satellite Transistor Integrated circuit Fiber-optics theory First PC (Xerox) Mobile cellular communications The Internet	Mobile satellite Broadband satellite systems Broadband millimeter-wave (MVDS) Advanced semiconductors Photonic integrated systems Broadband mobiles Global information superhighway

The overall concept of this computer/telecommunications convergence is illustrated in Figure 1.4. For most of the time following Alexander Graham Bell's invention of the telephone, telecommunications continued to proceed using *analog* techniques. Signals were amplitude modulated, that is, "strength" modulated, onto carriers or "bearers" that extended in frequency up to the radio bands. Channels were separated by frequency-division multiplexing (FDM) and telephone messages were routed using electromechanical (Strowger) switch exchanges.

Radio transmission and reception proceeded using similar principles—although, later on, frequency-modulation (FM) gave greatly

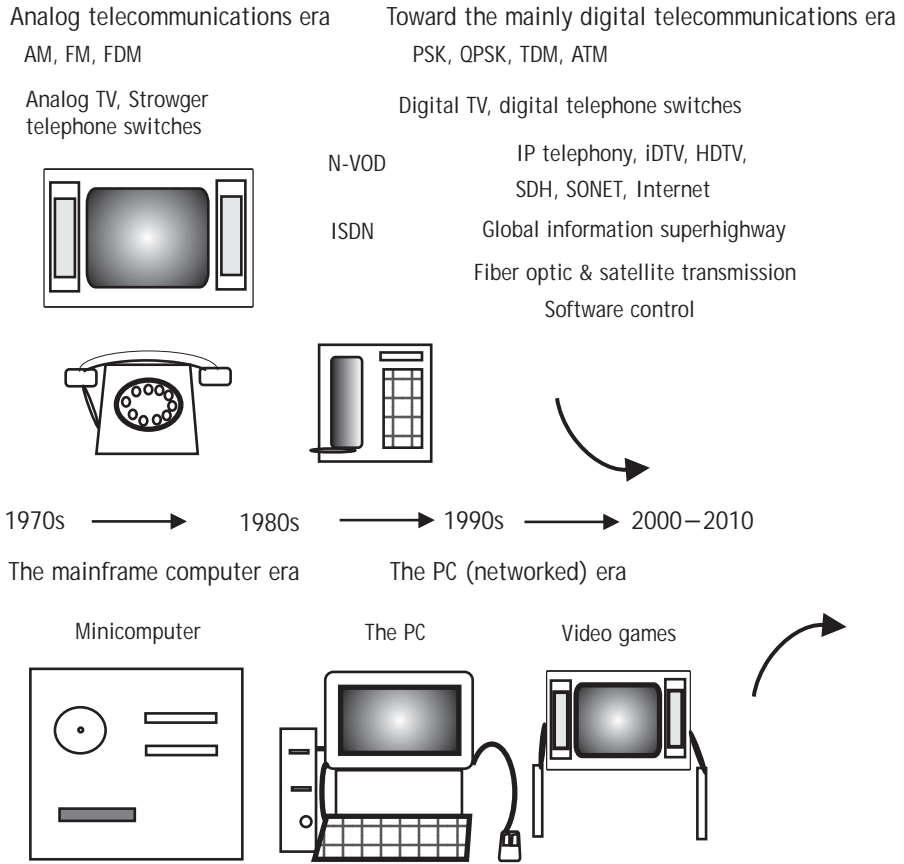


Figure 1.4 The convergence trend between telecommunications and computer systems.

improved radio reception quality. TV has remained steadfastly analog until comparatively recent times. Usable computers, of course, came along much later than the telephone, radio, or TV and no one could ever remotely consider owning a computer before the late 1970s (nobody had a room large enough, a pocket deep enough, or for that matter a need intense enough!). Through the 1970s minicomputers became vogue and interactive systems came into commercial use. Then, in the late 1970s, as we are all aware, nothing short of a revolution occurred with the commercial introduction of the PC.

Companies like Acorn, Commodore, IBM (the first to use the term *PC*), and many other contenders suddenly became household names and virtually everyone was talking computers. By the mid-1980s most school kids had a computer at their places of learning and mom and dad were becoming increasingly stressed-out with their children's ever more frequent requests for a PC at home. Games could be run on these amazing machines and sometimes even homework might be completed with the aid of that magical box of tricks!

The corporate and academic scenes became transformed by the new influx of PCs and soon these were becoming networked—connected together with a server that could manage such networks. Some of the PCs were little more than dumb terminals but this left the users feeling out of the mainstream so to speak. It's very interesting how most humans feel the personal need to remain in control of things and to have their own files of information.

By the late 1980s the world had transitioned from the “analog era” toward the mainly “digital telecommunications era.” Almost all telephony switches (within the exchanges) were now electronic and digital, and the Integrated Services Digital Network (ISDN), conceived during the predominantly analog 1970s, was now enjoying a more realistic revival. Fiber-optic and satellite transmission technologies and their implementations continued a strong expansionary phase and this continues today.

Then, in the late 1980s, along came Tim Berners-Lee—the “father of the Web”—and the world of telecommunications was changed forever. A “next level up” communicating technique had been invented by Berners-Lee who, while working as a software consultant at CERN, developed the hypertext-based search approach that eventually led to the Hypertext Markup Language (HTML) that evolved into today's Internet browsers.

The dramatic revolution in mobile phones, begun with analog systems in the 1980s, sped ahead with digital modulation in the 1990s as operators became customer-driven by increased quality desires and ever greater capacity demands. Everyone appreciated that by using digital technology and techniques more, many more, facilities could be added. This fact became epitomized by the successful launch of products such as Nokia's 9000 “Communicator,” that is, a PC-standard machine with 386-level power embodying a digital mobile phone with a text keyboard.

The user can send e-mail and faxes with this hand-held device because it links to the Internet via the local standard cellular network.

In the late 1990s, as the world rapidly approached the third millennium, digitization steadily expanded its horizons. The Internet was, of course, well in place with around forty million Web sites (and rising) being claimed in 1999, and Internet Protocol (IP) telephony was being seriously considered by increasing numbers of subscribers. Digital TV (DTV) was now very much on the scene (see Chapter 5) with interactive DTV (iDTV; also Web TV) gaining expanding acceptance. These types of developments drove up the long dormant interests in high-definition TV (HDTV).

Welcome to the gigahertz and terahertz high-speed digital millennium.

1.2 Increasingly interactive systems

Apart from the plain old telephone, most twentieth-century communications were one way at a time. Exceptions were audio and videoconferencing, but even here slow-motion video and other limitations (most notably cost) held growth back greatly.

Many CATV installations of the 1990s were largely fiber optic—at least as far as the street outside a group of subscribers. However, the fiber cables were what is known as multimode, which means that the bandwidth was limited to carrying only multichannel TV plus a number of telephone channels. Subscribers were generally content with the facility to watch, often on a pay-as-you-view near-video on demand (N-VOD) basis, whatever TV real-time programs or movies they wanted as well as in many cases to take advantage of the usually competitive telephone service. The service provider always built in a simple one-way keying option for the subscriber's use in program selection. As with the now all-digital systems, data could also be carried and hence computer (PC) modems could be connected.

By 1998 modem connection rates were as high as 51 Kbps in practice using such connections, and the existing fiber CATV networks could then also carry reasonably high-speed Internet connections. CATV modems, using special connections made available by some service providers, are

already as high as 10 Mbps theoretically—2 Mbps in practice. These are downstream speeds. Upstream, 640 Kbps is achieved.

With ISDN, 64 Kbps is achieved as a local standard—but this is a dedicated network connection and it really predates the Internet.

Generally the “civils”—the trenching of the streets and laying cables—amount to around two-thirds of the total investment associated with any cabled project. This investment has already been committed with many urban fiber CATV networks, and at the appropriate time in the future, broadband single-mode fiber cables can be threaded through the existing plastic ducts relatively inexpensively. Such a move provides those subscribers who desire it with broadband connection facilities.

For example, HDTV with many more channels could be supplied, interactive TV could be made available, and high-speed Internet access could be facilitated. Instead of the 51 Kbps of 1998 the user could be connecting upstream at, say, 2 Mbps or more and this would mean the rapid transmission of graphics-rich files.

Almost all modern communications systems are digital and employ time-division multiplexing (TDM) or packet switching. Signals transported on broadband single-mode fiber cables are generally assembled on the “SONET” basis. SONET stands for synchronous optical network and the TDM sequences with this standard follow the synchronous digital hierarchy (SDH) scheme. SONET and SDH both allow bit rates up to at least 9.953 Gbps, which is the equivalent of having one single-mode fiber carrying 86,016 voice channels simultaneously! This is commercial; over one million simultaneous voice channels have been demonstrated in R&D labs.

The asynchronous transfer mode (ATM being the telecommunications engineers’ abbreviation) represents a particularly important standard technique for assembling packets of information bits into a telecommunications bit stream. ATM is also sometimes known as “cell relay.” Each ATM cell is a total of 53 octets long, where an octet contains 8 bits of information. A header section, just 5 octets long, precedes the 48-octet information field (or “payload”) in every ATM cell. The overall structure is shown in Figure 1.5 and this technique is specified in the IEEE 802.6 as applying to metropolitan area networks (MANs), switched multimegabit digital services (SMDS), and the Broadband Integrated Services Digital Network (B-ISDN).

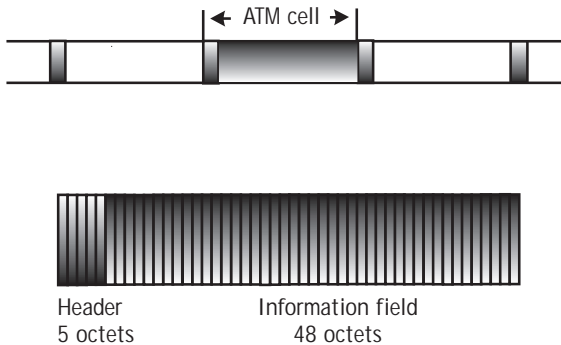


Figure 1.5 ATM cell. (From: Nellist, J.G., and E.M. Gilbert, *Understanding Modern Telecommunications and the Information Superhighway*, Norwood, MA: Artech House, Inc., 1999.)

The actual duration of an ATM cell varies according to the SDH level in which the cells are being transported. For example, in STM-1 the bit rate is 155.52 Mbps and therefore each bit has a duration of 6.43 ns. An octet therefore occupies eight times this, or 51.44 ns, and the complete 53-octet ATM cell must take up a 2.726 ms time slot. Obviously at higher SDH rates the duration is correspondingly reduced.

With these techniques available, digital compression approaches are feasible and have made great inroads into advanced digital telecoms. This is described in Chapter 5.

As we shall see later, new and ongoing developments are even more accommodating than the techniques described above.

Twentieth-century communications such as broadcast TV—terrestrial or satellite—remained essentially one-way and strictly receive-only. The basic concept of direct-to-home or direct broadcast by satellite (DTH or DBS) is illustrated in Figure 1.6. In this diagram a set-top box feeding into an HDTV set is shown, both of which are described in Chapter 5. However, in many cases traditionally a basic, even analog, TV is the receiving appliance for DTH or DBS satellite signals.

In North America satellite TV is provided by several companies including Primestar and USSB that are both now owned by DirecTV (itself owned by Hughes/RCA) and EchoStar. Dish reflector diameters vary considerably, being 90 cm for Primestar and just 45 cm in the cases

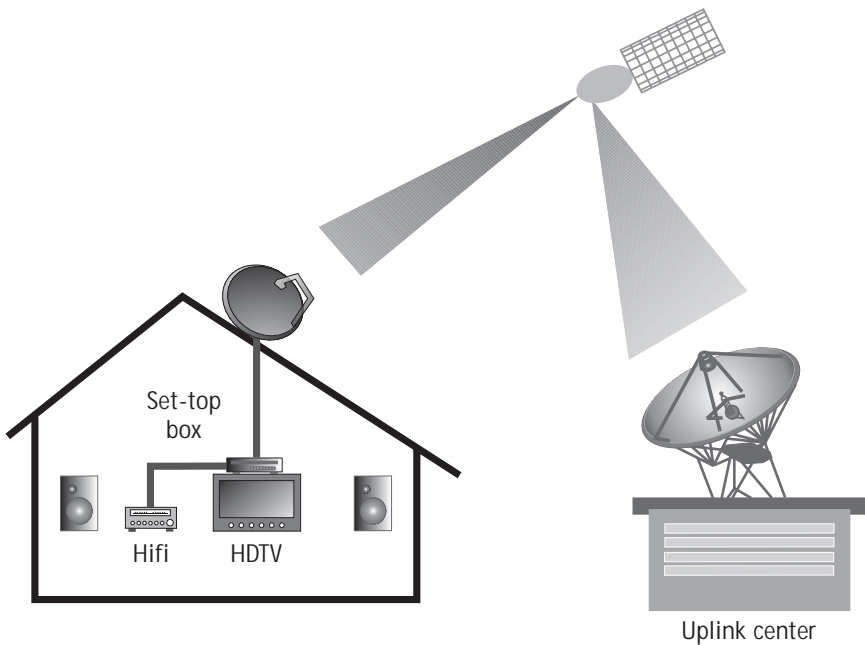


Figure 1.6 Direct-to-home (DTH) direct broadcast by satellite (DBS) system. (From: Nellist, J.G., and E.M. Gilbert, *Understanding Modern Telecommunications and the Information Superhighway*, Norwood, MA: Artech House, Inc., 1999.)

of DirecTV, EchoStar, and USSB. All programming is delivered from the uplink center and comprises a large selection of TV channels (e.g., live, local, news), movies, and music for all tastes at charges in the tens of dollars per month range.

Once thought of as a past opportunity, DBS enjoyed something of a revival in fortunes over the 1999–2000 time frame spurred on by digital TV, with its advantages of substantially improved signal-to-noise ratio and much greater programming flexibility including interactivity. The acquisition of e-mail and all other Internet usage was, however, also very much one way at a time with DTH and this is a significant disadvantage, although recently both DirecTV and EchoStar announced capabilities for Internet access.

One of the most exciting developments during the 1990s was the advent of mobile satellite systems (MSS). Iridium and Globalstar were

the main first contenders in this “new space race,” with Motorola and Loral as the lead contractors in the consortia. Although growth was slower than many hoped during the early period, notably in 1999, this approach led the way toward broadband MSS as an alternative to single-mode fiber—particularly in regions where cabling is completely uneconomic—and being mainly telephone connection systems two-way real-time conversations are made possible, including to and from remote regions of the planet. Only very low-speed connections are available, typically at just 4 Kbps.

Low earth orbit (LEO) satellites epitomized the early satellite TV of the 1960s and 1970s. However, the limitations of limited-period orbits and restricting technology soon meant that only geostationary orbiting spacecraft were used. Only advanced digital techniques and technologies have made the latest LEOs possible, but the economic viability of such operations, in particular narrowband LEOs like Iridium and Globalstar, has yet to be convincingly demonstrated.

Satellite trunks, mainly using the “Clarksian” (from the originator Arthur C. Clarke) constellations of three spacecraft in geostationary orbits (GEOs), also continue in importance. Their information-carrying capacities increase as on-board transponder capabilities improve and frequencies move ever higher, into Ka-band (26.5–36 GHz) and eventually V-band (46–56 GHz) also. Nellist and Gilbert describe many types of satellite systems, and broadband projects are discussed in Chapter 9 of this book.

Back on earth, broadband terrestrial wireless also continues to be of ever-growing importance. Bidirectional LMDS and MVDS systems are expanding in implementation, especially in regions where either satellite or fiber is uneconomic or impractical. Figure 1.7 shows a schematic of a point-to-multipoint configuration (more details are provided in Chapter 8). The millimeter-wave transceivers, complete with transmit-receive antennas (tightly focused MM-wave antennas A, B, and C), are mounted either on buildings or alternatively on dedicated units placed on hillsides or mountains. Line-of-sight trajectories are required between the main transceiver and A, B, and C, and the combination of “free-space,” atmospheric, and precipitation attenuation must be accounted for in the link design. Operating bands are usually 25–31 GHz and all forms of attenuation increase as frequencies shift into these millimeter-wave bands.

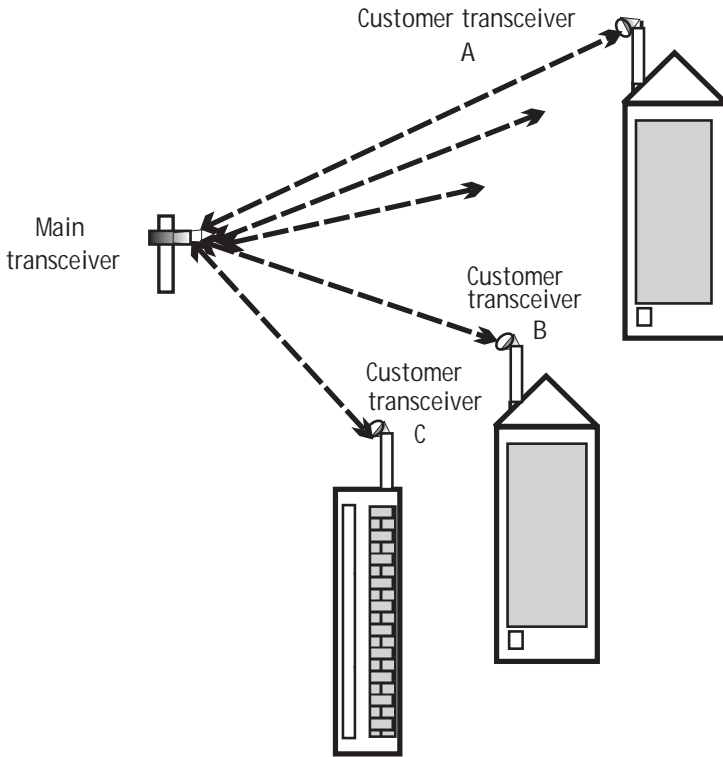


Figure 1.7 Point-to-multipoint communications.

While important technologies such as PCS and especially GSM remain in vogue for millions of mobile phone users and service providers globally, new “third-generation” (3G) specifications and associated products are also entering the markets. Two considerations that are of significance here are the Universal Mobile Telecommunications Systems (UMTS) specifications and wideband code-division multiple access (W-CDMA). This is also sometimes known as B-CDMA, broadband code-division multiple access, which is well covered by Brodsky in *Wireless: The Revolution in Personal Telecommunications*. Standards associated with these new developments are coming from the IEEE, ETSI (European), IMT, and other bodies. IMT 2000 represents just one group of such standards. New spectrum allocations are being made available by the World Administrative Radio Conference (WARC) in the year 2000.

An example of a multimedia “3G concept phone” being developed by Nokia is indicated in Figure 1.8. Important characteristics include the ability to operate using almost any of the standards available globally, that is, true global roaming capabilities. Such products also enable Internet access from the mobile. All this is made possible by implementing advanced single-chip technologies and highly adaptable antennas. Products of this general type are being dubbed “millennium phones” in North America.

These broadband satellite systems and terrestrial wireless services represent additional on-ramp options for the global information super-highway, complementing optical systems.

1.3 Why gigahertz wireless bearers?

Most conventional broadcast radios operate at carrier (bearer) frequencies anywhere in the approximate range from several hundred kilohertz (kHz) up to several thousand MHz (i.e., GHz). However, the familiar bands include long-wave and medium-wave (both kHz) and also VHF that extends from several tens of MHz to 300 MHz.



Figure 1.8 3G concept phone. (Artist's impression courtesy of Nokia Mobile Phones, 1999.)

Mobile (cellular) communications use bands extending from around 400 MHz to at least 2,000 MHz (2 GHz) for personal communications service (PCS) in North America. This also applies to DECT cordless in Europe or the personal handyphone system (PHS) in Japan. The latter carrier frequency, 2,000 MHz or 2 GHz, is within the lower microwave ranges and the antennas associated with most systems of this type are quite directional. This means that the transmitted signal energy is mainly concentrated into a spatially well-defined beam.

In contrast, an antenna transmitting on a carrier frequency of only about 500 kHz or even 200 MHz is almost omnidirectional, that is, the signals tend to propagate over wide surrounding areas. GSM mobile bands, in the 900–1,000-MHz range, naturally become associated with quite directional antennas. So your mobile phone antenna “looks” strongly in one principal direction wherever you are—at any particular location.

The types of possible antennas that can be implemented are very important determinants toward the directionality of transmitted and received signals. Paraboloidal dish reflectors, or similar antennas used in microwave, millimeter-wave, and satellite systems, lead to highly directional beams, and the general situation is illustrated in Figure 1.9.

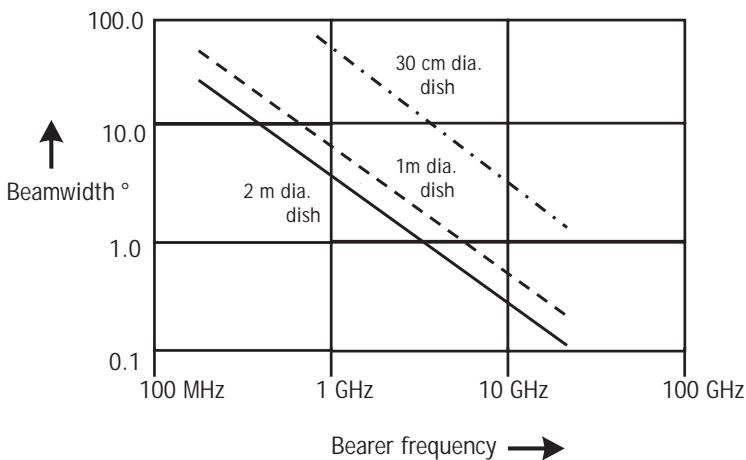


Figure 1.9 Antenna beamwidth versus frequency.

With antennas the so-called beamwidth is the main measure of directionality. The term *beamwidth* is really a misnomer because we actually mean the enclosed angle within the beam, measured at the half-power points. This beamwidth is a function of both frequency and dish diameter—decreasing if either or both of these parameters is increased. In Figure 1.9 it is assumed for simplicity that the same diameter (always 2m) antenna dish reflector applies in each case, for three different frequencies increasing by factors of 10: 200 MHz, 2 GHz, and 20 GHz. The beamwidth then progressively decreases by the same factors of 10: from a wide 38° at 200 MHz, down to 3.8° at 2 GHz, and finally right down to a very narrow 0.38° at 20 GHz. These trends are summarized in Figure 1.10, in which three dish diameters are the parameter, that is, 30 cm, 1m, and 2m.

This clearly shows that the beamwidth decreases linearly with frequency under conditions that are otherwise fixed. When the antenna is not of the dish reflector type, an equivalence applies and beamwidths still decrease with frequency.

It should be clear now that the general idea of this beamwidth is similar to those of light torches or car headlamps with their concentrated beams. The more focused the lens—the more concentrated the beam of light becomes—and the narrower the beamwidth is.

If we keep all other parameters constant and just continually raise the frequency then the beam becomes ever more concentrated—the beamwidth continually decreases. At lightwave frequencies, well into the terahertz ranges ($1 \text{ THz} = 1,000 \text{ GHz}$), beamwidths drop to small fractions of a degree and the beams are extremely tightly focused. This is why laser beams transmitted from earth and directed at the moon's surface are still only spread out to the extent of about 1 ft (around 0.3m). Yet such a beam will have traveled 239,000 miles or well over one third of a million kilometers. A microwave beam sent the same distance would cover all or most of the moon. Tight pencil beams provide for frequency reuse and improved information security.

The reception coverage area in the vicinity of the target, the region for which the signal is destined, is usually termed the *footprint* and this term is widely used in satellite communications. Similar considerations also apply in cellular (mobile) communications where the footprint is a single cell.

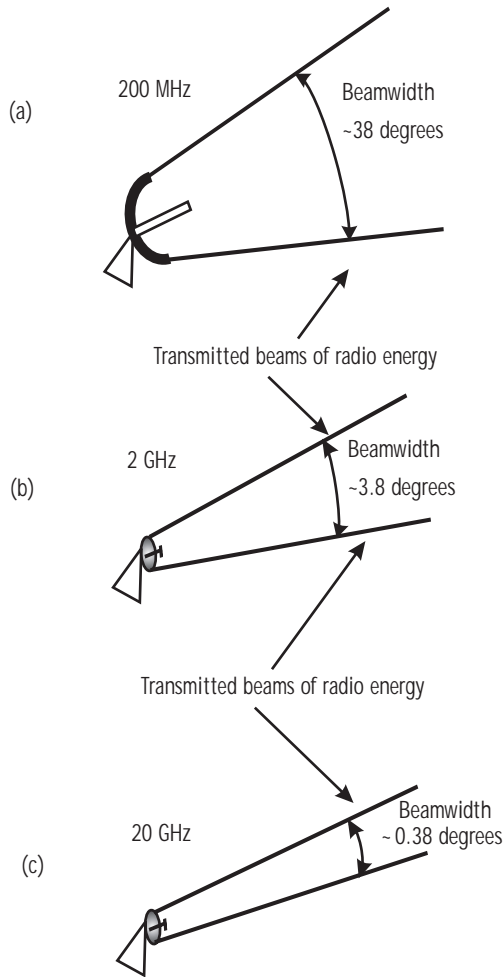


Figure 1.10 Beamwidths at three frequencies.

It is significant that the beams of radiation become particularly narrow as we shift toward millimeter-waves, which means that the pointing control for the antennas becomes increasingly critical due to the finely focused beams.

Directionality or narrow beams are, however, decidedly not the only reason for using gigahertz bearers. The other reason concerns available *bandwidth*. Bandwidth here means frequency bandwidth, that is, the range

of frequencies needed to transmit at a given bit rate. Figure 1.11(a–c) illustrates typical bandwidths, which are often quoted in percentage terms. These are generally termed either *frequency-domain charts* or more simply *spectra*.

Bit rates in the high hundreds of megabits per second and into gigabits per second are needed to cope with the ever increasing telecommunications traffic globally, interactive multimedia transmission, and the global information superhighway.

The transmission of digital signals with bit rates in the region of 622 Mbps or above (STM-4 level in the SDH hierarchy) requires at least comparable frequency bandwidths. Since it is impossible to have such

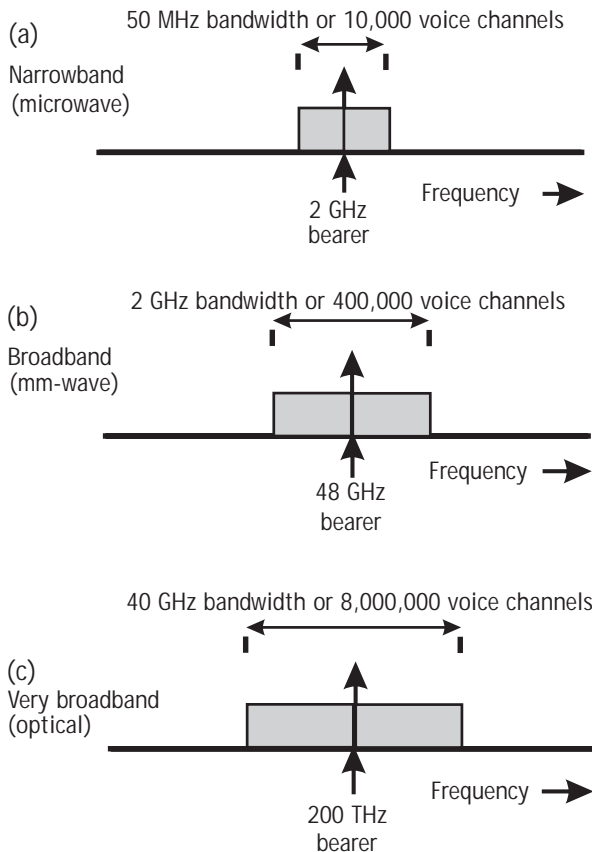


Figure 1.11 Three examples of relative bandwidths.

bandwidths with megahertz bearers, there is an absolute necessity to shift at least to gigahertz.

In Figure 1.11(a), the bearer frequency is 2 GHz and carries an information bandwidth of 50 MHz. This translates to a percentage bandwidth of 2.5%, which is definitely considered narrowband. The next spectrum shown in Figure 1.11(b) represents a 2-GHz bandwidth symmetrically distributed around a 48-GHz bearer and, using the same type of calculation, the percentage bandwidth in this case is just over 4%, which would be considered relatively broadband. Finally, Figure 1.11(c) shows that a very broadband transmission spectrum—with a 40-GHz bandwidth on a 200-THz optical bearer—is interpreted as 0.02%. Although this is a very narrow bandwidth in percentage terms, the available bandwidth as far as information transmission is concerned is actually large. A total of 8 million simultaneous phone conversations could be transported within this band.

The 622-Mbps signal could be carried by the 48-GHz bearer within the available 2-GHz band. However, higher bit rates require still more bandwidth and the pressure is on to shift to higher bearer frequencies. This shift comes at a price, however, because of millimeter-wave component scarcity and immaturity which leads to relatively high costs, and also limitations due to signal attenuation as it passes through the earth's atmosphere. This signal attenuation is a strong function of frequency and dictates, together with World Radio Conference (WRC) and other local regulations, the choice of frequencies for any radio-based system.

Microwave and millimeter-wave signal attenuation is presented and its implications are discussed in Chapter 2. Many new and proposed systems will operate at millimeter-wave frequencies where attenuation can become high (e.g., V-band which is 46–56 GHz), and therefore this signal attenuation feature is particularly significant. Apart from free-space loss and atmospheric attenuation, rainfall is also a serious issue at these high frequencies and 8 dB of additional loss through heavy rain is not uncommon.

1.4 Cabled systems and terahertz transmission

Until the advent of fiber optics, all cabled systems were of copper, either twisted wire pairs or coaxial for higher frequencies. Locally, for the final

drop to the subscriber's premises, whether residential or business, copper has been and often still is the name of the game.

By the early years of the third millennium a vast heritage of copper final drop connections were in place—notably in the G8 advanced economies. Again, digital techniques and clever technologies such as ADSL have enabled conventional copper cables to cope with higher bit rates than hitherto believed possible. For example, ADSL enables up to 6 Mbps signal transmission rates on copper twisted pair lines to a distance limit of approximately 2 km, which is suitable for the local loop.

Technologies such as ADSL work well enough until:

- Higher bit rates or bandwidths are required, reaching over similar distances.
- More modest bit rates are involved (e.g., 6 Mbps) but reach over longer distances.
- Both of the above.

For interactive multimedia transmission on the global information superhighway much wider bandwidths are demanded at the point of use, that is, at the subscriber. ADSL-like technologies no longer apply and single-mode fiber optics are essential.

The late twentieth century saw CATV networks increasingly implementing fiber optics as described above. But these were narrow-band systems compared with the capabilities of single mode fiber, and network providers have to reinstall this future-proofing type of cable into the existing ducting.

As remarked earlier, intelligent lightwave networks using DWDM are now state-of-the-art for trunk cabled telecommunications. Carrier frequencies, the “bearers” with this technology, are in the 200-THz class and available bandwidths are enormous even when compared with millimeter-wave radio [see Figure 1.11(c)].

Some of the types of services that require gigabit per second-to-terabit per second transmission and involve bandwidths in the gigahertz ranges are summarized in Figure 1.12.

Total aggregate bit rates on optical systems have increased from over one terabit per second in the late 1990s to many terabits per second now.

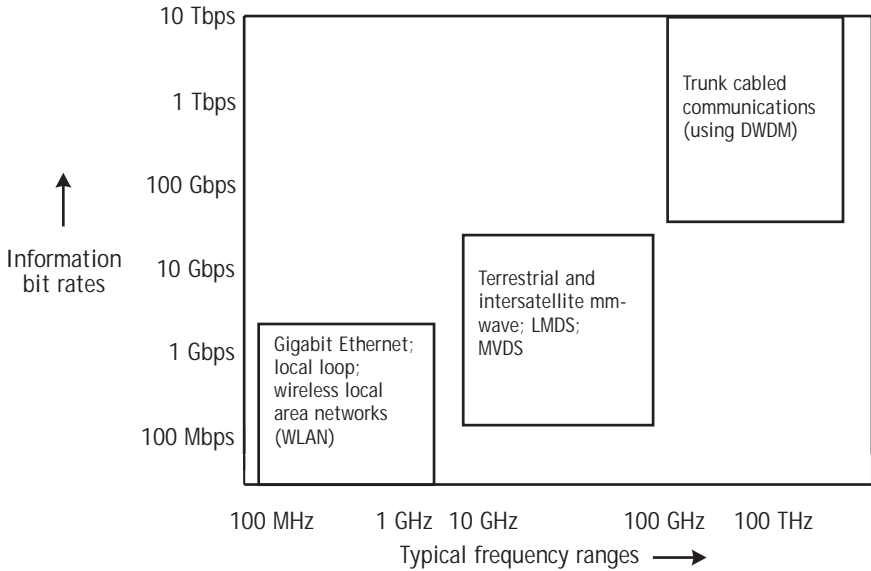


Figure 1.12 Systems applications: bit rates and frequency ranges.

It is a sobering thought that this vast information transfer rate all occurs in a glass fiber core only a few microns in diameter. Signal processing technologies have shifted inevitably from monolithic microwave integrated circuits (MMICs) to monolithic photonic integrated modules (MPIMs).

Major players in this sector include Fujitsu, Lucent Technologies, NEC, Nortel, and Pirelli, who supply products such as DWDM modules, fiber-optic amplifiers, lasers, and various time-division multiplexing (MUX) subsystems.

Another advantage of fiber-optic transmission is that microwave and millimeter-wave signals can be used to modulate the laser transmitters and hence ultimately transport the signal optically. A schematic view of this type of subsystem is indicated in Figure 1.13. The (usually) digitally modulated electrical signal, using a microwave or millimeter-wave bearer, is inputted to the semiconductor laser module. This module often comprises a distributed feedback (DFB) laser complete with DC power supply, electronic driver, and interconnections including provision for the optical fiber output.

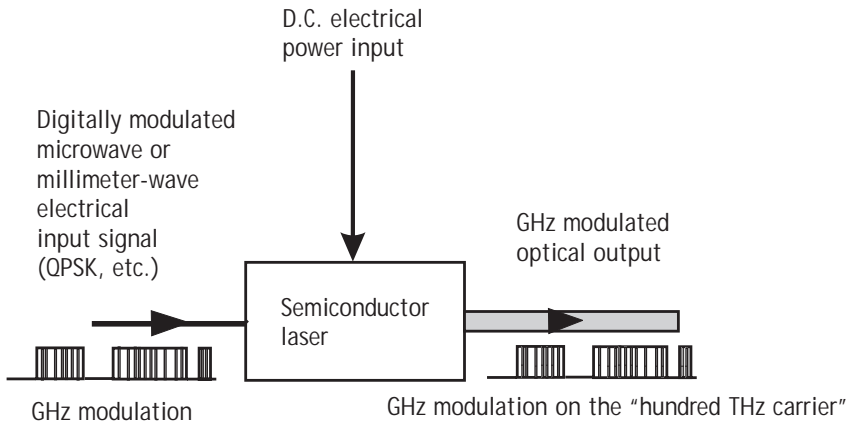


Figure 1.13 Microwave or millimeter-wave modulation of a laser (for very high-speed optical transmission).

The output signal format, frequently on a “bearer” at around 200 THz, is then either amplitude modulated or coherently modulated with the original microwave/millimeter-wave electrical input signal. In this case, *amplitude modulation* simply means that the power level of the photon stream is varied in accordance with the original electrical power level. Coherent modulation is considerably more sophisticated because here the relative phase or time-dependence of the optical signal is varied—and this is demanding at 200 THz.

In this way signals originating from wireless sources, including mobiles, can be rapidly and conveniently transferred onto the optical backbone.

1.5 The available component technologies

Fully solid state component implementation, mostly using integrated circuits, fits the bill for most systems functions. At microwave frequencies MMICs are extensively deployed, for the low-power sections of millimeter-wave systems MWMICs (millimeter-wave microwave integrated circuits) are available and, as mentioned above, MPIMs are being incorporated into photonic systems. An example of an MMIC, fabricated in gallium arsenide (GaAs), is shown in Figure 1.14. In common with

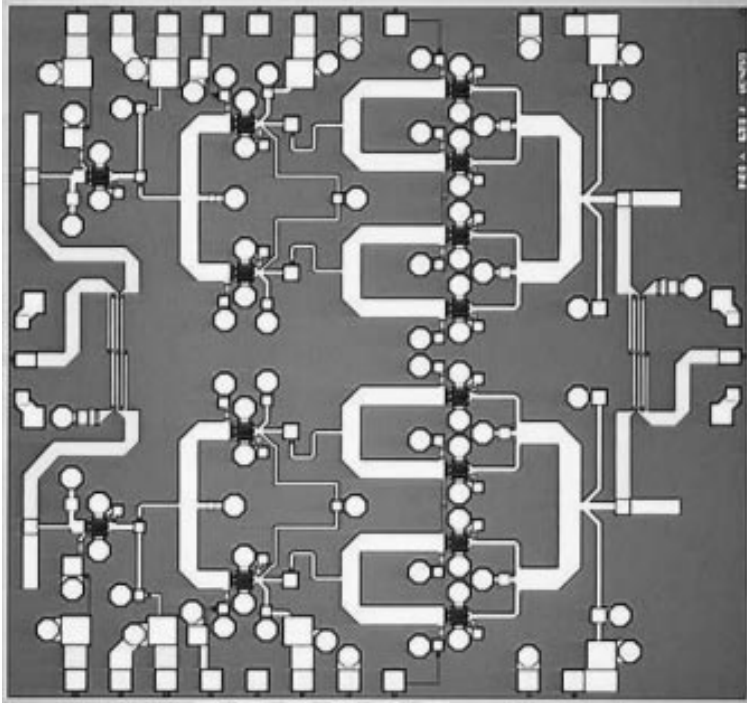


Figure 1.14 A GaAs MMIC chip. (Courtesy of Marconi Materials Technology.)

all ICs, these types of chips start their lives as rectangular pieces of semiconductor a few millimeters square and around one-fifth of 1 mm in thickness. Using micromanipulation techniques, often at least semi-automated, the chips are mounted into carriers and encapsulated for circuit handling and environmental protection.

MPIMs are described in Chapter 3.

In an overall sense we are already well into what could be described as the “nano age.” The trend from “micro” to “nano” ages is most clearly seen by examining how computer processor chips have progressed since the 286 and this is illustrated in Figure 1.15.

The march of progress has been dramatic and inexorable. When the personal computer was invented at Xerox in the late 1970s, 100,000-transistor chips with submegahertz clock rates were state-of-the-art and memory remained at a distinct premium. If you found a RAM

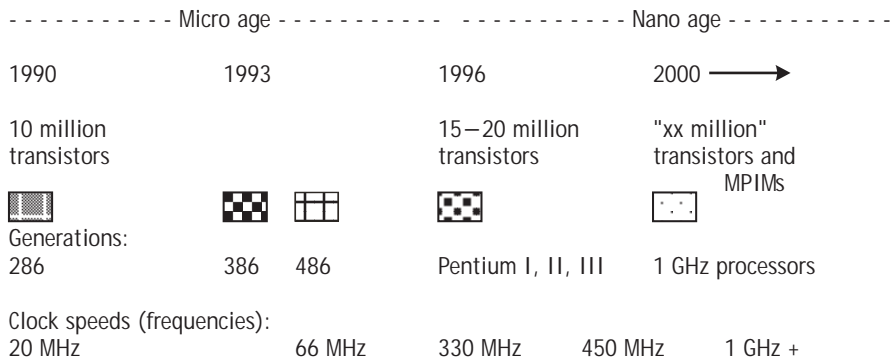


Figure 1.15 From micro age to nano age—from megahertz to gigahertz processors.

chip with 15K (yes, kilobytes) of memory you had done very well and disks were things you inserted into relatively large and expensive minicomputers.

Now, into the twenty-first century, processor chips clocked at above 1 GHz and with over 30 million transistors have become the state-of-the-art; 64- and 256-MB RAM chips are available and hard disk drives regularly enable up to 10 GB of memory capacity. In the nano age clock rates are very fast, processors are powerful, and memory capacity is almost unlimited.

With the now intense convergence between all things “computer” and everything associated with telecommunications, all these trends are vital considerations in the context of developing technologies.

Sometimes future system concepts are put forward to test the market and occasionally to book early for regulatory permission. Frequently, future system plans are launched to an unsuspecting public, many of whom marvel at the tremendous capabilities specified for the systems. Some of these same people wonder just how the technology is going to be developed to support the systems concepts and how the economics may work out.

This scenario is not uncommon with some millimeter-wave and satellite systems at their earliest stages. While suitable component technologies may be in advanced development, it is often many years before

such components can be remotely considered mature—and then there is the question of cost.

Although the electronics world understandably expects solid state technology to provide all the answers for every aspect of any system, this is far from the case in most millimeter-wave and satellite systems. In one word, the problem leading to a continued need for electron tubes is *power*. Continuous power levels in the tens-to-hundreds of watts can only be made available using semiconductors when the frequencies involved are in the lower microwave ranges. At higher frequencies electron tubes must still be used and the traveling wave tube (TWT) is the most important example.

Transmitters for satellite earth stations and for some MVDS systems frequently use TWTs and this scenario is likely to persist for another decade at least.

Other significant technological advances include aspects of filter structures, antennas, and the burgeoning area of software.

Frequency band filters are increasingly densely integrated, and hybrid microwave (and millimeter-wave) circuit modules provide the desired functions in many instances. However, for demanding specifications or high power applications, waveguide or coaxial filters still need to be implemented. One advantage, however, is that as frequencies increase into the millimeter-wave bands the physical dimensions of such filters and other “passive” modules decrease.

Up to frequencies of the order of 10 GHz, a novel and remarkable technology known as surface acoustic wave (SAW) continues to make great inroads. With this technology the electrical signal is converted into an acoustic vibratory replica, that is, corresponding mechanical (acoustic) vibrations traveling just beneath the surface of a quartz or lithium niobate chip. These chips have dimensions that are just a little larger than those of the semiconductor ICs, and tiny etched metallic patterns on their surfaces provide the filtering function. SAW filters and other related devices provide exceptional selectivity and stability.

SAW devices are used as highly selective frequency filters in many systems, including those using frequency-division multiplexing. Very low in-band loss and sharp band edges with strong out-of-band signal rejection are important characteristics of SAW filters used in gigahertz

systems, but this technology may never be able to reach the important Ku- and Ka-band frequencies.

Antennas represent another technology area where substantial advances continue to be made. Although the familiar parabolic dish reflectors will still be seen on many installations, new configurations are also making considerable inroads for many systems. These include flat-plate designs where a metallic array is etched onto a plastic sheet, modular lensed antennas for millimeter-wave transceivers, active arrays, and phased arrays.

Planar metallic arrays are an economical method of forming antennas, provided the application is not too demanding in terms of beamwidth and sidelobes. This applies to many instances, including several of the systems described in later chapters here. Modular lensed antennas, notable for their important applications in millimeter-wave transceivers, are described in Chapter 8 where stratospheric and terrestrial systems are considered.

The technological advances combined with unit price decline have conspired to make active microwave and millimeter-wave chips (MMICs) serious contenders for implementing directly into antenna arrays. This means that antenna arrays may have transceivers embedded within their structures, enabling independent control over each element's characteristics. While certain elements remain active transmitting, other selected elements may be switched "off," that is, not transmitting. This provides for a high degree of flexibility in both transmission and reception. Different elements may also be fed with the main signal in differing phases to obtain a similar overall resultant pattern—what is termed a *phased array*.

In the schematic shown in Figure 1.16, the filtered and multiplexed signal is fed into the structure from the left hand side. DC power also has to be supplied to each of the MMICs which are selectively driven with predetermined portions of the signal.

Examples of phased arrays include some of the antennas used for the Iridium mobile satellite system and many defense systems. Alcatel Espace is developing its "SkyBridge" broadband satellite system which implements an active array with a notably large number of MMICs and 10,000 solid state power amplifiers (SSPAs). More details on phased arrays and the SkyBridge active array are provided in Chapters 4 and 9.

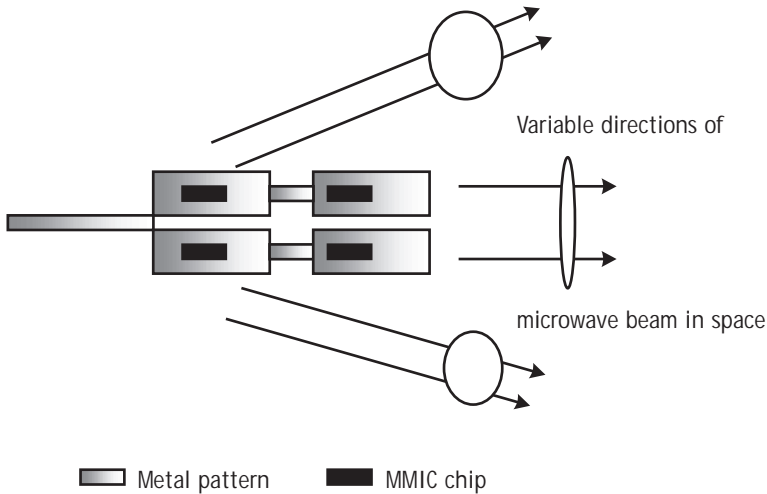


Figure 1.16 Conceptual schematic of an active or phased array planar antenna.

1.6 The ongoing communications revolution

Without any shadow of a doubt the world is continuing to enjoy the fruits of a radical revolution in communications. During the twentieth century major advances were seen in the digitization of most forms of communications including both fixed and, later, mobile networks. Increasingly powerful enabling technologies such as fiber optics and satellite transmission, supported synergistically by microminiaturized electronics (integrated circuits), transformed communications.

System link bandwidths were capable of handling hundreds of thousands of simultaneous telephone calls or data at bit rates up to several gigabits per second. Many people could be forgiven for imagining that this was practically the ultimate or at least that channel capacities would simply go on increasing—but not much else. Then, originally at CERN in the late 1980s, a guy named Tim Berners-Lee invented HTML—and the world of telecommunications was changed forever with what inevitably followed, namely the Internet.

Meanwhile very high-speed broadband systems using fiber optics, satellites, and terrestrial configurations were planned and these would definitely be making a dramatic improvement in terms of getting on to the Internet. Early in the twenty-first century the implementation of

broadband systems of several types will mean that the “world wide wait” will at last be transformed into a true “world wide wizard.”

Read on to find out much more about these key enabling technologies.

Select bibliography

Brodsky, I., *Wireless: The Revolution in Personal Telecommunications*, Norwood, MA: Artech House, Inc., 1995.

“FT Telecoms,” *Financial Times* Survey on Telecommunications, March 18, 1999.

Nellist, J.G., and E.M. Gilbert, *Understanding Modern Telecommunications and the Information Superhighway*, Norwood, MA: Artech House, Inc., 1999.

Willner, A.E., “Mining the Optical Bandwidth for a Terabit per Second,” *IEEE Spectrum*, April 1997, pp. 32–41.