FUTURE MICROWAVE MARKETS IN TELECOMMUNICATIONS AND AVIATION

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Abstract

Although the military is still the largest market for the U.S. microwave industry, growth in that sector has slowed. In response, the industry is seeking to develop commercial and industrial microwave markets where good prospects for growth exist. The most prominent of these non-military microwave markets are for telecommunications and air traffic control equipment.

Currently, the U.S. share of the $1.75 billion world microwave radio and multiplex equipment market is about $380 million. We expect that U.S. sales will grow about 7%/year, reaching $490 million by 1980. Virtually all the market growth in the next five years will be due to the introduction of digital microwave products. We expect that sales of independently produced U.S. digital microwave radio equipment will grow from a negligible value in 1975 to $50 million by 1980. Further growth of 20%/year in the digital market will continue through the mid-1980's.

In satellite communications, the Intelsat space system will continue to provide an important market for microwave equipment. However, the high-growth markets for the next ten years will be in domestic and regional telecommunication systems. World sales for satellite communications equipment (satellites and earth stations) may reach about $3 billion in the period 1976-80. The world market for satellite spacecraft is now about $100 million/year, while the market for earth stations is expected to grow to over $250 million in 1980. These figures do not include the effects of new aeronautical and maritime satellite systems, which will add to the market after 1980.

In the civil aviation field, air traffic control (ATC) and civil avionics provide one of the largest markets for microwave systems. The FAA plans to begin installing microwave landing systems (MLS) in the late 1970's. After international approval of one of several competing approaches, a long term market of hundreds of millions of dollars is expected. Another important new ATC System is the Discrete Address Beacon System (DABS). The FAA will have spent over $100 million in DABS development costs by the early 1980's.

Introduction

In the past, the U.S. microwave industry developed its sophisticated, high-technology products for the military market. But with the substantial reduction of defense procurement in the early 1970's, the microwave companies began seeking new non-military markets for their products and technical skills in the hope that civilian applications for microwave technology will provide growth markets. To capitalize on new opportunities, the U.S. microwave industry must adapt to the development and production of non-military products. However, given the traditional specialization in military product development, many U.S. companies lack the capability to undertake integrated, cost-effective product development programs.

The situation differs in Europe and Japan where the microwave industry is much less dependent on military procurement. In these countries, the industry has been expanding to meet growing needs for equipment and components for telecommunications, civil radar, and a variety of other civilian applications. These countries already dominate several microwave-related markets. The United Kingdom is the leading supplier of civil marine radars, while Japan manufactures more microwave ovens than the rest of the world combined. Even in terrestrial microwave telecommunications, an industry pioneered in the United States, Japan now equals and West Germany is only slightly behind total U.S. production; several countries exceed American penetration in markets outside the United States. Among significant world markets for commercial and industrial microwave systems, the United States dominates only the satellite communications and avionics equipment markets (the latter because of the dominant U.S. position in the aircraft industry).

In the past few years, the U.S. situation has changed, however. Although the predominant market for the U.S. microwave industry is still military systems, overall growth in that sector has slowed. We believe though that growth prospects for commercial and industrial markets are good on balance. Markets for microwave telecommunications equipment--both terrestrial and satellite--will show continued growth. Microwave air traffic control and avionics equipment will also show steady growth with pronounced increases coming in the early 1980's with the phasing in of major new equipment.

Among other civilian applications of microwave technology are those for marine radar, anti-intrusion alarms, vehicle control and warning systems, industrial heating, moisture sensing, and speed and proximity measuring devices. Except for marine radar, none of these applications has been developed into a significant market yet, although substantial potential volume exists. Marine radar markets in the U.S. are mainly served by foreign suppliers. In this paper, those commercial and industrial markets that presently offer the best prospects for growth of microwave-related products will be discussed. These include terrestrial and satellite communications systems and equipment for air traffic control.

In the consumer area, which is outside the scope of this paper, the microwave oven has achieved a high level of acceptance in recent years. In 1974, more than 600,000 units were sold in the United States, and within a few years this number should exceed one million units per year.

Microwave Radio and Multiplex Equipment

Microwave radio is the predominant long-haul telecommunications transmission medium in the United States. Systems operate in a number of frequency bands between approximately 1- and 13-GHz assigned by the Federal Communications Commission, according to the class of service. Common carriers share frequency band assignments with the new specialized common carriers; but other users are assigned different bands for public safety, industrial and land transportation voice and data services and for TV auxiliary broadcast services. In addition, the FCC has recently authorized the use of frequency bands above 17.7 GHz for civil terrestrial telecommunications use.

Two classes of microwave radios are in use today: analog systems, which are mostly based on linear frequency modulation (FM) and frequency division multiplex (FDM) technology; and digital systems, which are based on pulse code modulation (PCM) and time division multiplex (TDM) technology.

Among the users of microwave radio are AT&T and the major independent telephone companies, which together use microwave to provide over 60% of all toll quality voice-channel mileage in the United States. Western Union, the traditional record communications common carrier, uses microwave radio to carry the majority of its long-distance traffic. Other common carrier users include newly-formed specialized companies, such as MCI, Datran, Southern Pacific Communications and others, which compete with their intercity networks against the established telephone common carriers in the business communications sector of the telecommunications services market.

Microwave radio is also the primary medium used by industrial companies and public utilities that own and operate their own private, long-distance telecommunications networks; by state and local governments; broadcasters and intercity cable TV operators, as well as for a variety of other specialized communications services. At present, the market for terrestrial microwave radio equipment is divided almost equally between the telephone common carriers and the other sectors of the market. Table 1 lists the division of the U.S. microwave radio market by user sector.

The U.S. Microwave Radio Equipment Market

The U.S. microwave market is divided into two major sectors; almost one-third is captive to Western Electric and the remainder is competitive. The captive sector consists of equipment supplied by Western Electric exclusively to AT&T's Long Lines Department and about one-half of the microwave equipment purchased by Bell System companies. The competitive market is supplied by companies other than Western Electric. Other independent manufacturers supply Bell operating companies, competing against Western Electric for this business.

Table 1

U.S. Microwave Radio Market
by Market Sector, 1975

Market Sector	Percent
Telephone Common Carriers	51
Specialized Common Carriers	8
Private Microwave Systems	15
State and Local Government	5
Broadcasters, Cable TV and Other Video Transmission	16
Export	5
Total	100

Market Size and Growth

The world microwave radio and multiplex equipment market was an estimated $1.25 billion in 1975 excluding the Eastern Bloc. The U.S. share of this market was about $380 million, or 30%. Table 2 lists estimated U.S. microwave radio and associated multiplex sales, 1975-80.*

The strongest growth area should occur in Bell's outside purchases and purchases by other Common Carriers.

Market growth will be due to the introduction of digital microwave products. Over the next five years, the independent FDM/FM radio market will remain at about the present level ($80 million/year for radio equipment alone). The captive market for this conventional-type equipment will rise slowly until 1978, then decline sharply, as digital systems become more pervasive. In this period, however, the independent market share for digital equpment will grow from an estimated $3 million volume in 1975 to $50 million by 1980. We expect further growth in the digital market of 20%/year to continue through the mid-1980's. The most important reason for this rapid growth of digital microwave is the lower equipment cost, particularly for the associated time division multiplex (TDM) equipment.

Table 2

Estimated U.S. Sales of Microwave Radio
and Associated Multiplex Equipment, 1975-1980

($millions)

	1975	1980
Microwave Radio	150	200
Associated Multiplex	230	280
Total	380	490

Source: Arthur D. Little Estimates

*These figures do not include the additional value of sales of antennas, towers, and other ancillary equipment or the cost of installation.

Outlook for Digital Equipment

Digital modulation on microwave radio is the area of most active development in the microwave communications equipment industry today. Compared to traditional analog modulation, (such as FDM-FM, the type used in nearly all existing microwave radio systems), digital modulation offers a number of technical advantages:

- Higher immunity to signal distortion, noise, and interference.
- Lower carrier-to-noise ratio permissible for equal signal transmission quality.
- Signal regeneration possible at each repeater, thus minimizing repeater-to-repeater noise addition.
- Most efficient signal format for digital information transmission.
- Lower costs for associated time-division multiplex equipment than for frequencv-division multiplex used with analog (FDM-FM) systems.

The long-range plans of the telecommunications industry include increasing use of digital transmission on wire, cable, radio, waveguide, and satellite paths, ranging from simple 24-voice channel T-1 carrier systems to enormously complex underground millimeter waveguide systems having capacities of more than 200,000 voice channels each.

We believe that the future of digital modulation systems in the microwave radio field is assured by the following:

- Use of higher frequencies necessitated by congestion of the lower frequencies, favoring digital transmission technology.
- Increasing data traffic on common carrier networks.
- Proliferation of digital modulation in other transmission media and in switching systems, leading to a nearly all-digital environment in the future.

Presently, digital microwave is most advanced in Japan, where 2GHz digital links have been in operation since the mid-1960's. The first digital microwave radios installed in the U.S. (for the Bell's New York Telephone operating subsidiary) were supplied by Nippon Electric in 1971. AT&T's first Western Electric-made digital radios, for high-capacity (274 Mbps), short-haul use, are scheduled to go into use in 1976, and will operate in the 18-GHz band. Digital radios operating at more modest rates, from 1.544 to over 80 Mbps, are now commercially available in the United States, Japan and Italy.

The greatest advantage of digital over analog systems is the cost of TDM equipment,which can be as little as one-half the cost of FDM equipment. Therefore, despite the fact that currently available digital radios offer no price advantage over conventional FDM/FM radios, overall system cost--for transmission of PCM-encoded voice channels as well as for data--is an average of about 25% lower for digital systems today. Eventually, as digital radio production increases, we also expect lower costs for radio, since a number of potential cost savings are available in the design of the equipment, such as technically simpler modulators, and lower permissable power levels.

Satellite Communications Markets

The International Telecommunications Satellite Consortium (Intelsat) was established in 1964 by agreement among fourteen nations to promote the growth of satellite communications internationally. Intelsat now has 85 member countries. Each member either owns, or shares ownership with other members in, one or more earth stations; by the end of 1975, there were 106 earth stations (or antennas) in 61 countries. U.S. interests are represented in Intelsat through the Communications Satellite Corporation (Comsat), a company chartered in 1964, which both manages Intelsat and owns the U.S. earth stations in the system.

Since 1965, Intelsat's space system has grown from one satellite--Early Bird--with 240 voice circuits to five Intelsat IV satellites, built by the Hughes Aircraft Company, each with a capacity of about 5,000 two-way voice circuits. These satellites have served as the design models of other communications satellites, such as Canada's Aniks, Western Union's Westar and proposed satellites in other countries. In 1975, the first of six planned Intelsat IV-A satellites, also built by Hughes, was launched. Each has 20 transponders, providing a total of about 6,250 two-way voice circuits, plus two television channels. The Intelsat IV-A satellites will serve as an interim spacecraft to accommodate expected traffic growth until a new generation of satellites, the Intelsat V series, goes into service late in the decade. The new satellite will incorporate such technological advances as time division multiple access (TDMA) and more advanced digital modulation techniques, both of which will increase transmission capacity.

Installed prices for the early Intelsat earth stations were as high as $8-10 million. Development of smaller earth stations is now being undertaken with increased emphasis on low initial cost. Already some earth stations for use in domestic satellite systems are being sold at prices, including installation, from $300,000 to $500,000. Cost reduction has been achieved through use of simpler design, modern solid-state technology, and more sensitive uncooled paramp receivers, which permit the use of smaller antennae. Further goals call for improvements in reliability and remote performance monitoring that will enable unattended operation and further reduce costs of owning and operating satellite earth stations.

Market Size and Growth

Satellite communications systems are composed of essentially two products--satellites and earth stations; earth stations account for one-half or more of the investment in satellite communications hardware. The two major products are usually purchased separately as only a few manufacturers have attempted to produce both satellites and earth stations, although teams of companies or consortia, often combine their specialized capabilities to sell and install complete systems, particularly in the international market. Although Intelsat growth continues (and military satellite communication expenditures are sizable as well), the high growth opportunities of the next ten years will involve the development of many domestic and regional networks. In 1975, the total world market for satellite communications equipment (satellites and earth stations) was over $300 million. We expect that between 1976 and 1980 worldwide expenditures for satellite communications will total about $3 billion.

Satellites

The world market for communication satellites now amounts to about $100 million/year. The fact that the market has doubled every five years makes it appear quite attractive to suppliers. However, there are only a handful of customers and only a few successful suppliers in the satellite business. Large capital resources and highly sophisticated aerospace technology are essential to compete in this market.

Earth Stations

The market for earth stations is more diverse and accessible to many companies having expertise in microwave technology. Capital investments are much lower, and smaller companies with limited resources have been able to compete successfully.

Table 3 divides earth stations into five categories and gives estimated cost breakdowns for each, ranging from simple receive-only stations (used for TV reception in remote areas or for CATV) to typical domestic satellite system terminals for two-way telephony and TV. Table 4 shows a cost breakdown for a standard Intelsat station, including 30 meter antenna.

Unlike the market for terrestrial microwave radio of which a majority is protected for domestic suppliers in producing countries, the market for earth stations is international and competition is keen among many suppliers. While the United States is the largest consumer, the majority of the world market is in developing countries, where domestic suppliers are non-existent. The market for transmit/receive earth stations will grow from an estimated $124 million in 1975 to about $258 million in 1980 (see Table 6).

Table 3

Earth Station Equipment Costs

($000's)

	12-GHZ Receive Only	4 GHz Receive Only	4/6-GHz Thin Route TX-RX	12/14-GHz Heavy Route TX-RX	4/6-GHz Heavy Route TX-RX
Transmitter	--	--	80	110	110
Receiver	21	44	52	37	112
Antenna	20	20	22	95	95
Test Equipment and Integration	10	20	45	60	74
Installation	3	4	11	17	19
Total	54	88	210	319	410

Table 4

Standard Intelsat Earth Station Price

Antenna System	$1,150K
GCE, HPA, LNA, MUX	1,410
Power System, Buildings and Test Equipment	700
Spares, Training, O&M	700
Integration, Program Management	300
Total	$4,210K

Table 5

Satellite Earth Station Equipment Market Forecast ($M)

	1975	1980
Intelsat	68	48
US Domsat	32	50
Foreign	24	160
Total	124	258

As seen in the table, we expect the market for Intelsat earth stations to slowly decline in the future, as fewer new stations are added each year to the already mature global system. However, after 1980, when the next generation of satellites - Intelsat V - become operational, employing some transponders operating at higher frequencies (12- and 14-GHz bands) than the present 4- and 6-GHz satellites, and using TDMA, many of the older earth stations will be rebuilt or replaced. Therefore, we expect an upturn in this sector of the market in the early 1980's.

Western Union, American Satellite and RCA have all established domestic satellite systems since 1973. AT&T and GT&E will soon have systems in operation also. The recent restructuring of the former CML Satellite Corporation into Satellite Business Systems, Inc., is considered by many to be the most significant development in the domestic satellite communications industry since its inception.

The SBS plan is to deploy a large number of sophisticated earth stations (37 stations initially, but the number may be increased ultimately to several hundred) operating in the 12- and 14-GHz bands, using 16 to 23 foot diameter antennas, located at or near customers' premises. Digital transmission and TDMA will be used, with demand assigned channels, to serve a wide variety of large corporate user requirements for data, voice and image transmission. SBS may become a strong competitor to AT&T and other common carriers and specialized common carriers in the overall business communications field. The system is scheduled to become operational in 1979, so the greatest earth station market impact will begin at about that time, and should provide for continued market growth well into the 1980's.

In addition to domestic commercial customers for earth stations, private communications users are expected to purchase earth station equipment. The Public Broadcasting Service (which recently announced plans to build a 155 earth station network to interconnect PBS stations at a capital cost of $38 million) and several oil companies are interested in small earth stations on off-shore drilling platforms. Although such private purchases thus far total only about $1 million/year, we expect that this market will grow rapidly in the 1980's.

An early satellite communication market, the Defense Department still is a large customer. In addition the various communication R&D experiments related to NASA's ATS series of satellites and the recently launched joint NASA-Canadian Communications Technology Satellite (CTS)-which involve several million dollars worth of earth stations purchased by NASA and the U.S. Department of Health, Education and Welfare - continue to expand, and by the 1980's, the U.S. Postal Service may have an experimental satellite-oriented electronic mail network in place.

As seen in Table 5, the greatest growth area is in foreign domestic and regional satellite systems. These systems include those planned for highly developed countries in Europe and Japan, but the largest number is expected to be in developing countries, where satellite communications systems offer a quick, relatively inexpensive medium to establish a national telecommunications infrastructure where little or none exists.

Canada's Telesat system was the first domestic satellite system in the world using geostationary satellites. It has been in operation since 1972, and now includes two operational and one ground-based spare satellite, and a network of more than 50 earth stations. Elsewhere, many new satellite systems are in operation, under construction, or planned. These are listed in Table , with the expected year of initial operation, and notation of whether the system will use its own satellite or leased transponders from an Intelsat satellite. The latter approach has appealed to many of the smaller nations as a least cost method of establishing a domestic satellite system. At least 75% of the market represented by the listed systems should be available to U.S. suppliers.

Table 6

Existing and Planned Foreign Domestic and Regional Satellite Systems

I. Systems Using Dedicated Satellites

Country or Regional System	Expected Year Operational
Canada	1972
Indonesia	1976
Arabsat (Arab League)	1977
Japan Broadcast Satellite	1977
European Communications Satellite System (ECCS)	1977-79
Japan Communications Satellite	1978

II. Systems Using Leased Intelsat Transponders

Country	Expected Year Operational
Algeria	1974
Brazil	1974
Malaysia	1975
Norway	1975
Chile	1976
Nigeria	1976

III. Systems Under Study

Country or Regional System	Estimated Year Operational
Afrosat	1977
Australia	1980
Argentina	N.A.
Brazil*	1977
Iran	1979
Mexico	N.A.
Philippines	1977

*Planned dedicated system to expand and replace existing leased Intelsat Transponder system.

Aeronautical Communications Satellite (AEROSAT)

Since the early 1960's, much discussion has centered on improving aeronautical communications over the oceans, where capabilities are primitive. The only means available is long-distance transmission by HF radio, which suffers many deficiencies.

Most avaiation and communications authorities agree that satellite communications technology offers the most promising answer to the problem. An experimental system, AEROSAT, has been proposed by the European Space Agency (ESA), acting for European interests, and by the FAA for the United States, with additional sponsorship by Canada. AEROSAT calls for two geostationary satellites to be placed over the North Atlantic. This system, which would provide relay links between both shores and aircraft en route, would, according to the most recent estimates, begin operation during 1978. Following a series of tests, a fully operational system would be deployed by the mid-1980's, to be followed by similar systems over the Pacific and other oceans. The FAA estimates that the total cost of the experimental North Atlantic system will be about $150 million, the costs to be shared on .47-47-6% basis among ESA, the United States, and Canada. The U.S. share is proposed to be underwritten by Comsat General which was selected to be the owner in 1974, from whom the FAA will lease facilities.

Beyond purely technical problems, several obstacles remain in implementating an operational system following completion of the experimental AEROSAT program. One of the most formidable is the marked lack of enthusiasm of the airlines (particularly in the United States), which believe the system will be too costly and will not be urgently needed for a long time. Another problem is a dispute over the selection of frequencies for the aircraft-to-space links. ESA, FAA, ICAO and most equipment manufacturers decided several years ago that L-band frequencies (1.5 to 1.6 GHz) are most suitable, but the U.S. airlines insist that frequencies in the VHF aeronautical band (118-136 MHz) be used.To satisfy the airlines, the decision was finally made to use both L-band and VHF frequencies in the AEROSAT program.

ICAO began planning for an aeronautical satellite system in 1968, when its Air Navigation Commission established the Application of Space Techniques Relating to Aviation (ASTRA) Panel. After meetings held between 1968 and 1972, a plan was developed for introduction of aeronautical satellite systems in three phases:

- Phase I: Development and evaluation of hardware and operational concepts in an operational environment. The present AEROSAT program is tailored to meet Phase I objectives.
- Phase II: Operational proving phase, to ensure technical and operational acceptability of system elements before full operational application.
- Phase III: Operational service phase. Aircraft will be required to install and use satellite system avionics by a specified deadline, and the present oceanic communications and navigation systems will be phased out.

The ASTRA Panel set no exact timetable for the three phases, since it lacked control over the political and institutional problems that arose.

As now set forth, the salient features of the ESRO-FAA plan for AEROSAT are the following:

- ESA, Comsat General, and Canada will be the owners of the space segment of the AEROSAT system. The U.S. government will not be involved in ownership.
- The space segment will be built to meet specifications determined by the FAA and European users. Two satellites are to be placed in geostationary orbit over the North Atlantic.
- The owners will select a prime contractor and the major subcontractors to build system hardware. The prime contractor is to be American, but subcontracts will ensure full European participation.
- The FAA will lease up to half the capacity of the system from Comsat General. ESA will make the remainder available directly to European users. Canada may also be a user.
- Two communications ground stations will be built, one in Europe and one in the United States. A satellite control station will also be built at a location as yet undecided.

- Avionics equipment and ground transmission facilities will be provided by the users.

Requests for proposals for the satellite contract were issued by Comsat General in February 1976, following several months delay while FAA sought approval from Congress to allocate funds to cover the costs of future rental of the system. Bids from several U.S.-led international consortia are expected by June 1976.

Although there appear to be no insurmountable obstacles, prospects for operational implementation are still unclear. Institutional problems surrounding AEROSAT have been so difficult that the program has been allowed to proceed only on an experimental basis, with a conspicuous lack of commitment so far on the part of the airlines to go any further. Operational introduction will probably not begin until 1984 or 1985 at the earliest and could well be postponed if the current depression in trans-Atlantic airline traffic continues for very long.

Maritime Satellite Communications

To improve communications and navigation at sea, a new system of satellites is now planned. Efforts are under way that will lead to an operational L-band system by the late 1970's.

The availability of maritime satellite communications should make possible virtually fade-free links capable of carrying all the maritime communications services now so sparingly provided by out-moded MF/HF radio, plus many new types of traffic not provided today, including high-quality voice transmission, facsimile, and high-speed data transmission. The Inter-Governmental Maritime Consultative Organization (IMCO) has promoted the development of an international satellite communications system for commercial maritime use. Following IMCO-sponsored institutional planning that is scheduled to be completed this year, a new inter-governmental organization (INMARSAT) will be established to implement and supervise the operation of this system. Operational requirements and technical specifications for the system have been developed by an IMCO Panel of Experts on Maritime Satellites, representing member governments, international telecommunications and space research organizations, and international maritime and trade organizations. The possibility of creating for both aeronautical and maritime interests, a single shared-use system, with common space segment and shore facilities, has been considered by both IMCO and ICAO, as well as by the CCIR, but sharing was judged to be inappropriate because of the widely divergent operational needs of the two types of service.

During the first phase of the INMARSAT program between three and six satellites are to be placed in orbit to provide global coverage. The exact number will be determined by budgetary constraints, the philosophy adopted regarding the need for spare capacity and system reliability requirements. Frequencies used for the various links in the system are specified by the 1971 World Administrative Radio Conference, as shown in Table 7.

A typical ship terminal would consist of an antenna system, transmitter and receiver units, an access control and signaling unit (including provision for selective calling), and appropriate modems for telephony, telegraphy, facsimile, and data traffic. Automatic, unattended equipment is also desired.

Table 7

Frequency Assignments for INMARSAT

Shore-to-Satellite	5.925 to 6.425-GHz or 14.0 to 14.5-GHZ
Satellite-to-Shore	3.7 to 4.2-GHZ or 11.45 to 11.70-GHz
Satellite-to-Ship	1535 to 1542.5-MHz (also 1542.5 to 1543.5-MHz)
Ship-to-Satellite	1636.5 to 1644-MHz (also 1644 to 1644.5-MHz)

We expect that when formation of the International Maritime Satellite Organization is completed, its form and organization will be similar to that of INTELSAT. Like INTELSAT, INMARSAT will contract with some entity to be overall system manager; Comsat General may compete with the European Space Agency (ESA) for that role.

The MARISAT Program

A joint Navy-Air Force advanced communiations/navigation satellite, Fleet SatCom, is scheduled to begin operation about 1978. Meanwhile, the Navy has awarded a contract to Comsat General (in partnership with other U.S. international communications carriers) to provide interim communications to the Navy with its new "MARISAT" satellites, the first of which was launched in February of this year. The Navy will relinquish its lease on this system when Fleet Satcom becomes operational, so that Comsat General, which initially will offer both Navy and Commercial services, can then offer commercial services exclusively. Comsat General hopes its MARISAT will establish an interim capability leading to its acceptance, in principle, as a forerunner of the INMARSAT system.

Comsat General plans to provide service via two satellites, one over the Atlantic and one over the Pacific. Hughes is supplying three satellites, one of which will be a spare on the ground. Each of the new satellites will be equiped with three UHF-band transponders for the Navy, plus two transponders for commercial maritime service, one translating shore-to-ship signals from 6 GHz to 1.5 GHz, and the other translating ship-to-shore signals from 1.6 GHz to 4 GHz. The Navy will use only the UHF transponders, but the higher-frequency transponders will be available on only a limited basis because of spacecraft electrical power limitations. When the Navy's UHF transponders are turned off, power will be applied to the others, for full commercial service.

Comsat General's investment in the system may run well over $100 million, including $69 million for three Hughes satellites and NASA launch services; $2.7 million for two earth stations, including tracking facilities; and about $40 million for shipboard terminal hardware and installation. Comsat General estimates that 1100 ships will use the system by 1981 and that ship terminals will cost about $50,000 each. Scientific Atlanta is to deliver 200 complete ship terminals to Comsat General for use by its commercial customers.

Civil Aviation Microwave Markets

Air TrafficControl (ATC) is the technique for safe and efficient management, direction and coordination of the flow of manned aircraft from take-off to landing. In the early days of aviation, the entire air traffic control function was performed by the pilot alone; later the pilot gained the aid of radio communication with other aircraft or the ground. After World War II, microwave radars were introduced, first in military aviation. Then in the late 1940's, primary surveillance radars were installed at many civilian airports, and later at en-route traffic control stations. In 1953, radar beacons were introduced in civil aviation; by the early 1960's, radar could determine automatically an aircraft's three space coordinates. Today, ATC is performed by a highly complicated system of electronic equipment, including complexes of instruments at way stations along heavily traveled airways and at air terminal locations. Table 8 lists the present complement of microwave equipment, including both ground and airborne components, used in the ATC system.

The air traffic control system has grown in piecemeal fashion, however. Despite the attempt to achieve equipment compatibility, the system is not fully integrated and functioning smoothly. The capabilities of the system are often limited by interference. It is still basically a manually-operated system, still depending strongly on visual observations (of radar displays, for example) and voice communications. Indeed, many small airports still operate without benefit of any of the latest technical advancements. While it still has deficiences, the ATC system has performed well enough to ensure a high degree of safety and economy in the face of constantly rising air traffic demands. Nevertheless, technology will be increasingly employed to improve the ATC system. Some of the most important improvements planned for the ATC system will involve the development and implementation of new microwave equipment.

Table 8

Microwave Air Traffic Control Equipment

	Frequency Range
Ground Equipment	
Air Route Surveillance Radar (ARSR)	1250-1350 MHz
Airport Surveillance Radar (ASR) (Primary Radar)	2700-2900 MHz
ATC Radar Beacon System (ATCRBS) (Secondary Surveillance Radar)	Transmit: 1030 MHz Receive: 1090 MHz
Airport Surface Detector Equipment (ASDE)	23.5-24.5 GHz
Distance Measuring Equipment (DME)	Transmit: 962-1213 MHz Receive: 1025-1150 MHz
Radar Microwave Link (RML)	7125-8400 MHz
Airborne Equipment	
ATCRBS Transponder	Transmit: 1090 MHz Receive: 1030 MHz
Distance Measuring Equipment (DME)	Transmit: 1025 1150 MHz Receive: 962-1213 MHz
Radio Altimeter	4250-4350 MHz
Weather Radar	9345-50 MHz*

*Also a few at other frequencies

Planned ATC Improvements

Plans for the next decade are to implement what is known in the United States as the Up-Graded Third Generation ATC System. Its various elements are now under development; two which rely heavily on microwave technology, and which will provide significant future markets for microwave systems and components are the Discrete Address Beacon System (DABS), and the Microwave Landing System (MLS).

Discrete Address Beacon System

The Discrete Address Beacon System (DABS) is to be an improved radar beacon system, compatible with the existing Air Traffic Control Radar Beacon System (ATCRBS) but offering data link and discrete address capability. It is also intended to be the basis of Intermittent Positive Control (IPC), a method for ground-based collision avoidance warning communicated to endangered aircraft by a data link integral with the DABS interrogation signal.

The DABS surveillance system in effect is a modified ATCRBS; that is, a network of radar beacon sensors, each measuring range and azimuth of airborne aircraft within its range of coverage, and obtaining aircraft identity and altitude from coded replies. The chief difference lies in the fact that each interrogation is addressed to a specific aircraft which recognizes its own discrete address and only then replies to the ground interrogator.

Since aircraft are addressed individually in DABS, the surveillance system provides a natural vehicle for a data-link between the ground and the aircraft. This link may be used for control purposes, including IPC.

As an extension of ATCRBS, DABS will have to coexist with ATCRBS for a transition period of about ten years. During this time, each system's ground interrogators must be able to receive replies from the other system's transponders. This compatibility requirement imposes restrictions on the design of both software and hardware for DABS; coding must remain compatible and the hardware must allow for use of the same frequencies and similar RF subsystems.

However, the cost of modifying existing ATCRBS transponders either through an add-on converter or through internal replacement and addition of parts, will probably be unattractive compared to the cost of new equipment, considering the average age of equipment in use at the time DABS will be introduced. More likely, DABS transponders will emerge as new equipment to be phased into the system over a ten-year period, with each new DABS unit built during the transition period also including conventional ATCRBS capability. New DABS ground interrogator beacons will be needed to serve both DABS and ATCRBS transponders, until the transition is complete.

A technical development plan conceived for the FAA by the MIT Lincoln Laboratory has been under way since 1972. A Phase I contract was awarded to Bendix Avionics for experimental equipment; initial flight tests were completed in 1974. The Bendix equipment incorporated the additional capability -- not part of the original concept -- to synchronize each DABS airborne transponder with others in nearby airspace, so that each aircraft may listen in on other aircraft responses to ground interrogations. With this modification, called Synchro-DABS, an independent air-derived collision avoidance, or proximity warning function is obtained, in addition to the ground-derived IPC function originally conceived. Synchro-DABS therefore combines the functions of a discrete address radar beacon system with the type of independent collision avoidance system long favored by the Air Transport Association, which represents the interests of the commercial airlines.

Texas Instruments was recently awarded an FAA contract to develop a prototype DABS system. The DABS system is scheduled to become operational in the early 1980's, by which time the FAA will have spent over $100 million on its development, and a lively market for new aircraft transponders will be growing.

Microwave Landing System (MLS)

Most major airports in the world as well as many smaller ones throughout are equipped with instrument landing systems (ILS) to assist pilots in making safe landings in poor weather. The first VHF/UHF voice ILS was demonstrated by the U.S. Civil Aeronautics Authority in 1939. It was adopted nationally in 1941 and internationally by ICAO in 1949.

Unfortunately, ILS has not proved to be a completely effective solution to the problem of landing aircraft safely under all weather conditions. It permits only a single straight-in approach path within a narrowly defined corridor in space, and has proven to be highly susceptible to interference caused by terrain obstructions and other aircraft in the air and on the ground. The FAA, which had been working since 1959 to develop an improved civil microwave landing system, requested the Radio Technical Commission for Aeronautics (RTCA) in 1967 to prepare a technical plan for the development of a new "precision guidance system concept for approach and landing and an associated signal structure." In that year, RTCA Special Committee 117 (SC-117) was formed to undertake the task. Membership in RTCA-SC-117 and its various administrative and technical groups and teams included representatives of a broad spectrum of U.S. and foreign organizations. In 1970, the Committee recommended a new signal format based upon the microwave scanning beam concept, but left room for possible alternative acceptance of a microwave Doppler scanning system which was originally conceived in the United Kingdom, and was favored by most European interests. The technical recommendations of RTCA-SC-117 were accepted as goals for a new FAA development program.

In 1971, the FAA began to implement the technical recommendations of RTCA-SC-117 with a development plan funded at an estimated $100 million. Following a two-phase competitive development program, which included testing of two scanning beam and two Doppler scan systems, the scanning beam approach was selected in January 1975 for submission as the U.S. proposal to ICAO for international approval.

Not surprisingly, the choice of the scanning beam technique caused dispute in Europe. Britain soon announced it would submit a Doppler-scan proposal to ICAO, while the French and West Germans are now planning to submit entirely different MLS proposals, based on ground-derived interferometer techniques, which were rejected on conceptual grounds by the RCTA in its original study in 1970. Aside from the United States, Australia is the only country supporting a scanning beam approach.

Whatever approach is finally chosen by ICAO, a future U.S. market for ground and airborne equipment is expected to total about $100 million for ground-based equipment, and over $200 million for aircraft equipment by the mid-1980's, with continued market growth through the remainder of this century.

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