MIT COMMUNICATIONS FORUM

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"A Global Review of Satellite Communications
Systems and Technologies"

10 March 1994
Massachusetts Institute of Technology
Bartos Theatre
20 Ames Street
Cambridge, Massachusetts
4:00 to 6:00 p.m.

MIT COMMUNICATIONS FORUM
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MASSACHUSETTS INSTITUTE OF TECHNOLOGY
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Moderator VINCENT CHAN [VC]: Welcome to today's M.I.T. Communications Forum. At the beginning of 1992, an 18-month project, funded by the National Science Foundation and NASA, was launched to assess the state of satellite communications technology, internationally. We are pleased to have two members of the project team, including the chairman Burt Edelson, here today to give us a complete synopsis of the project's findings.

Because both of today's speakers have had very distinguished careers, a full introduction would be very lengthy, so I will just give you a brief picture of each speaker. Burt Edelson is currently the Director of the Institute for Applied Space Research and a professor of electrical engineering and computer science at George Washington University. He is also a consultant to many different government agencies and industrial firms. From 1982 to 1987 he was the Associate Administrator for Space Science and Application for NASA. From 1962 to 1982, he held executive positions at ComSat, including director at ComSat Laboratories and Vice-President for Systems Engineering and Senior Vice-President. He received his bachelor's degree from the U.S. Naval Academy in 1947 and his Ph.D. from Yale University in 1960. He has received numerous awards and honors, including the Navy's Legion of Merit, the NASA Exceptional Service Medal, and the Yale University Wolpole Cross Medal.

Our second speaker is Neil Helm, who is currently a senior research scientist in the Electrical Engineering Department, and the Deputy Director of the Institute for Applied Space Research, at the George Washington University. From 1984 to 1990, he was President of Helm Communications, a consulting firm providing satellite communications systems and services consulting. In this capacity, he was the director for the Integration Testing Launch of an in-orbit demonstration of a DoD satellite. He also provided consulting services to the NASA ACTS program. From 1967 to 1984, he was a member of ComSat, where he held senior technical and management positions, including Director of Marketing for the Technical Service Division. From 1971 to 1979, he was responsible for the commercialization of R&D into operational systems and products. He was also active in ComSat's experiment on the CTS program. He received his degree from Georgetown University in 1966. He is a senior member of the IEEE, an associate fellow of the AAE, and has published many articles in his area of expertise.

BURT EDELSON [BE]: As you probably picked up from my biography, I graduated from college in 1947, which makes me an old-timer. I bring this up because when I went to school there was no such thing as digital electronics. In fact, I do not think there were any digits in those days! There were no computers and no solid state electronics. I went on to get my PhD in metallurgy, but what I actually studied was solid state electronics. It was on that basis that I followed my present career path.

As Vincent mentioned, we are going to talk about the NASA and NSF sponsored study, entitled "Satellite Communications Systems and Technology." The project's 12 member team spent more than a year doing this study, and traveled to six countries in Europe, to Japan, and to Russia. We visited 41 different sites in those countries, including industrial and government research centers as well as a number of operating bases, such as INMARSAT and EUTELSAT. At each site we visited, we were given presentations and tours. And because there was a free exchange of information, we also made presentations and gave lectures on the state of our own satellite communications systems. After these exchanges, we wrote up our 500-plus page report, all of which Neil and I hope to cover for you.

I will try to state in a few words what our conclusions were. First, satellite communications is big business throughout the world today. It is a global business, and it is thriving. Second, very rapid technological development and operational progress is going on all around the world. Third, the United States no longer leads across the board in these technologies and systems. Fourth, satellite communications has a very bright future. Despite the laying of fiber-optic cables throughout the country and the world, satellite communications look brighter today than ever before. Fifth, there are many opportunities for international cooperation. Although this is a commercial field and there is intense competition, there are also developments that require cooperation. Sixth, and finally, high data rate satellite communications [HDRC] , an area in which Neil and I are particularly engaged, is one in which the U.S. is leading. HDRC has a real opportunity to become a significant part of the National Information Infrastructure [NII].

Satellite communications, as we know it, started with President Kennedy's famous statement in 1961. What he said, in essence, was that the technology had progressed far enough that satellite communications was beginning to look like a great opportunity for a workable operational capability; a capability that we wanted to exploit here in the United States for the benefit of the world. What is even more important is that he decided to develop satellite communications through a commercial organization. When Kennedy made his speech, the only complete civil communications satellite that had flown was the ECHO balloon, a passive reflector.

It is terribly interesting that the President of the United States got up and made a policy statement about promoting a new technology at a time when this technology was only in a very rudimentary stage of development. TELSTAR, the first active satellite, was a year in the future. SYNCOM, the first geostationary satellite, was two years in the future. President Kennedy made his policy statement, and submitted the Communications Satellite Act to Congress [which was passed in 1962]. COMSAT was formed in 1963, while an international organization called INTELSAT was formed in 1964, and the first commercial satellite was launched in 1965. Think how bold and fast and prescient this process was, and compare it to how difficult it is to get anything done by the government today.

Now what do you call this process? The answer is, of course, industrial policy. Satellite communications as we know it was borne of United States industrial policy. What we found in our trip around the world is that satellite communications is still pursued as industrial policy by every other country in the world. But the U.S. no longer has such a policy, and because of this, to some extent, now foundering in this land of opportunity called satellite communications today.

Satellite communications is big business. There are more than 150 countries and territories in the world, and practically every civilized place is connected to and involved with satellite communications. There are at least ten countries with significant industrial capability in satellite communications equipment and technology. There are at least 200 operating satellites in geostationary orbit today. There are 20 different kinds of systems--international, fixed, mobile, broadcast, domestic, regional--in operation today. About $15 billion per year is spent on sales and service, about $10 billion of that is spent on services and the other $5 billion is spent in the equipment market [i.e., satellites, launch vehicles, ground terminals, and transmission systems]. Though $15 billion may not seem like a great deal of money compared to the whole telecommunications industry, the satellite communications industry is growing rapidly and is expected to double in size within the next decade.

I would now like to identify some emerging system and technology trends in the satellite communications industry. First, there are satellite communications between fixed points on Earth. Second, there are mobile communications between fixed and moving platforms, such as ships and planes. Third, there are broadcast services, which are point to multi-point communications. The fixed service is the one mature service, largely seen in telephone and TV distribution today. Despite the fact that undersea cables criss-cross the globe, almost 60% of intercontinental traffic goes by satellite, including virtually all television transmission. Moreover, approximately 40 percent of all telephone transmission goes by satellite. Actually I should not say "telephone", I should say "voice-grade," because an increasing percentage of voice-grade traffic today is facsimile. In fact, 70 percent of the voice-grade traffic going between the U.S. and Japan today is facsimile. Fixed services are mature and growing very slowly, and there is a certain fear in the industry that fixed service will begin to decline as fiber-optic cables become more globally encompassing.

Broadcast service, on the other hand, is growing quickly--about 20 percent per year, whereas fixed service is growing at about eight percent per year. Mobile services are growing even faster, at about 25 to 30 percent per year. [Incidentally, INTELSAT grew at 30 percent per year for more than a decade. Now it has slowed to approximately eight percent per year.] Two new areas are also emerging. One is personal communications, which is satellite communications through hand-held telephone. Many of you know that there are a number of exciting proposals being made in this field, though they are not yet in effect. Motorola, Loral, and Inmarsat have all submitted proposals. Inmarsat has, for example, proposed to spend $2.5 billion to develop their personal communications satellite, Inmarsat-T. The big question now facing the industry is "At what altitude can satellites most effectively provide personal communications through hand-held sets?"

Lastly is high data rate communications [HDRC], which will be inaugurated with NASA's Advanced Communications Technology Satellite [ACTS] satellite, now in orbit. ACTS, which was launched in September, is already demonstrating low bit rate capability. ACTS is the first satellite, [and the only one planned], that can provide high data rate satellite service up to a gigabit per second. We have firm plans to operate from 155 megabits per second up to 622 megabits per second, which are the fiber-optic data rates. In order to find the role for satellite communications in a fiber-optic world, there are four things to prove: 1) that we can transmit data at the same rate as fiber-optics; 2) that we can provide the same quality as fiber-optics; 3) that the delay in satellite circuits is not disqualifying; and 4) that there is an economic advantage, in some configurations, in choosing satellites over fiber-optics. Indeed, in five to ten percent of the cases we could envisage over the next two decades, there would be distinct advantages in using satellites. All of this must be proven, which is what we aim to do during the next three years. HDRC is the one area in which the United States is leading the rest of the world. On the other hand, we are behind both Japan and Europe in both broadcast and mobile services.

Next, I will share with you what we view as the major overall system trends. It is hard to put technology trends on a chart, but I have tried to do so. The very important satellite technologies in which rapid progress has been made are millimeter wave and KA band, multi-beam antennas, and microwave components and devices. Equally important areas where slower progress has been made include opto-electronics, optical communications, on-board processing, satellite switching, inter-satellite links, large scale antennas, high data rate communications, and personal communications. Unfortunately, an area that is equally important, launch vehicles, has seen little or no progress. Frankly, the United States has no good launch vehicles. Currently, the best launch vehicles in the world are made by Ariane, but on the whole, little progress has been made in this area. All of our systems are using technologies that are at least two decades old.

A few other trends that we either observed or had presented to us, during our travels, are worth mentioning. In particular, as the Japanese pointed out to us, to increase cost effectiveness, satellites are growing both in weight and bandwidth. What is state of the art today, a gigabit satellite, is what will be required by an operator, such as INTELSAT, to provide capabilities that will be competitive with fiber-optic cable. The hope for the future are large platforms in geostationary [GEO] orbit. Today's satellites weigh up to 5,000 pounds in orbit. Eventually we want to get up to 50,000 pounds and more. But presently there are no plans for anything bigger than a gigabit satellite. [Consider that a 20,000 pound satellite in orbit is what is currently required to compete with fiber-optic cables.]

Another issue raised by our study are the comparative values of GEO and low Earth orbit satellites [LEO] satellites, so I would like to take some time to compare GEO to LEO. GEO is what is used today for all commercial satellite communications; these satellites are parked at 22,000 miles up in space over the equator, and they appear to hover in space. The advantages of GEO satellites are that they carry more capacity per pound and per dollar. A single broadcast satellite can have hemispheric and selective coverage, [covering all areas but the North and South Poles] wide area broadcast, video, and high data rate capabilities. LEO satellites, on the other hand, can orbit at any altitude between 3,000 to 5,000 miles above the Earth. In terms of advantages, LEOs provide much cheaper and faster communications but yield far less capacity. Therefore in terms of cost-effectiveness, GEOs are better. However, LEOs can achieve full global coverage, including the Poles and have a shorter transmission delay. Likely applications for GEO systems are high-performance systems, high capacity service, and broadcast, and for LEO systems, low-capacity and multiple services. The ideal situation would be a combination of LEO and remote-sensing satellites riding on common platforms for such services as emergency communications and disaster observation and communications.

The other burning issue on everyone's minds is the debate between cable and satellites. The fact is, satellites have certain advantages over cable, and cable has certain advantages over satellites. Of the four services, trunking, broadcast, mobile, and networks, satellites hold all of the advantages in broadcast and mobile. Cable possesses most of the advantages in trunking. But in networks, [i.e., the joining of various nodes], satellites and cables are more or less on equal footing. The greater the number of nodes and the greater the distance between them, the greater the advantage of satellites because of their multiple access and demand assignment capabilities. The other advantages of satellites are wide area coverage, distance insensitivity and rapid installation. The advantages of cable are high capacity, low cost per channel, and low latency and delay.

The issue of satellite versus cable aside, the really crucial question surrounds how the United States is faring compared with the rest of the world. In the 1960s and 1970s, the United States was spending [in constant dollars] more than $100 million per year in the development of satellite communications and technology. However, in about 1970, both Europe and Japan got started. At the present time, Europe and Japan each spending on the order of $200 million per year in satellite communications system and technology development, whereas the United States is only spending about $20 to $30 million per year, most of which is being spent on the ACTS system.

The recent history is interesting. During the 1960s the United States was clearly ahead in every phase of technology. We followed up very well on President Kennedy's policy statement by developing the technology and giving it to the world. But in the 1970s, something interesting happened. The United States made the decision not to promote civil satellite communications because it was commercially successful, and did not put up any more communications satellites. So in the twenty or so years since the launch of ATS 6 [the last NASA satellite], Japan and Europe put up 22 experimental communications satellites, while the United States did not launch a single one. Now the United States is back with the ACTS, though we have no plans for future satellites. Thus, currently we have one, Europe has five, and Japan has four communications satellite projects. What is worth noting here is that those 200 operating communications satellites now in orbit will not make major advancements in satellite technology; experimental satellites are the way progress is made.

For those interested in making progress, then, the question becomes, do you have a good industrial policy in your region? Do you have a good plan for satellite communications? Are you [the government] promoting advanced technology development? Does the government support industry? Does the government support the international systems in which their country is involved? In Japan, there is strong governmental support in all of these areas. In the United States, we are weak in most of these same areas. For example, Europe and Japan have a policy with regard to satellite communications. The U.S. has no stated policy, although one could say that our actions do indicate a reasonable policy. But no piece of paper stating our industrial policy regarding satellite communications exists. The European Space Agency has their Industrial Policy Committee, and not surprisingly, they have a piece of paper stating their industrial policy. As far as planning is concerned, the Japanese have a strong plan and a strong commitment for carrying out their plan. In Europe they have quite a good plan, but not everyone follows the plan because separate countries are involved. Conversely, in the United States, we have no plan.

A similar situation exists with respect to industrial R & D. In the United States, there is virtually no industrial communications satellite research going on. There is also little or no such research going on in Europe. In Japan, in a few cases, there is some industry-led R&D going on. It is interesting that INMARSAT, an international system, has no R&D program of its own. Their R&D is done for them by the European Space Agency in their laboratory in Holland. It is done explicitly to help European industry get contracts for the INMARSAT satellites and system work.

There are five technologies in which the U.S. is leading, including high data rate satellite communications, USATS and personal communications transceivers, small satellites, on-board processing, and space applications for high temperature superconductivity. There are an additional five technologies in which the U.S. is tied with the Europeans and the Japanese: traveling wave tubes, electric propulsion, spacecraft antennas, inter-satellite links, and autonomous control systems. Finally, there are seven technology areas and two system areas where the U.S. lags behind Europe and Japan. They are HEMT technology, free space optical communications, advanced batteries, solar array systems, solid state power amplifiers, pointing and positioning systems, large scale deployable antenna systems, advanced system design and long range planning concepts, and new application development. It is not worth arguing about any specific technologies, [and whether we are ahead or behind in said technology], what is important is that in some areas we are still ahead. BUT we are behind in some technologies, and in some cases, far behind. And this is quite different from what most people thought before we did this study, and likewise, different from the real situation that existed in the 1960s and 1970s.

Everywhere we went there were suggestions that we should pursue more international cooperation. Currently, very extensive international cooperation exists in satellite communications operations. For instance, the INTELSAT system and the INMARSAT system, the EUTELSAT system are all international operational systems. There is, on the other hand, very little international cooperation in research and development. To be sure, in Europe, various countries cooperate with each other through the European Space Agency, which is obviously a positive thing. The United States is not involved in any cooperative enterprises, nor has it been involved in any such enterprise since the CTS satellite in the mid-1970s.

The reason that the U.S. government has not been involved in R&D itself, let alone cooperated with other countries, is that satellite communications is considered to be a commercial enterprise and a competitive enterprise. Thus the government, at least until the ACTS program, pursued a hands-off approach, and even the ACTS program has been principally dedicated to regaining U.S. leadership in high data rate satellite communications.

There are a number of areas in which there are very good possibilities for international cooperation in satellite communications. High data rate communications heads the list largely because of the fiber-optic bugaboo. Then there are others, like links, where international cooperation is important because the whole idea is to interconnect satellite communications systems by microwave or optical links. By doing so, we can eliminate double-hoping on the ground. Moreover, the satellites themselves would be more cost-effective because of the ability to interconnect in space rather than go through switches on the ground. Both Japan and Europe have flight systems planned, which would be reciprocal to the high data rate communications. The U.S. should work with either the Japanese or the Europeans, or both, to develop inter-satellite links, both microwave and lasers, depending on which technology turns out to be best.

Neil Helm will now talk about a number of programs we observed around the world, and will say a few words about the ACTS satellite, which is America's pride and joy. . .

NEIL HELM [NH]: Thank you Burt and Vincent. I am very pleased to be here at MIT. I wish I had time to get into discussion of the technologies in some detail, though most of you did not come here to hear about solar cells and on-board switching. But to understand the make-up of the satellites, I will occasionally refer to the fact that one of these systems has made great in-roads in some of these technologies.

The systems I will talk about today are as follows: three from Europe [OLYMPUS, ARTEMIS, and ARCHIMEDES], three from Japan [ETS V, ETS VI, and COMETS], three from Russia [GONETS, KOSKON, and COMETA], and one from the U.S. [ACTS]. I will focus most specifically on what has happened from 1990 to the present. First, the OLYMPUS satellite, which was the first of the advanced satellites launched. It was the first of the wide-band satellites, capable of doing high data rate communications, but it was not utilized as such. The system had some problems right from the start. The telemetry froze up, and the satellite drifted around the world. They were able to do some interesting tests and demonstrations with it before it died, however.

Next is the ITALSAT, which was launched in the early 1990s. It was also a high data rate satellite, with high definition television capabilities. The ITALSAT experimental satellite will be followed with an operational satellite. Another European satellite, the ARTEMIS, will be launched in 1995. It is going to look at some of the future data relay and related technologies. It is a smaller, but more advanced, system--the future of European satellites. Finally, ARCHIMEDES is another advanced European satellite that is planned and funded. The interesting aspect of this satellite is in what is called a HEO, which is a highly elliptical orbit. There are many advocates for this medium-level, highly elliptical orbit, especially Europe, Russia, and Canada, countries with large populations and communications needs in the far north. The other interesting thing is that this system will also provide good quality audio broadcasting to automobiles in the future.

The first of the large Japanese satellites is the ETS V, which was launched in 1987. This satellite tested a number of areas, including structures and power. It also had an excellent experiments program. I talked to the Japanese about what they were doing with this program, and they said they combined a remote-sensing satellite with communications capability to a large trawler fleet, which allowed them enhance their catch. The fleet was able to harvest many more thousands of tons of fish by using satellite technology. This is an example of how the Japanese policy allows for the interaction of industry and government, better than we do in the United States, where we believe the government should not be working with any firms that are making money.

The ETS VI satellite, which will be launched soon by the Japanese, is a very advanced satellite. It is advanced in frequencies, in on-board processing, and, in fact, in nearly every area. It is a system which will really propel the Japanese into many of these advanced technology areas. It was ready for launch already last year, but the Japanese launcher industry has had some problems, which led the ETS VI launch to be delayed until the summer of 1994. The COMETS satellite system, also produced by the Japanese, is primarily a broadcasting satellite, but since it will be used for point to multi-point communications, will also be useful for mobile and for personal communications.

During my trip to Russia I talked to the academics and the planners, as well as travelled to Siberia, where their satellites are being constructed. Russians have a noteworthy production capability in satellites, and are really good at building a reliable, respectable level of technology. They do not have many advanced technologies; nonetheless, what they do, they do well. They also launch more satellites than we do, have more satellites in orbit, and thus, really cannot be discounted despite the tremendous economic and political chaos going on today.

The Russians had hoped, to no avail, that GONETS would be commercially viable. They plan to follow GONETS with a system called KOSKON, which I think you will see and hear much more of in the future. It is quite similar to Motorola's IRIDIUM--it has on-board processing, forward, backwards and cross-satellite links--though does not carry quite as large a communications package as IRIDIUM, and in some areas, is not quite as sophisticated. On the other hand, it will likely be a third to a fifth of the cost of IRIDIUM, satellite per satellite.

I really went to Russia to see their large aperture antenna, a project which I had heard so much about. They have already demonstrated functioning large aperture antennas. They opened and flew a 21 meter solar sail last year. The Russians have the ability to build and fly antennas larger than any that have been flown [in non-classified programs] here. I really believe these large antenna platforms in space are the wave of the future. The Russians, the Japanese, and to a lesser extent, the Europeans, are building, testing, and demonstrating these large arrays; I only hope the U.S. does so as well.

The United States' Advanced Communications Technology Satellite [ACTS] satellite was launched in September, and is working very well. It took more than ten years to be built and launched, but it will do a great job. Many universities and industrial groups have experiments on it. The major technology areas addressed by the ACTS are hopping spot beams [rapid beams which "hop" around and collect data], on-board switching and processing [the switching is in the satellite, not on the ground], Ka Band [ACTS can be a gigabit satellite, if desired], Gb/s Data Rates, and HDTV.

One experiment we are working on, as part of ACTS, is the development of a national high performance satellite network, for both government and commercial needs. We feel that advanced satellite communications has significant industrial and commercial value, and will become a crucial part of the National Information Infrastructure. As part of this experiment, we intend to interconnect a number of supercomputers. We want the high performance computers to interact with each other, not just dump back and forth in an in and out mode. We really want to work on large national and/or scientific problems that require more than one high-performance computer. We also want computer in fiber connected systems working together in a true hybrid network.

Our particular experiment team consists of industry, government agencies, and several universities. The associated organizations include the George Washington University, COMSAT Laboratories. Cray Research, NASA Goddard Flight Center, NASA's JPL, Martin Marietta Corporation, and the University of Hawaii. Our initial network with go from JPL to Goddard Space Flight Center. Each of these NASA centers have several very high-performance computers, and each have large problems which require using more than one computer, simultaneously. Thus, as you might expect, this experimental system will consist of a number of high-performance computers tied together via satellite.

One interesting thing we plan to do is to connect the satellite network to one or more of the current HPCC high performance computing and communications testbeds. We chose the testbed at the Jet Propulsion Laboratory [JPL] at CalTech, which comes out of Pasadena and goes down to the San Diego Supercomputer Center, and then on over to Los Alamos. We then recently connected it to the national capitol fiber cable that is going around the Washington Beltway, which will connect a number of large national centers and laboratories, such as the Naval Research Lab, the Defense Information Systems Agency, and a number of government agencies that will be connected by fiber to Goddard. The network will travel from Goddard to JPL by satellite, and will then travel from JPL to, among other places, Los Alamos.

We also intend to hook up to the University of Hawaii, where we will have a link that will allow us to do some astronomical studies with the Keck Telescope. This particular aspect of the experiment will allow astronomers at JPL [and elsewhere] to sit at work stations at their home bases and run the telescope. If any of you have been to astronomical observatories, you know that often the conditions there are not very hospitable. We would like to find a way for astronomers to work without having to endure such harsh conditions. With the satellite link, they will be able to calibrate the telescope, move it around, and literally be able to do everything from back at their own workstations.

Another part of our experiment involves global climate modeling, where the atmospheric part of the global climate model on the high-performance computer is at JPL, while the ocean part of the model is at Goddard. We hope to have these two systems working together dynamically in areas like the Los Angeles Basin where there are, every minute of the day, sensors picking up information on a supercomputer. We plan to move out into the Pacific Ocean, and see how the water content, the temperature, the salinity, and the wind direction off the water all affect the climate in the Basin. We will have both supercomputers working together, modeling this and telling the administrative people what they can see in changes in weather, etc.

That is our experiment, what we are working on, why we feel high-performance computing is important, and why we believe satellites are going to continue to be a very important aspect of that and other industrial uses. Thank you.

QUESTION 1: Will you elaborate a bit on ACTS research, please. Are they, for instance, working on a way to overcome delays up to geosync?

BE: Those of us who have been involved in satellite communications have always had to fight off the question of transmission delay, particularly through geostationary orbit. The up and down path is close to 50,000 miles out of 186,000 miles per second, so there is a quarter second delay. Those of you who have talked over satellite link recognize that you can sense that delay because, when you ask a question, the party on the other end often responds with a half second delay.

Thirty years of experience have indicated that this is an undesirable, but not disqualifying condition. Satellite links are acceptable irrespective of the delay. What people object to, primarily, is the echo--often you will hear your own voice bounced back when going from a two wire to a four wire connection in satellite links. That problem has basically been alleviated through the use of echo suppressers and echo cancellers. The problem today is that telephone is a point to point system, telephone lines are put into trunks wherever it is feasible to do so, and cables are better than satellites and have much less delay. Satellites are almost never used for telephone communications in the United States. They are used, on the other hand, for lightly loaded links, such as to countries in South America and in Africa, or where there is a network, or either a political or geographic boundary.

Interestingly, satellite communications is thriving in Europe for telephone communications. We wondered why that was, and nobody seemed to know until we had a little round table discussion. It then surfaced that the main reason for this is that satellite communications overcome political boundaries. Between Sweden and Italy they like to use satellite because, if they use cable, they have to pay transit charges through Denmark, Germany, Switzerland, and Italy.

Now this whole bugaboo is coming back in supercomputer networking. As Neil pointed out, we have this Cray WPM in Greenbelt, Maryland, which we are trying to tie to a machine in Pasadena, California. These machines are cranking away at very high speeds, and we have a quarter second delay. Is it then feasible to connect these two machines? The answer is yes, and compared with fiber-optic links, it is only an engineering problem. The point is there has to be a very good reason for using two computer separated by a continent. You must want to cross the country for some particular reason, to use both computers simultaneously, and then the question becomes, do you use fiber-optic or satellite? With cable you have got a five milli-second delay, and with a satellite you have a 250 milli-second delay [only two orders of magnitude difference]. But the computers are churning away in nanoseconds, and the difference between a nanosecond and five milliseconds is many orders of magnitude difference, and it is just as bothersome.

Again, this is just an engineering problem. So what to you do? Partition your computer programs differently, use longer block lengths, use different size ATM cells, etc. These measures seem to work very well in tests; now we just have to try them across satellite links.

QUESTION 2 by VC: I just want to follow-up on the high data rate question. First, how does ACTS differ from the OLYMPUS satellite, which can, like ACTS, also provide hundreds of megabit per second connections? What I am thinking about is, with respect to fiber-optics today, if you go and rent a gigabit line, it will be awfully expensive. This has nothing to do with the cost of the fiber-optics equipment; it has to do with rate tariffs and utilities, etc. When the demand arrives [if it arrives], the threat from fiber-optic is that the price may be able to be cut by a factor of ten, maybe a factor of 50. So, you are chasing something with tremendous potential. How do you compete with that kind of technology?

BE: The quick answer is that in a network configuration the satellite has many advantages. That is shown in the T1 networks that we have today, the networks that operate at 1.5 megabits per second. Some of these are huge networks, but even those where there are only a dozen or so nodes in the network, satellites are very much more cost-effective than the fiber-optic cable on the ground. For example, you only need one transmission node irrespective if you have three, five or ten nodes on the ground. But on the ground, you need N times N minus one over two to connect up N points on the ground. Those fiber optic links are expensive. All of the V-Sat networks are thriving because of companies like General Motors and Wal-Mart, who each have their own V-Sat networks. Those are satellite networks that connect hundreds or even thousands of nodes on the ground. Now, there is nothing magic about 150 megabits per second rather than 1.5; it is just 100 times faster.

The system configurations, whether they are cable on the ground or satellites in the sky, are going to be the same. What I cannot tell you is whether a satellite network will be more cost-effective than a terrestrial network with three nodes, or five nodes, or seven nodes, or twenty nodes. What the cross-over point will be depends on a number of things about which I know nothing. But there surely is a cross-over point, and it probably lies somewhere between three and twenty.

QUESTION 3: You have commented on the large number of personal communications satellite proposals. Is this just a repeat of the flurry of activity we saw approximately ten years ago surrounding spectrum allocation? In other words, just how real is this phenomenon?

BE: That is a really good question. It is more than applying for spectrum. First of all, Motorola is behind the IRIDIUM, a $2.25 billion, 66 satellite system. They have raised the money for it, $500 million of their own money plus funds they have raised around the world. They are deadly serious about it. They have set up an international organization, have gotten sub-contractors to build the satellites, and are arranging for launches. Motorola et al. are really serious, and have convinced themselves and others, that it is a feasible system.

However, I do not agree for a number of reasons. First, I do not believe it will work because of the way that the market and this complicated set of technologies that have to come together. What I have observed in my lifetime is that they tend not to come together very well. The IRIDIUM system is optimized for users who are wealthy and far from terrestrial communications links. True, one does get true global coverage, but how many people actually need it? For example, just how many American businessmen will be traveling in, say, Nigeria or at the North or South Pole, and will require communications links?

Second, the launching, deployment, operationalization, and maintenance of 66 satellites poses a very formidable problem that we have not solved. Third, the IRIDIUM is a bypass system that circumvents the local PPTs. A better system is the Loral GLOBALSTAR, which just connects up the PPTs. This technological complication is yet another hurdle for IRIDIUM to tackle. Moreover, as might be imagined, operational terrestrial systems do not like the idea that they will be bypassed by IRIDIUM, and so prefer GLOBALSTAR, which is yet another problem.

NH: I am going to differ with my boss slightly, and say that there is room for perhaps one or two of these systems. Certainly, the technology problems Dr. Edelson talks to are very real problems. On the other hand, we have GPS now, a multi-satellite system. And although I certainly believe that five or six of the proposed systems are going to wash out, I believe at least one will be economically successful.

The other reason I disagree is that, traveling as much as I do, I still have communications troubles around the world. Current systems have not solved all of our communications difficulties. As business expands globally, communications is the real key to a firm's potential. Therefore I think a lot more traffic will grow on an IRIDIUM-type system. One, or possibly two, such systems will benefit those kinds of internationally active customers.

VC: I want to make a final comment. Earlier someone asked whether DoD technologies had been included in the assessment. As an employee of Lincoln Lab, I have quite a bit of exposure to DoD technologies, so I can provide a fair assessment of these systems. If one looks at DoD investment on satellite technologies in the 1980s and 1990s, and adds those figures to the reported U.S. totals, you will find that the total far exceeds Japanese and European totals.

Why is it then that American companies are not leading in all technology areas? It turns out that most of this investment is in very high performance systems--at any cost--for military applications. I think that in the military world, some of the technologies are far more advanced than those of Europe and Japan, but they are prohibitively expensive. What we now need to do is learn how to transition DoD technology to a form that is competitive in the marketplace. I think that with some effort this transition can be an effective avenue that will allow the United States to become competitive in the commercial marketplace.

Many thanks to our speakers, and thank you all for coming.

SATELLITE COMMUNICATIONS SYSTEMS AND TECHNOLOGY

MIT Communications Forum

Massachusetts Institute of Technology
Cambridge, MA

Burton I. Edelson
George Washington University

March 10, 1994

VG26878 03/93

NASA -

NSF Satellite Communications Panel

- **Purpose:** Survey R&D in satellite communications in Europe and Japan and assess relative to U.S. position
- **Panel:** Chairman: Dr. Joe Pelton, Director Grad. Telecomm., University of Colorado

  Co-Chairman: Dr. Burt Edelson, George Washington University

  Members:

  Prof. Charles Bostian
  VPI

  William Brandon
  MITRE Corporation

  Dr. Vincent Chan
  Lincoln Laboratory

  E. Paul Hager
  George Mason University

  Neil Helm
  George Washington University

  Dr. Christoph E. Mahle, COMSAT Labs
  Ex. Dir., Technical Division

  Dr. Ed Miller
  NASA Lewis Research

  Dr. Lance Riley
  JPL

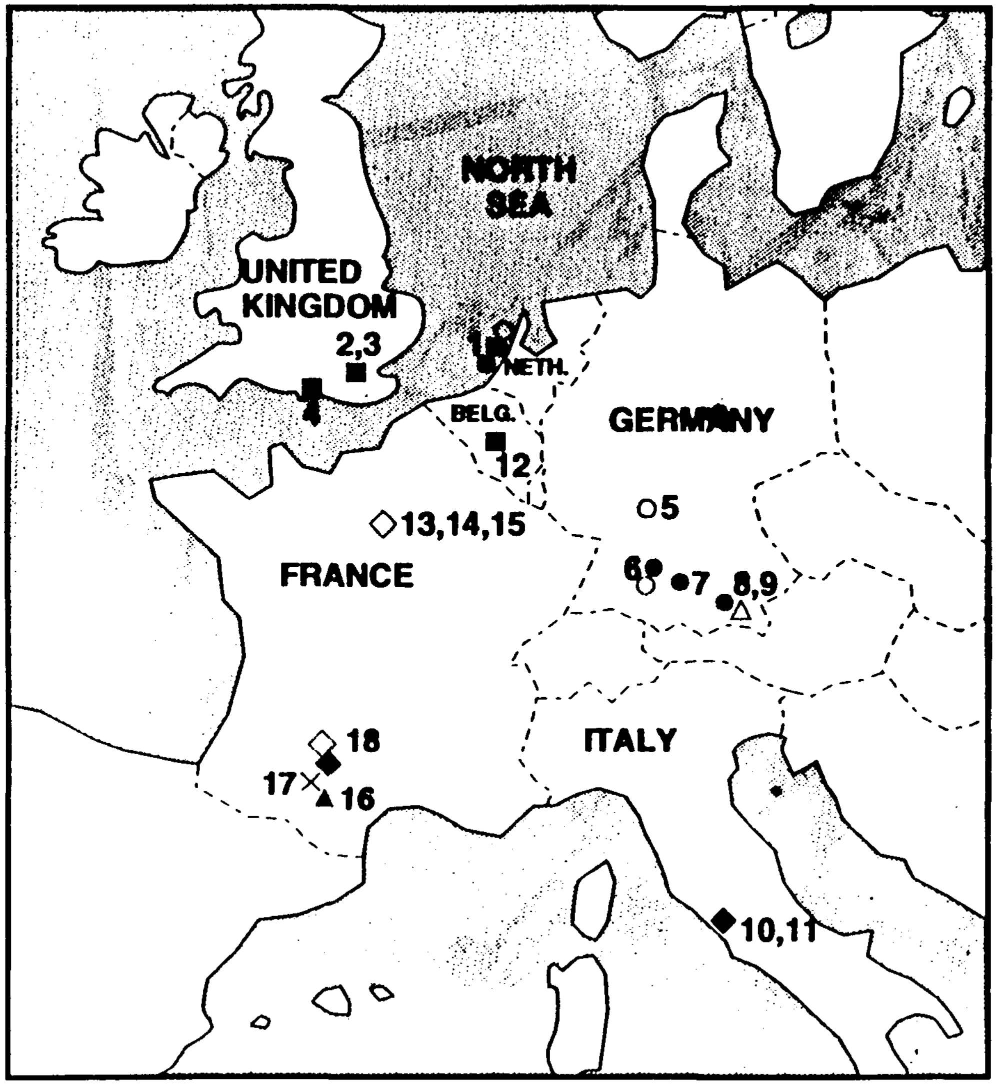
  Raymond Jennings
  Institute for Telecomm. Sciences

  Ramon DePaula
  NASA Headquarters

  Dr. Michael DeHaemer
  Loyola College (JTEC/WTEC)

VG26878

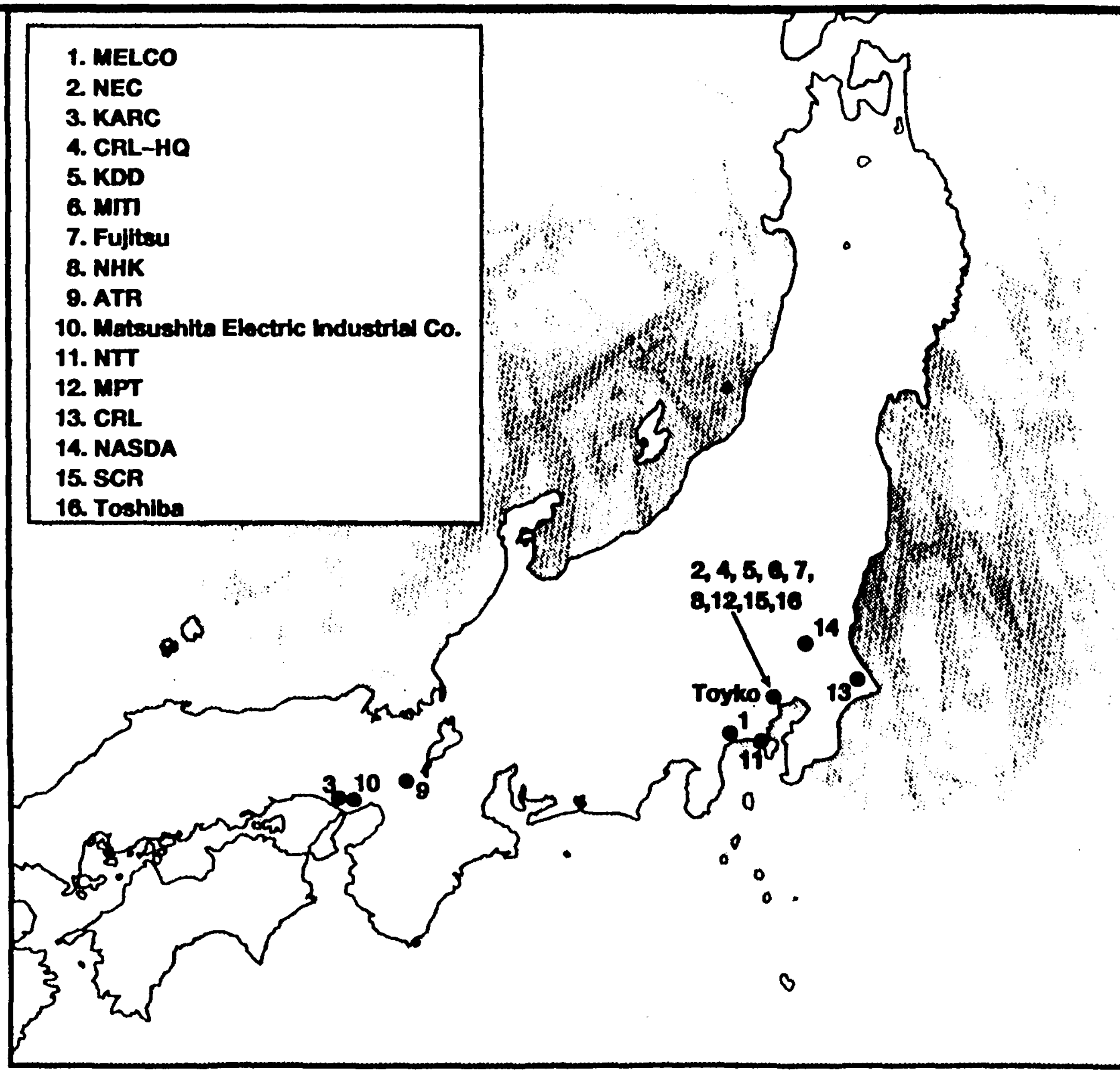
WTEC Study Sites (Satellite Communications)



- ■ Pelton, Edelson, Brandon, Chan, Riley, DePaula
- ○ Mahle, Bostian, DeHaemer
- ● Jennings, Miller, Helm, Hager
- ◆ Helm, Jennings, Bostian, Hager, Mahle, Riley
- △ Bostian, Helm, Mahle, Miller
- ▲ Chan, DePaula
- ◇ Brandon, Miller
- × Helm, Brandon, Jennings

1. ESA (6/22)
2. INMARSAT (6/23)
3. Euro Study Commission (Pelton) (6/23)
4. Matra-Marconi (6/24)
5. Deutsche Telecom Labs (6/23)
6. ANT (6/23)
7. AEG (Miller) (6/24)
8. DLR (6/24)
9. MBB (6/24)
10. Alenia/Italspazio/ISA (6/25)
11. Telespazio (6/25)
12. EC (Pelton) (6/24)
13. Thompson CSF (6/25)
14. EUTELSAT (6/25) (Edelson)
15. ESA Hq. (Pelton, Edelson, DeHaemer) (6/26)
16. Matra-Marconi Toulouse (6/25)
17. CNES (6/26)
18. Alcatel (6/26)

JTEC Itinerary



CAVG0351

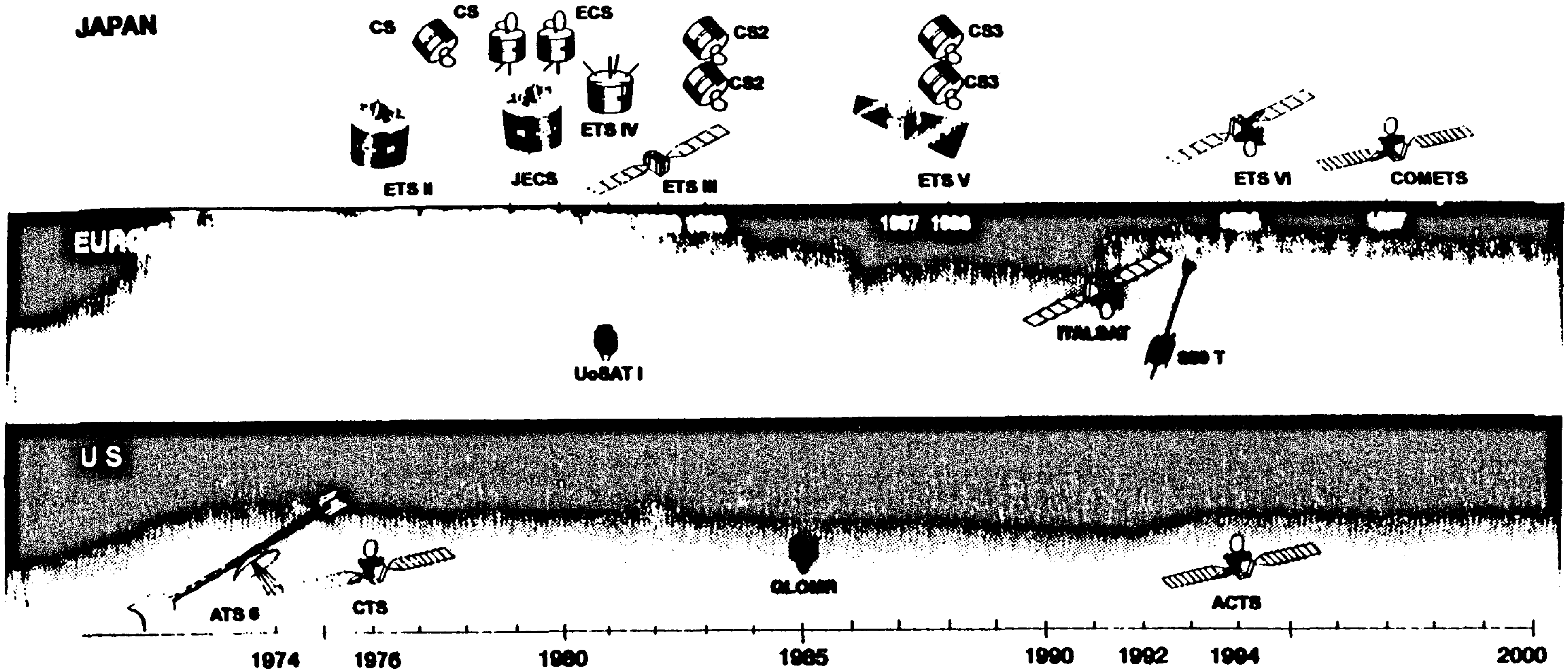
"Science and technology have progressed to such a degree that communications through the use of space satellites has become possible. Through this country's leadership, this competence should be developed for the global benefit at the earliest practicable time."

John F. Kennedy
July 24, 1961

SATELLITE COMMUNICATIONS: THE FIRST, THE MOST OBVIOUS, (AND STILL THE ONLY) BIG PAY-OFF FROM SPACE!!

- 160 COUNTRIES AND TERRITORIES INVOLVED
- 10 COUNTRIES WITH SIGNIFICANT INDUSTRIAL CAPABILITY IN SATELLITE COMMUNICATIONS EQUIPMENT AND TECHNOLOGY
- 100 SATELLITES IN GEOSTATIONARY ORBIT
- 20 OPERATIONAL INTERNATIONAL, REGIONAL AND NATIONAL SYSTEMS
- $10 BILLION/YEAR REVENUES
- $5 BILLION/YEAR EQUIPMENT MARKET (SATELLITES, LAUNCH VEHICLES, GROUND TERMINALS, TRANSMISSION SYSTEMS)
- THOUSANDS OF LARGE EARTH STATIONS AND MOBILE TERMINALS, MILLIONS OF BROADCAST RECEIVE TERMINALS

World Development of Communications Satellite Advances



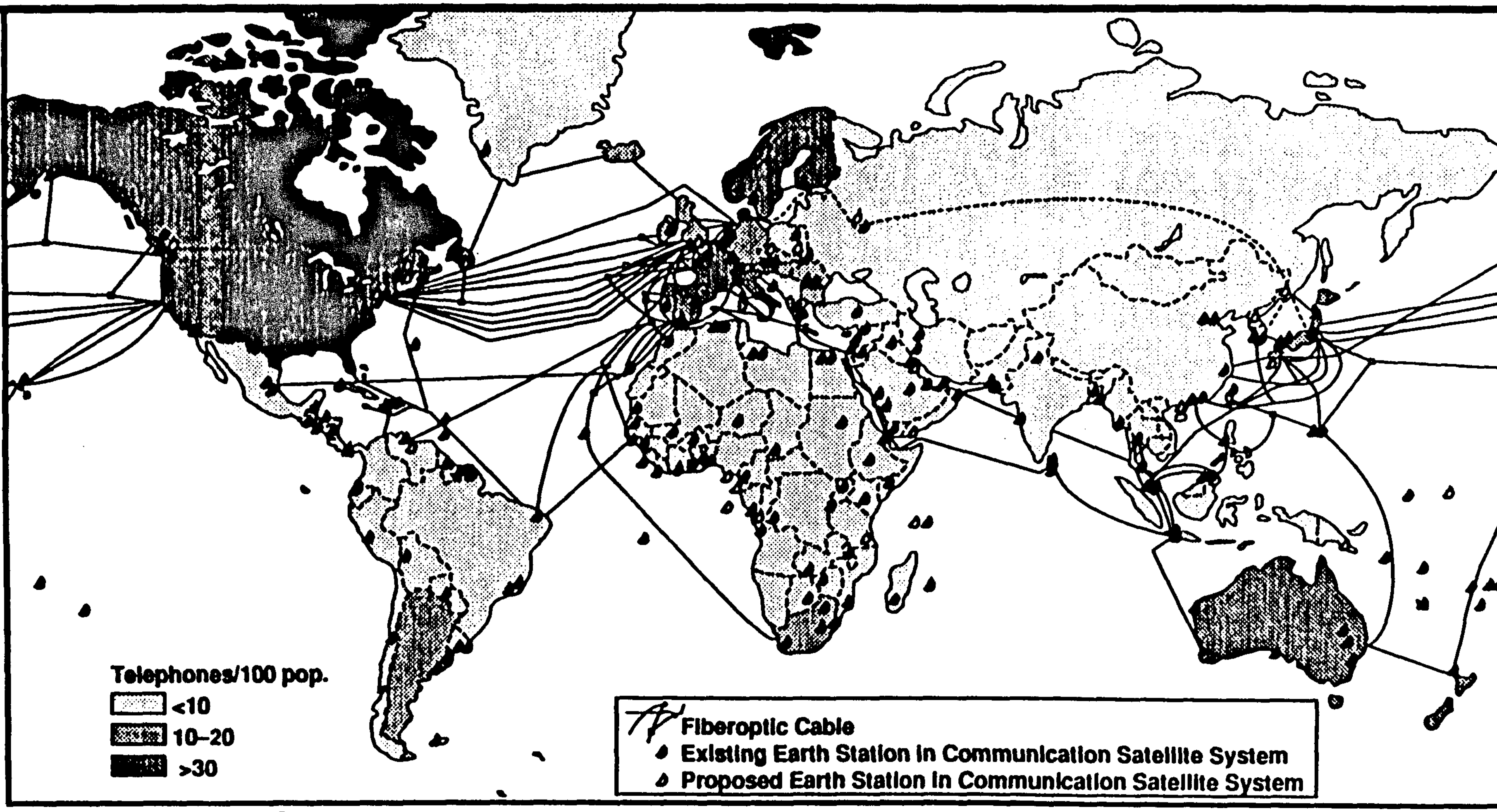
CTS to ACTS Interval

- 12 Japanese R&D Satellites
- 10 European Satellites
- No U.S. Launches

Nothing Planned by US

VG25680

World Satellite and Cable Communications (1992)



Data Sources:

- Telephones/100 Population Taken From 1982 ATT&T Survey (Latest Update)
- Earth Stations, INTELSAT Data
- Fibre, Synthesis of 5 Sources

CVAVG0239-2

MAJOR SYSTEM TRENDS IN SATELLITE COMMUNICATIONS

FIXED SERVICE	TELEPHONY GROWING SLOWLY; VIDEO DISTRIBUTION, MODERATELY; VSATs, FAST-- COMPETITION FROM FIBER OPTICS
BROADCAST SERVICE	GROWING FAST, NEW SYSTEMS AND USES, APPLICATIONS TO THIRD WORLD EMERGING
MOBILE SERVICES	GROWING VERY FAST, NEW CONCEPTS, SYSTEMS AND SERVICES
PERSONAL COMMUNICATIONS	NEW SYSTEMS IN PLANNING, NEW CONCEPTS UNDER STUDY
HDR COMMUNICATIONS	LARGE POTENTIAL, AWAITING ACTS DEMO

TECHNOLOGY TRENDS

	IMPORTANCE	PROGRESS
MILLIMETER WAVE AND KA BAND	++	++
OPTO-ELECTRONICS, OPTICAL COMMUNICATIONS	++	+
ON-BOARD PROCESSING	++	+
SATELLITE SWITCHING	++	+
INTERSATELLITE LINKS	++	+
MULTI-BEAM ANTENNAS	+++	++
LARGE SCALE ANTENNAS	++	+
MICROWAVE COMPONENTS, DEVICES	++	++

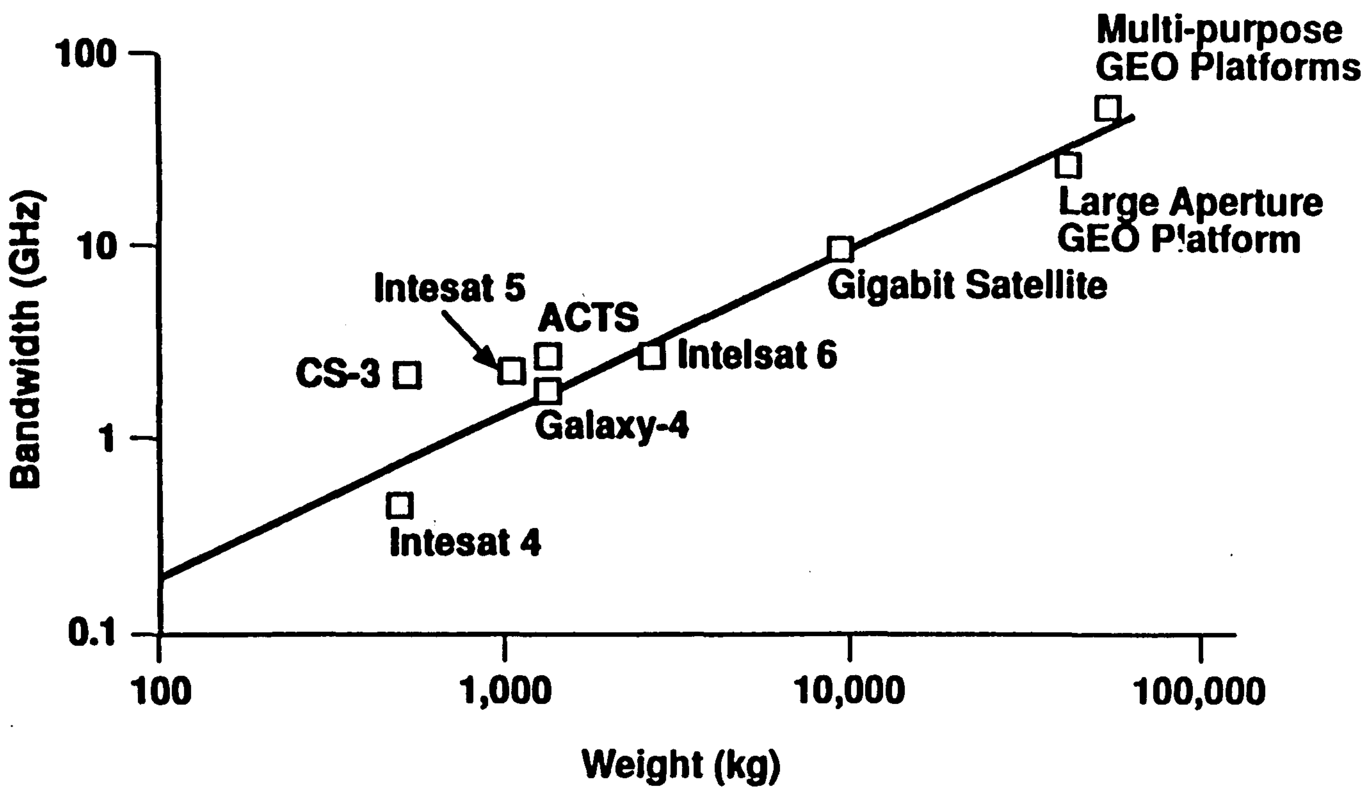
++	Very important - Rapid progress
+	Important - Good progress
0	Not important - Little or no progress

TECHNOLOGY TRENDS
(continued)

	IMPORTANCE	PROGRESS
LAUNCH VEHICLES	++	0
SPACECRAFT TECHNOLOGIES (STABILIZATION, CONTROL, PROPULSION, POWER)	+	+
HIGH DATA RATE COMMUNICATIONS	++	+
PERSONAL COMMUNICATIONS	++	+

++	Very important - Rapid progress
+	Important - Good progress
0	Not important - Little or no progress

GEO Satellite Growth – Capacity vs. Weight



VG25880

GEOSTATIONARY (GEO) AND LOW EARTH ORBIT (LEO) COMPARISONS

ADVANTAGES OF GEO SYSTEMS

- o MORE CAPABILITY PER POUND, AND PER $
- o HEMISPHERIC AND SELECTIVE COVERAGE
- o WIDE AREA BROADCAST, VIDEO, HIGH DATA RATE CAPABILITIES

ADVANTAGES OF LEO SYSTEMS

- o FULL GLOBAL COVERAGE
- o DECREASED TRANSMISSION DELAY
- o LOWER INVESTMENT AND RISK

LIKELY APPLICATIONS

- o GEO SYSTEMS - HIGH PERFORMANCE, HIGH CAPACITY SERVICE

- o LEO SYSTEMS - LOW CAPACITY, STORE-AND-FORWARD SERVICE COMBINED WITH REMOTE SENSING FOR DISASTER AND EMERGENCY SERVICE

Satellites vs Fiber Optic Cables

Satellite advantages:

- Wide area coverage
- Distance insensitivity
- Rapid installation
- Multiple access, demand assignment

Cable advantages:

- High capacity
- Low cost/channel
- Low latency/delay

Services	Satellites	Cables
Trunking	✓	✓✓
Broadcast	✓✓	0
Mobile	✓✓	0
Networks	✓	✓

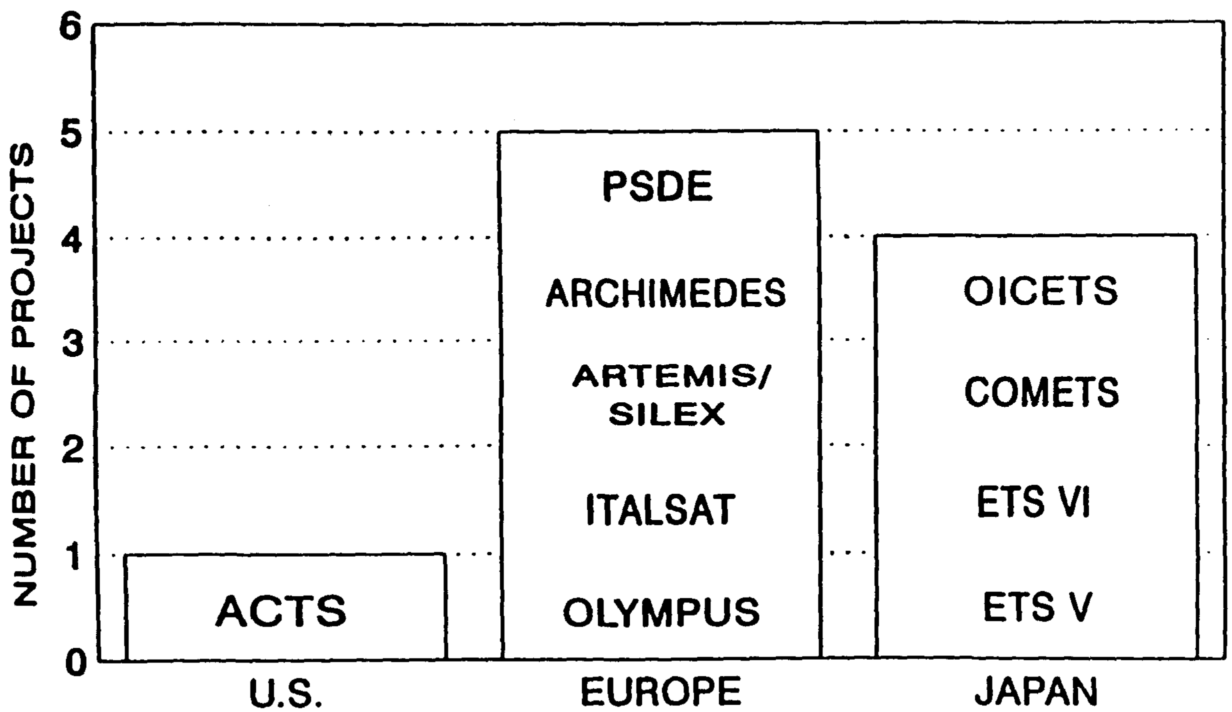
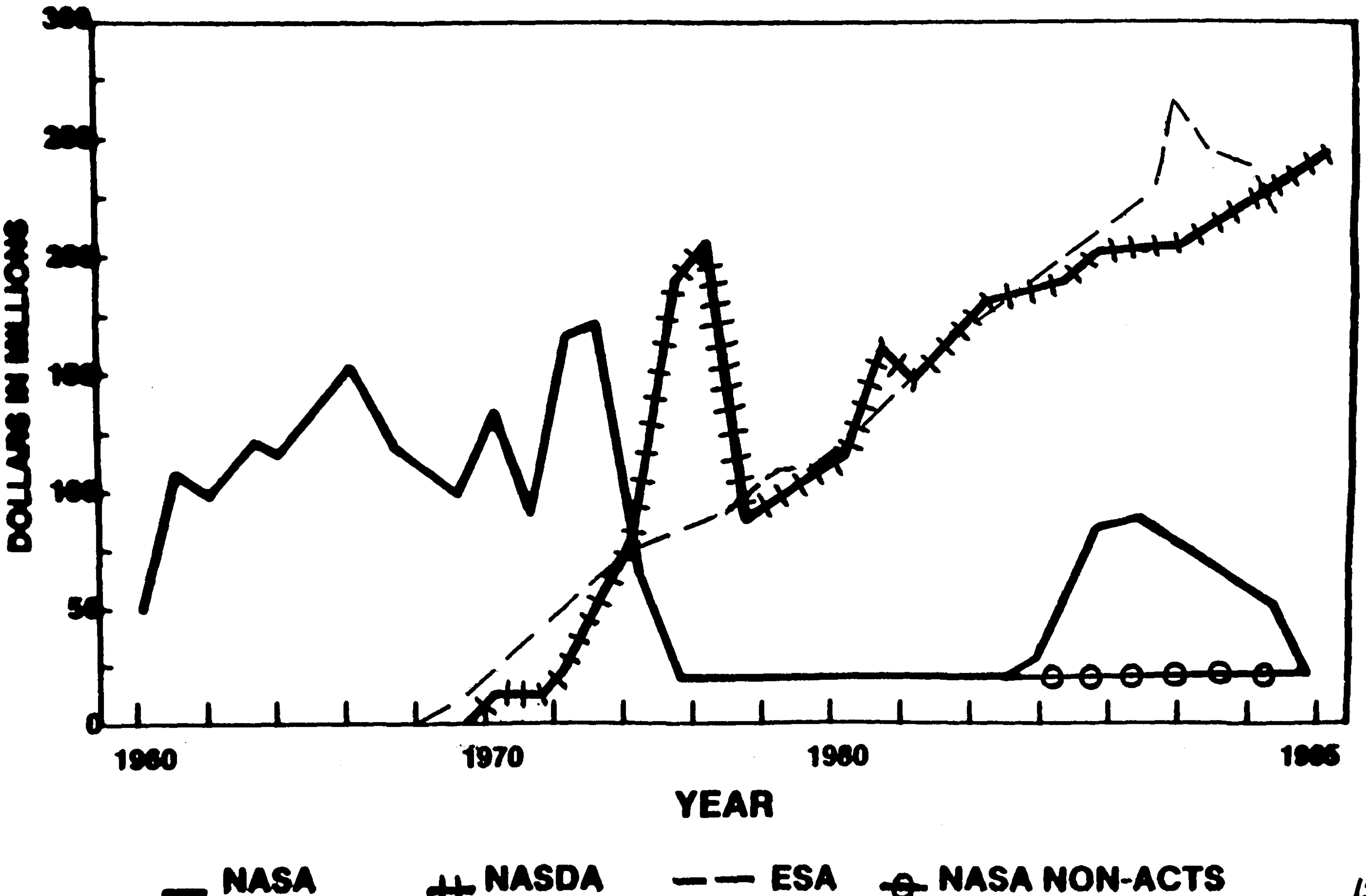


Figure 2. A Comparative View: Experimental Communications Satellite Projects in the United States, Japan, and Europe

Annual Funding for Communications Programs



GOVERNMENTS' ROLES IN SATELLITE COMMUNICATIONS

	EUROPE	JAPAN	USA
POLICY	S	S	M
PLANNING	M	S	W
ADVANCED DEVELOPMENT	S	S	M
SUPPORT TO INDUSTRY	S	S	W
SUPPORT TO INTERNATIONAL SYSTEMS	S	S	W

Key: S Strong role; M Moderate role; W weak or no role

U.S. Scorecard in Advanced Satellite Communications Technologies

U.S. TECHNOLOGY LEAD	
High Data Rate Satellite Communications	
USATs and Personal Communications Transceivers	
Small Satellites	
Space Applications for High Temperature Superconductivity	
On-Board Processing	
U.S. TECHNOLOGY TIE	**WITH**
Traveling Wave Tubes	Europe
Electric Propulsion	Japan & Russia
Spacecraft Antennas	Japan & Europe
Intersatellite Links	Japan
Autonomous Control Systems	Japan & Europe
U.S. TECHNOLOGY LAG	**LEADER**
HEMT Technology	Japan
Free Space Optical Communications	Japan & Europe
Advanced Batteries	Japan
Solar Array Systems	Japan
Solid State Power Amplifiers (FETs)	Japan
Pointing and Positioning Systems	Japan
Large Scale Deployable Antenna Systems	Japan and Russia
Advanced System Design and Long Range Planning Concepts	Japan
New Application Development	Japan

INTERNATIONAL COOPERATION IN SATELLITE COMMUNICATIONS

- STATUS-

INTERNATIONAL AND REGIONAL SYSTEMS
- INTELSAT, INMARSAT, EUTELSAT

- o OPERATIONAL SYSTEMS, LIMITED R&D
- o NO EXPERIMENTAL SATELLITES

EUROPE
- o INTERNATIONAL COOPERATION IS A "WAY OF LIFE"
- o COOPERATIVE R&D, EXPERIMENTAL SATELLITES

JAPAN
- o PROMOTING EAST ASIA AND PACIFIC COOPERATION, MAY LEAD TO REGIONAL SYSTEMS

EUROPE/JAPAN
- o DISCUSSIONS ON COOPERATIVE R&D (ESA, FRANCE)

US/JAPAN
- o WORKING GROUP ON SATELLITE COMMUNICATIONS

INTERNATIONAL COOPERATION IN SATELLITE COMMUNICATIONS

-PERSPECTIVES-

- SATELLITE COMMUNICATIONS VIEWED AS "COMMERCIAL" AND "COMPETITIVE"
- NO SIGNIFICANT INTERNATIONAL COOPERATIVE PROGRAM EXISTS IN SATELLITE COMMUNICATIONS TECHNOLOGY OR APPLICATIONS
- LAST U.S. INTERNATIONAL COOPERATIVE PROJECT, CTS (HERMES), 1975
- INTERNATIONAL COOPERATION NECESSARY FOR NEW SYSTEMS AND TECHNIQUES (ISLs, HDR COMMUNICATIONS, LARGE ANTENNAS); ESSENTIAL TO DETERMINE ROLE WITH FIBER OPTIC CABLES
- ESA, JAPAN, RUSSIA ALL INTERESTED IN COOPERATION WITH U.S. IN DEVELOPMENT OF ADVANCED SATELLITE COMMUNICATIONS TECHNOLOGY AND APPLICATIONS

OPPORTUNITIES FOR INTERNATIONAL COOPERATION IN SATELLITE COMMUNICATIONS

- o HIGH DATA RATE TRANSMISSION SYSTEMS, TESTS, AND DEMONSTRATIONS FOR SUPERCOMPUTER NETWORKING, HDTV, B-ISDN
- o DEVELOPMENT OF LARGE APERATURE ANTENNAS (30 METERS)
- o GEOSTATIONARY PLATFORMS (10,000 Kg)
- o ON-BOARD PROCESSING
- o INTERSATELLITE LINKS - OPTICAL AND MILLIMETER WAVE
- o HIGHLY MOBILE, PERSONAL COMMUNICATIONS, DISASTER COMMUNICATIONS
- o LEO SYSTEMS, COMBINED COMMUNICATIONS AND REMOTE SENSING SYSTEMS
- o MICROWAVE AND Ka-BAND PROPAGATION EXPERIMENTS

MAJOR SATELLITE TECHNOLOGY SYSTEMS

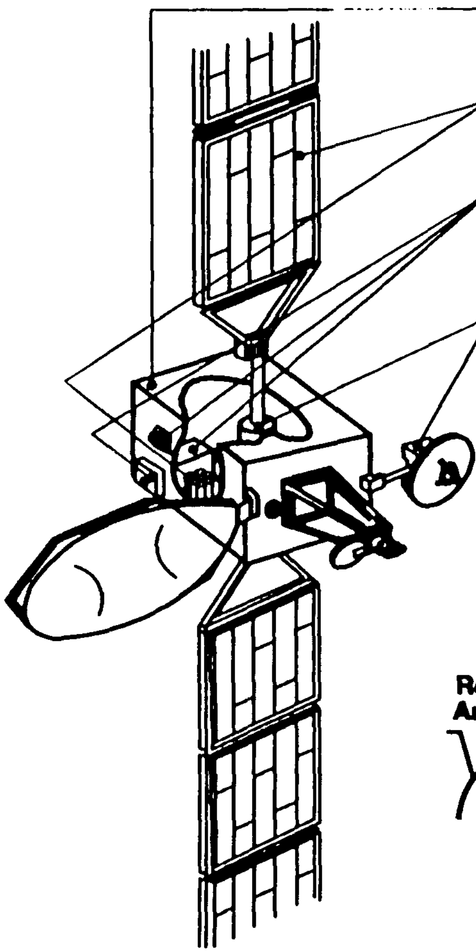
MIT Communications Forum

Massachusetts Institute of Technology
Cambridge, MA

Neil R. Helm
George Washington University

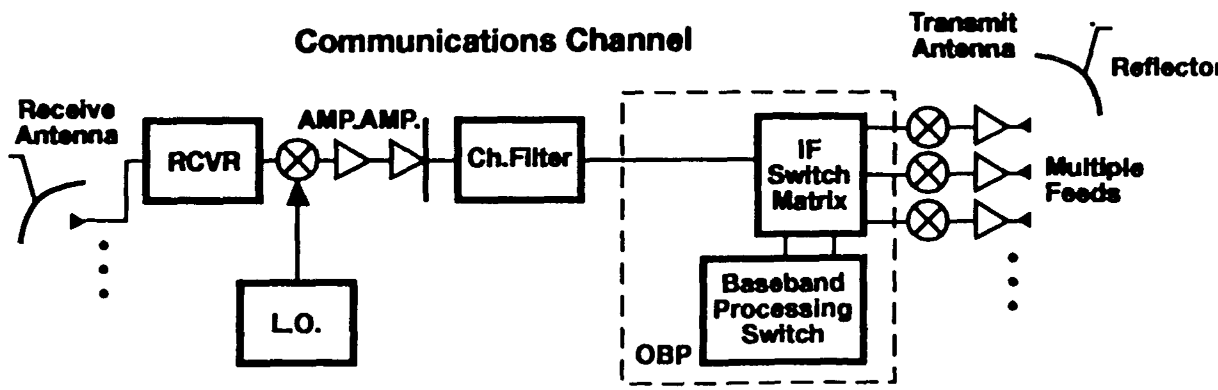
March 10, 1994

Satellite Communications Key Technologies



- **Structure** .... • Composite materials • Deployable, reformable structures
- **Electrical power** ... • Solar array • Batteries
- **Control** .... • Attitude control electronics • Sensors • Ion engines
- **Mechatronics** .... • Paddle drive • Instument pointing systems

Communications Channel



MAJOR SATELLITE TECHNOLOGY PROJECTS

EUROPE

- OLYMPUS
- ARTEMIS
- ARCHIMEDES

JAPAN

- ETS V
- ETS VI
- COMETS

RUSSIA

- GONETS
- KOSKON
- COMETA

OLYMPUS

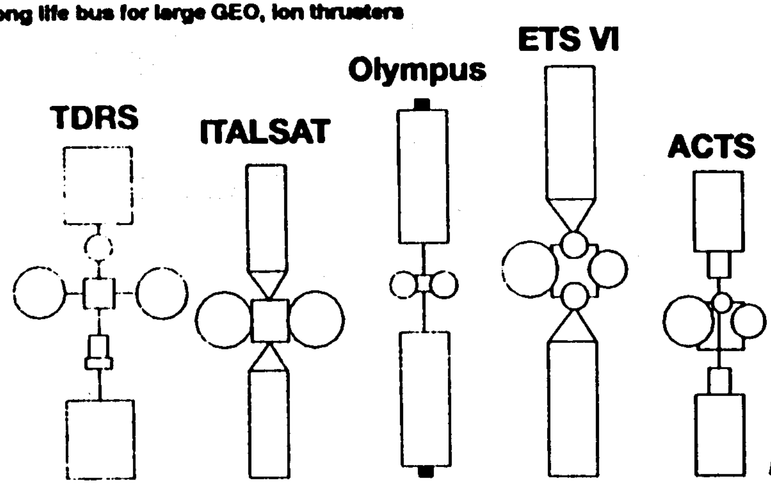
Sponsor	Launch Date	Mission
ESA	1989	Communications Development

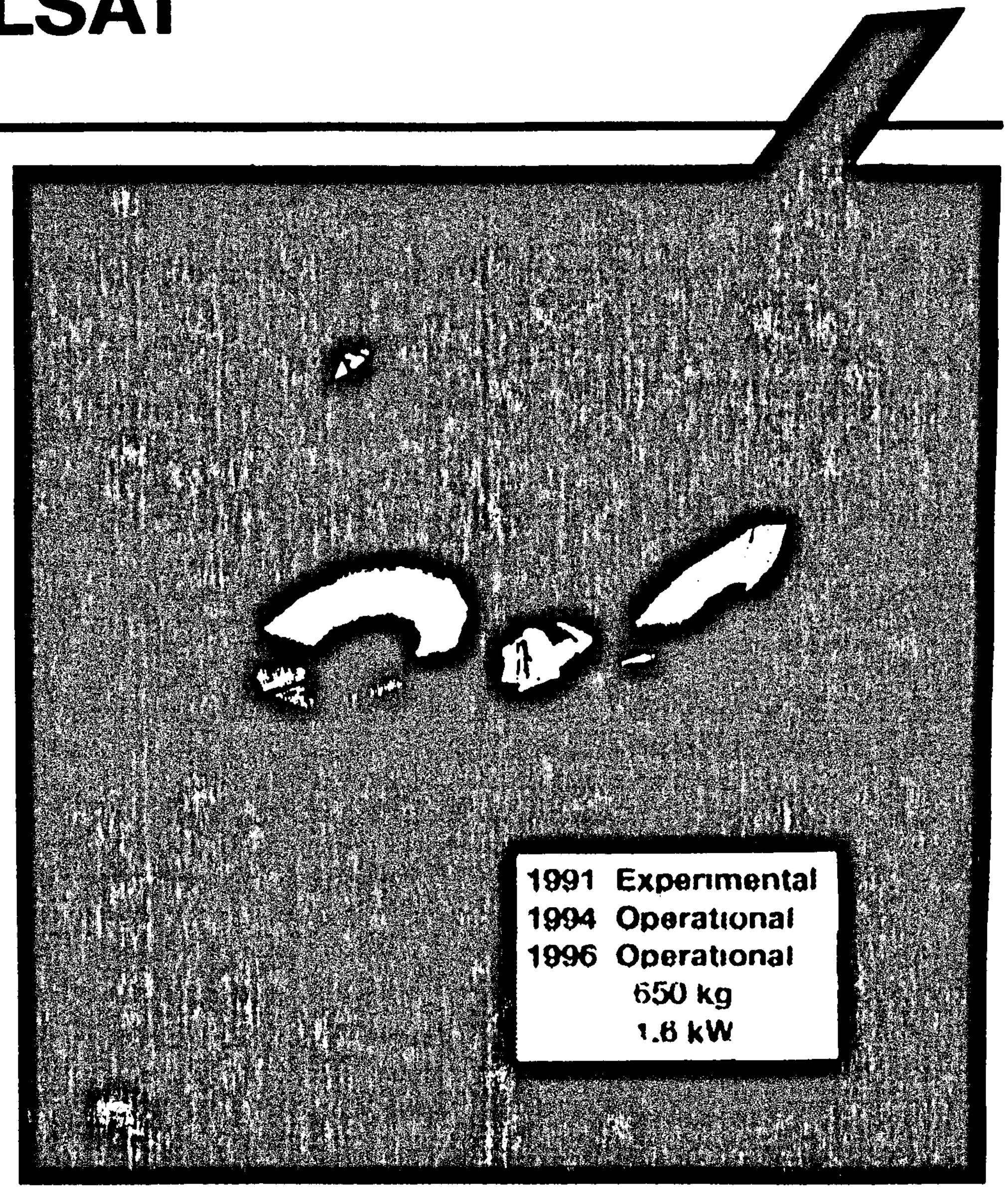
Characteristics	Advanced Technologies
GEO	Ka Band Technologies
Ku, Ka Bands	Wide-Band 700 MHz
SS-TDMA	800 Mb/s Transmission
Mass 2612 kg	HDTV
Prime Power 3.6 kW	Propagation Research Package

ITALSAT

Experiments	Frequency (GHz)				
	2/2.6	14/12	30/20	43/38	.51 μm
Mobile			✓		
Personal			✓		
Broadcast HDTV		✓	✓		
FSS		✓	✓		
ISL			✓		
Data Relay					
OBP		✓	✓		

- Long life bus for large GEO, Ion thrusters



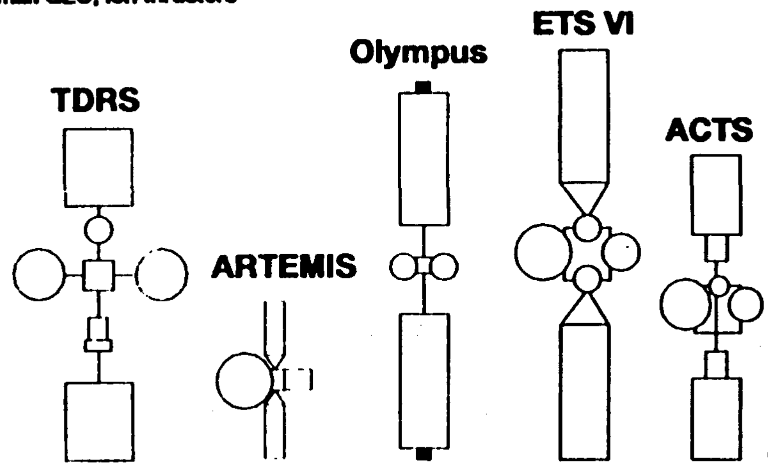


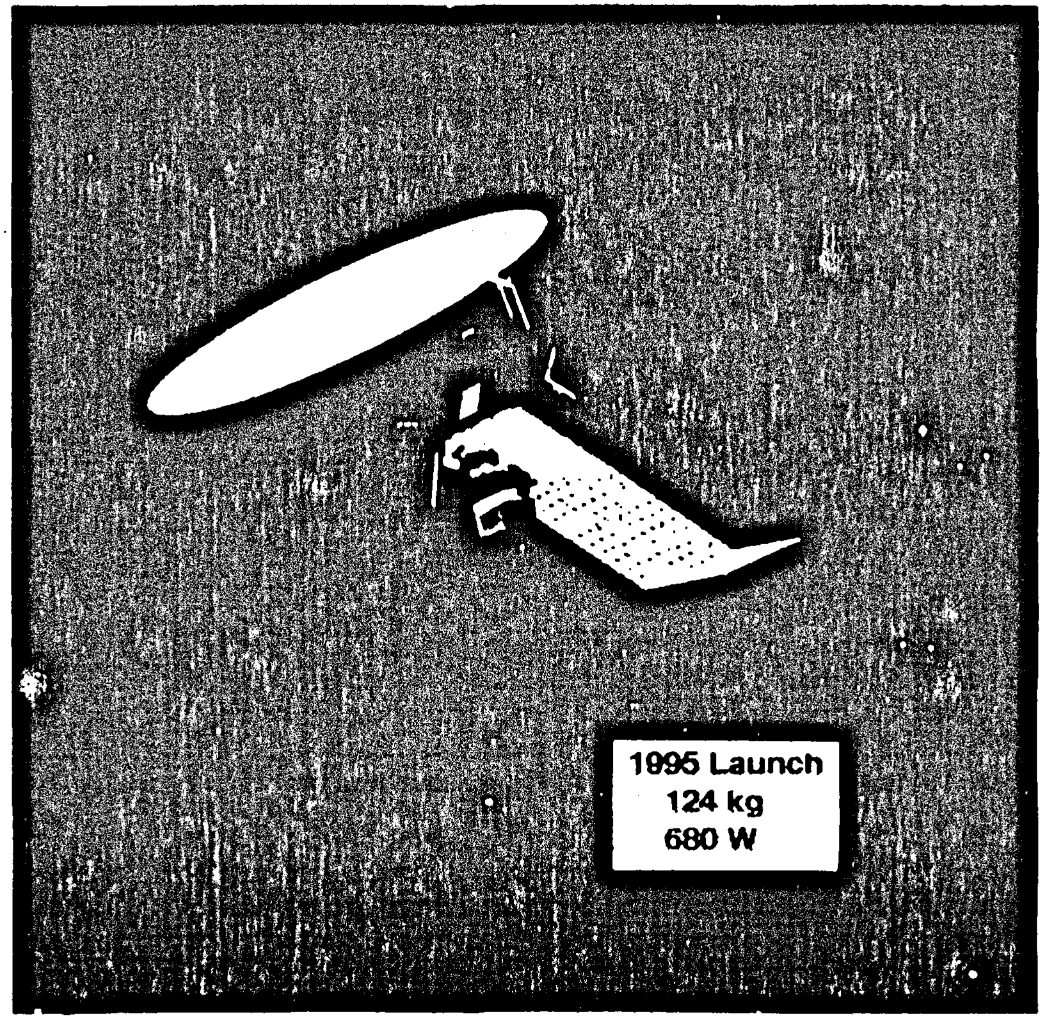
MITRE

ARTEMIS

Experiments	Frequency (GHz)				
	2/2.6	1.6	30/20	43/38	.82/.84 µm
Mobile		✓	✓		
Personal					
Broadcast HDTV			✓		
FSS			✓		
ISL	✓		✓		100 mw
Data Relay	✓				
OBP			✓		

- Small GEO, Ion thrusters





MITRE

ARCHIMEDES

Sponsor	Launch Date	Mission
ESA	1998	Communications & Broadcast Development

Characteristics	Advanced Technologies
HEO	Sound Broadcasting
Mobile	Inexpensive Receivers - Cars
Broadcast	

ENGINEERING TEST SATELLITE V

(ETS V)

Sponsor(s)	Launch Date	Mission
Japan, NASDA	1987	Communications Development

Characteristics	Advanced Technologies
GEO	L,C Band Mobile
L,S,C Bands	Three Axis Stabilization
550 kg	CFRP Monocoque Structure
Prime Power 800W	Semi-Rigid Solar Panel
Design Life 1.5 Yr	

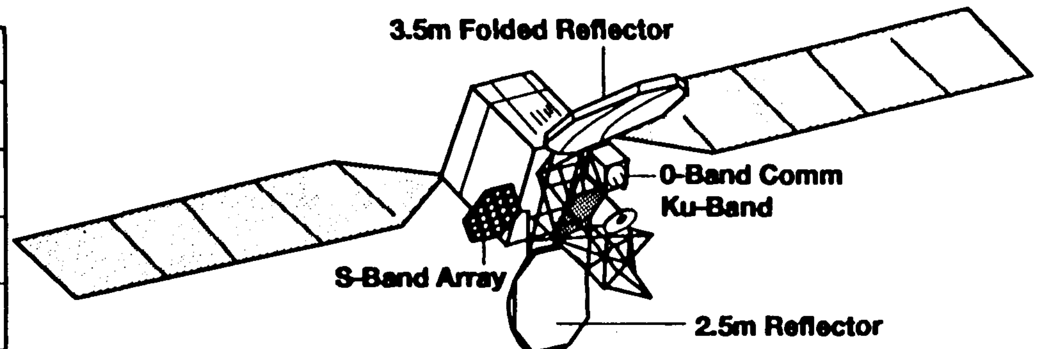
Comments

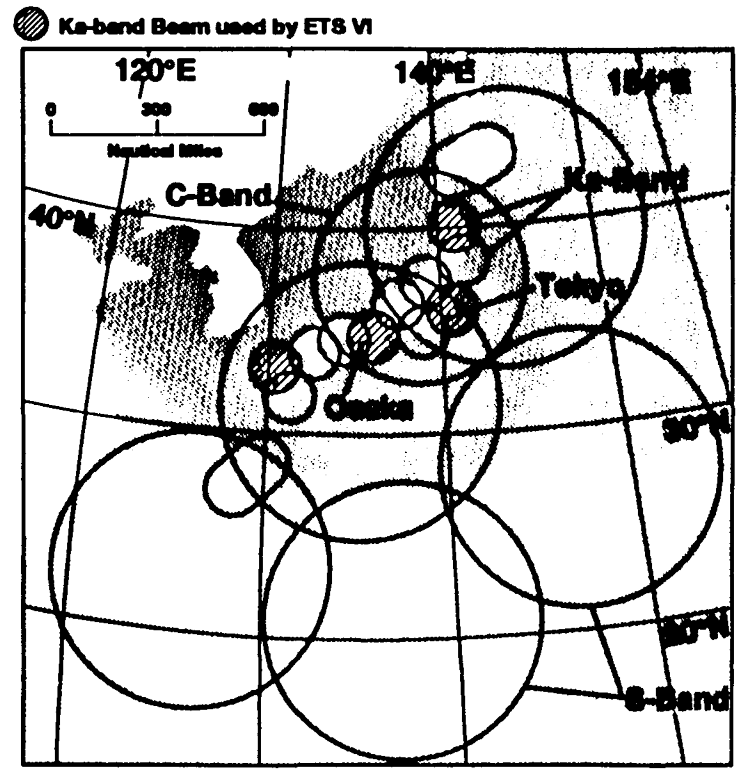
A series of commercially viable aviation and maritime (fishing) experiments were organized to exploit the technologies developed in the satellite.

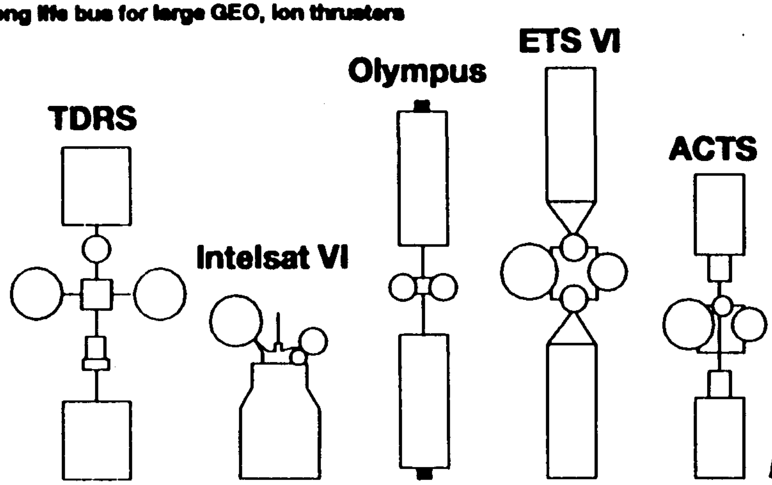
Engineering Test Satellite (ETS) VI

Experiments	Frequency (GHz)				
	2/2.6	6/4	30/20	43/38	.83/.51 µm
Mobile	✓		✓	✓	
Personal			✓	✓	
Broadcast		✓	✓		
FSS		✓	✓		
ISL	✓		✓		✓
Data Relay	✓				✓
TTC	✓		✓		

- Long life bus for large GEO, Ion thrusters





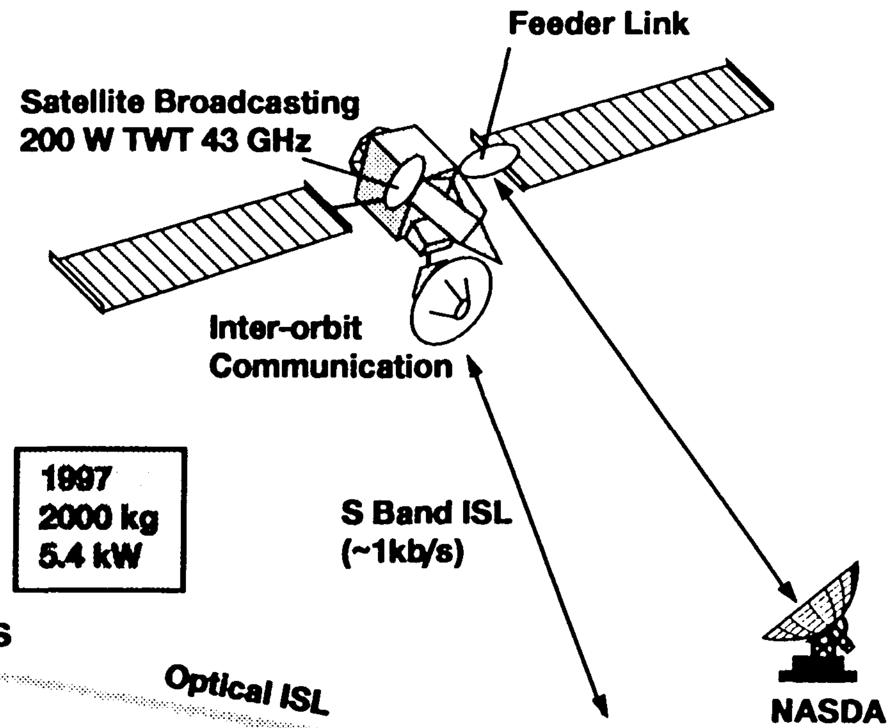


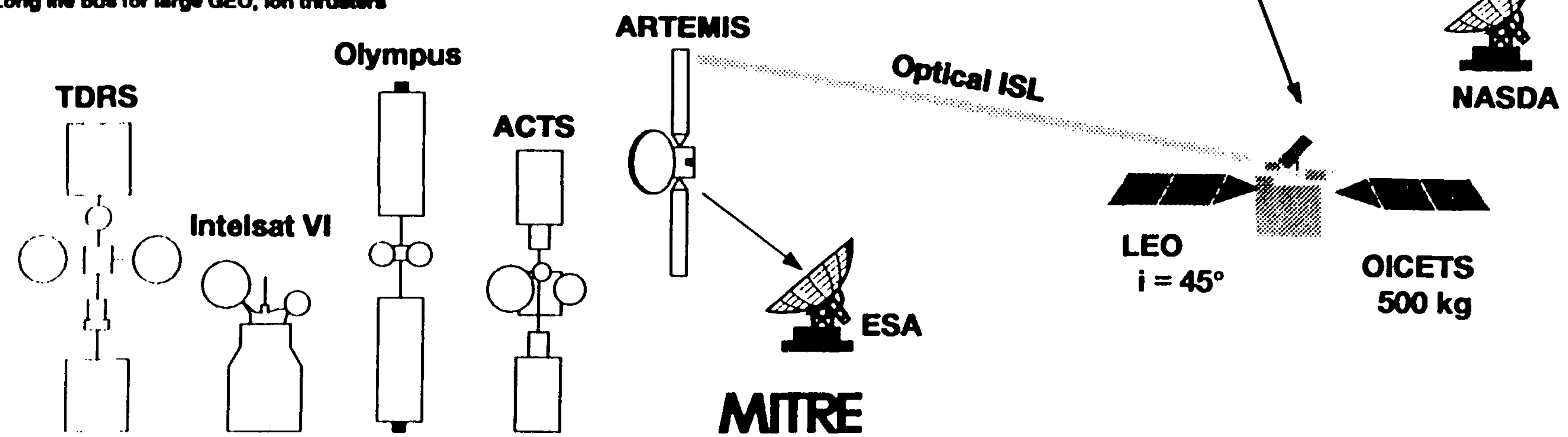
MITRE

COMETS (Japan)

Experiments	Frequency (GHz)				
	2/2.6	6/4	30/20	46/43	.83/.51 μm
Mobile	✓		✓	✓	
Personal			✓	✓	
Broadcast HDTV			✓		
FSS			✓		
ISL	✓		✓		
Data Relay	✓				
TTC	✓		✓		

• Long life bus for large GEO, Ion thrusters





MITRE

VG26532

GONETS

Sponsor	Launch Date	Mission
Russia SMOLSAT Consortium	1992 - 1st 2 of 36	Communications

Characteristics

LEO
36 Spacecraft in
6 Orbital Planes
225 kg
UHF Band
8,16, & 64 kb/s channels
Store & Forward Operation
Operates with Small,
Inexpensive Receivers (<$1000)

Advanced Technologies

Second Generation (1997) will have
Intersatellite Links
Operates with Hand-Held Receivers

KOSKON

(COSCON)

Sponsor	Launch Date	Mission
Russia	Early 1993	Communications

Characteristics

LEO (GEO)
50 Spacecraft
5 Orbital Planes
Mass 800 kg
Voice/Data 16 & 32 kHz Channels
Hand-Held Receivers
Positioning (OMNITRACS Type)

Advanced Technologies

Forward-Backward-Cross Plane ISL's
Improved Positioning
On-Board Processing

COMETA/GLOBIS

Sponsor	Launch Date	Mission
Russia	1996-97	Communications

Characteristics

GEO
Fixed & Mobile
L, C, Ku Band
19,000 kg
30 Meter Antenna
84 Spot/Scanning Beams
5 million 64 kb/s channels
10 Year Life
Energia Launch

Advanced Technologies

30 M Deployable Antenna
Spot and Scanning Beams
Hand-Held Receivers

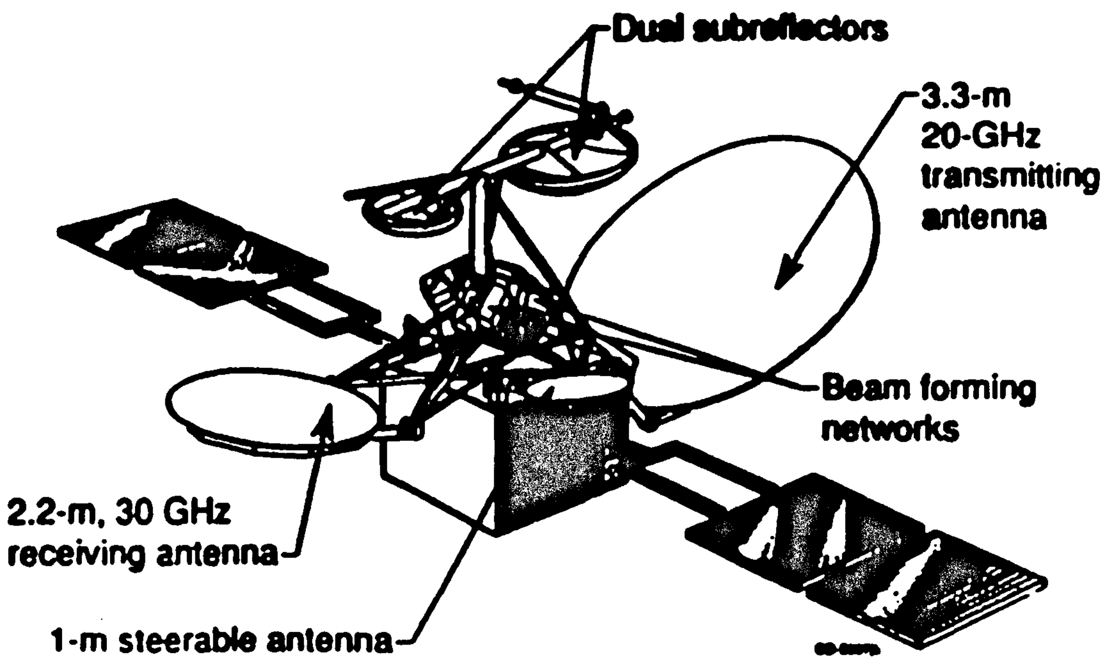


Figure 2 - Advanced Communications Technology Satellite

ADVANCED COMMUNICATIONS TECHNOLOGY SATELLITE (ACTS)

Sponsor(s)
NASA

Launch Date
1993

Mission
Communications Development

Characteristics

GEO
Ka Band
Mass 1450 kg
Power 1800 W
Life = 2-4 Years

Advanced Technologies

Hopping Spot Beams
On-Board Switching & Processing
Ka Band
Gb/s Data Rates
HDTV

A National High Performance Satellite Network

Concept: Develop, test, demonstrate, and operate a satellite-based network to interconnect the five gigabit testbeds and supercomputers at major national research centers

Benefits:

(1) Serve internal needs of US Government agencies (e.g., NASA, DOE, etc.) for distributed computation programs

(2) Provide major contribution to national HPCC program

(3) Develop vital national defense and emergency communications, and computation capability

(4) Develop advanced communications and computational technology of significant industrial and commercial value

(5) Determine proper role for satellite links in "Information Superhighway"

SUPERCOMPUTER NETWORKING APPLICATIONS

MEASUREMENTS:

WE INTEND TO INTERCONNECT A NUMBER OF SUPERCOMPUTERS, HIGH-SPEED/HIGH VOLUME DATA ARCHIVES AND HIGH RESOLUTION GRAPHIC DISPLAY DEVICES INTO A DISTRIBUTED SUPERCOMPUTER NETWORK. WE WILL MEASURE THE DATA TRANSMISSION INFORMATION, THROUGHPUT, AND MOST IMPORTANTLY THE ABILITY OF SUPERCOMPUTERS TO COMMUNICATE WITH EACH OTHER IN A REAL TIME DOMAIN.

SUPERCOMPUTER NETWORKING APPLICATIONS

<u>ASSOCIATED ORGANIZATIONS:</u>

THE GEORGE WASHINGTON UNIVERSITY

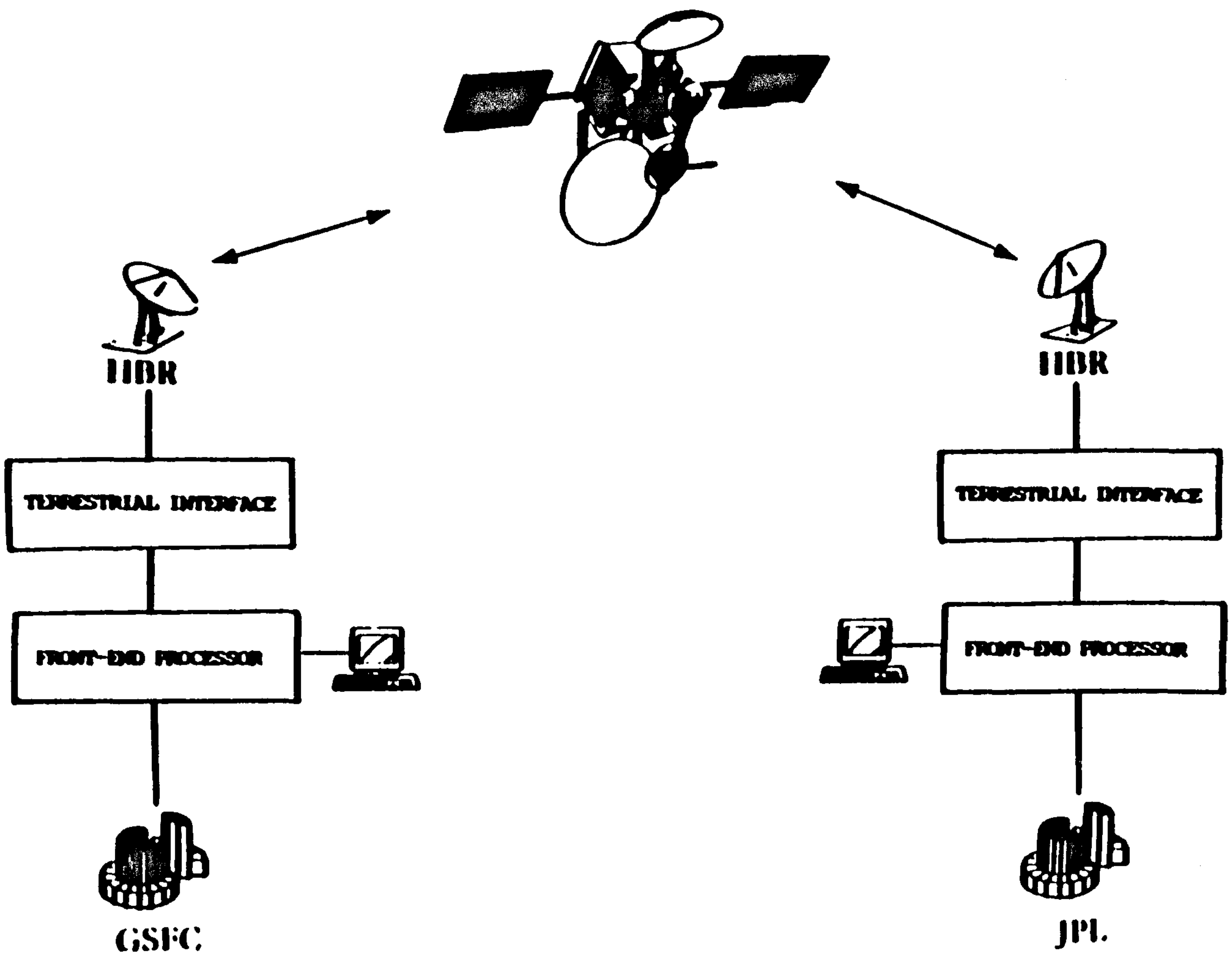
COMSAT LABORATORIES

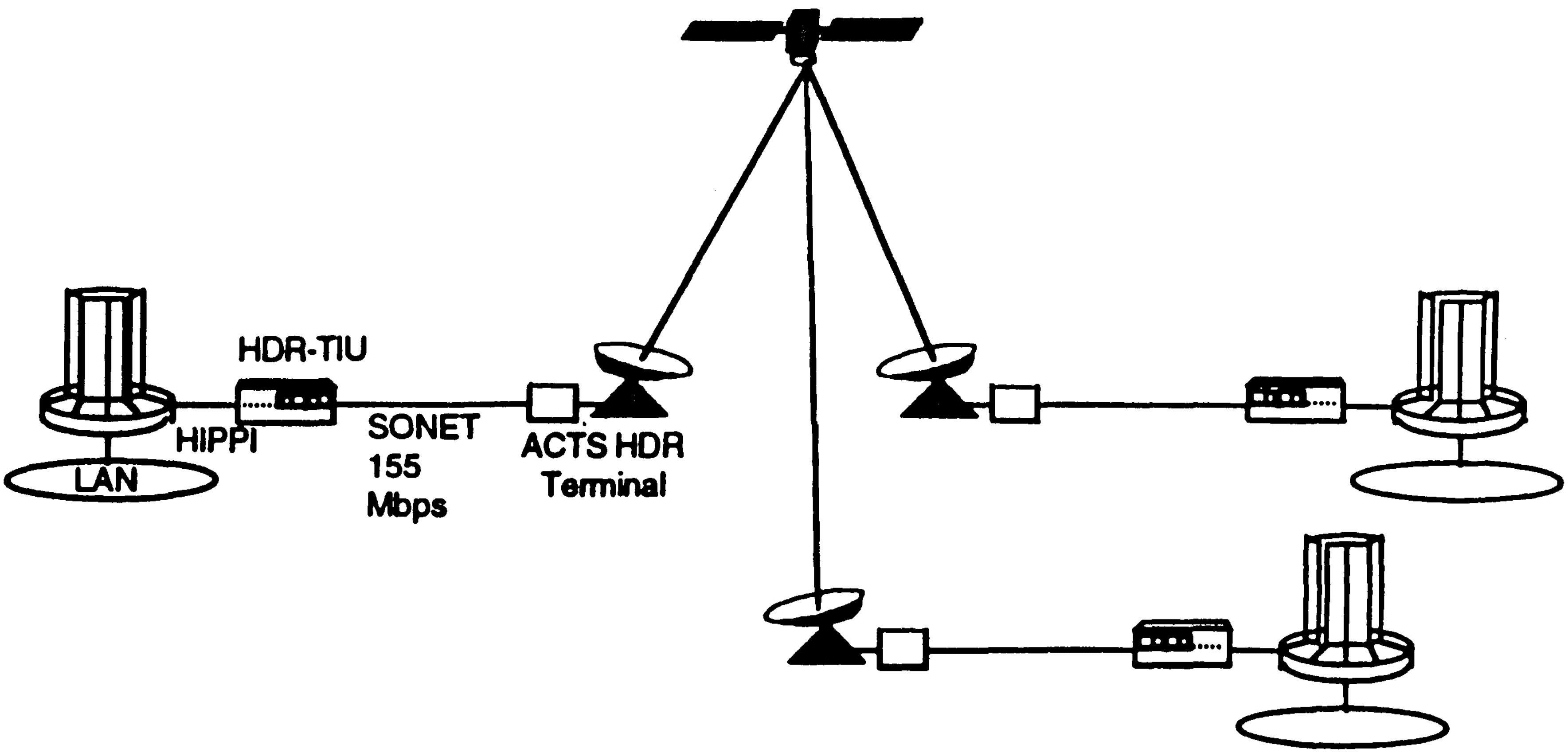
CRAY RESEARCH, INC.

NASA GODDARD SPACE FLIGHT CENTER

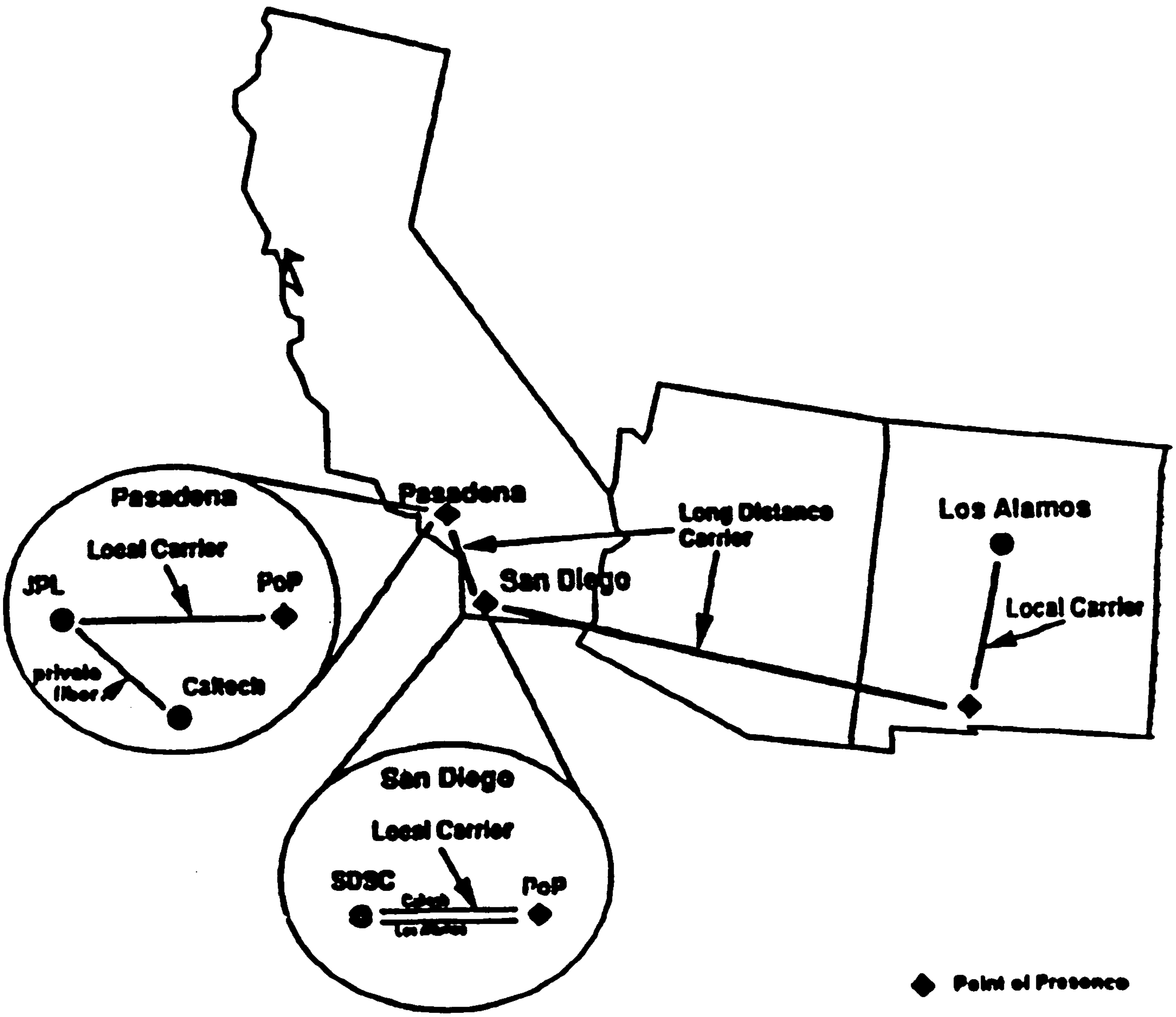
NASA JET PROPULSION LABORATORY

NASA Supercomputer Network

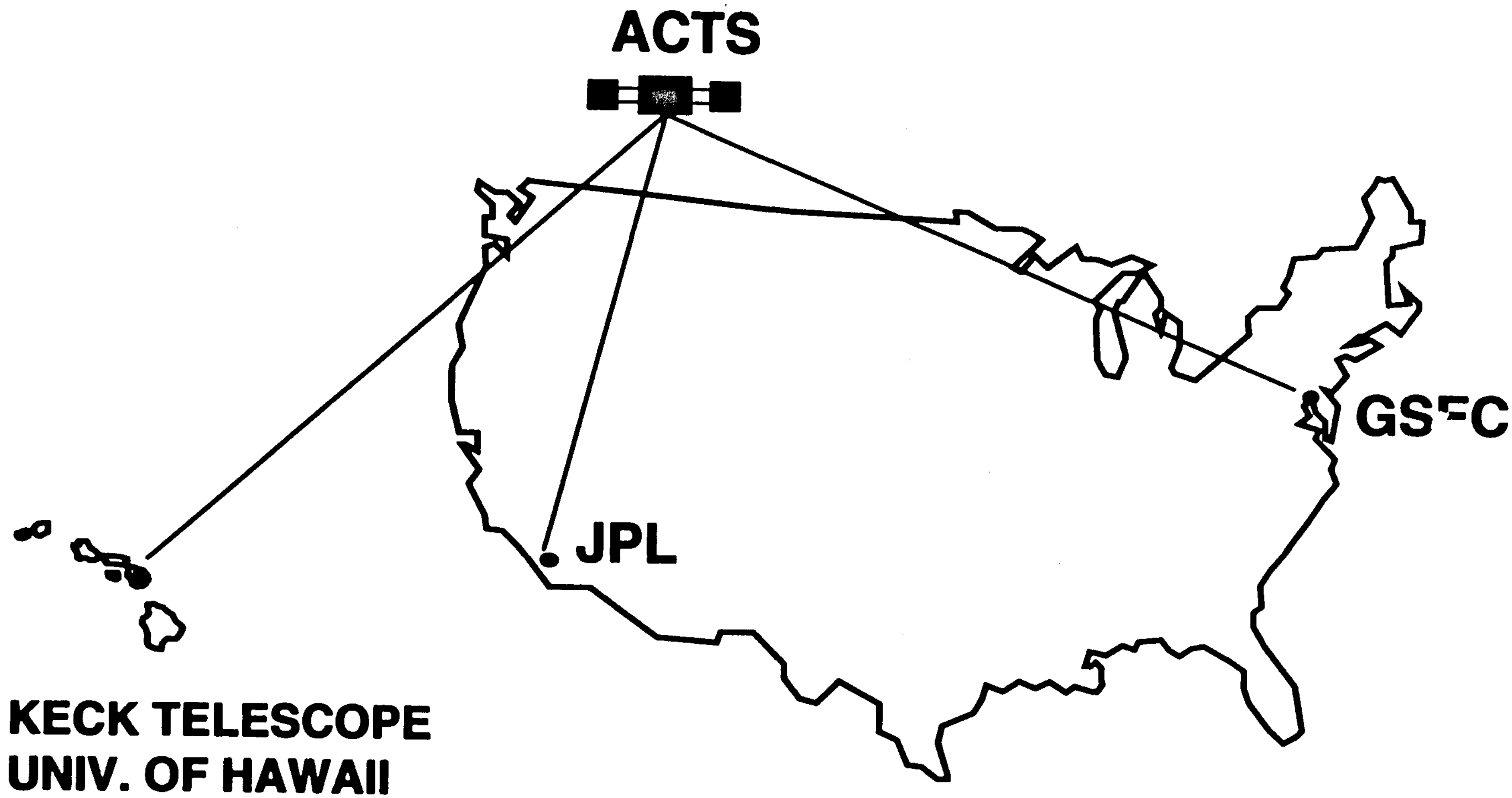



HDR-TIU
HIPPI
LAN
SONET
155
Mbps
ACTS HDR
Terminal

CASA GIGABIT WAN



Topology of Distributed High Performance Computing Network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