https://ntrs.nasa.gov/search.jsp?R=19830014042 2018-02-20T22:00:13+00:00Z

General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.

- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.

- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.

- This document is paginated as submitted by the original source.

- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

Produced by the NASA Center for Aerospace Information (CASI)

NASA Technical Memorandum 83344

Application of MMIC Modules in Future Multiple Beam Satellite Antenna Systems

(NASA-TM-83344) APPLICATION OF MMIC MODULES IN FUTURE MULTIPLE BEAM SATELLITE ANTENNA SYSTEMS (NASA) 14 p HC A02/MF A01 CSCL 17B
N83-22313
Unclas
G3/17 09645

APR 1983
RECEIVED
NASA STI FACILITY
ACCESS DEPT.

Jerry Smetana
Lewis Research Center
Cleveland, Ohio

Prepared for the
1982 Antenna Applications Symposium
cosponsored by the University of Illinois and the
Rome Air Development Center
Monticello, Illinois, September 22-24, 1982

NASA

E-1598

APPLICATIONS OF MMIC MODULES IN FUTURE MULTIPLE BEAM SATELLITE ANTENNA SYSTEMS

Jerry Smetana

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

ABSTRACT

The NASA Lewis Research Center is currently developing multiple beam antenna systems for advanced communication satellites operating in the 30/20 GHz frequency bands (30 GHz uplink, 20 GHz downlink). Up to twenty 0.3° HPBW fixed spot beams and six 0.3° HPBW scanning spot beams will be required.

This paper describes NASA's program for investigating and developing future array-fed dual reflector antenna systems in which monolithic microwave integrated circuit (MMIC) phase shift and amplifier modules are used with each radiating element of the feed array for beam pointing and power gain. The objectives of this work are to demonstrate the feasibility of distributed power amplification and beam pointing with MMIC modules in the elements of an array and to develop a data base for future development.

The technical discussion centers around the potential advantages of "monolithic" antennas for specific applications as compared to systems using high powered TWT's. These include:

1. Reduced losses in the beam forming network;
2. Advantage of space combining and graceful degradation;
3. Dynamic control of beam pointing and illumination contour; and
4. Possibilities for cost and weight reduction.

Also discussed are NASA's program goals and approach.

(Another paper, "30/20 GHz Multiple Beam Antennas for Communications Satellites" by Royce W. Myhre, describes near term technology developments on advanced multiple beam systems using conventional ferrite phase shifters, power dividers, and switches in the beam forming and control networks).

INTRODUCTION

Two phased array-fed dual reflector antenna configuration studies are currently being conducted by COMSAT Laboratories and Harris Corporation for NASA. The studies are the first part of a program to develop antenna systems with array feeds having a GaAs monolithic microwave integrated circuit (MMIC) module at each radiating element. This work is being done as part of NASA's Communications Base R&T program to develop multiple fixed spot beam and multiple scanning spot beam satellite communication systems in the 20 and 30 GHz bands.

Background

The continued rapid growth of communications message traffic (voice, data and video) will require the use of additional satellite communications frequency bands before the 1990 decade. The satellite communications bands currently in use at 4 and 6 GHz (C-band) are already crowded and have resulted in the development of operational systems at 12 and 14 GHz (Ku-band). The service demand through the year 2000 was investigated in market studies conducted by ITT and Western Union (1, 2). This assessment was revised by NASA in 1980. Figure 1 shows demand (expressed as equivalent 36 MHz transponders) rising even faster than originally estimated in spite of projected improvements with time of the capability of transponders to handle more throughput. The capacity of a typical (36 MHz) transponder has grown from a few hundred half circuits in the early seventies to 1,000 or more today. Within the next decade, individual transponder capacities of up to 3,000 half circuits are expected to be in operation by using advanced modulation, coding and bandwidth compression techniques.

The limit of estimated capacity of domestic satellites (DOMSATS) using C and/or Ku-band frequencies (Figure 1) was also increased from the earlier estimate of 430 transponders to about 1,200 transponders. This increase reflected projected improvements in frequency reuse. Even with these improvements, it may be seen from Figure 1 that the C and Ku-bands will be saturated in the early 1990's. In fact, given today's orbit spacing contraints (4^{o} between C-band satellites and 3^{o} between Ku-band satellites), the orbit space for existing plus planned C-band DOMSATS is already saturated. Closer spacing is currently under consideration by the FCC (down to 2^{o} at C-band) and potentially offers additional orbit capacity. It is not expected that this will delay the onset of saturation by more than a few years.

To meet future needs NASA is developing the technology required for achieving space communications at 20 and 30 GHz (Ka-band). The technology developed in NASA programs will emphasize high risk technology usable in other frequency bands, frequency reuse, orbital conservation and increased throughput. In order to implement frequency reuse, new spacecraft antenna technologies are required for multiple, independent, fixed and/or scanning beams. Narrow fixed spot beams (0.3 degree) will permit large volume traffic between single ground terminals located at a carrier's facility in each of ten to twenty major communication centers in the United States. One to six narrow scanning spot beams will provide individual services to a larger number (1,000 to 10,000) of smaller ground terminals located on the premises of large commercial firms and their subdivisions. To implement conservation of orbital space, the new technology is concerned with developing highly reliable, efficient communications systems and antennas with low sidelobes and low cross polarization. The required technologies fall into two categories (a) those that resolve near term needs (for satellites operational by 1990) and (b) those for future needs (operational beyond the year 2000). Among the technology elements identified that require immediate development in order to support an operational system by 1990 is a multiple beam antenna system. This technology development is currently well underway.

Concurrently to meet long term needs, NASA is sponsoring investigations of future technology that have the potential of improving system efficiency, through-put and reliability; increasing versatility; and lowering weight and/or cost. This paper describes one of these investigations, the development of a 20 GHz multibeam antenna system that takes advantage of linear space combination to generate higher power levels using solid state devices in the radiating elements of an array. The program objectives, the approach and some expected benefits of the antenna development will be discussed.

Advanced Technology Program

The discussion in this section will describe briefly the overall goals and the approach in the development of the advanced MMIC antenna technology. The objectives of this program are to develop an antenna system that stresses technology extendable to other frequency bands and facilitates frequency reuse, the increase of orbital utilization and increased throughput. To accomplish these objectives NASA plans to develop the technology for high gain, multibeam antenna systems that use MMIC modules in each radiating element of an array-feed.

NASA plans to investigate a 20 GHz phased array-fed dual reflector transmit antenna and a 30 GHz phased array-fed dual reflector receive antenna separately and then integrate the two into a single aperture system. A multi-year program is planned starting with contractual configration studies to develop a data base of relevant configurations and to develop detailed design concepts. The investigative studies are performed by COMSAT Laboratories, contract NAS 3-23250, and Harris Corporation, contract NAS 3-23252. Concurrently two types of MMIC modules are being developed by Texas Instruments, Incorporated, contract NAS 3-22886, and Rockwell International, contract NAS 3-23247. A follow-on contractual effort is planned to design and fabricate an experimental antenna system. The experimental antenna system will be tested and evaluated in-house to demonstrate proof-of-feasibility.

ANTENNA TECHNOLOGY DEVELOPMENT

This section presents a discussion of NASA's approach to the investigation of the 20 GHz transmit antenna, some of the benefits that are expected from this research effort, the comparative performance of the MMIC system to the conventional systems using TWT amplifiers and the characteristics of the MMIC modules.

Antenna Configuration

Initially, NASA plans to limit its investigations to array-fed dual reflector systems. Two optical configurations of offset-fed dual reflector systems shown in Figure 2 can be used for beam steering given the choice of phase shift or variable power amplitude modules. In a confocal paraboloidal configuration, a nonfocused optical system, Figure 2a, with the subreflector in the near field, beam steering is accomplished by tilting the phase front. In a focused optical system using a parabolic main reflector and hyperbolic subreflector, as in Figure 2b, beam pointing is achieved by scanning the phase center of a cluster of elements across the focal surface. However, when a large number of beams and/or high EIRP are required some trade-offs become necessary. High EIRP requires large arrays and the multiplicity of beams must share the same aperture space. They share the space either by interleaving the elements or each array occupies a smaller block of the available aperture space. Both lead to reduced efficiency. An alternate approach is to use linear combining of several beams so that each beam uses the same array of elements. In this approach the loss (10 log n (in dB) for n combinations) can be overwhelming. This kind of trade-off as well as the selection of the type of radiating element, the type of power divider, the number of elements, the element spacing, the illumination control and the thermal analysis are under consideration in the configuration studies.

MMIC Modules

Two types of 20 GHz MMIC modules were selected for development. A phase control module having a five bit phase shifter and a constant gain amplifier is being developed by Rockwell International and a variable power amplifier having five power amplitudes is being developed by Texas Instruments, Inc. The characteristics of these modules are listed in Table 1 and Figure 3a and 3b are diagrams of the Phase Shift Module and Variable Power Module, respectively, showing the expected layout and estimated size. These modules represent a cross-section of the required GaAs MMIC technology developments. In actual systems, combinations of modules listed below might be used:

a. Variable Power Amplifier
b. Variable Phase Shifter with Constant Gain Amplifier
c. Variable Phase Shifter
d. Constant Gain Amplifier
e. Variable Phase Shifter with Variable Power Amplifier.

MMIC Systems

Some of the predictable potential benefits of array feeds using MMIC modules near the aperture of each radiating element are:

(a) The evolution of 20 and 30 GHz solid state sources for space application from the linear combination of a large number of MMIC modules. It is expected, that, as the efficiency and output power increase in the next generation of device technology, the benefits will be more significant.

(b) The implicit reliability derived from graceful degradation of the linear combination of a large number of amplifiers.

(c) The increased versatility of MMIC systems derived from the high speed scanning capability.

(d) The improved isolation and reduced scan loss derived from a large number of variable phase shift and variable amplifier modules to perform dynamic phase and amplitude weighting control. The analysis of coupling effects and amplifier mismatch will bring about a better understanding and, hence, improved isolation and scan performance.

(e) The reduction of weight and cost.

Comparison to TWT System

Figure 4 shows the block diagrams of the transmit portion of TWT and MMIC 20 GHz scanning spot beam satellite communications systems. The efficiencies shown for the TWT (25 percent) and the MMIC (15 percent) amplifiers are based on linear operation backed-off 2.5 dB below the 1 dB compression point. The beam forming network of the TWT system is shown in two blocks to identify separately the DC loss and RF loss. The DC loss is a function of the switching speed and the number of scanning increments needed to scan a required coverage area or sector. The RF heat loss is a function of the complexity of the beam forming network and directly proportional to the RF output power. The DC switching logic loss in the MMIC system is not shown because the loss (145 mW/module) is already accounted for in the 15 percent power added efficiency of the MMIC module.

Figure 5 is a comparison of the prime power requirements for the two systems where in the TWT system is operated at a low scan rate (where the switching power is negligible) and the complexity of the beam forming network (BFN) is low (where the insertion loss is only 3 dB). The divergence of the two plots occurs because in the TWT system the BFN insertion loss occurs at higher power levels than the loss in the power divider network (PDN) of the MMIC system. The performance potential for these two systems is not comparable, when one of the systems is configured in its near optimum mode of operation and the other is not. In Figure 5 both systems are configured in a mode favorable to the TWT system. An alternate comparison is shown in Figure 6 where a TWT is used to drive a large array with a ferrite phase shifter at each radiating element, an operating mode more favorable to the MMIC system. (PIN diode or FET phase shifters are not able to handle the higher TWT output power levels). This comparison is made to show that the MMIC system is even more efficient when a large array is necessary. The BFN losses for the TWT systems increase approximately as $\log_2 N$ (where N is the number of levels) due to extra levels of power division required.

In the comparisons shown in Figure 5 and 6, the TWT system is assumed to have digitally controlled ferrite devices (variable power dividers, variable phase shifters or waveguide switches) that have 0.5 microsecond switching speed and are operated at a two kilohertz scan rate. The FET switches in the MMIC modules have a 10 nanosecond switching speed. To try to drive the ferrite devices faster one pays an even higher penalty in additional prime power as seen in Figure 7. The operating speeds greater than $(10)^4$ for the TWT system are limited so that two switching transient times are equal to one percent of the dwell time.

It is evident, that even though the GaAs module efficiency is lower than that of the TWT, the MMIC system efficiency can be higher. It is significantly higher when scanning rates greater than ten kilohertz are required. In addition, the MMIC system has advantages (previously discussed) such as dynamic illumination control, graceful degradation, and the potential for weight and cost reduction.

CONCLUDING REMARKS

It has been pointed out that, because of projected overcrowding of the lower frequency bands, there is a need to develop the technology for the 30/20 GHz satellite communications bands by 1990. NASA has identified the use of several narrow spot beams with spacial isolation as an effective means for frequency reuse and the conservation of orbital space. To implement frequency reuse NASA has sponsored the development of multiple fixed spot beam and multiple scanning spot beam antennas.

One program, using current technology, is intended to satisfy immediate needs (operational by 1990). Another, using advanced technology, is being investigated to fulfill future needs (beyond the year 2000).

The advanced investigations make use of monolithic microwave integrated circuit (MMIC) modules having phase shift and power amplification functions on one GaAs substrate. The MMIC modules are placed in each element of an array feed to produce higher power levels (through distributed amplification), beam steering and dynamic illumination control (with phase and amplitude weighting).

Satellite communications systems using this "monolithic" antenna approach are shown to have potential advantages, such as, implicit reliability through graceful degradaton, high speed (10 nanoseconds) scanning capability, improved beam isolation, reduced scan loss, lower weight, lower cost and higher overall system efficiency.

REFERENCES

1. Gamble, R. B.; et al.: 30/20 GHz Fixed Communications Systems Service Demand Assessment, U.S. Telephone and Telegraph Corporation. NASA CR-159620, Aug. 1979.

2. Gabriszeski, T.; et al.: The 18/30 GHz Fixed Communications System Service Demand Assessment - Vol. 2: Main Text. NASA CR-159547, June 1979.

3. Gabriszeski, T.; et al: The 18/30 GHz Fixed Communications System Service Demand Assessment - Vol. 1: Executive Summary. NASA CR-159546, June 1979.

TABLE 1.0 CHARACTERISTICS OF THE PHASE CONTROL AND VARIABLE POWER AMPLIFIER MODULES

	Variable Phase Control Module	Variable Power Amplifier Module
Frequency (GHz)	17.7 to 20.2	17.7 to 20.2
Impedance	50 ohms (nominal)	50 ohms (nominal)
VSWR	Less than 1.3:1	Less than 1.3:1
RF Output Power	200 mW	500 mW 125 mW 50 mW 12.5 mW 0
Gain	16 dB	20 dB (at full power)
Gain Variation	1.0 dB (2.5 GHz Band) 0.4 dB (any 500 MHz BW)	1.0 dB (2.5 GHz Band) 0.4 dB (any 500 MHz BW)
Power Added Efficiency	15 percent	15 percent 12 percent 9 percent 6 percent * percent
Phase Shifter	Time Delay Type	
Control	5 bit	
Lowest Bit	11.25 degrees	
Tolerance	+3 degrees	
Response Time	10 nanoseconds	10 nanoseconds

*Max Dissipation = 50 mW

ORIGINAL PAGE IS
OF POOR QUALITY

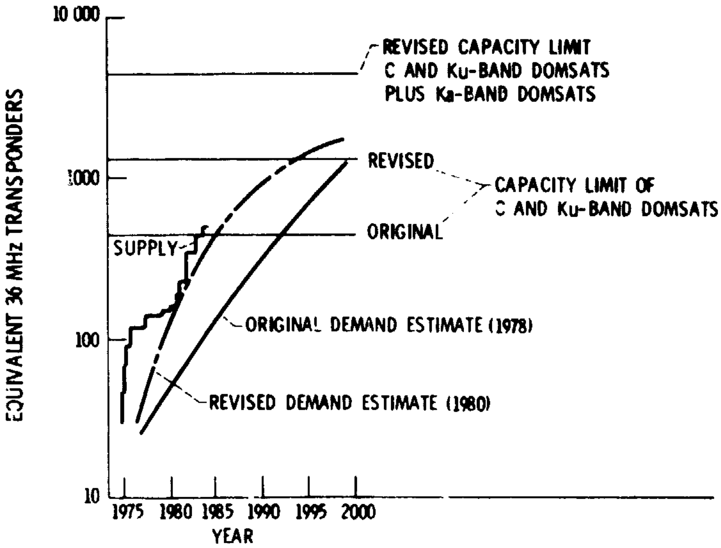
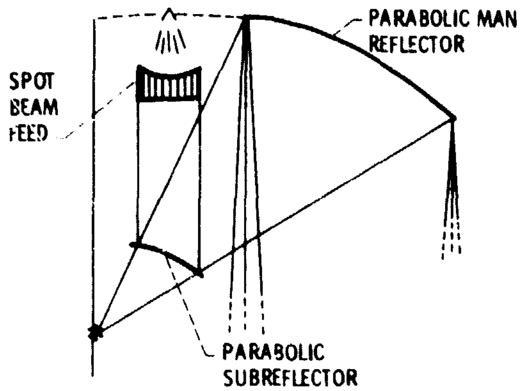
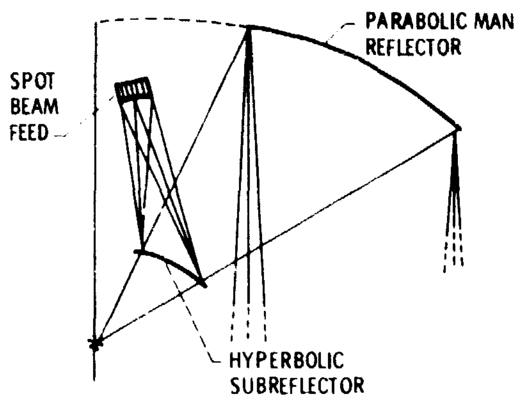


Figure 1. - U.S. Domestic Communications Satellite supply and demand.

ORIGINAL PAGE IS
OF POOR QUALITY



(a)

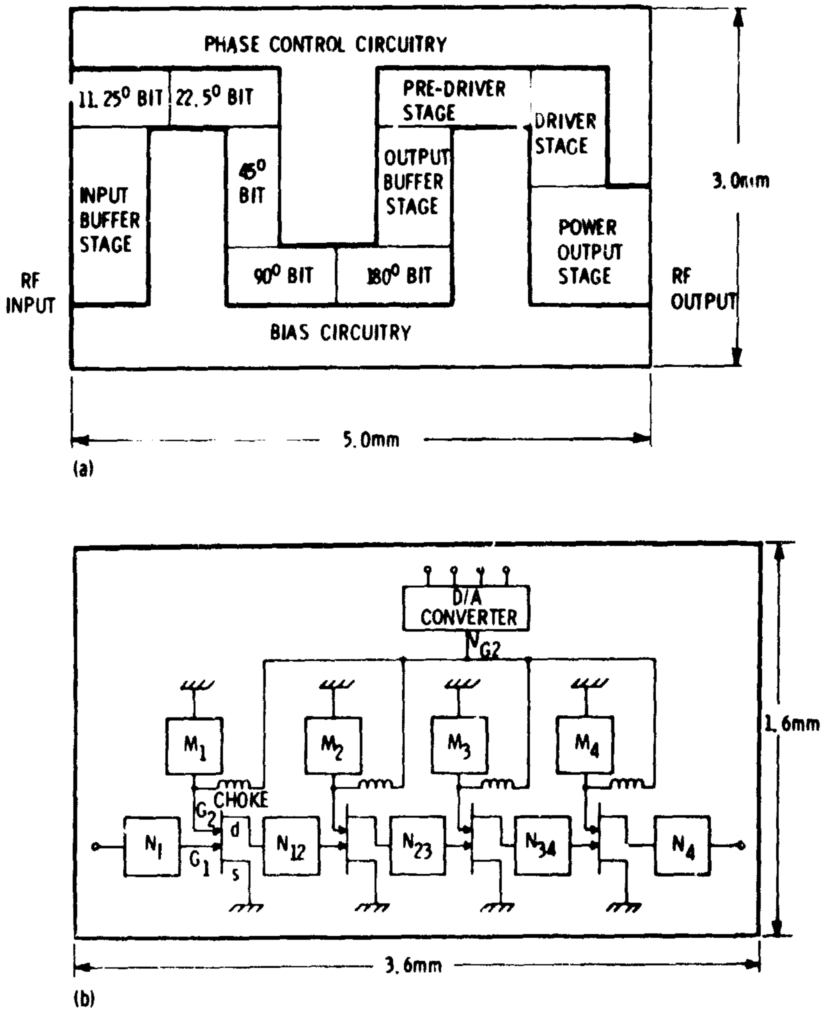


(b)

(a) Confocal parabolic subreflector.
(b) Hyperbolic subreflector.

Figure 2. - Dual reflector optics.

ORIGINAL PAGE IS
OF POOR QUALITY

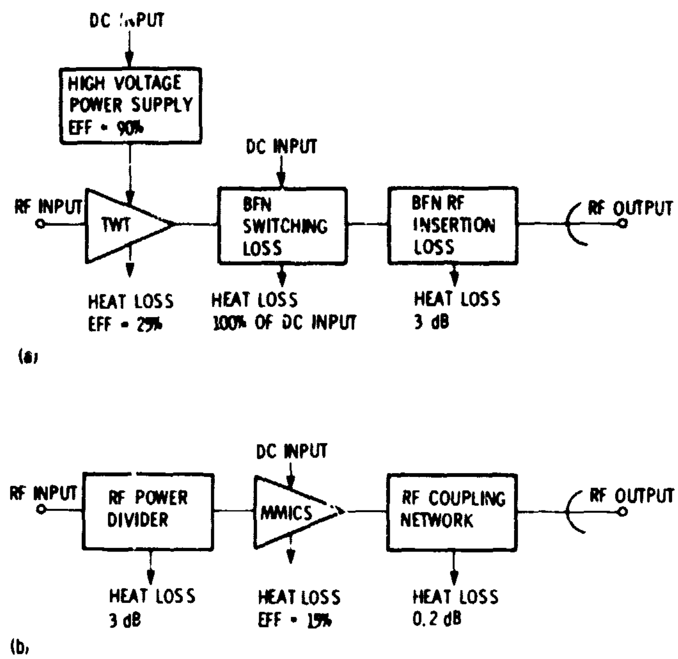


(a) Variable phase shift module.

(b) Variable power amplifier module.

Figure 3. - Layout block diagrams of the VPS and VPA modules.

ORIGINAL PAGE IS
OF POOR QUALITY



(a) TWT System

(b) MMIC System.

Figure 4. - Block diagram of satellite communications 20 GHz transmitter using (a) TWT Amplifier System and (b) MMIC Amplifier System for scanning beams.

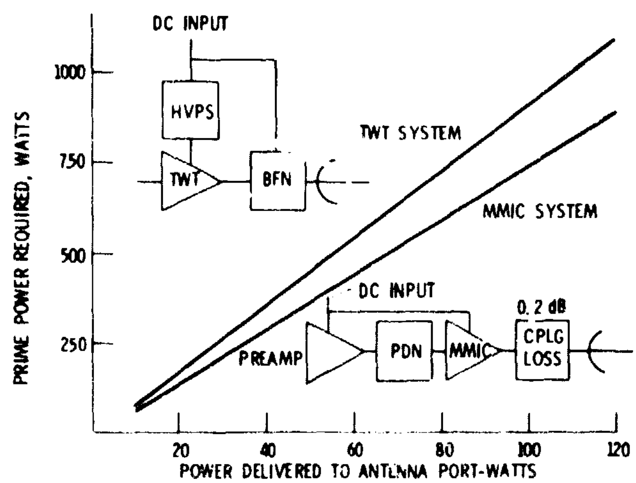


Figure 5. - Prime power requirements for TWT and MMIC Systems.

ORIGINAL PAGE IS
OF POOR QUALITY

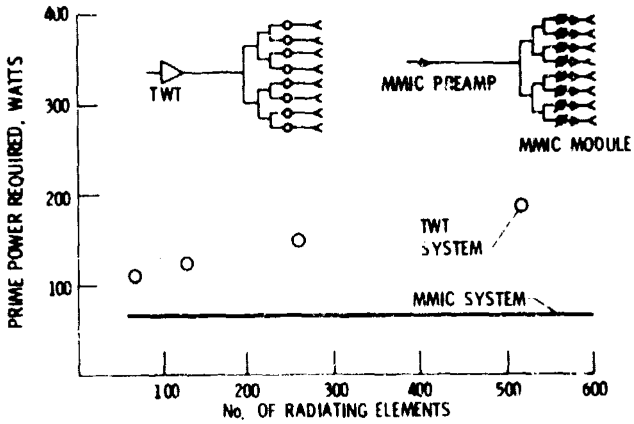


Figure 6. - Prime power requirements for electronically scanned arrays.

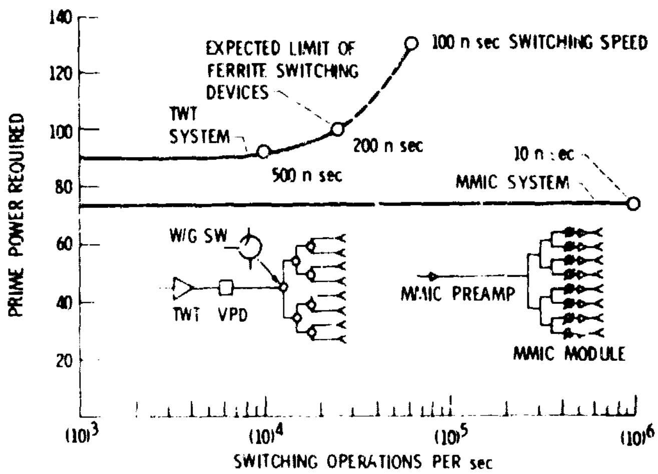


Figure 7. - Prime power vs switching speed for scanning arrays.