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A SYSTEM FOR THE SIMULATION AND EVALUATION OF SATELLITE COMMUNICATION NETWORKS

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Abstract

With the emergence of a new era in satellite communications brought about by NASA's thrust into the Ka band with multibeam and onboard processing technologies, new and innovative techniques for evaluating these concepts and systems are required. To this end, NASA, in conjunction with its extensive program for advanced communications technology development, has undertaken to develop a concept for the simulation and evaluation of a complete communications network. Incorporated in this network will be proof-of-concept models of the latest technologies proposed for future satellite communications systems. These include low noise receivers, matrix switches, baseband processors, and solid state and tube type high power amplifiers. To provide a meaningful simulation capable of evaluating all aspects of a communications network, the concept has been extended to include five major areas: (1) User Signal Source Characteristics, up to 220 megabits/second burst rates, (2) Ground Terminals, a minimum of four in hardware, (3) Link Characteristics, dynamic rain-fade and range delay, (4) Satellite Transponder, and (5) Network Control. To accomplish this, numerous supporting technologies must be added to those aforementioned proof-of-concept models. These include controllers for synchronization, orderwire, and resource allocation; gain compensation, signal leveling, power augmentation, and rain-fade and range delay simulation. Taken together, these will be assembled to comprise a system capable of addressing a growing list of issues. To date, these include the following: (1) Transponder configuration and design, (2) Ground terminal requirements and design, (3) Path delay and attenuation, (4) Network synchronization and control, (5) Signalling techniques and protocols, (6) Ground terminal user interfaces, (7) Demand access vs. channel efficiency, (8) Component and system interfaces, and (9) Component and system performance requirements. The simulation and evaluation system as planned will be modular in design and implementation, capable of modification and updating to track and evaluate a continuum of emerging concepts and technologies. Data sources will be real or realistically simulated. Path losses and delays will be realistic and variable. Modern state-of-the-art test instruments are introduced at each appropriate point in the system where measured performance is of importance. All of the above are under the control of a real-time Experiment Control and Monitoring Computer. This will make possible the preprogramming of complete communications scenarios for the simulated network including varying traffic loads, environmental effects, and spacecraft control ranges. In conjunction with the laboratory system, a computer based analytical modeling program will be employed to predict system performance of various proposed configurations. The results of the modeling analysis will then be compared with those measured in the laboratory. The simulation and evaluation system is currently under development at NASA's Lewis Research Center. Designs for all subsystems are complete and the first phase of communications link integration is underway. Although systems development and reconfiguration are continuing processes, the first complete network simulation is planned for the third quarter of 1984.

Introduction

With the re-entry of NASA into communications satellite technology in 1978 came the emergence of a new era in satellite communications. Having recognized the need to make both technical and economic advances to conserve frequency spectrum and counter threats of foreign competition, the President directed NASA to renew its role in communications technology research and development. As a result, NASA has been pursuing a $40 million advanced technology program over the last 4 years. To date, the first phase of technology development is nearing completion. The areas being worked were all identified through government sponsored industry studies as essential and involving high risk.

Success will ultimately be determined by the extent to which the communications satellite industry applies the NASA developed technology in building its next generation of satellites targeted for the early 1990's. Until then, it is essential that NASA pursue a program of risk mitigation through a vigorous laboratory based test and evaluation program and an experimental satellite to verify and evaluate those features beyond validation through ground test. The experimental flight named ACTS, for Advanced Communication Technology Satellite, is planned for launch in 1988 with a 2 year on-orbit experiment period. Until then, an extensive ground based test and evaluation program will be conducted using a comprehensive laboratory test bed currently being developed at NASA's Lewis Research Center. The initial development and description of this laboratory system is the subject of this paper.

Technology Program Overview

The technology program referred to above and reported previously in Refs. 1 to 3, has focused primarily on those elements required to open the 30/20 GHz satellite communications band and thereby provide multibeam communications capability. These concepts are more fully described in Ref. 4.

For a better understanding of the system and its operation described herein, some of the fundamental concepts and operating principles of a multibeam satellite communications system, as presently conceived, will be described here.

Multibeam communication, as the name implies, consists of a number of simultaneous fixed beams, say 18, and possibly 6 scanning beams blanketing the continental United States. The 2.5 GHz bandwidth available in the 30/20 band can be effectively reused many times in such a scheme due to the narrow beam width and high beam isolation possible. Large high data rate stations in the fixed beams may be bursting at an aggregate rate of 550 Mega Bits Per Second (MBPS) per beam. Other low data rate stations in the scanning beams may be bursting at from 27.5 to 110 MBPS, yet when frequency multiplexed, consume the same bandwidth as a 550 MBPS channel. Since it is possible to have thousands of individual message circuits requested at any one time, most requiring a beam pair to complete, an active switching and processing system is required on the satellite between the up and down link multibeam antennas. This capability is supplied by the IF matrix switch in a 20 X 20 crosspoint configuration and the baseband processor capable of processing the equivalent of 60,000 telephone calls simultaneously. These combine to provide a total satellite throughput of 10 GBPS of which 4 GBPS passes through the baseband processor.

To cause this capability to be realized using a Time Division Multiple Access (TDMA), digital transmission mode, computers on-board the satellite and in each ground station must work in concert with each other to synchronize all data flow in the network. A master control station (MCS), on the ground, communicates with each ground station through an in-band orderwire network and with the satellite computer to control all communications traffic.

NASA has selected from all elements in the above concept those which are both new and pose the highest risk for development. With the successful development of these as a goal, contractors, multiple in most cases, were selected to develop those components as listed in Table 1. Proof-of-concept (POC) versions of each component targeted for satellite use have been delivered.

Ground terminal POC hardware will be delivered by the third quarter of 1984. The extent of development for POC varies with each item. Form factor and design are nearly flight prototype for the receivers, but a functional breadboard, consisting of equipment racks, resulted from the baseband processor effort.

Each component was specified such that the highest level of performance possible could be achieved without constraints imposed by overall system limits such as common IF frequency bands. This fact consequently posed some unusual integration considerations in the evaluation system design which ultimately resulted in a more general purpose configuration. Each POC component was extensively tested by its developer prior to delivery to NASA.

Subsequently, all have undergone extensive evaluation at Lewis. This effort has allowed the Lewis engineering team to become thoroughly familiar with the performance of each POC component prior to its integration into the laboratory communications system.

Communications System Objective

In developing a laboratory capability for evaluating a wide variety of advanced satellite communication components, the issues shown in Table 2 have been established as goals for the system. To achieve this, the system must provide a comprehensive simulation of a satellite communications network complete with multiple ground terminals comprising a representative user network. The overall objective is to provide a system capable of not only evaluating individual components of new technology but new concepts of system application and control. Although initially implemented using 30/20 GHz multibeam components the goal is to end up with a system with a long term generic capability for applications at other frequencies and other service scenarios.

Approach

When simulating a system such as a satellite communications network, both hardware and software techniques are available. As a result of approximately 25 manyears of effort, the government has developed a Channel Model Simulation Program, CMSP, capable of simulating a complete digital satellite communications channel in software including effects of filtering, interference, nonlinearities, coding, and baseband processing. Examples of uses of this software simulator include the evaluation of benefits of new devices (effects of linearity, group delay, etc.), evaluation of compromises in specifications of devices, and trade-offs between exotic modulation methods versus spectrum confinement via filtering.

In addition to using the CMSP, the main focus of the communication system simulation effort is the hardware simulator being developed in the Lewis laboratory. Figure 1 depicts the overall functional layout of the hardware simulator.

The intent is that there will be at least one, preferably more, complete hardware paths through the network from user to user. Where loading is a factor in the network performance, additional traffic will be simulated in software. The goal of this approach is to always strive for as much realism in the network simulation as possible. Actual flight and ground POC hardware are used wherever possible. All necessary frequency translation and signal conditioning hardware are employed to create realistic communications paths. Due to laboratory constraints, actual antennas are not used. Instead, their electrical characteristics are matched in hardware and, where appropriate, beam switches are employed to simulate multibeam operation.

All controls normally found in an advanced digital communications network have been included using interactive microprocessors and digital computers. To inject realism and permit comprehensive system control and monitoring, a large minicomputer system (Experiment Control & Monitoring, or EC&M Computer) controls all simulated environmental effects, dynamically profiles user traffic, and monitors and reports all responses throughout the network.

System Description

Transponder

The transponder portion of the system represents the spaceborne portion of the communications network. In most instances, the transponder will contain the majority of the new high risk components. A block diagram of the transponder for a 30/20 GHz multibeam communications package is shown in Fig. 2. Not all elements of this configuration are planned to be functional at any one time. As will be described later, the test and evaluation program will evolve in three transponder phases. These are the translating, switching, and processing phases.

In the translating phase, Phase I, the matrix switch is employed as a static element only. Dual beam operation will be evaluated at data rates of 220 MBPS. Also, an FDM operation of two or more channels will be tested. In Phase II, the IF switch is dynamically controlled to implement a switching transponder with burst transmissions and power augmentation added. Finally, in Phase III, the baseband processor is added for full on-board demodulation, routing and remodulation along with simulation of scanning beams.

The interfaces being developed will allow for a variety of receivers and matrix switches to be evaluated. Amplitude and delay equalization are being incorporated to compensate for deviations introduced by the low noise receiver, AGC amplifier, matrix switch, upconverter/mixer, driver amplifier, and high power output amplifier.

Propagation Effect Simulators

The RF propagation path, both up and down, between satellite and ground constitutes a significant part of the communications link at 30/20 GHz. Not only does rain pose the threat of severe attenuation, up to 20 dB, but TDMA transmissions are affected by satellite motion relative to the ground terminals.

The effects of rain fade can be compensated for by either coding or power augmentation. Both techniques will be evaluated through the course of system testing. Both require timely sensing of the onset of attenuation and the development of techniques for initiation of the proper response both in space and on the ground. A system for power augmentation control and evaluation is shown in Fig. 3.

Rain fade simulation is provided by computer controlled rotary vane attenuators. These will be implemented in the downlink, have a range of 0-30 dB, and have a rate of change of up to 1 dB per second.

Coding solutions require encoders and decoders on the ground and satellite. When these become available, the effects of coding compensation will be evaluated.

In an actual satellite communications system, individual ground terminals must compensate for variable satellite range by constantly adjusting burst times so that data bursts from separate ground terminals, each with a different range and range variation, arrive at the satellite in their designated time slots to keep the system in synchronism. For accurate link effects range delay simulators are being built to provide controlled, variable time delays. These hardware simulators are based on digital storage and retrieval principles due to the need for large delays and the difficulty in achie ng them through analog means. Having decided on . Jigital delay unit, integration and operational techniques were investigated. Although similar delays exist on both up and down links, simulation on the downlink side poses severe control and synchronization problems. It was therefore decided to implement the range delay on the uplink only. Being digital in nature, its physical location is within the ground terminal prior to the modulator.

The heart of the range delay simulator shown in Fig. 4, is a 64K X 80 first-in/first-out memory. The delay unit can operate at a bit rate of 220 MBPS. The total delay capacity ranges from 19 milliseconds at a full frame traffic density to 125 milliseconds (equivalent to real time delay) at 15 percent frame traffic density. The range simulators output date rate is controlled by the EC&M computer. Variations in this rate relative to the input rate produce the variable delay by slowly filling or draining the FIFO. The Doppler shift in data rate is also simulated using this technique. Thus, the EC&M computer controls the amount of delay and its variations. Delay variations introduced by the range delay unit will be corrected in the ground terminal by means of bit-time insertion/deletion during frame guard words. If the proper corrections are made, the overall data rate reaching the satellite will remain in synchronism with the satellite's switching.

Ground Terminals

The ground terminals being developed must work in the network being built around probable 30/20 operational principles. Since studies[5], have shown the most effective data format to be time division, multiple access (TDMA) rather than the currently more popular frequency division, multiple access (FDMA), both space and ground segments have been limited to TDMA concepts and operational principles. In accomplishing this, the ground terminal is being developed from three separate and functionally distinct parts. These are, as shown in Fig. 5, the IF/RF section consisting of receiver, down converter, upconverter, high power amplifier, and associated components; the digital data section consisting of user data buffers, encoders/decoders, scramblers/descramblers, modulators, demodulators, and associated components; and the digital control section consisting of control word generators and checkers, user interface control processors, orderwire processor, and timing and control circuitry.

Fairly conventional techniques are used in the IF/RF section. New technology evaluation will initially be limited to the 30 GHz high power amplifier currently under contract. The use of C-band IF frequencies is intended to provide some equipment commonality with existing components. Since the ground terminal is an area where cost will be a significant factor, future technology efforts to reduce ground terminal cost may provide additional subjects for evaluation.

The digital data section along with the digital control section comprise a large area of systems technology rather than component technology. It is envisioned that current component technology efforts will likely provide large scale integrated (LSI) versions of common functions such as modulators, demodulators, encoders, decoders, and high speed building blocks such as shift registers. The LSI functions should significantly reduce the cost of replicating ground terminals. The system technology, on the other hand, is inextricably tied to the myriad of common carrier and computer system communication protocols and interface standards and the unique network requirements of the proposed multibeam communication system.

The ground terminal being developed for use in the laboratory will be an attempt to functionally if not physically resemble those to be employed in an operational network such as ACTS. Some of the features being employed as shown in Fig. 5 include compression and expansion buffers in each data path consisting of first-in/first-out memories. Critical control information such as "valid word count" is error encoded to ensure accurate receipt. All data is scrambled to ensure an adequate number of level transitions.

As with the satellite transponder, the ground terminals will be implemented minus their antennas. Ground terminal deployment in the system will be limited to two terminals through Phase II but will be increased to four for Phase III.

User Simulators

The effectiveness of a comprehensive system evaluation depends greatly on the quantity and quality of data that can be stimulated and the ability to evaluate the effect the system has on the data. Commercial bit-error-rate (BER) testers exist and will be used where possible. Their cost, though, prohibits their use in multiples representing large numbers of users. The coding sequences used by such units also makes difficult their application to bursted data streams. To overcome these problems, a special purpose data generator and a companion data checker have been developed.

The data generator/checker is shown in Fig. 6 and uses a programmable control word to initialize the generator to produce a pseudo-random data stream. The data stream contains the control word, heavily error encoded and periodically sent in a known location. The data checker reads and decodes the control word and, using it, reconstructs the source bit stream for comparison with the received data bits.

The data generator can produce a continuous pseudo-random data stream from 1 MBPS to 220 MBPS. The data checker can test for and compute BER's from 10^{-3} to 10^{-7} for tests up to one hour in duration. Used in combination, both transmitting and receiving users can be simulated. The cost per unit is low so a different generator/checker can be employed for each user thus avoiding any phase coherence of data which could mask system problems. Each data generator and checker is separately controllable from the EC&M computer thus allowing each to be programmed to appear as a normal user entering and leaving the network.

Additional data sources will be used for a more subjective analysis. These include both live and taped video, human subjects and test patterns, and actual voice and data transmission. Where the originating signal is analog suitable digitizing will be performed. Commercial, common carrier type, switching equipment will be employed so that any unique terminal interface modules can be developed and evaluated.

Network Control

One element of an operational communications system remains. In the system described here it is called the Master Control Station (MCS). It is the brain or nerve center of the whole network. In operation it knows the status and current configuration of the satellite and all active ground terminals, receives service requests from all ground terminals, determines and apportions all available communications resources, notifies all ground terminals and the satellite of new required configurations, and monitors network performance and takes corrective action when required.

The main element of the MCS is a sufficiently large digital computer to compute the switching algorithms and apportion resources in a time frame such that latency in completing a call is kept to an acceptable limit. Although it is doubtful that actual service requests from the system simulated in hardware can effectively load the MCS, those along with a software simulated load should provide an effective test bed for algorithms being developed.

Systems Operation and Control

The remaining portion of the laboratory simulation is the Experiment Control and Monitoring (EC&M) computer. The role of this computer is to make the portions that represent operational elements: ground terminals, satellite transponder and the master control station, see what appears to be a real operational environment. The EC&M computer controls the occurance and characteristics of all user traffic, creates the up and downlink environments, monitors the performance of all system elements and reports all in easily read and understood forms.

To accomplish this end, instruments have been purchased with compatible IEEE-488 bus interfaces, RS-232 interfaces, and remotely programmable and controllable options. All custom designed units can be remotely controlled and programmed. Microprocessors, which are liberally used throughout the system, can report their status and that of the subsystem they are controlling. Remote terminals tied to the EC&M computer are placed throughout the laboratory near key areas of the hardware simulator. From these terminals portions of the network can be broken out, including segments of the transponder, and individually tested, a very useful tool during buildup and initial checkout.

Buildup and Testing

As mentioned earlier, the buildup of the hardware network simulation is basically paced by the plan to develop the satellite transponder in three phases, i.e. translating, switching, and processing. Each succeeding phase adds to the complexity of the transponder and to the number and complexity of the tests that can be conducted. In each of phases II and III, the preceding phase's tests should provide a functional, known baseline on which to build the next test. The current planned tests to be performed during each phase are shown in Table 3, along with an overall schedule in Fig. 7.

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Current Status

The Phase I transponder has been assembled. The remainder of the network using the Phase I transponder will not be complete until delivery of modulators and demodulators currently scheduled for the third quarter of 1984. Until then, testing will be limited to that possible using standard signal generators, spectrum analyzers, and automatic network analyzers. Performance testing and system evaluation is expected to proceed in accordance with the schedule in Fig. 7.

References

1. Sivo, J. N., "NASA's Program in Communication Satellites," Space, Shuttle: Dawn of an Era, edited by W. F. Rector III and P. A. Penzo, Univelt for American Astronautical Society, San Diego, 1980, pp. 659-675.

2. Sivo, J. N., "Advanced Communications Satellites," NASA TM-81599, 1980.

3. Sivo, J. N., "The 30/20 GHz Experimental Communications Satellite System," NASA TM-82683, 1981.

4. Ramler, J. R., and Salzman, J. A., "Concept for Advanced Satellite Communications and Required Technologies," NASA TM-82984, 1982.

5. Stevens, G., "A Comparison of Frequency Domain Multiple Access (FDMA) and Time Domain Multiple Access (TDMA) Approaches to Satellite Service for Low Data Rate Earth Stations," NASA TM-83430, 1983

TABLE I. - COMPONENTS DEVELOPED TO POC UNDER NASA TECHNOLOGY DEVELOPMENT PROGRAM

Technology	Contractors
Low noise 30 GHz receiver	LNR, ITT
IF Switch matrix	Ford Aerospace, GE
20 GHz Impatt transmitter	LNR, TRW
20 GHz GaAs FET transmitter	TRW, TI
20 GHz multimode TWT	Hughes
Power processor for multimode TWT	TRW
Baseband processor	Motorola
30 GHz Solid state transmitter	TRW
Low cost ground terminal antennas	Scientific Atlanta

TABLE 2. - ISSUES FOR LABORATORY EVALUATION

- Design
  - Transponder design and configuration
  - Communication system modeling program verification
  - Ground terminal design and confirmation
  - Path delay and attenuation
  - Terminal interfaces
  - User simulators
  - Components and system interfaces
- Operating techniques
  - Synchronization and control
  - Network control
  - Signaling techniques and protocols
- Performance measurement
  - Channel utilization efficiency
  - Component and system performance
  - Measurement and analysis techniques

TABLE 3. - PLANNED SYSTEM EVALUATION TESTS

Phase I
- RF (CW) transponder and ground terminal
- Continuous data transmission (220 MBPS)
- Multimode TWT operation, continuous data

Phase II
- Burst operation through dynamic matrix switch
- Switch synchronization tests
- Multichannel tests
  - Synchronization of second station
  - Order wire operation
  - Range variation
  - Rain fade simulation
  - Demand assignment
- Tests with ACTS experimental terminal

Phase III
- Bursts operation through baseband processor
- Addition of BBP controller
- Operation under automated network control
- Multiple station operation including ACTS experimental terminal

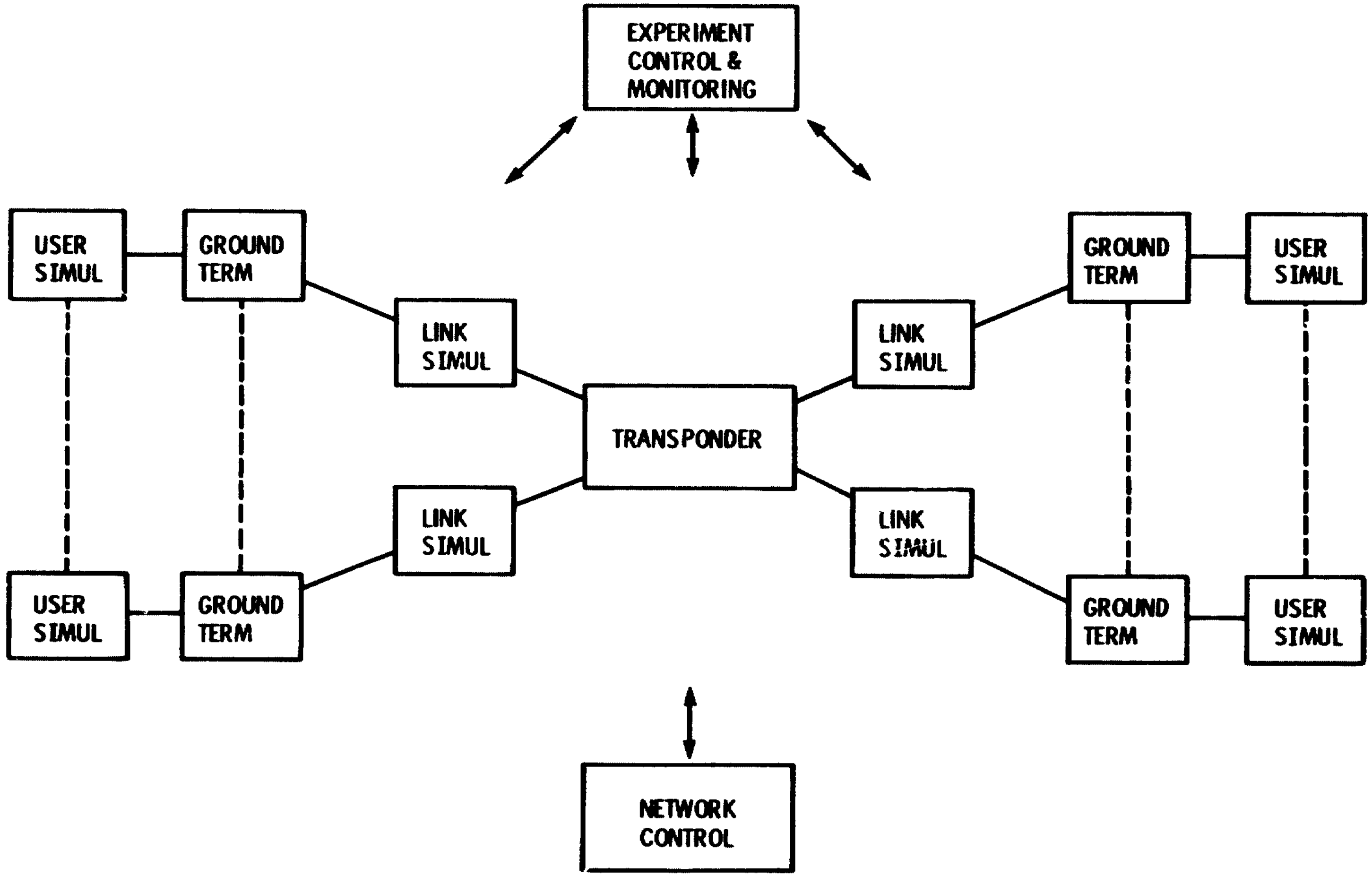

Figure 1. - Hardware simulation of communication network.

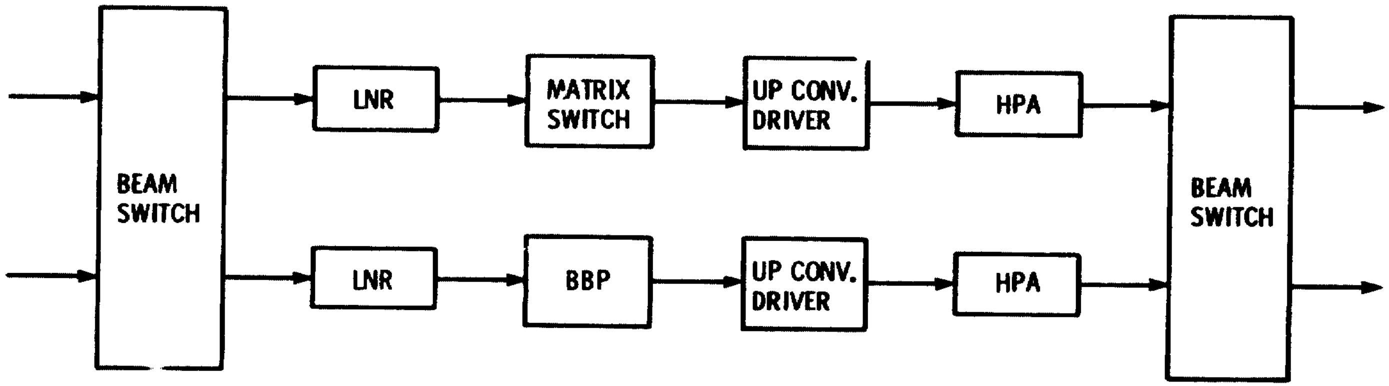

Figure 2. - Transponder block diagram.

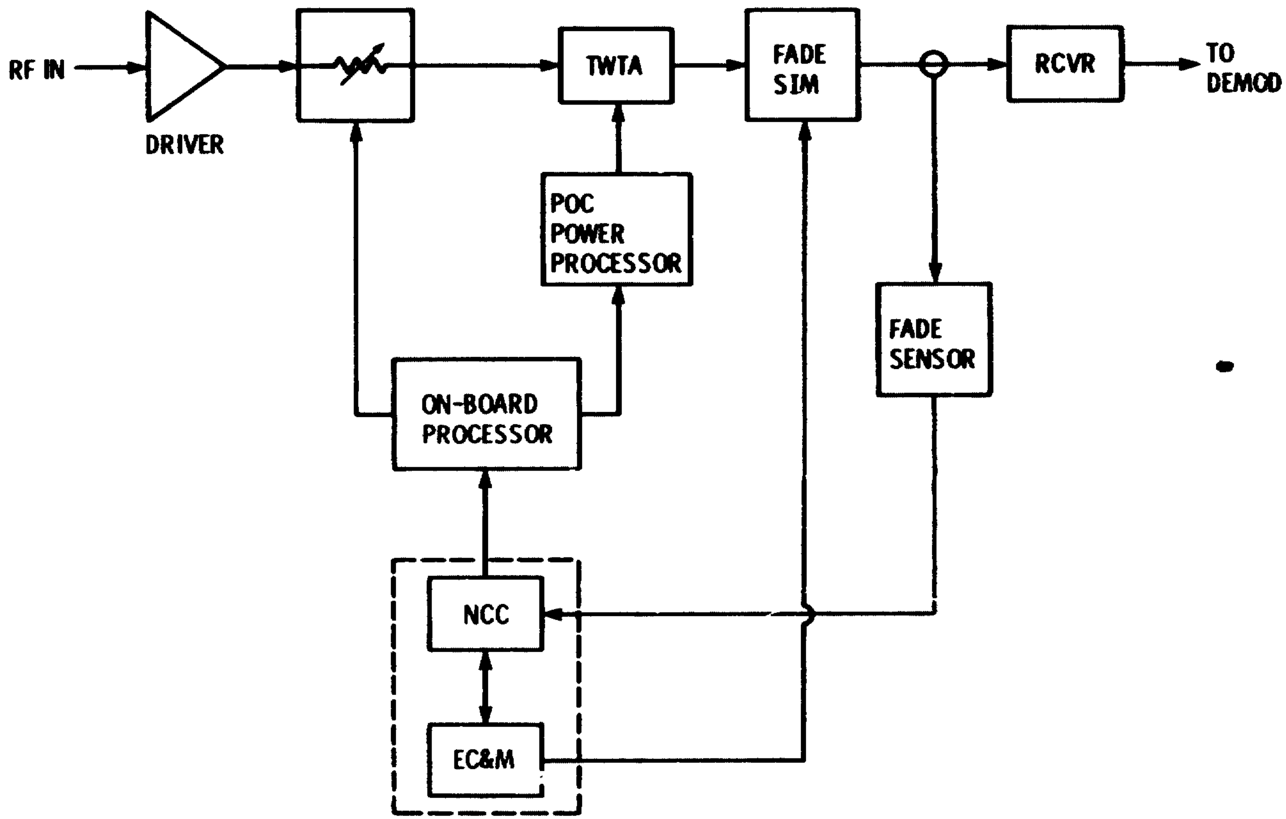

Figure 3. - Power augmentation control and evaluation system.

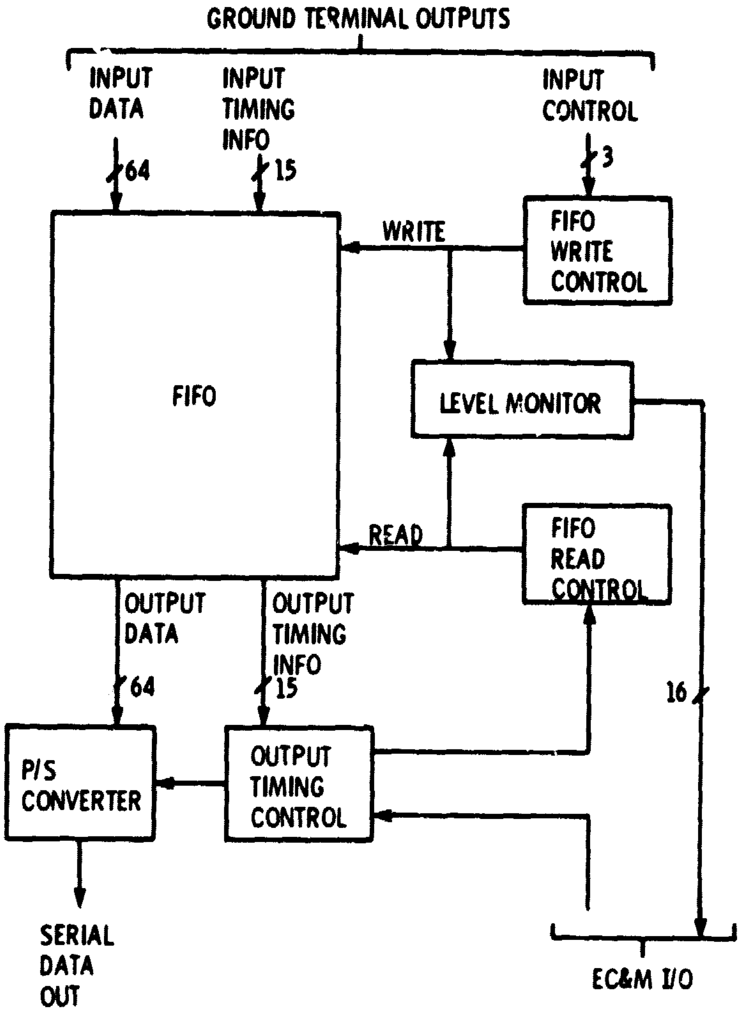

Figure 4. - Range delay simulator block diagram.

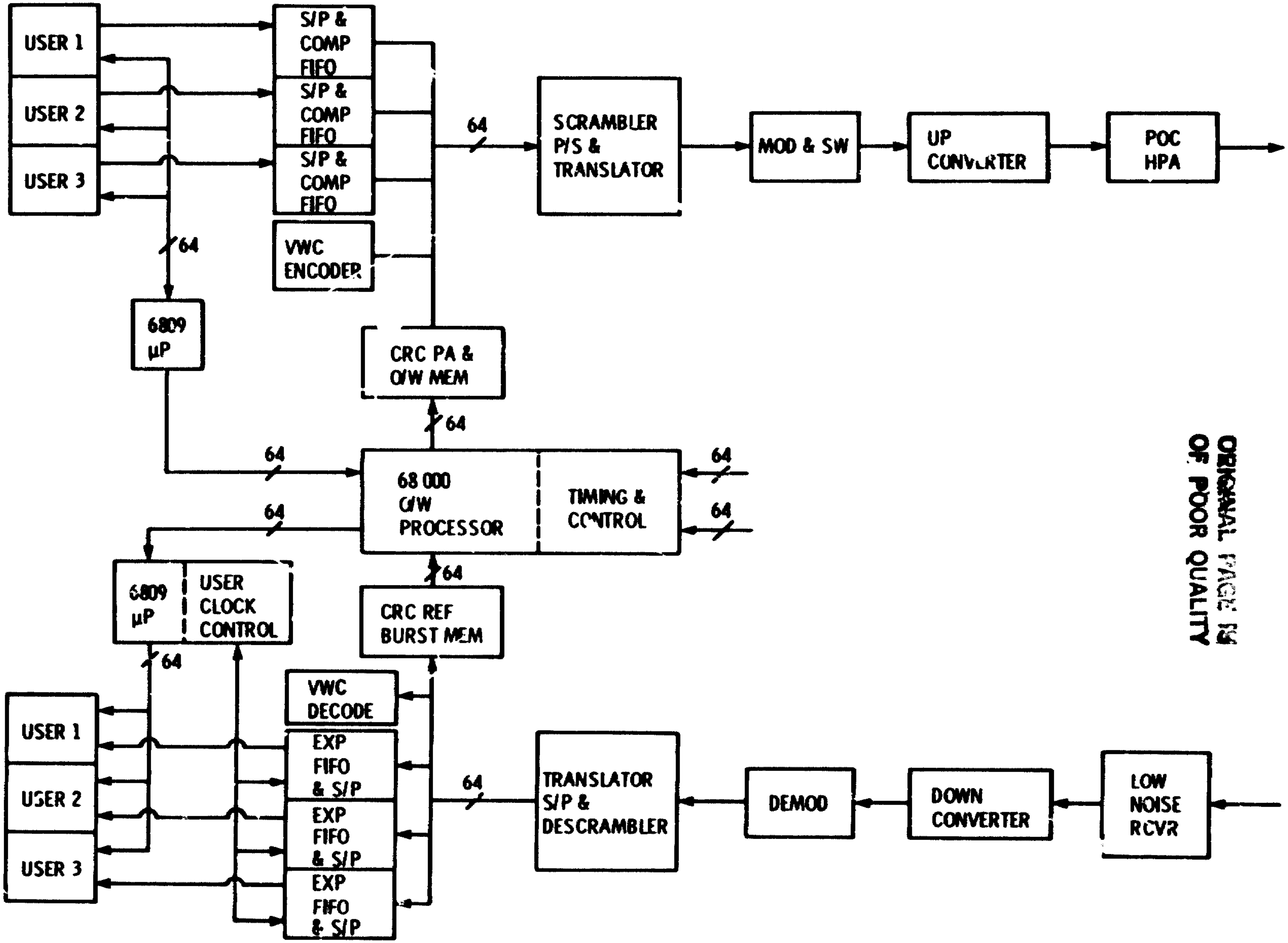

Figure 5. - Test system ground terminal.

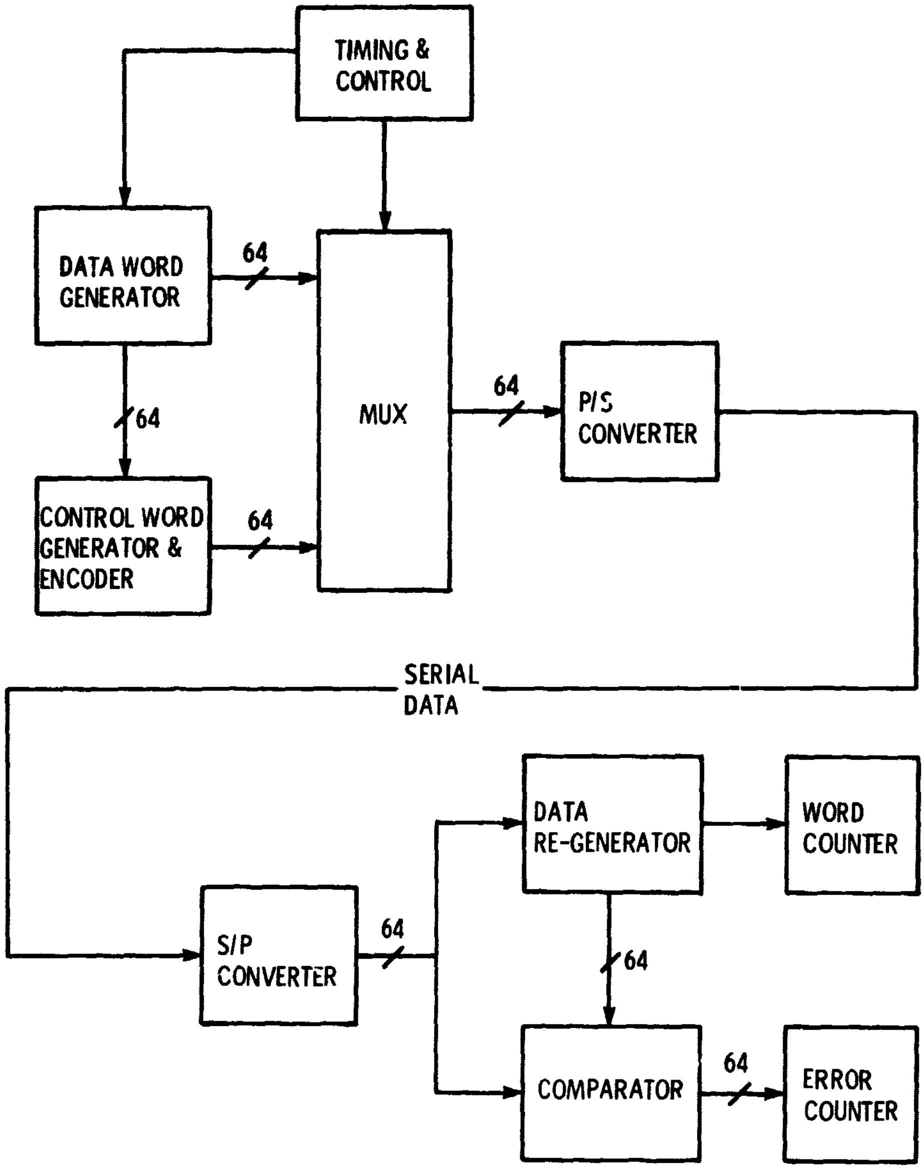

Figure 6. - Data generator & checker system.

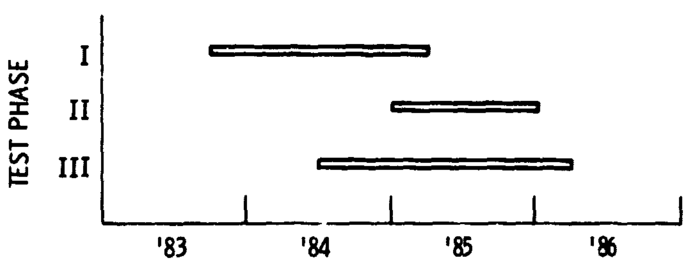

Figure 7. - System test schedule.