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Automated Testing of Developmental Satellite Communications Systems and Subsystems

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SUMMARY

Lower frequency bands allocated for satellite communications use are rapidly becoming saturated due to steadily increasing demand. NASA has an ongoing program to develop the new technologies required to meet the demands of future systems. Under this program, higher frequency components and more efficient system techniques are being developed and tested. In order to accurately evaluate the performance of these technologies, an automated test system has been designed and built at NASA's Lewis Research Center. This paper describes the automated system's design and discusses its capabilities.

INTRODUCTION

To meet the growing demand on satellite communications resources, NASA is developing, and promoting the development of technologies which will improve the efficiency of future systems and allow the use of higher frequency bands. Under a "Proof Of Concept" (POC) development program, several contractors have built and delivered developmental communications satellite components and subsystems including 30 GHz low noise receivers, 20 GHz high power amplifiers (TWT's, GaAsFET, and IMPATT devices), microwave switch matrices, baseband processors, and high data rate modulators and demodulators. Contracts are also underway to develop 20 GHz ground terminal receivers, improved 20 and 30 GHz high power amplifiers, and advanced modulators and demodulators. In addition, in-house efforts are aimed at ground terminal digital system development, networking and control concepts, bit error rate measurement, and overall system design techniques. This work will support NASA's Advanced Communications Technology Satellite Program as well as identify areas where future development work is necessary.

The need to test the individual component technologies, as well as the system concepts, has led to the design of an automated test bed where RF and data transmission parameters can be measured over a wide range of conditions, for both individual components and the entire system.

The work of controlling such measurements and experiments and collecting, processing, storing, and displaying the data can be efficiently performed by one computer with appropriate test bed interfaces and output devices. Placing control and monitoring functions at a number of points in the system allows operating conditions to be varied and the effects of such variations to be measured. Thus, operating characteristics for a single component can be observed while a complex system experiment is being performed.

Tests for Satellite Communication System Components

A number of general RF measurements are required to be performed on all of the major satellite components mentioned above. These include power measurements (output power, power gain, and power linearity), amplitude response and group delay response versus frequency, input and output standing wave ratio, noise figure, intermodulation response, and spurious response measurements. Automating these tests provides standardized measurement techniques for all of the satellite components, improves the accuracy of the measurements, and greatly reduces the time required to obtain the test data.

Tests for a Satellite Communication System

As part of NASA Lewis Research Center's In-House Communication System Development and Test Program, the POC components will be assembled as a simulated Ka-band satellite communications link. This will enable NASA to assess the performance of these components under system conditions, to test system and network control concepts, and to investigate the general characteristics of a next-generation satellite communication system.

End-to-end RF system tests needed to characterize the link include system power linearity, amplitude and group delay response versus frequency, intermodulation and spurious response measurement, and carrier-to-noise ratio degradation. Other more complex experiments require the measurement of digital data transmission parameters while monitoring the system's RF characteristics. Examples of such experiments are adjacent channel and co-channel interference measurements, end-to-end bit error rate (versus signal-to-noise ratio) in the presence of varying system RF parameters, TDMA network control experiments, and system response to satellite link stimuli such as downlink rain fade and satellite range variation.

Given the large number of system variables which must be controlled, monitored, and measured, an automated measurement and experiment control system is a necessity.

Requirements of an Automated Test System

For an automated system to be capable of performing the tests mentioned above, it must include provisions for all of the hardware required for these tests. The hardware requirements can be defined by examining the measurement methods and experimental procedures to be used. A description of these methods and procedures is given below. Some of these methods apply to component tests, some to system tests, and some to both.

Power measurements. - Power measurements include output power, power gain, and power linearity. These tests are usually done by inserting a CW signal (at the desired frequency) into the device under test and measuring the power at the input and output ports via RF power meters. The input power to the device is varied either from the signal generator or by an in-line attenuator. In order to avoid damaging power sensors with excess power, the measurements are usually obtained by coupling some portion of the signal through a directional coupler. Thus, a calibration routine is required to remove the frequency-variant effects of the couplers and power sensors.

<u>Amplitude response</u>. - Three methods are available for obtaining the amplitude response of a device or system. The choice depends on accuracy and resolution requirements.

The first method involves the use of power meters at the input and output of the device, similar to the power measurement method. The signal generator being used to supply the device input is stepped across the frequency range of interest at intervals which will give the desired resolution. Note that this measurement can be combined with the power measurements by doing simultaneous frequency and power sweeps. The result is a matrix of input power versus output power versus frequency data, from which can be obtained power linearity, output power, power gain, and amplitude response data under all desired input power and frequency conditions. As with the power measurements, a calibration is necessary to remove frequency-variant coupler and power sensor characteristics.

When a high degree of amplitude response resolution is desired, a swept CW input signal can be used, with the device output displayed on a spectrum analyzer. The display can then be plotted on a digital plotter.

An automatic network analyzer is available as the third method for measuring amplitude response when a high degree of accuracy is required. The network analyzer will also give phase (and group delay) data and input and output reflection (SWR) data. The network analyzer is not useful when frequency conversions occur in the device under test (e.g., receivers) and cannot be used for system tests.

<u>Group delay</u>. - As stated above, the automatic network analyzer can provide group delay measurements under some conditions. When the network analyzer can not be used (as for frequency conversion devices), a second automated technique has been developed. It is based on a manual technique and is described in figure 1. The CW input signal is amplitude modulated, the modulation envelope is detected and its phase shift (relative to the input modulation) is measured using a vector voltmeter. This phase shift can then be mathematically related to the group delay through the device (ref. 1). By stepping the input CW frequency across the band of interest, while keeping the modulation frequency constant, the group delay response can be measured as a function of frequency. Note that the modulation frequency is available at the device output even when the carrier (i.e., input CW signal) frequency has been modified by the device under test; thus, a frequency conversion device or system can be measured with this technique. Note that a digital multimeter with IEEE-488 bus capability is used to monitor the vector voltmeter's phase shift reading.

<u>Standing wave ratio</u>. - In some cases, the automatic network analyzer can be used to measure input and output SWR. When the network analyzer cannot be used, the input and output reflected power must be measured by power meters via directional couplers. A CW signal must be incident on the input or output port, with the incident and reflected powers being measured. The signal generator is stepped across the frequency band of interest, and the difference

between the incident and reflected powers is used to calculate the standing wave ratio. As with the previously mentioned coupled power measurements, a calibration is required for accurate results.

Noise figure. - The noise figure is measured as shown in figure 2. The noise figure meter is the Hewlett-Packard (HP) 8970A. It has the capability of controlling a calibration and measurement sequence without an external controller. The controller is used to select the proper measurement parameters and to collect and present the data. It must also vary the local oscillator's frequency when noise figure measurements are being made at intervals across a frequency band.

Intermodulation and spurious responses. - Intermodulation responses are measured by applying two CW signals of different frequencies to the device under test and measuring the relative level of the resulting intermodulation products which occur in the frequency band of interest. The intermodulation products are identified and measured with a spectrum analyzer. Since it is the relative values of the input signals and intermods which are of concern, all of the information required is available from the spectrum analyzer. However, the precise power and frequency of the input signals must be known, thus a calibration at the device input must be made.

Spurious responses originating in the device under test are measured at the device output with a spectrum analyzer. These responses are measured relative to the desired output signal (usually one CW input signal is used, at the device's required frequency and power level) and all of the measurement information is available from the spectrum analyzer. Calibration of the input signal frequency and power level may also be desirable.

Carrier-to-noise ratio degradation. - This is an end-to-end system RF measurement designed to measure the amount by which a given carrier-to-noise (C/N) ratio at the system input is degraded by the system hardware. A computer-controlled noise insertion system was designed to allow a variable C/N to be set at the system input. This noise insertion hardware is also used to perform Bit Error Rate (BER) versus signal-to-noise ratio (S/N) tests. The noise insertion system is shown in figure 3. The calibration port allows monitoring of the carrier and noise power via a power meter by turning the carrier off and measuring the noise power, and vice-versa. The two attenuators provide a means of adjusting the carrier and noise powers to obtain the desired ratio. Two means of measuring the output C/N (and thus the system C/N degradation) exist. A power meter may be used, measuring the carrier power and noise power separately, as in the input calibration, or, a spectrum analyzer may be used to measure the two powers simultaneously. In some cases, it has been found that noise suppression occurs in the system when the carrier is present, thus the spectrum analyzer will provide a more realistic measurement. This effect can be seen in figure 10. However, with proper calibration of the power sensors and couplers, the power meters provide a more accurate power measurement.

Bit error rate measurement. - With a compatible digital modulator and demodulator, end-to-end system bit error rates versus S/N can be measured. For this system, the modulator and demodulator are 220 Mbps Minimum-shift-keyed devices, developed under the same program as the other POC hardware. Thus, they are part of the system under test as well as the test system.

Psuedorandom data is generated for the modulator, and a desired S/N at the modulator output is obtained with the noise insertion hardware mentioned previously. At the demodulator output, the data is checked for errors, and the bit error rate is calculated.

The effect of the variation of RF parameters on the system bit error rate is observed by first performing an RF characterization test with a CW signal and then performing the bit error rate test as described above. The effect of adjacent and co-channel interferers on the BER can be observed by inserting the interfering signal (it can be a CW or modulated signal) in the test channel or an adjacent channel and measuring the resulting bit error rates. The relative magnitude of the interfering signal is measured with a spectrum analyzer (as in spurious response measurements).

Satellite downlink rain fade simulation. - An example of a complex system experiment is the rain-fade simulation test. The onset of rain fade in the downlink portion of a Ka-band satellite system can be simulated using a remotely-controlled rotary vane attenuator. Such an attenuator, with its computer interface, is described in figure 4. The test also involves the ability of the satellite system's network control to sense the rain fade and adjust the satellite transmitter (a multimode TWT amplifier) into a higher power mode while simultaneously changing the transmitter input power to the proper value with another attenuator. The effect on bit error rates of data transmitted while these adjustments are being made is of interest. Note that the remotely-controlled attenuators have been built at both the uplink and downlink frequencies. Thus, the effect of uplink rain fade can also be observed.

Frequency and power requirements. - The operating frequencies and power levels of the POC components force the test hardware and instrumentation at various points in the system to meet the requirements given in table I.

The hardware and instrumentation necessary to meet all of the above requirements is given in table II.

Software requirements. - In order to effectively control system and component testing, a computer possessing a number of specific capabilities is required. A list of the critical performance parameters includes mass storage capacity, data handling and graphic capabilities, computation speed, adaptability, and ease of operation. In addition, the computer must be versatile enough to meet the interfacing needs of a wide variety of instruments on both IEEE-488 and RS-232 interface buses. During system networking experiments, the computer must also be able to monitor communication link network status through the network's control computer. The large number of tests outlined in previous sections adds the additional requirement that the computer must be capable of simultaneously supporting and controlling large numbers of instruments and devices.

Many of the RF measurement instruments under computer control must undergo routine periodic calibration and zeroing sequences. These cycles are often time consuming when performed manually and make logical candidates for automatic control. The program code for these tasks, as well as standard device operation commands, is stored as subroutines to a mainline program. It is therefore necessary that the computer be able to maintain a large software library from which individual subroutines may be accessed. For system tests involving numerous control and measurement points, disc mass storage with capacity on the order of several megabytes is required. For component tests, fewer test points are considered and storage requirements can be relaxed significantly.

Proper system calibration is required in order to produce accurate test results. To ensure such results, the effects of devices such as pre-amplfiers, directional couplers, attenuators, and isolators must be subtracted from the measurements. For this reason, additional software must be written to record the frequency and input power responses of numerous lab components. Such calibration data can be collected once, and stored in nonvolotile memory arrays such that it maybe rapidly recalled during measurement sequences. Modifications to the test system require only that different component calibration arrays must be accessed.

The subroutine library must include the control sequences needed to operate the individual instruments. Devices such as signal generators, sweepers, power meters, spectrum analyzers, remote control RVAs, noise figure meters, and BER measurement devices, all require unique and complex control instructions. Routines must be available to initialize each instrument to bus control, set up the device parameters such as output power level or frequency, and perform the measurement. The library must also be large enough to support equally heavy instrumentation on a possible second channel of the communications link.

One of the most critical tasks of the control computer is the sequential regulation of the power-up and power-down of the link and the POC components. This is especially important when high-power devices such as traveling wave tube amplifiers are involved that may perhaps be damaged or damage other components if not properly regulated. Again the need for software flexibility exists.

The data processing abilities of the computer are another strict requirement. In order to effectively control an overall system experiment, a very high speed central processing unit must be able to take measurements in virtually real time. The computer must have the capability of controlling a large number of control and measurement points without delaying the experiment. The collected data must then be processed and calibration factors removed. The finished data is then stored and presented to the experiment control engineer in either tabular or graphic form.

Design of an Automated System

Hardware Description. - An automated test system designed to meet the requirements given above is shown in figure 5. It is configured as a baseband-to-baseband simulated satellite communication link, with eight test points located at the interfaces between the major system components. The system controller is the Experiment Control and Monitor Computer (EC&M).

The eight test points, in addition to the baseband data generator and error checker, are accessible to the EC&M. These test points, located at the input and output of each major component, allow the component's operating characteristics to be monitored independently of system operations. RF signal sources, also under EC&M control, are available at the IF and uplink frequencies to provide for unmodulated system or device tests. Thus, the system can be operated baseband-to-baseband, IF-to-IF, or uplink-to-downlink for unmodulated RF testing, and baseband-to-baseband for data transmission tests.

Each test point contains one or more of the following capabilities: RF power measurements, spectral measurements, frequency measurement, noise insertion, noise measurement, amplitude modulation and envelope detection (for group delay measurement), and RF power control (amplification and/or attenuation). These capabilities are all not available simultaneously; that is, each test point contains one or two coupled ports and instrumentation for a particular test must be connected or disconnected as required.

Several of the test points must have power control capability in order to match the output power of one system component with the input power of the next component, and to allow direct interchanging of various models of a particular component. For example, it is of interest to compare system performance with two different manufacturer's models of satellite receivers, or to compare a solid state transmitter with a traveling wave tube transmitter. The power control capability also allows the input power to a device to be varied independently of the power levels through the rest of the system. Figure 6 shows one of these test points.

Description of computers. - Two computers were selected to meet the design requirements of the automated test system. For system tests, a Perkin-Elmer model 3240 (PE-3240) computer was chosen. For component tests, a Hewlett-Packard desktop computer-controller easily performs the necessary functions.

The PE-3240 meets all the requirements needed to automate the full-scale, multichannel communication link. Additional features of the computer permit several programs to be run simultaneously when configurations permit. The PE-3240 utilizes 32 bit processing with 2.5 Mbyte active data memory. The computer is supported by 300 Mbyte hard disc storage and two 9-track magnetic tape drives. Hardcopy outputs are available through a 600 line/min printer or a Tektronix thermal graphics plotter. The computer operates using the standard Fortran 7 source language.

The controllers selected for automatic component testing were from Hewlett-Packards' 200 series line of desktop computers. Both the models 9845 and 9836 permit control and monitoring functions over the IEEE-488 parallel interface bus. The computers both support approximately 1 Mbyte of data storage capacity with magnetic tape or floppy disc storage options. The computers are served by hardcopy devices including multipen graphics plotters and thermal printers. The computers are programmed using the BASIC 2.1 source language with the option to change to FORTRAN or PASCAL operating systems.

Software design. - As dictated by the requirements of the automated test system, the structure of the control program involves numerous subroutines. By selecting this structure, the mainline program can be easily modified to perform a variety of tasks by simply rearranging the "call" order of the subroutines and/or calling different subroutines.

A typical program begins with a series of initialization calls. Each call initializes one of the instruments and provides it with the necessary start-up parameters. Arrays are loaded into active memory with any needed calibration data. The mainline program then begins the power-up of the test configuration. Any critical element, such as a high-power traveling wave tube or matrix switch is sequenced through a succession of prompted power-up events. Each of the unique power-up (or down) sequences appears as a separate subroutine. To perform a given test, the mainline program then steps through an ordered list of events (calls) necessary to control the test equipment. For example, in a power linearity test, the CW test signal is controlled through a call to the signal generator subroutine. Once the power levels have settled, calls are made to appropriate power meters to make power level readings. Upon completion, the signal source is again addressed with new (incremented) power level instructions. The cycle continues until an entire power sweep has been completed. Calls can then be made to error correction subroutines and output subroutines to supply the control engineer with accurate test results.

Power linearity testing is a simple example of the automatic test capabilities of the NASA system. Separate programs can be written for a wide range of tests depending on the interests at hand. If only one program to perform all testing is more suitable, the specialized mainline program steps can be joined and menus included to select the desired test. The general program structure applicable to both the PE-3240 and HP desktop computers is presented in figure 7.

Prior to the testing of a POC component or system, calibration factors must be obtained for each frequency-variant and power-variant device used in the test link. These factors will be placed in memory arrays so that their effects on test results may be mathematically eliminated. Magnitude calibration data can be obtained from isolated component tests using either computer. The calibration testing of the remote-controlled rotary vane attenuators (remote RVAs) is a descriptive example of this process.

The RVA is placed into a configuration as shown in figure 8. The mainline calibration program moves the RVA to a minimum attenuation position as indicated by the limit switches. The program places the signal source at a given frequency/power state and records the offset between the two power meters. The RVA is then moved from the point to a position where the power meter offset increases by 1 dB. The position counter of the motor-indexer is recorded in a calibration table. The indexer is again instructed to increment until a 2 dB offset occurs. The new position count is read into the calibration array. The cycle continues for the full dynamic range of the attenuator. The program then changes the source frequency and recycles the program commands. By this method, a matrix of calibration (control) factors is created for each attenuator. The accuracy of the RVAs and calibration setup permit attenuator precision on the order of ± 0.05 dB for a 30 dB range. Mechanical backlash is avoided by always approaching the attenuation position from the same endpoint. Motor shaft position resolution of up to 50 000 steps per revolution is possible.

Example of component RF tests. - A solid state GaAs FET transmitter was used to verify the performance of the automatic test system. Power versus frequency, gain versus frequency, and power linearity data is presented in figures 9(a) through 9(c). Acquiring this data was a full exercise of many of the system components. To obtain the power linearity data, the signal source was required to make power level increments at a given frequency. For the other two tests, the signal source was required to increment frequency at a given power level. A leveling subroutine allowed power leveling to within ± 0.1 dB for the full test bandwidth. Power meters were used throughout all testing and yielded accurate and repeatable results. Calibration factors from the input and output directional couplers were used to obtain the corrected data. Graphics packages available on the PE-3240 permitted a plotted output in the form shown.

Examples of system RF tests. - Three examples of the system RF test capabilities are given. The first example is of a C/N degradation test. This test was performed over the IF-to-IF portion of the link (excluding the modulator and demodulator, see fig 5). Using the computer-controlled noise insertion system (fig. 3), a constant power level CW carrier with a variable noise level is applied to the system. A range of C/N from 5 to 25 dB in 1 dB steps was used. Since the noise insertion system uses 1 dB step attenuators, the controller attains an input C/N as close as possible to that desired for the test. The output C/N was measured with a power meter. The results as tabulated by the computer (an HP desktop computer was used to control this measurement) are shown in figure 10(a), and are plotted by a thermal printer in figure 10(b).

The second example is of a system group delay measurement. This test was performed for the IF-to-IF portion of the link, over a 330 MHz bandwidth. In addition, the group delay of the satellite transmitter, a solid state high power amplifier (HPA), was measured. This required three sets of data to be taken: at the HPA input, the HPA output, and the system output. The difference between the first two measurements gives the group delay of the HPA. The controller, an HP desktop computer, plots the results on a digital plotter as in figure 11. Measurements were made at 10 MHz intervals across the 330 MHz band. The system results are plotted on the left axis, the HPA results on the right axis.

The effects of a single component on the performance of a communications link can easily be seen through the output of a system test. These effects can supply the test engineer with valuable insight into the capabilities of the communications system. Much valuable information is also obtained through the direct substitution of one POC component for another. To observe this effect, the solid state GaAs FET transmitter was replaced by a traveling wave tube transmitter. System and component gain versus frequency data was measured simultaneously in this test via power meters at the system input, transmitter input, transmitter output, and system output. The results, after calibration correction, are plotted in figure 12(a) for the solid state transmitter and figure 12(b) for the traveling wave tube transmitter.

CONCLUSION

This paper describes an automated test facility for satellite communication systems designed and being implemented at NASA Lewis Research Center. The test bed is capable of performing system experiments while monitoring and regulating component performance. The system provides for the assessment of a large number of components and technologies, while being sufficiently flexible to support long term technology development activities. Unique capabilities for RF and data transmission experiments are provided by this facility.

REFERENCE

1. "Swept-Frequency Group Delay Measurements", Hewlett-Packard Applications Note 77-4, Hewlett-Packard Co., Palo Alto, CA, Sept., 1968.

TABLE I. - COMPONENT OPERATING FREQUENCIES AND POWER LEVELS

Component	Input freq., GHz	Output freq., GHz	Input power, dBm	Output power, dBm
Satellite receivers	27.5 - 30.0	2 - 8	-70 to -10	-50 to + 10
Satellite transmitters	17.7 - 20.2	17.7 - 20.2	-15 to +16	+20 to +50
Satellite matrix switch	2 - 8	2 - 8	-40 to 0	-60 to -20
Ground receiver	17.7 - 20.2	3.21 - 3.5[illegible]	-80 to -40	-50 to -10
Ground transmitter	27.5 - 30.0	27.5 - 30.0	+8	+53
Ground upconverter	3.0 - 3.5	27.5 - 30.0	-10	-35
Ground downconverter	17.7 - 20.2	3.0 - 3.5	-41	-33
Modulator	-----------	3.373 (f_o)	----------	-10
Demodulator	3.373 (f_o)	-----------	-33	-----------

TABLE II. - HARDWARE AND INSTRUMENTATION REQUIREMENTS

RF signal generators[a]	2-8 GHz, 27.5 - 30.0 GHz
RF power meters[a]	2-8 GHz, 17.7 - 20.2 GHz, 27.5 - 30.0 GHz
Spectrum analyzer[a]	2 - 30 GHz
Frequency counter[a]	0 - 30.0 GHz
Vector voltmeter	0 - 1 GHz
Digital voltmeter	DC
Automatic network analyzer[a]	2 - 20.2 GHz
Noise figure meter[a]	0 - 30 GHz
Noise generators	2 - 18 GHz, 17.7 - 20.2 GHz, 27.5 - 30.0 GHz
PIN modulators	2 - 8 GHz, 17.7 - 20.2 GHz, 27.5 - 30.0 GHz
Couplers	2 - 18 GHz, 17.7 - 20.2 GHz, 27.5 - 30.0 GHz 10 dB, 20 dB
Amplifiers	2 - 8 GHz, 17.7 - 20.2 GHz
Attenuators[a]	2 - 18 GHz, 17.7 - 20.2 GHz, 27.5 - 30.0 GHz
Data generator, error counter[a]	220 Mbps
Noise insertion hardware[a]	3 - 3.5 GHz
Envelope detectors	2 - 8 GHz, 17.7 - 20.2 GHz, 27.5 - 30 GHz

[a]IEEE-488 or RS-232 capability.

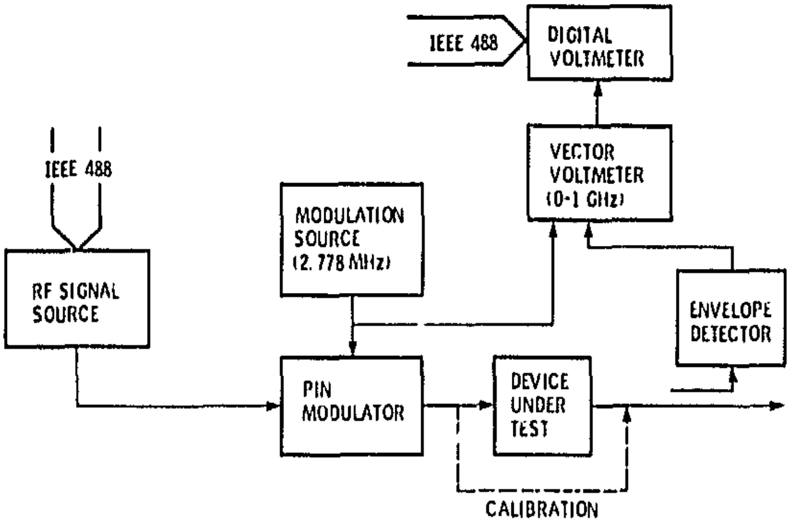

Figure 1. - Group delay measurement system.

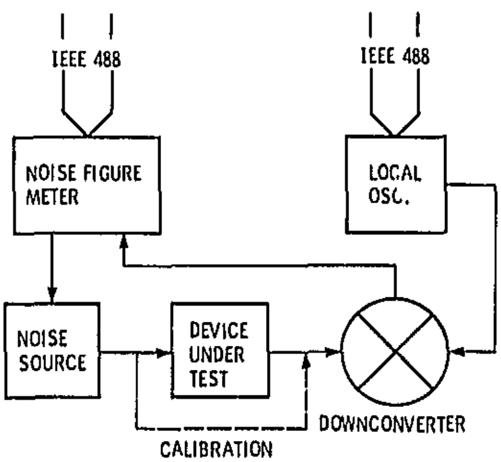

Figure 2. - Noise figure measurement system.

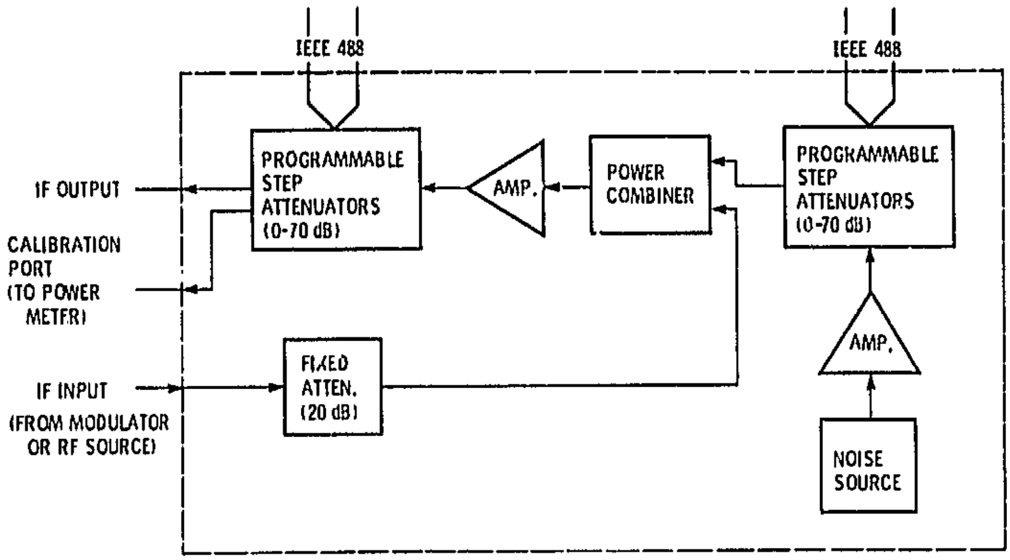

Figure 3. - Computer-controlled noise insertion system.

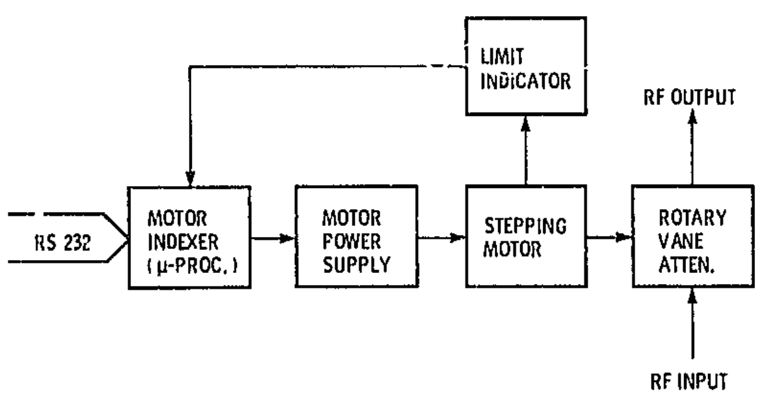

Figure 4. - Computer-controlled continuously variable rotary vane attenuator.

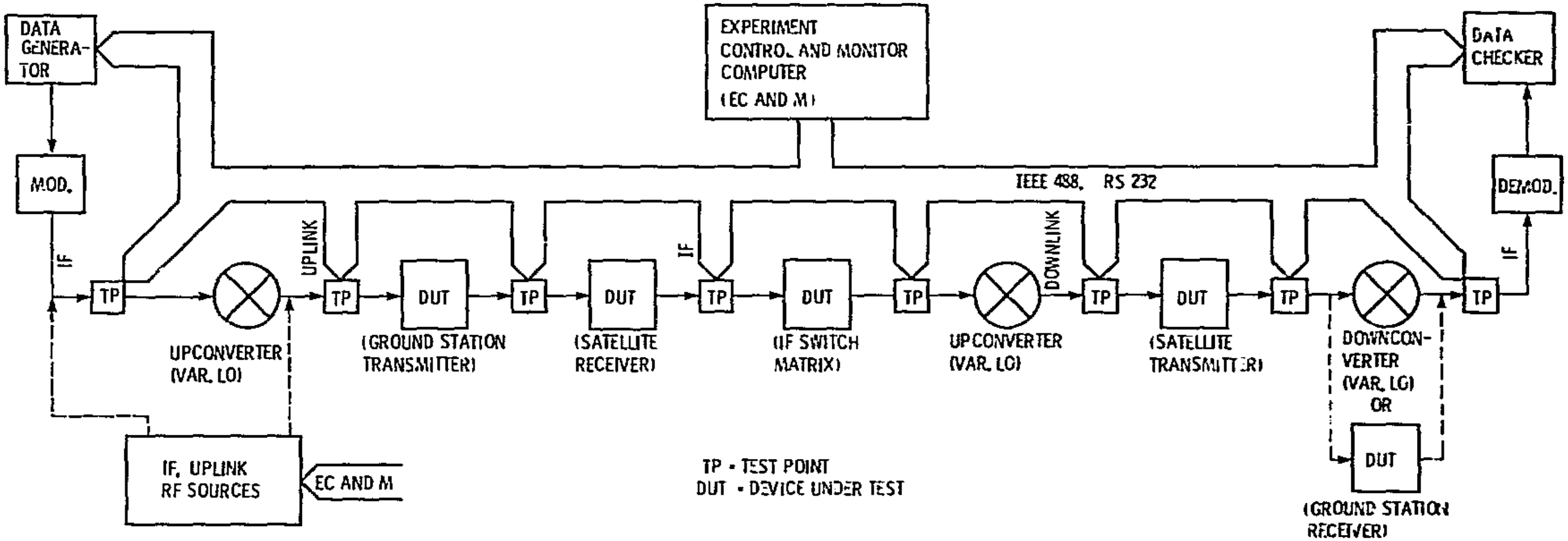

Figure 5. - Automated test bed for satellite communications systems and subsystems.

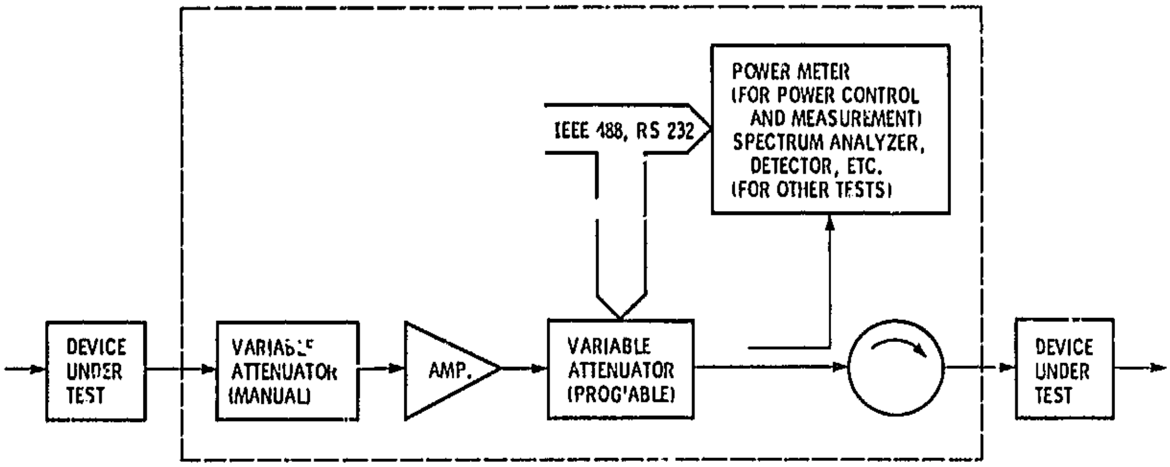

Figure 6. - Example of an RF test point.

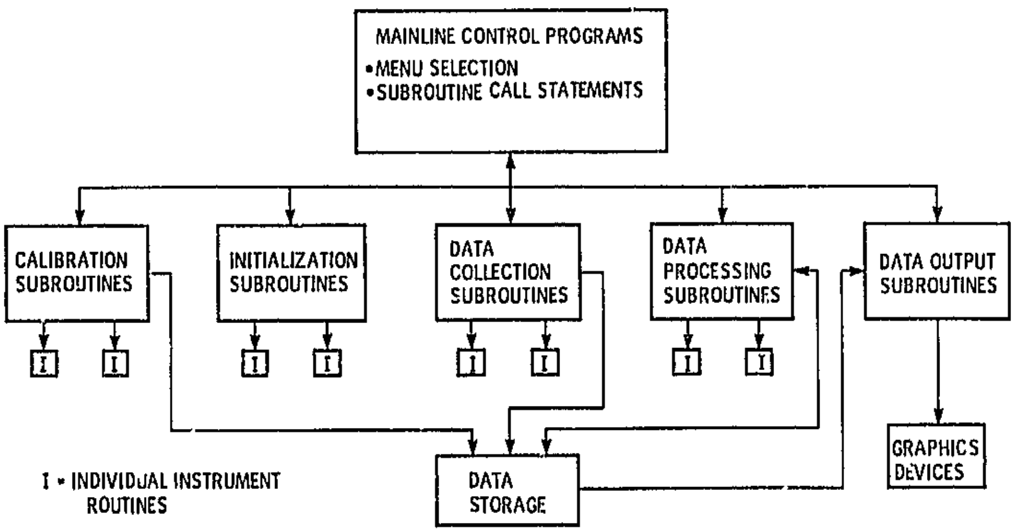

Figure 7. - Software structure for automated testing.

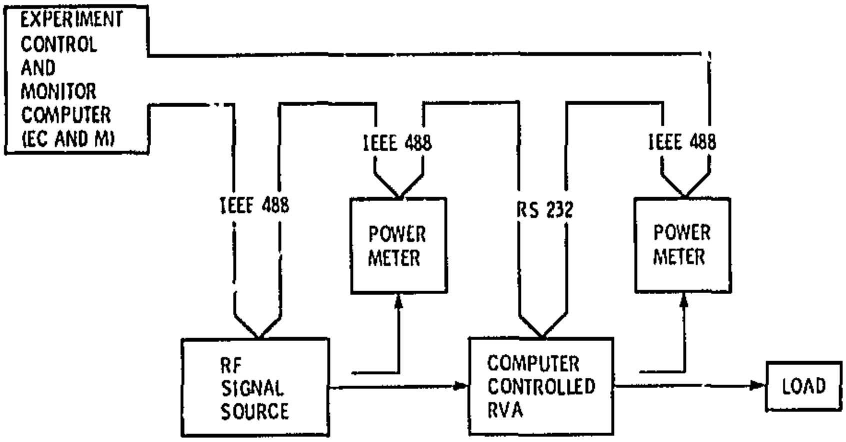

Figure 8. - Computer-controlled RVA Calibration system.

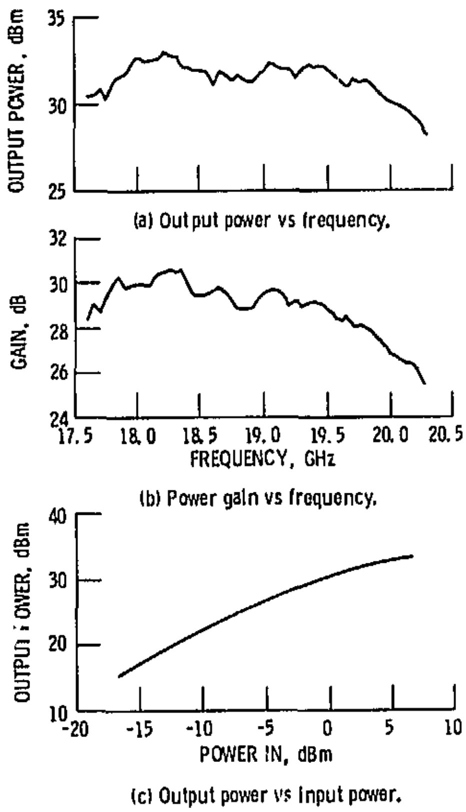

Figure 9. -20-GHz GaAs FET amplifier data.

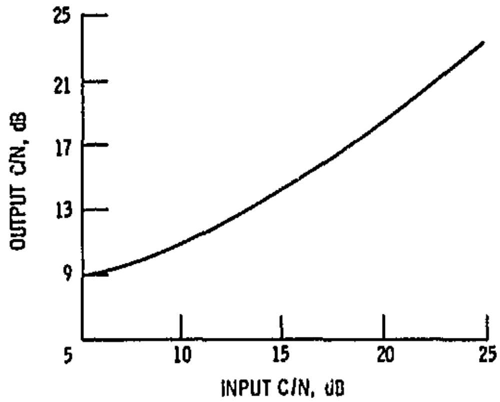

Figure 10. - System C/N degradation, data plot.

SYSTEM RESPONSE WITH SS-HPA

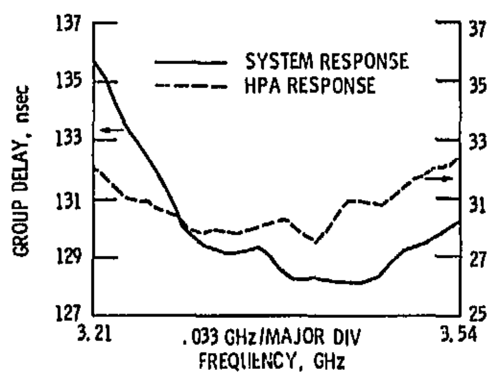

Figure 11. - System and HPA group delay response.

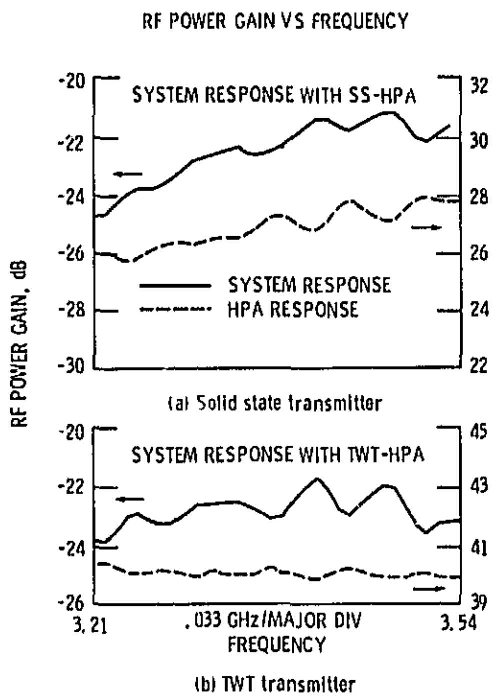

Figure 12. - System and HPA gain vs frequency.

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16. Abstract

Lower frequency bands allocated for satellite communications use are rapidly becoming saturated due to steadily increasing demand. NASA has an ongoing program to develop the new technologies required to meet the demands of future systems. Under this program, higher frequency components and more efficient system techniques are being developed and tested. In order to accurately evaluate the performance of these technologies, an automated test system has been designed and built at NASA's Lewis Research Center. This paper describes the automated system's design and discusses its capabilities.

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