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20 × 20 High Speed Microwave Matrix Switches

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20 X 20 HIGH SPEED MICROWAVE MATRIX SWITCHES

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SUMMARY

Tests were conducted at NASA Lewis Research Center to characterize the proof-of-concept matrix switches built under NASA contract by Ford Aerospace and Communications Corporation at Palo Alto, California, and the General Electric Company at Valley Forge, Pennsylvania. The contract requirements and goals are tabulated along with the results of the NASA tests. Characteristics examined are bandwidth, insertion loss, ripple, switching speed, isolation, standing wave ratio (input and output), deviation from linear phase, noise figure, reconfiguration rates, spurious responses, gain compression, and third order intermodulation distortion. A brief description of the testing method and a statistical analysis of the test results for each of the switches are provided.

E-2182

INTRODUCTION

NASA, having recognized the necessity of conserving frequency spectrum in future communication systems, and of providing communication coverage to the contiguous United States, has conducted a focussed program to advance the technology for future generations of communications satellites. One aspect of that technology development has been the production of proof-of-concept (POC) models of those components or assemblies identified as critical for the utilization of the 30/20 GHz band. A second aspect of that development is an extensive ground-based program for test and evaluation of those POC models (ref. 1).

Future generations of communication satellites will derive significant weight and power consumption advantages as well as overall economic advantages from a multiple fixed beam, Satellite Switched, Time Division, Multiple Access, (SS-TDMA) communication system (ref. 2). An SS-TDMA communication system is best implemented with a very high speed, on-board computer controlled, microwave matrix switch.

A practical switch for the SS-TDMA function should provide for the routing of any uplink microwave beam to any downlink beam as directed by computer control with a minimum of loss in the data stream due to the time required for the switching function. As well as providing an interconnection from any uplink channel to any downlink channel, it must accommodate a broad bandwidth and appear transparent to the data stream.

To explore operational characteristics and identify problems associated with the fabrication and operation of a microwave switch matrix with a practical switching speed, NASA, in 1980, entered into two, almost identical contracts with the Ford Aerospace and Communications Corporation at Palo Alto, California and with the General Electric Company at Valley Forge, Pennsylvania to develop the technology required for such a switch. Also to fabricate and demonstrate a proof-of-concept (POC) model. Requirements for some characteristics were not rigidly specified to enable the contractors to design in a way that would advance the technology.

This Technical Memorandum describes the tests conducted at NASA Lewis Research Center to examine the important characteristics of each of the microwave, high speed POC model matrix switches developed under NASA contracts NAS 3-22500 (GE) and NAS 3-22501 (Ford). Results of the tests, and where appropriate, a comparison with the contractor's data are shown.

POC MODEL DESCRIPTION

The POC matrix switch size is 20 input ports by 20 output ports. However, all 400 crosspoints were not populated with active switch elements. The GE POC model consisted of 57 active crosspoint elements and the Ford POC model had 65 active crosspoints. Diagrams identifying the populated GE and Ford switch crosspoints are presented in figures 1 and 2 respectively.

The architecture consists of orthogonal input (uplink) and output (downlink) transmission lines which are indirectly connected by input and output directional couplers through the actual switching elements of Gallium Arsenide dual gate field effect transistors. Figure 3 is a schematic representation of the GE architecture and figure 4 is a more detailed representation of a single cross bar or crosspoint circuit. Figure 5 is a photograph of a row of completed modules. Each module is one half of a crosspoint and includes coupling, matching and the dual gate FET. An orthogonal column of similar modules provides the other one half of a crosspoint.

Figure 6 is a schematic representation of a Ford crosspoint and figure 7 is the photo of a module crosspoint pair.

Table I presents a summary description of the POC matrix switches produced by the contractors.

The design goals as identified in the contracts are listed in table II.

TEST DESCRIPTION AND RESULTS

<u>Swept frequency measurements</u>. - (Spectrum Analyzer) Crosspoint swept frequency measurements of bandwidth, insertion loss and passband ripple of every active crosspoint were measured from a hard copy of the stored display on the Hewlett packard spectrum analyzer (Model 8566A). The test setup for these measurements is shown in figure 8. The sweep generator was adjusted for a rapid, auto-triggered frequency sweep (approximately 1 sweep each 50 ms) while the Spectrum Analyzer (SA) was swept slowly (approx. 2 min per sweep) in the max store mode. In this mode of operation, the signal source sweeps across the slow moving acceptance window of the SA, which stores the maximum signal level arriving at its input. This frequency domain data remains available for additional processing and/or transfer to a hard copy.

A reference sweep of the frequency band was stored in the SA with the matrix switch by-passed to obtain all level variations of the sweeper combined with the insertion loss of all the associated cables and connectors required in the setup. A matrix switch crosspoint in a closed static state was then inserted between the signal generator and SA. A second sweep of the spectrum was obtained and stored in the same manner as the reference sweep.

An internal feature of the HP 8566A was then employed to subtract the reference trace from the crosspoint trace, thus normalizing it so that the crosspoint characteristics alone are displayed. This accurate normalized record of crosspoint insertion loss vs. frequency was then transferred to a permanent hardcopy via a HP plotter (HP 7047A), for analysis to determine insertion loss, bandwidth, and passband ripple.

A typical copy of the data for a crosspoint obtained this way is shown in figure 9.

Insertion loss. - Insertion loss was measured from the hardcopy record (fig. 9) by measuring the area under the curve with a planimeter over a 1.8 GHz frequency range. The area was divided by the base width of the measured area, which result is the average height of the curve above the area selected. The calculated average height was drawn on the curve and recorded as the mean value of insertion loss. The average value for all active crosspoints was 20.7 dB for Ford and 18.0 dB for GE.

Bandwidth. - A line drawn 3 dB below the average insertion loss value intersects the curve at the passband edge. The frequency span of the passband at this 1 dB line is taken as bandwidth. The average bandwidth value for the Ford POC model was 2.7 GHz and for the GE POC model was 1.2 GHz.

Ripple. - For this test, ripple is defined as the dB difference between the maximum and minimum values within the passband.

The mean values and standard deviation of the data obtained by the swept frequency tests for all the crosspoints are shown in table III.

INSERTION LOSS (VIA ANA)

The Automatic Network Analyzer test in a set up as shown in figure 10 also provided insertion loss data.

A comparison of insertion loss as shown by the ANA with that of the spectrum analyzer shows no more than 0.5 dB difference for the crosspoints compared.

In figure 11, insertion loss data for the Ford crosspoint (refs. 3 and 5) as recorded by the ANA has been superimposed on the insertion loss curve recorded from the spectrum analyzer. The maximum difference is 0.4 dB.

SWEPT FREQUENCY MEASUREMENTS - (Automatic Network Analyzer)

Spurious response. - All crosspoints were examined for spurious responses from 2 to 22 GHz. Of the 66 Ford crosspoints, nine show some small second harmonic response at 10 GHz which are down at least 33 dB from the passband primary output.

Spurious responses were evident from 25 of the 57 GE switch crosspoints at 10.5 GHz. Most levels were at least 30 dB below the passband signal level, but 8 crosspoints were between 12 and 30 dB below. Eleven crosspoints showed multiple harmonics with one crosspoint showing spurs at each harmonic up to the 4th, all at about -25 dB. One GE crosspoint oscillated, producing a spurious output at 15 GHz in the absence of an input signal.

Standing wave ratio. - Standing wave ratios, at both the input port and output port of the matrix switch were measured with the Hewlett Packard Automatic Network Analyzer Model 8409. The setup is shown in figure 10.

Standing wave ratios were obtained for 55 GE and 62 Ford crosspoints over a band of frequencies determined by the crosspoint bandwidth. Bandwidth for this test was identified as the frequency band over which the insertion loss was no greater than 3 dB below the peak.

The highest SWR (worst case) within the 3 dB bandwidth was tabulated. Those worst case values were then grouped under rather arbitrary group limits. The percentage of crosspoints with a worst case SWR falling within those group limits are shown in table IV.

Deviation from linear phase. - The automatic network analyzer in the same setup as shown in figure 10 was programmed to take phase data and convert it to deviation from linear phase. To do this some minor modifications were made to the standard HP 11862F software. Lines of program were added to compute a straight line fit (least squares method) to the stored phase data and to print data deviation from the computed straight line.

The distribution of worst case deviations from the straight line is presented in table V.

SWEPT FREQUENCY MEASUREMENT - (Noise Meter)

Noise figure. - The noise figure (NF) of each matrix switch crosspoint, including the total path through the switch from input port to output port, was measured using the Hewlett Packard noise figure meter model 8970A. The test setup for the measurement is as shown in figure 12.

A program for the H.P. 9845 computer controlled both the noise figure meter and the LO. The signal level returned to the NF meter was low in level for some matrix switch crosspoints causing the NF meter to display a code indicating an invalid value for noise figure.

The software was revised to recycle the sequence until a valid NF was obtained. The noise figure displayed by the NF meter was the mean value of 64 measurements accomplished automatically under the standard measurement program.

The worst case noise figure value from within the passband of each crosspoint is shown as a percentage of crosspoints tested falling within arbitrarily selected limits. Other statistical values are also recorded in table VI.

FIXED FREQUENCY MEASUREMENTS

Switching speed. - Switching speed is defined as the time between "turn off" of one crosspoint and "turn on" of another of a pair of crosspoints. The switching speed time period begins when the "turned off" signal has fallen to 90 percent of the original RF signal and ends when the "turned on" signal has increased to 90 percent of its final value. Time was measured on a very high speed (1 GHz) oscilloscope (Tektronix 7104). The setup for these measurements is shown in figure 13.

A signal frequency selected to be within the passband of a pair of crosspoints in the same column was divided by a two-way power splitter. Each output of the splitter was connected to the input port of the selected crosspoint pair. A variable manual attenuator was inserted in the cable route to one of the two matrix switch input ports. The purpose of the attenuator is simply to identify which signal as displayed on the scope is turning "off" and which is turning "on".

The special test equipment (STE) is programmed for this test to alternately connect first one and then the other of the selected input ports to a single output port which is connected to the oscilloscope. The STE provided for reconfiguration rates up to 500 000 per second.

A typical trace is shown in figure 14. The switching time for this crosspoint is 12 ns.

The statistics for the switching speed of all the crosspoints of each of the switches are shown in table VII. There were four Ford crosspoints where a time overlap occurred. Those are not included in the statistics.

Isolation, off state. - The off state isolation test is a measure of the signal leakage through a "turned off" crosspoint.

To make the measurement, a high level (+10 dBm) fixed frequency signal was connected to an input port of the matrix switch. A matrix switch output port was connected to a spectrum analyzer (H.P. 8566A) in a set-up as shown in figure 8 except for operation of the signal source at a fixed frequency at the center of the crosspoint passband. A spectrum analyzer scale was selected such that the RF amplitude at the peak of the crosspoint passband was displayed as well as the noise floor of the set-up. A hard copy of the crosspoint passband was recorded with the crosspoint in the "on" state. The crosspoint was then turned "off" and a second sweep superimposed on the hard copy recording. Any signal in the passband of the crosspoint from the "off state" record above the noise floor of the passband frequency is considered leakage. The decibel difference between the "on" state peak and the "off" state peak is recorded as isolation.

A record of a typical crosspoint is shown in figure 15.

The statistics for Ford and GE isolation are shown in table VIII. The mean value of isolation for Ford was 54 dBc and for the GE switch 58 dBc.

Reconfiguration rate. - A practical SS-TDMA communication system should be capable of reconfiguration in short time periods. The matrix switch contracts called for the capability to reconfigure all 20 inputs and outputs every 2 μs.

The GE switch was operated in many reconfiguration sequences including broadcast modes where an input signal was simultaneously routed to as many as five output ports. All of the reconfiguration sequences examined, changed at the 2 μs rate without failures. The special test equipment could also reconfigure at slower rates. No failures occurred at the slower rates.

The Ford matrix switch reconfiguration rate was also examined while operating in a wide variety of arbitrary sequences with no failures observed. Design of the Ford switch permitted operation at even faster reconfiguration rates. No malfunctions occurred up to a 1 μs rate.

These tests were made with a setup as shown in figure 13.

Compression. - Tests were made to identify the power output level at which output power no longer retained a linear relation with the input signal level. This characteristic is identifed as power compression and is recorded as the input power level at which output power has decayed 1 dB from the straight line relation with input power.

The test setup for this measurement is shown in figure 16.

A program was written to automate the test under control of the model 9825 hp computer. Input power was calculated in the computer program from measured incident and reflected power and plotted by computer along with output power.

Instrumentation was not available with sufficient power to drive all crosspoints to 1 dB compression. Of the 64 GE crosspoints measured, 34 did not reach 1 dB of compression with the maximum available input signal power of +12 dBm.

Ford compression (1 dB) was measured on 54 crosspoints. Only two of the 54 crosspoints could be driven to 1 dB of compression with the +10 dBm of input power available. The 1 dB point for those crosspoints was measured to be at an input power of +2.5 dBm.

Third order intermodulation distortion. - Third order intermodulation distortion was examined by introducing a mixed signal of two frequencies separated by 2 MHz but of equal amplitude. The output was displayed on a Hewlett Packard spectrum analyzer model 8566A. The test setup is shown in figure 17.

The third order products appear on the analyzer at [2 (f1)-f2] and at [2(f2)-f1] where f1 and f2 are the mixer input frequencies. The amplitude of the third order products are compared to the input signals. The statistics of these tests at the mid band frequency for the active crosspoints is shown in table IX.

CONTRACT REQUIREMENTS VS. DATA

Tables X and XI show the contract requirements or target values, the data measured by the contractor and the data as measured by NASA LeRC.

A direct numerical comparison of some parameters as measured by the contractor and as measured by NASA is not a valid analysis due to different interpretations of the definition of the parameters. For example: Ford measured ripple over only the best 1 GHz band within the total pass band of some crosspoints that received special tuning. The NASA data is derived from the full bandwidth of all crosspoints.

Likewise the "switching speed" is defined differently by Ford from the definition used by NASA. Ford measured the time duration of signal decay of an "off" going crosspoint from the time of 90 percent of full amplitude to the time of 10 percent of full amplitude. An "on" going switch likewise was measured from 10 percent to 90 percent. The NASA definition is from 90 percent of an "off" going crosspoint to 90 percent of full amplitude of an "on" coming crosspoint where each crosspoint routes its input to a common output.

FUTURE TESTING

Testing for amplitude modulation conversion to phase modulation is planned for the near future. A variable directional coupler with a very low phase shift is needed to complete these tests.

CONCLUSIONS

A multibeam, satellite switched, time division, multiple access communication system will require a high speed microwave matrix switch. The state of the technology described in this report and the test data presented identifies those parameters that are satisfactory and those that will require additional development for satellite communication switches incorporated in future designs. The reconfiguration time, routing flexibility, off-state isolation and impedance match are good for both switches. Switching speed for the Ford switch was very good. Insertion loss and ripple were not as good as expected.

These tests indicate that crosspoints in a large matrix switch can be adjusted for switching speed of less than 20 ns and bandwidth of greater than 1 GHz for the TDMA applications anticipated today.

Insertion loss and in-band ripple were greater than anticipated and it is assumed that additional effort will be expended to improve those parameters in the next generation of matrix switches.

Flexibility of TDMA routing and reconfiguration characteristics appear to be quite satisfactory as does harmonic and spurious suppressions. Off state isolation and SWRs are both good.

The next generation of satellite switched matrix switches will of course be designed to the specific requirements of that communication system. However, these POC high speed matrix switches produced by Ford Aerospace and the General Electric Company demonstrate significant advances in the satellite communication state-of-the-art.

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2. Stevens, Grady: 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.

3. Cory, Bernard J.: Spacecraft IF Switch Matrix for Wide Band Service Applications in 30/20 GHz Communications Satellite Systems (General Electric Co.; NAS3-22500.) NASA CR-168089, 1982.

4. Coban, Eugene; and Pelose, John: Spacecraft IF Switch Matrix for Advanced Technology Communication Satellite Systems, Task VII, Proof-of-Concept Test and Analysis Report. WDL-TR9963, Ford Aerospace and Communications Corporation, 1983.

TABLE I. - SUMMARY DESCRIPTION OF POC MODELS

Parameter	Ford	GE
Matrix size		
Input ports	20	20
Output ports	20	20
POC model active crosspoints	66	57
Active input ports	12	20
Active output ports	8	6
Physical size, in	18.75x19x3.25	18.6x16.6x6.6
Weight, lb	19.25	24
Power required		
Switch matrix	5.7	[a]33
Control logic	6.25	
Frame duration (ms)	1	1
Number of states per frame	256	16
Reconfiguration rate (μs)	1	2
If center frequency design objective	4.75	6.5

[a]Matrix and control logic combined.

TABLE II. - CONTRACT GOALS

Parameter	Goal
Size (crosspoints in and out)	20x20
Bandwidth (GHz min between 1 dB end points)	2.5
Insertion loss (dB max)	15
Ripple (dB max over bandwidth)	1.0
Switching speed (ns max)	10.
Isoltion (dBC min)	40
Input voltage standing wave ratio (max)	1.2:1
Output voltage standing wave ratio (max)	1.2:1
Phase linearity deviation (degrees)	±5
Noise (dB below output signal level)	35
Reconfiguration rate (microseconds max)	2

TABLE III. - INSERTION LOSS, BANDWIDTH AND RIPPLE

	Ford		GE	
	Mean	Standard deviation	Mean	Standard deviation
Bandwidth, 3 dB (GHz)	2.7	0.35	1.28	0.21
Insertion loss (dB)	20.7	7.62	18.0	4.06
Ripple (dB)	5.6	1.4	2.23	1.45

TABLE IV. - WORST CASE STANDING WAVE RATIO WITHIN THE PASSBAND

	GE				
	Percentage of 55 crosspoints tested				
	< 1.2:1	1.2≤1.3:1	1.3≤1.4:1	1.4≤1.5:1	>1.5
In	5.4 percent	54.6 percent	18.2 percent	16.4 percent	5.5 percent
Out	1.8 percent	23.3 percent	12.7 percent	45.5 percent	12.7 percent
In	Mean value of worst case points Standard deviation Max value			1.3:1 0.09:1 1.6:1	
Out	Mean value of worst case points Standard deviation Max value			1.4 0.12 1.68	

	Ford						
	Percentage of 62 crosspoints tested						
	<1.5	1.5 to 1.6	1.6 to 1.7	1.7 to 1.8	1.8 to 1.9	1.9 to 2.0	>2.0
In	9.7	12.9	9.7	19.4	16.1	8.1	24.2
Out	21.0	13.0	14.5	14.5	17.7	9.1	9.7
In	Mean value of worst case points Standard deviation Max value						1.82:1 0.30 2.75
Out	Mean value of worst case points Standard deviation Max value						1.7 0.26 2.37

TABLE V. - PHASE DEVIATION

Worst case phase deviation from a straignt line as percentage of crosspoints tested.

	<10°	10 to 12°	12 to 15°	15 to 18°	18 to 20°	7 to 20°
GE	10.9	25.4	10.9	23.6	10.9	21.8
Ford	15.8	4.8	22.2	27.0	9.5	20.6

TABLE VI. - WORST CASE NOISE FIGURE

	Ford Worst case noise figure					
Noise figure, dB	<27	27 to 28	28 to 29	29 to 30	30 to 31	731
Percent of crosspoints	3.28	11.5	31.2	14.8	19.7	19.7

The FORD N.F. was examined at mid band (4.7 GHz) and the following statistics recorded for 61 crosspoints.

Mean Value	29.3	Maximum	31.9
Standard Deviation	1.84	Minimum	26.6

	GE worst case noise figure							
Noise figure, dB	<24	24 to 25	25 to 26	26 to 27	27 to 28	28 to 29	29 to 30	>30
Percent of crosspoints	12.5	8.9	33.9	23.2	7.14	7.14	5.36	1.8

The N.F. was examined at mid band (6.5 GHz) and the following statistics recorded for 61 crosspoints.

Mean value	24.4	Maximum value	35
Standard deviation	2.28	Minimum value	10.4

TABLE VII. - SWITCHING SPEED STATISTICS

	Ford	GE
Switch speed mean (ns)	15.6	32.2
Maximum (ns)	54.0	40
Minimum (ns)	7.0	21
Standard deviation	10.9	3.6
Number of data points	99	56

TABLE VIII. - OFF STATE ISOLATION

	Ford	GE
Isolation - mean value (dBc)	54	58
Standard deviation	5.7	5.7
Maximum dBc	64	66
Minimum dBc	39	45
Number of crosspoints	60	54

TABLE IX. - INTERMODULATION DISTORTION, THIRD ORDER

Contractor	N	Max. dB	Min. dB	Mean dB	Standard deviation	Variance dB
GE	57	49	28.5	42.5	3.9	15.2
Ford	60	57	34	43.9	5.7	32.5

TABLE X. – FORD DATA COMPARISON

Parameter	Requirement	Contractor	NASA
Bandwidth target 2.5 GHz	1 min	2.5	2.7
Insertion loss (dB)	15 min	20.0	20.7
Gain ripple (dB)	1 max	<1.0	5.3
Switching time (ns)	10 max	5	16
Isolation (db)	-40 min	<-45	-54
SWR IN	1.2:1 max	<1.5:1	1.8:1
SWR OUT	1.2:1 max	1.5:1	1.7:1
Deviation from linear phase – vs. powr in – (°)	±5	±5	-----
Deviation vs. frequency (°)			15.5
Reconfiguration rate (μs)	2.0	1.0	1.0
Intermediate frequency	3 to 8 GHz	3.5-6	
Intermodulation distortion 3rd order (dB)	----------	--------	-43.9
1 dB Gain Compression (dBm)	----------	±16	>+10
Noise (below output level) (dB)	35	>50	-----
Noise figure (mid boad) (dB)	----------	--------	24.1

TABLE XI. – GE DATA COMPARISON

Parameter	Requirement	Contractor	NASA
Bandwidth 1 dB (GHz)	1.0 min	0.95	-----
Bandwidth 3 dB (GHz)			1.2
Insertion loss (dB)	15 dB min	16.1	18.0
Gain ripple (dB)	1.0 max	1.1	2.2
Switching time (ns)	10.0 max	24.9	37.0
Isolation (db)	-40.0 min	>-75	-40.0
SWR IN	1.2:1 max	1.3:1	1.3:1
SWR OUT	1.2:1 max	1.4:1	1.4:1
Deviation from linear phase (°) versus power in	±5° max	8.9	-----
Deviation, mean of max. deviation versus frequency			14.6
Reconfiguration rate	2 μs max	2.0	2.0
Intermediate frequency	3 to 8 GHz	6.5	-----
Intermodulation distortion 3rd	35 dBc min	52	42.5
1 dB Gain Compression (dBm)	----------	0	+12
Signal to noise at 6.5 GHz dBc	35 min.	50	-----
Noise figure (mid boad) (dB)	----------	--------	24.1

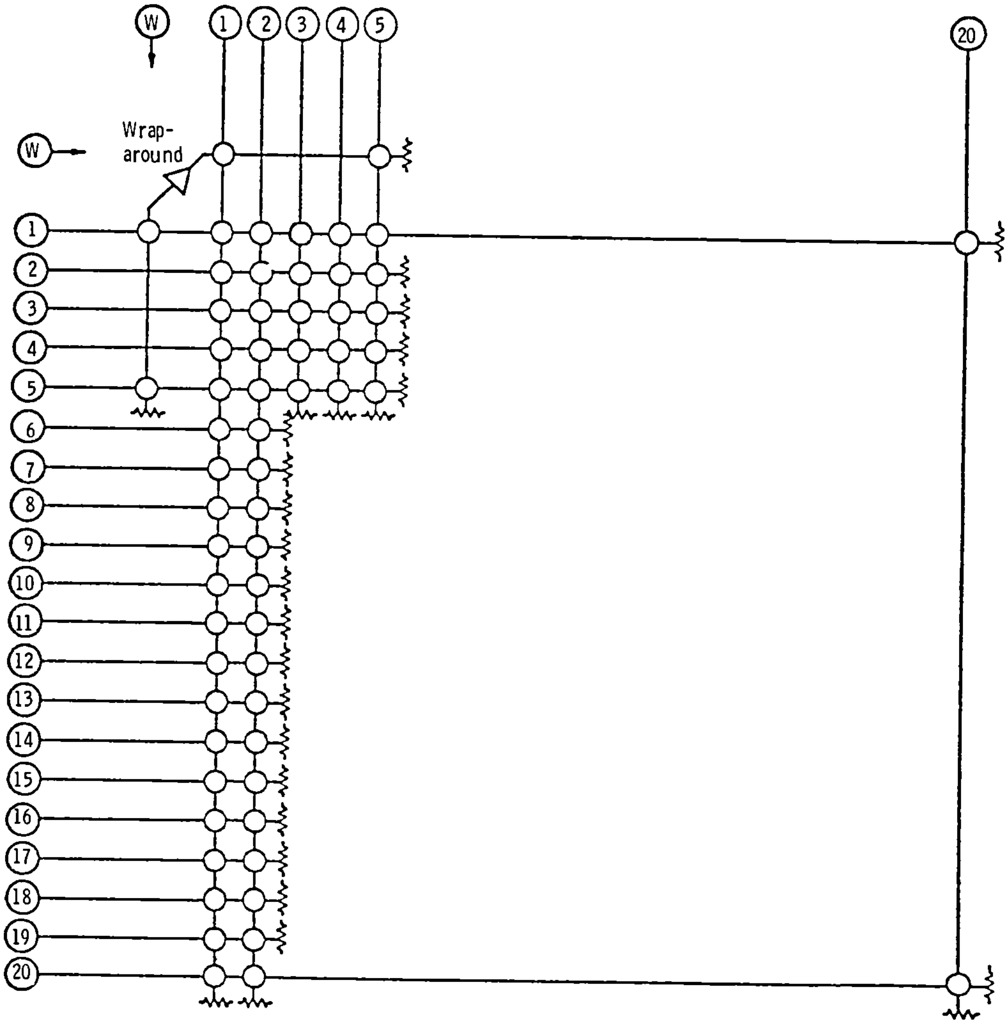

Figure 1. - G.E. POC switch matrix crosspoint distribution.

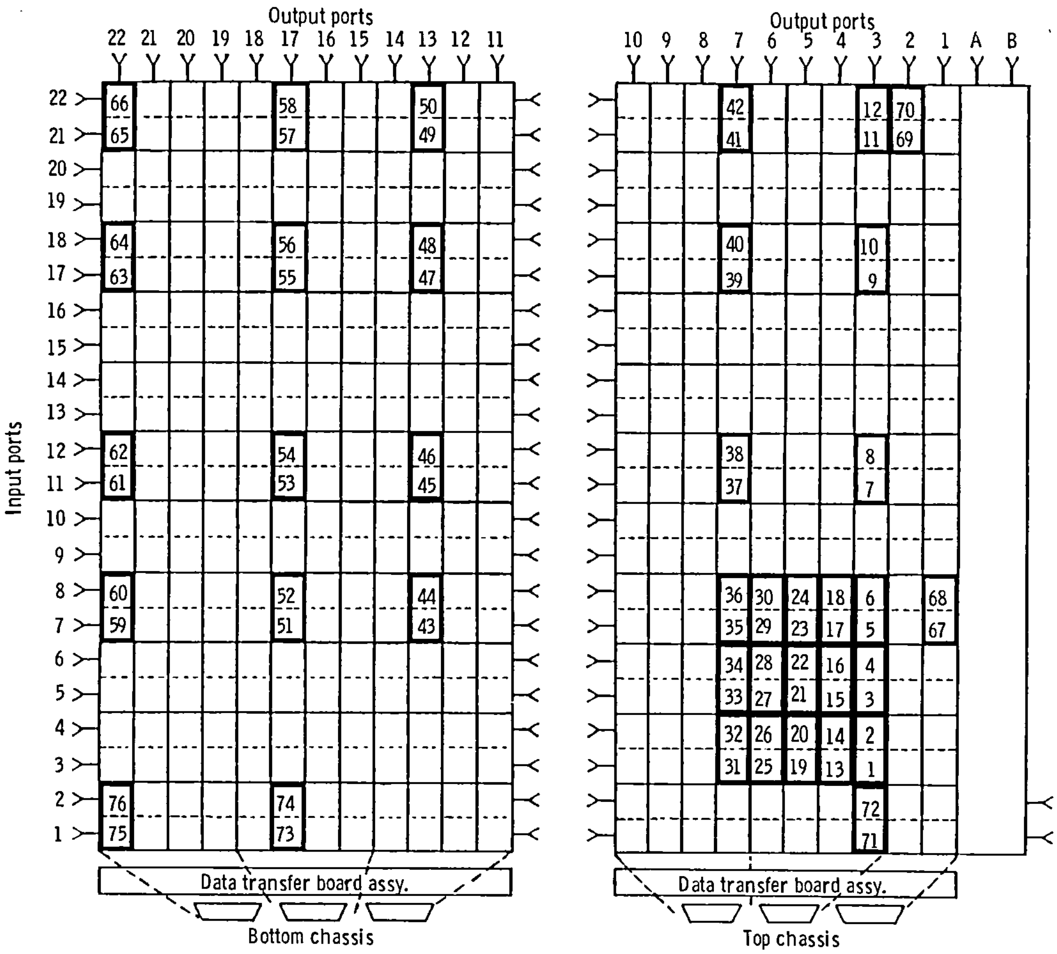

Figure 2. - Ford crosspoint locations.

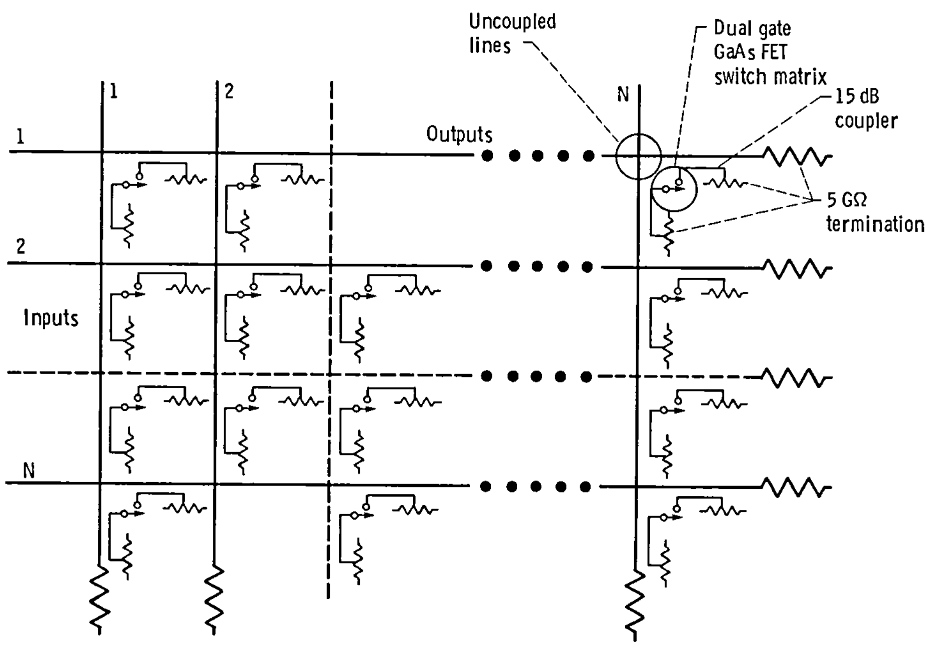

Figure 3. - G. E. coupled crossbar architecture.

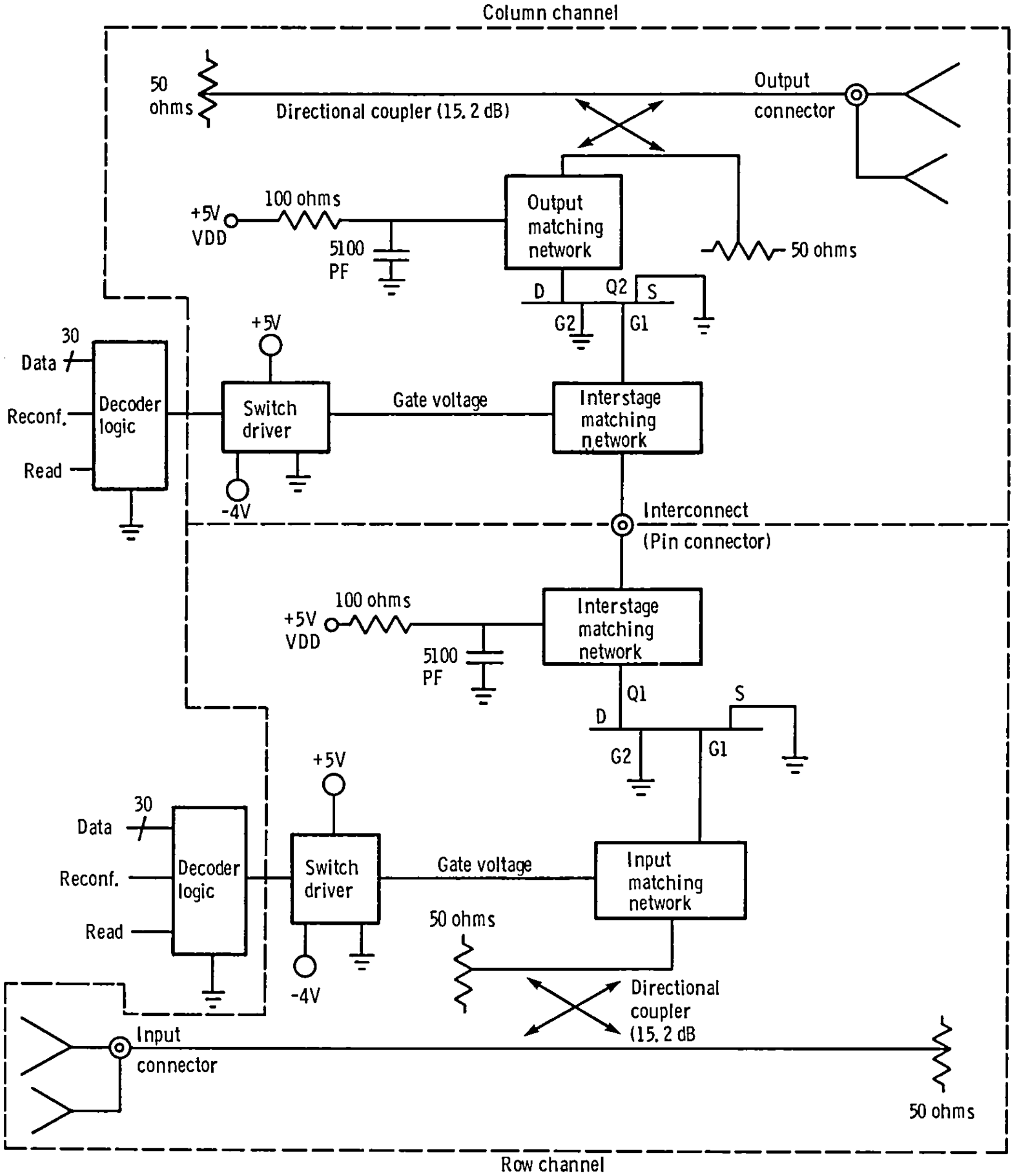

Figure 4. - G. E. crosspoint block diagram.

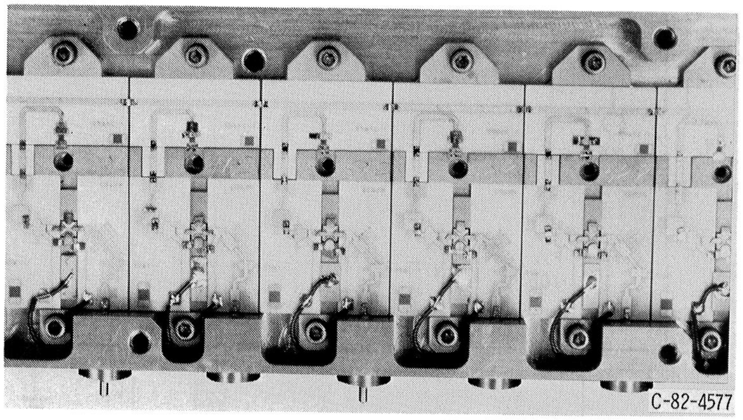

Figure 5. - G.E. crosspoint modules.

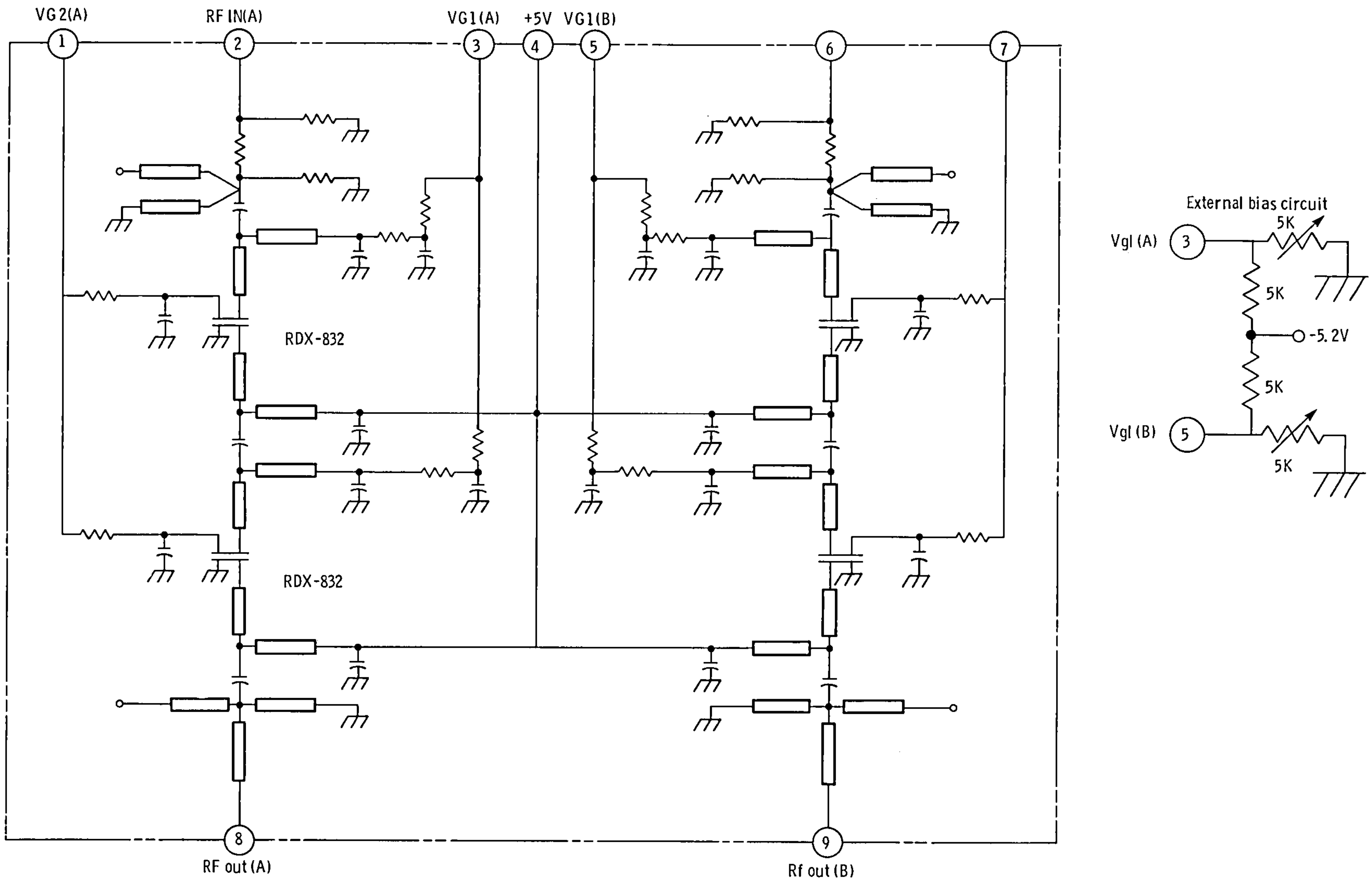

Figure 6. - Ford switch amplifier module.

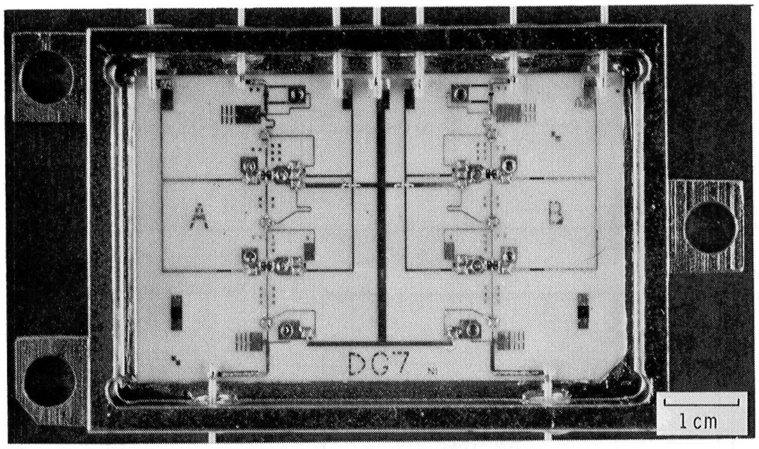

Figure 7. - Ford crosspoint pair module.

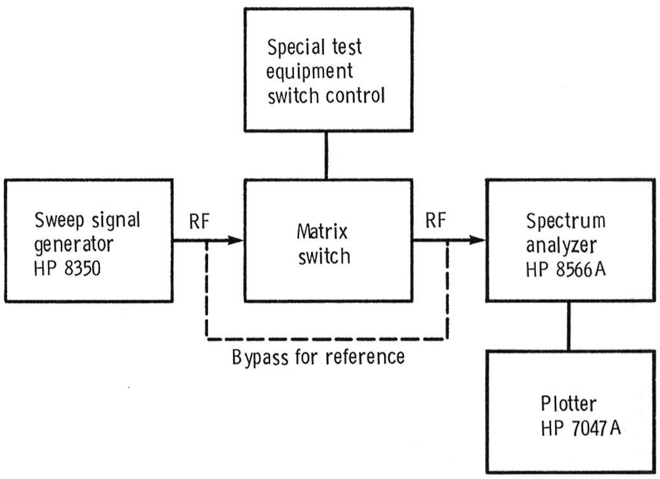

Figure 8. - Experimental arrangement for measurement of insertion loss, bandwidth and ripple.

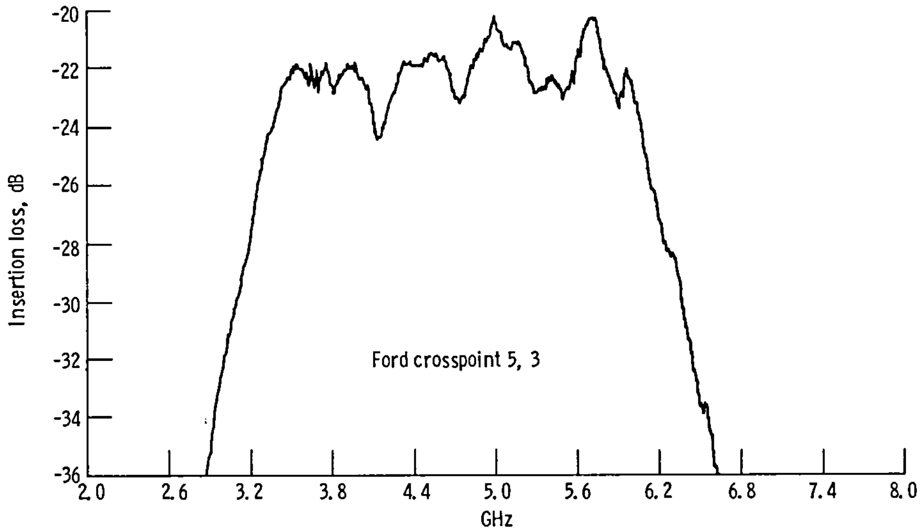

Figure 9. - Insertion loss.

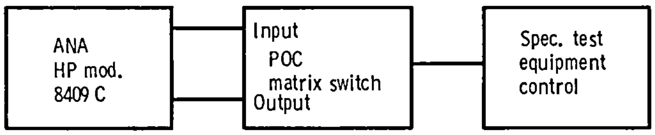

Figure 10. - Setup for measurement of standing wave ratio, insertion loss and deviation from linear phase.

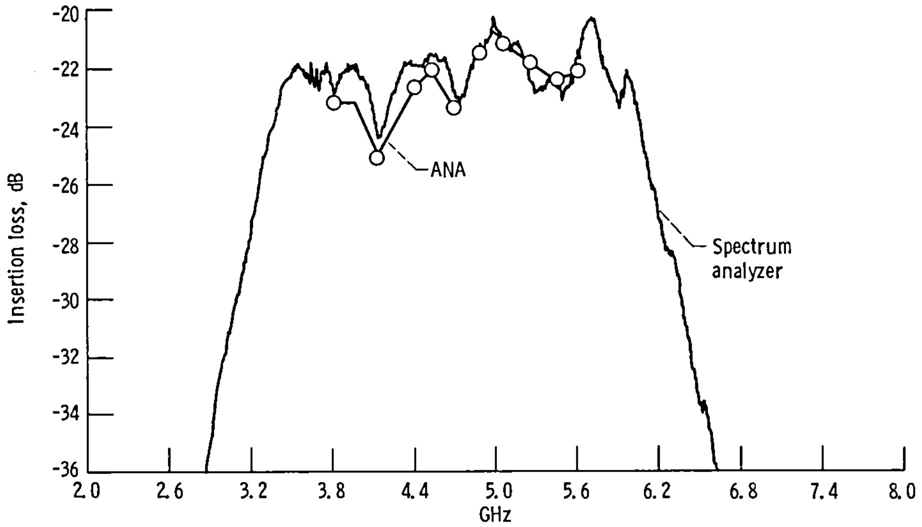

Figure 11. - Insertion loss by spectrum analyzer and ANA.

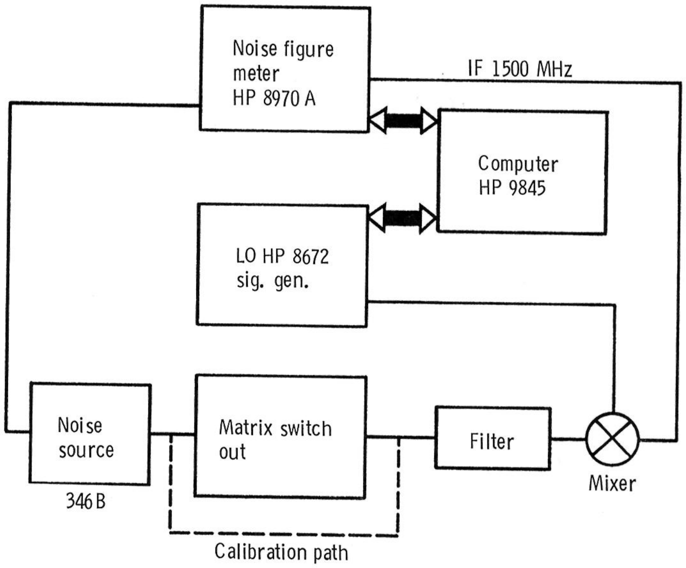

Figure 12. - Noise figure measurement.

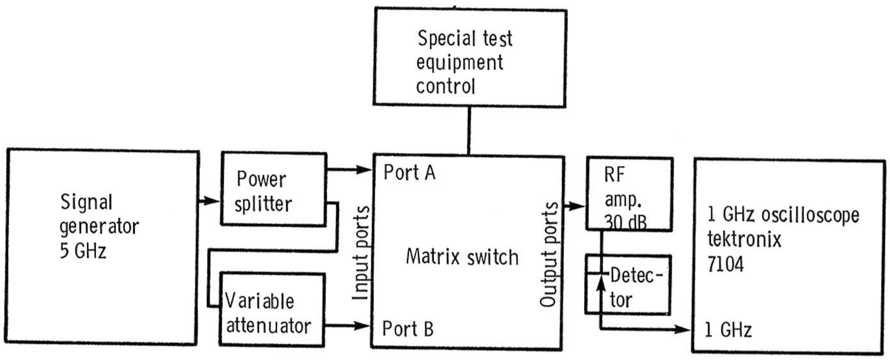

Figure 13. - Switching speed.

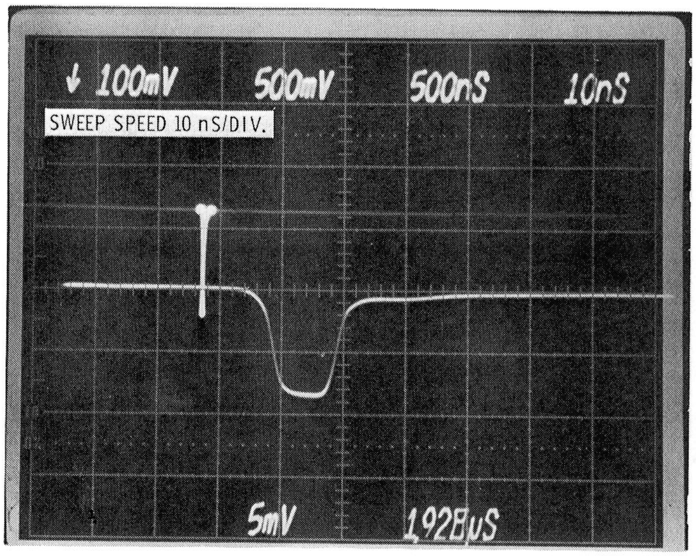

Figure 14. - Ford crosspoint switching time, (18.22 off), (12.22 on).

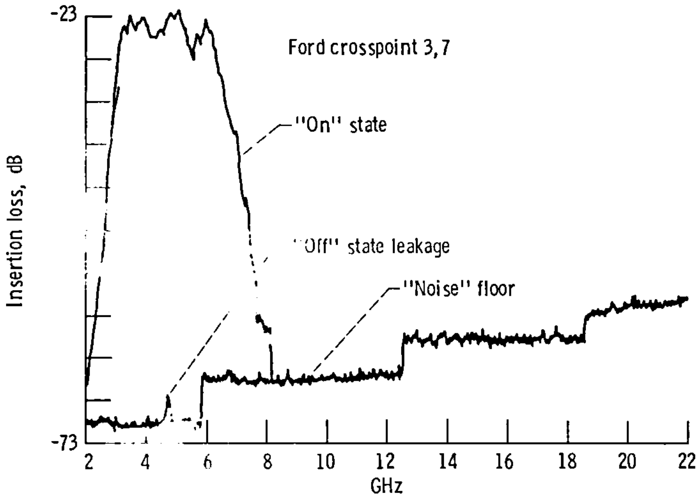

Figure 15. - Typical isolation.

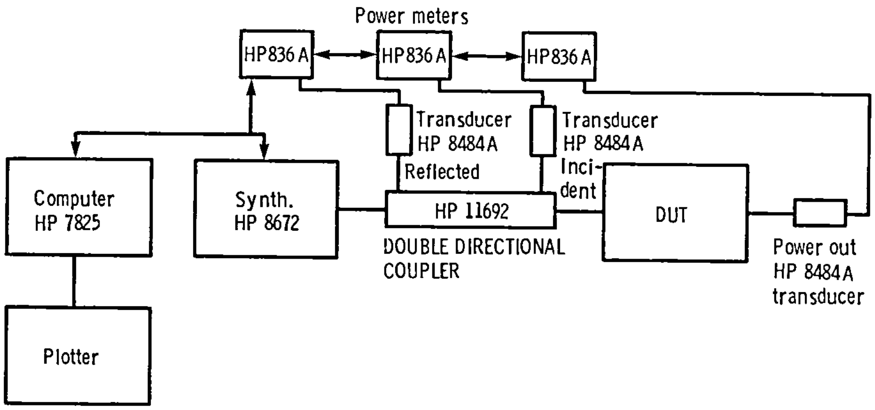

Figure 16. - Power linearity.

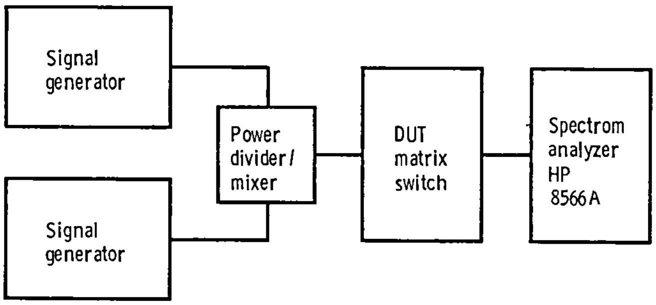

Figure 17. - Intermodulation distortion.

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15. Supplementary Notes

16. Abstract

Tests were conducted at NASA Lewis Research Center to characterize the proof-of-concept matrix switches built under NASA contract by Ford Aerospace and Aeronautics Corporation at Palo Alto, California, and the General Electric Company at Valley Forge, Pennsylvania. The contract requirements and goals are tabulated along with the results of the NASA tests. Characteristics examined are bandwidth, insertion loss, ripple, switching speed, isolation, standing wave ratio (input and output), deviation from linear phase, noise figure, reconfiguration rates, spurious responses, gain compression, and third order intermodulation distortion. A brief description of the testing method and a statistical analysis of the test results for each of the switches are provided.

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