HIGH SPEED MEASUREMENTS OF T/R MODULES

John R. Jones
Curtis E. Green

Scientific-Atlanta, Inc.

ABSTRACT

An s-parameter measurement system and a procedure are described for making fast s-parameter measurements on multi-state devices. A sample test problem is considered and the application of the system and the procedure to this test problem is discussed. The important features of the system are described and timing measurements of system operation are presented.

Keywords: s-parameters, network analyzers, receivers, t/r modules, on-wafer testing

1. Introduction

One of the most important antenna test problems to be addressed in recent years is the testing of array antennas with multiple and/or steerable beams. These antennas represent a difficult test problem because they are designed to rapidly change their performance characteristics over wide ranges in response to control signals from the system in which they are used. In a radar application, for example, the multiple beams of such an antenna might be steered in response to control signals from the radar signal processor to track multiple targets in real time.

In testing these antennas, one is faced with the problem of measuring the performance characteristics of an antenna which is designed to change its performance characteristics in response to control signals. A useful characterization of such an antenna requires measurements as functions of the control signal inputs and as functions of direction and frequency, the usual independent variables for an antenna measurement. When such a measurement is performed, an extremely large amount of data must be collected under computer control between physical reconfigurations of the measurement setup such as connecting and disconnecting cables. It is in this type of measurement scenario that the use of a high speed measurement receiver becomes critical to measurement throughput. It was to address this test problem, among others, that the Scientific-Atlanta Model 1795 receiver was designed.

It is clear that the t/r modules which provide amplitude and phase control over the individual radiating elements of an array antenna pose a similar test problem. A single array antenna might contain hundreds or even thousands of these t/r modules. In order to fully characterize the performance of an array feeder network, s-parameter measurements on these hundreds or thousands of t/r modules for a large number of amplitude and phase control states at a large number of frequencies must be performed. This leads again to the type of measurement scenario in which a high speed measurement receiver under computer control becomes critical to measurement throughput. It was to address this test problem, among others, that the Scientific-Atlanta Model 1795 receiver was integrated into the Scientific-Atlanta Model 2096 s-parameter measurement system.

2. Definition of the Test Problem

Production testing of t/r modules on the scale required for the production of array antennas can be an intractably time-consuming and expensive process. These devices necessarily have two or more ports, and the number of s-parameters required to characterize a device at a single frequency is the square of the number of ports. Thus four s-parameter measurements are required to characterize a two-port at a single frequency, nine are required to characterize a three-port at a single frequency, and so on.

The s-parameter measurements must also be performed for a significant number of control states for each device. For example, to fully characterize a 12-bit phase shifter, a simple t/r module without amplitude control, at a single frequency requires measurements of all its s-parameters for 4096 different control states. If the phase shifter is a two-port device (as opposed to three or more ports), this means that at each frequency, 16,384 s-parameter measurements must be made.

Next we note that s-parameter measurements are usually made as a function of frequency rather than at a single frequency. Even if a small number of frequencies, for example 30, is required, this brings the total number of s-parameter measurements required to characterize a single 12-bit four-port phase shifter to 491,520. Finally, note that more than one device is required for each antenna to be produced and the devices themselves are usually produced in the largest possible production runs to take advantage of economies of scale. A two-inch MMIC wafer might contain 100 t/r modules. It would be most cost-effective to measure the 49,152,000 s-parameters required to characterize all the devices on the wafer before it is diced and the devices are connectorized.

In what follows, we will use the wafer-probe measurement scenario described above as our typical test problem. We will demonstrate that the speed of the Scientific-Atlanta Model 2096 s-parameter measurement system can be used to good advantage to make the measurements required for this test problem in a time-efficient and cost-effective manner.

3. MEASUREMENT STRATEGY

Acquisition of the amount of data required by this test problem with a general-purpose laboratory network analyzer would be extremely time-consuming and expensive. The network analyzer is designed to measure s-parameters of relatively simple devices as a function of frequency. It does not provide for measurements as a function of the control state of the device, so a frequency sweep or set of sweeps would be required for each control state of the device under test. In addition, the network analyzer is not designed to switch from measuring one s-parameter to measuring another quickly. The fact that acquisition of all four s-parameters during each frequency sweep or set of sweeps is required for two-port vector error correction means that the relatively slow process of switching from one s-parameter to another must take place many times during the measurement.

Clearly, the measurement sequence which is natural for a general-purpose laboratory network analyzer is poorly suited to the test problem under consideration here. The best strategy for optimizing measurement throughput in a measurement scenario with multiple independent variables (like the one considered here) is to change most often the independent variables which can be changed most rapidly and least often those which can only be changed slowly.

For the test problem considered here, a general-purpose laboratory network analyzer requires changing independent variables in exactly the opposite order to the most efficient sequence described above. The independent variable which requires the most time to change, <u>i.e.</u> s-parameter, is changed most often. The measurement frequency, the next slowest independent variable to change, is changed next most often. The device state, typically the independent variable requiring the least time to change, is changed least often. This makes for an inefficient measurement sequence in the test problem considered here.

It is possible to use a network analyzer under computer control to make the measurements required by our test problem in a more efficient sequence[1]. In this configuration, the network analyzer operating in its fastest mode of operation is used as a measurement receiver. The error-correction and processing is done either by the system controller or by an auxiliary computer rather than by the network analyzer itself. A system configured in this way utilizing an HP8510B network analyzer in fast CW mode as the measurement receiver could perform the measurements required by the test problem much faster than a stand-alone network analyzer could.

The Scientific-Atlanta Model 2096 system is configured as described above with the Scientific - Atlanta Model 1795 receiver as the measurement receiver. Because the Scientific-Atlanta Model 1795 receiver is five times as fast as the HP8510B (5000 measurements per second for the SA 1795 as opposed to 1000 measurements per second for the HP8510B), the Model 2096 s-parameter measurement system can perform the measurements required by the test problem about five times faster than a similar system configured using the HP8510B[1]. Compared to a general-purpose laboratory network analyzer (not configured in a special fast measurement system), the Scientific-Atlanta Model 2096 system is much more than five times faster.

4. System Communication and Control

As critical as the availability of a fast measurement receiver for performing the measurements called for by our test problem is a system configuration which can utilize the speed of the receiver to optimize measurement throughput. The preceding section described the optimum measurement strategy. The other essential item for efficient measurements is a means for controlling the independent variables for the measurement and for reading the measured data from the measurement receiver at the full measurement speed. The Scientific-Atlanta Model 2096 s-parameter measurement system addresses these considerations by devoting a secondary processor solely to the data acquisition process.

The system controller in the Model 2096 s-parameter measurement system is a Compaq Deskpro 386/33®. The microprocessor in this computer is the Intel 386 DX®. This is one of the fastest and most powerful microprocessors ever designed. It is not fast enough, however, to perform the measurement control functions and the data acquisition functions for the Model 2096 s-parameter measurement system at the full 5000 measurements per second speed of the Model 1795 receiver.

In order to take full advantage of the speed of the receiver, the Model 2096 s-parameter measurement system incorporates a secondary processor called a Data Acquisition Coprocessor or DAC. The DAC consists of an add-in printed wiring board which is resident in the system controller and which communicates with the system controller's microprocessor over its internal AT® bus, and an external printed wiring board from which the connections are made to the instruments in the system and to the device under test. A simplified block diagram of the measurement system including the DAC is shown in Figure 1.

The system controller writes a data acquisition program to the DAC prior to data acquisition. This program specifies the measurement sequence, the timing, triggering requirements, the amount of data to buffer on the DAC for transfer to the system controller's memory, and all other data acquisition parameters. When data acquisition is begun, the DAC takes over control of all the instruments in the system by means of dedicated hardwired interface lines. The DAC triggers the signal source to change frequencies and the receiver to acquire data. It also sends control information to the device under test, causing it to switch control states at the appropriate time.

In addition to controlling the measurement sequence, the DAC reads the measured data from the receiver over a dedicated high-speed parallel interface. Random access memory on the DAC board buffers the incoming data and it is transferred via a DMA-like process to the memory of the system controller in blocks of the pre-programmed size. It is the DAC which permits the Model 2096 s-parameter measurement system to utilize the full 5000 measurements per second speed of the Model 1795 receiver.

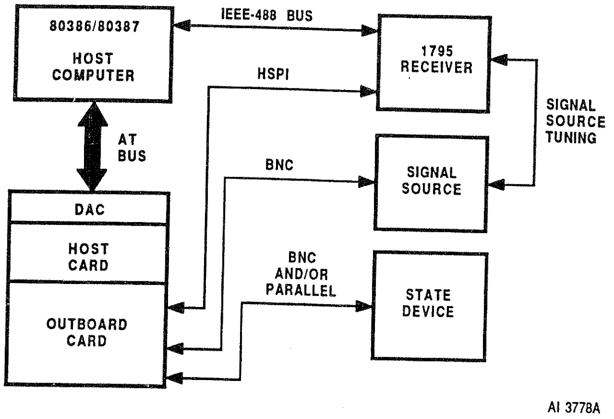


Figure 1: Simplified Block Diagram of the Model 2096 System. Note Triggering, Device State Control, and Data Acquisition Are Handled by the DAC

5. Full Speed Measurement Experiment

A test case was developed in which a 12-bit control word was written to an output port of the DAC. This simulated the 12-bit control of the phase shifter in our test problem described above. A 5 µs strobe output was also provided to simulate a strobe signal used to clock the control word into the device under test.

The DAC managed this device state output and strobe as well as the 1795 receiver trigger in the available 20 µs. The timing diagrams for this test are shown in Figures 2-5.

Figure 2 shows that 16.6 µs were required from the time the IF processor became idle (IDLE goes high) to the time the next trigger is sent to the 1795 receiver (SATRIG is driven low). The 5 µs device state strobe (DUTSTR for Device Under Test STRobe) was embedded in this 16.6 µs. The least significant bit of the 12-bit control word is also shown in the figure to toggle (DB0 for Data Bit 0).

Figure 3 shows the sustained data rate of 200 µs per measurement. Figure 4 shows that the actual strobe width was 5.4 µs. Figure 5 shows 6.6 µs between the start of the 5.4 µs device state strobe and the leading edge of the 1795 receiver trigger. This allowed 1.2 µs for the device under test to settle.

6. Application to Test Problem

Returning to the test problem of the 12-bit phase shifter described above, we can determine the approximate measurement time required for each device using the Model 2096 measurement results cited. The device has 4096 phase states. If we assume that the phase state can be changed within the 20 µs device state change window demonstrated, then a 5000 measurements per second data rate can be sustained. If the device state change requires more time, the measurement time will increase accordingly.

For measurement of all four s-parameters at 4096 device states and a single frequency, the time required would be 3.28 seconds. Each frequency change is accomplished in about 11 ms, so the 30 frequency changes add 0.33 seconds to the measurement. Therefore, the total time to measure a single device for our test problem would be 30 X 3.28 seconds + 0.33 seconds or 98.73 seconds. The time to measure all the devices on the wafer would be heavily dependent on the speed with which the wafer probes could be repositioned, but it is almost certain that during this repositioning interval all the buffered data could be transferred from the DAC to the host and the DAC could be reset for the next device acquisition.

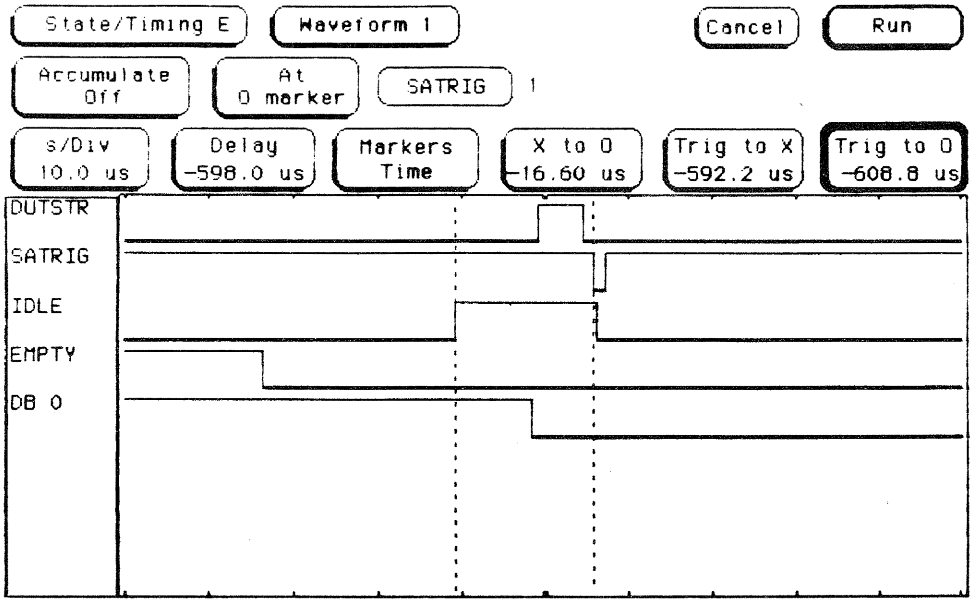
7. Summary and Conclusions

We have demonstrated operation of the 2096 system using a relatively inexpensive controller with a Data Acquisition Coprocessor. This system can utilize the full 5000 measurements per second speed of the Model 1795 receiver. We have demonstrated that a measurement strategy can be devised which permits s-parameter data to be usefully acquired at this measurement speed. We have also postulated an example test problem and computed the approximate measurement time for this problem using the 2096 s-parameter measurement system.

The 2096 s-parameter measurement system can dramatically reduce the test time required in production of t/r modules for array antennas. This improvement in measurement throughput can significantly reduce the cost of producing both the t/r modules and the array antennas in which they are used. The price/performance ratio of the Model 2096 s-parameter measurement system is much lower than that of any other s-parameter measurement system available today.

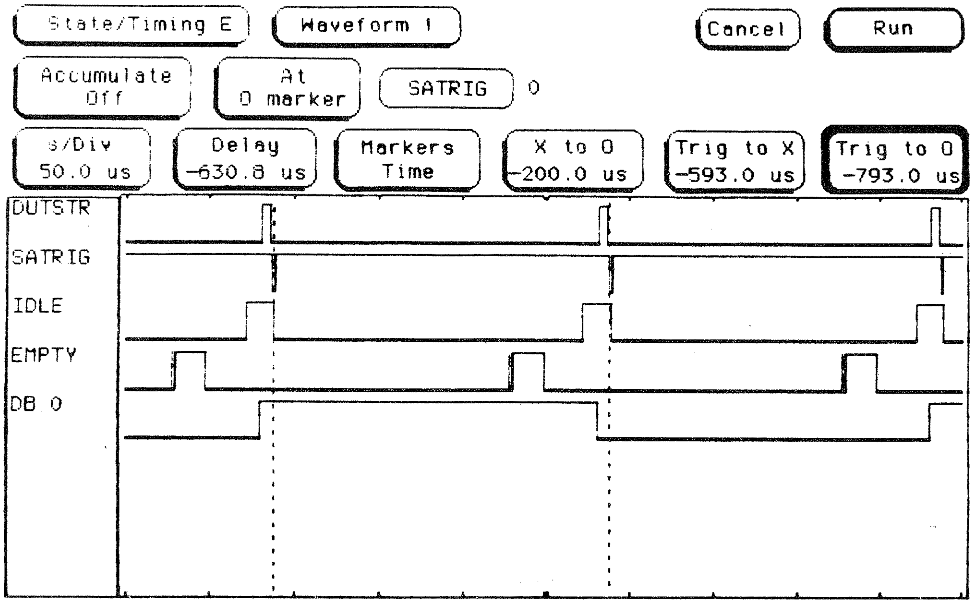
8. References

[1] Huff, J. D., Caldwell, O. M., and Jones, J. R., "The Application of a High Speed Microwave Receiver to the Measurement of s-parameters of Multi-State Devices," in Proceedings of the 35th ARFTG Conference, Dallas, TX, May, 1990.



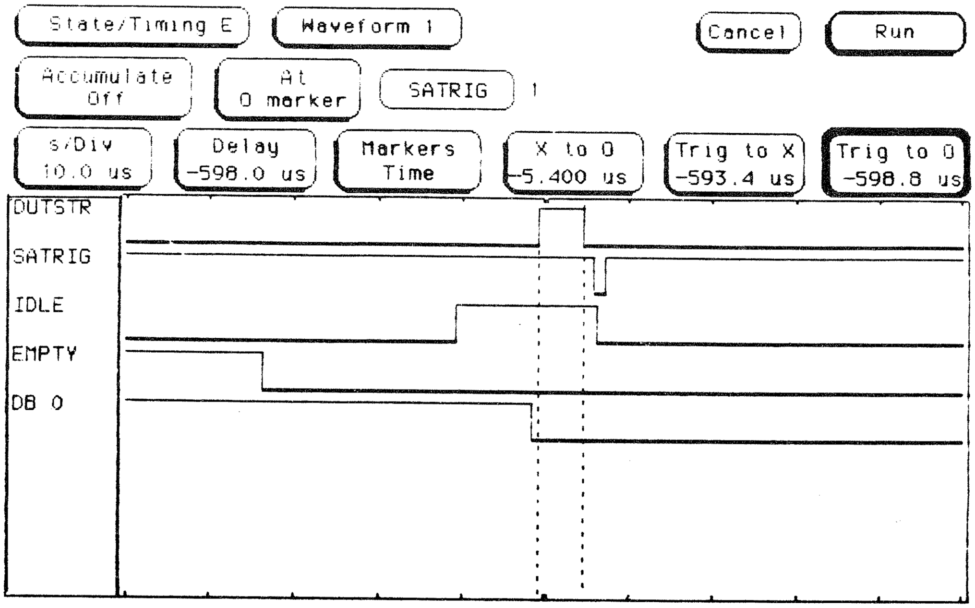
Accumulate Off
At 0 marker
SATRIG 1
s/Div 10.0 us
Delay -598.0 us
X to 0 -16.60 us
Trig to X -592.2 us
Trig to 0 -608.8 us

Figure 2: 2096 Timing Measurement Showing 16.6 us From Receiver Idle to Trigger



Accumulate Off
At 0 marker
SATRIG 0
s/Div 50.0 us
Delay -630.8 us
X to 0 -200.0 us
Trig to X -593.0 us
Trig to 0 -793.0 us

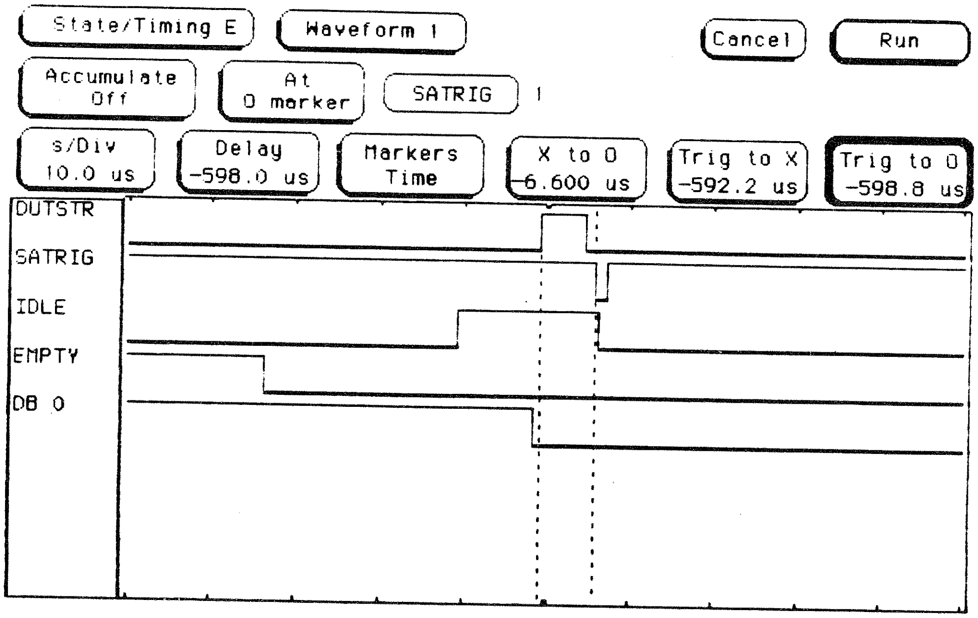
Figure 3: 2096 Timing Measurement Showing Sustained 5000 Measurements Per Second Data Acquisition Rate



Accumulate Off
At O marker
SATRIG 1
s/Div 10.0 us
Delay -598.0 us
Markers Time
X to O -5.400 us
Trig to X -593.4 us
Trig to O -598.8 us

AI 3775A

Figure 4: 2096 Timing Measurement Showing 5.4 us Width of Device State Strobe



Accumulate Off
At O marker
SATRIG 1
s/Div 10.0 us
Delay -598.0 us
Markers Time
X to O -6.600 us
Trig to X -592.2 us
Trig to O -598.8 us

AI 3776A

Figure 5: 2096 Timing Measurement Showing 1.2 us Device State Settling time (6.6 us - 5.4 us)

NOTES