Automated MIMIC Wafer RF Test System

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1. Objective

Scientific-Atlanta is presently developing a new family of high-speed, general purpose, on-wafer test systems which greatly reduces RF test times and thereby can alleviate test bottlenecks at MMIC foundries. The primary objective for the equipment developed on the Scientific-Atlanta MIMIC Phase 3 program is to reduce present MIMIC chip RF test times by an order of magnitude compared to test systems presently in use.

On this MIMIC Phase 3 Program, Scientific-Atlanta plans to demonstrate high speed measurement and analysis techniques covering a wide range of test types. These techniques provide comprehensive measurement capabilities of the following RF parameters under both pulsed and CW conditions;

- Small signal vector s-parameters
- Large signal vector s-parameters
- Power and compression points
- Noise figure
- Intermodulation products and intercept points
- Spectral content including spurious and harmonic components
- Q-point
- DC parametrics

These capabilities, coupled with the unique 3-port RF architecture, allow complete testing of essentially all chip types using a single touchdown of the wafer probes.

The chip types targeted on this program are slated for insertions in radar, communications and Electronic Warfare applications. They include;

- Mixers
- Low Noise Amplifiers
- Power Amplifiers (CW and Pulsed)
- Phase Shifters/Attenuators
- Integrated Front Ends

Modules, assemblies, and MCMs can also be tested with the general purpose test system hardware and software if supplied with appropriate handling equipment and DUT interfaces.

2. Approach

The MIMIC Test System architecture is optimized for high speed data acquisition and analysis. Speed improvements are realized utilizing the following key implementation techniques.

Multiple Data/Control Bus Architecture

The Scientific-Atlanta MIMIC test system differs from conventional RF test systems by utilizing multiple busses for data transfer and instrument control. The multiple busses are of two general types. The first is the IEEE-488 standard interface, which is used only for system initialization, instrument error reporting and low speed data requirements. The second bus type is a general purpose high speed parallel binary interface. This interface type is used for both control and data transfer activities during the actual data acquisition process. Separate interfaces are provided for the high speed instruments and the DUT I/O requirements.

High Speed Instruments

In addition to the multi-function high speed 3-Port RF test set, the Scientific-Atlanta MIMIC Phase 3 test system incorporates the new Scientific-Atlanta Model 1795P Microwave Receiver. This receiver provides both vector measurements for s-parameters and scalar measurements for power and noise figure parameters at a sustained data rate of 10,000 measurements per second. The receiver provides a spectral content measurement mode which eliminates the need for a separate spectrum analyzer in the system. Another enhancement in this system compared to present test systems is the high speed DC bias and DUT control interface. This unit allows state change commands at a rate up to 10,000 events per second over 16 DUT control lines. Threfore, complete state space testing of multi-state devices such as phase shifters and attenuators is fully coordinated with the RF measurements, including data strobing, triggering holdoff, and delay functions. The DC bias portion of the unit provides high speed DC bias control and measurement for up to 6 low power supplies and 1 high power supply.

Multi-Tasking and Multi-Processing Operating System

The Scientific-Atlanta MIMIC Phase 3 test system is based on a low cost 80486 based personal computer for data collection, data storage, data analysis, data display, and networking operations. Data acquisition speed is improved over that obtainable using only the 80486 processor by utilizing a separate Data Acquisition Coprocessor incorporated into the system controller. This coprocessor frees the main system controller for other tasks by handling the real-time aspects of the data collection process. This feature, coupled with the multi-tasking, multi-threaded feature of the IBM OS/2 Operating System, eliminates any potential delay on data acquisition caused by excessive main processor loading.

3. Results

Results to date are based on system tests performed with development software and slower instrumentation than that expected in the final configuration. However, the system configured with instruments providing a peak data rate of 5,000 measurements per second show the viability of the design concepts. A frequency change rate of only 50 frequencies per second was used versus the 10,000 frequencies per second rate expected in the final configuration.

Preliminary Test Data

Device	Test Parameters	Test Time
Raytheon 6 Bit Phase Shifter	4 s-parameters @ 64 phase states @ 3 frequencies	220 millisec
Texas Instruments EG 8310 Low Noise Amplifier	4-s-parameters @ 33 frequencies	700 millisec

When the final configuration of the Scientific-Atlanta MIMIC Phase 3 Test System is available in the early autumn of 1993, estimated test times for key test scenarios are given in the table below.

Projected Typical Test Times

Test Type	Test Parameters	Test Time
Multi-State Multi-Frequency	4 s-parameters @ 64 states @ 3 frequencies	134 millisec
Multi-Frequency	4 s-parameters @ 15 frequencies	10.5 millisec
Noise Figure	Noise figure to 1 dB @ 6 frequencies	1,078 millisec
Spurious	10 GHz sweep 5 spurious components	65 millisec

4. MIMIC Program Phase 2 Interface

Scientific-Atlanta has compiled MIMIC Program chip characteristics and test plan information from each of the Phase 2 teams. Also, visits to the various foundries and discussions have identified which test types present the greatest challenges to the MIMIC community. We have also had the opportunity to observe operations in each of these foundries to gain insight on the practical aspects of wafer testing.

A subset of "target" chips which represent all the various test requirements were chosen for demonstration on the new MIMIC Test System based on the collected wafer data. A summary of the target chips is shown below. Wafers of the target chips from the Phase 2 contractors are presently being received.

Target Chips for Demonstration

Device Number	Device Type	Source
HEP 450B	Pulsed Power Amp	Hughes
EG8437	Mixer (Upconverter)	Texas Instruments
JVCHIP23	Phase Shifter	Raytheon
EG8310	LNA (Broadband)	TI, Raytheon, Sanders, Teledyne
QHH101C	LNA (mm-wave)	TRW

5. Transition Plans

As stated in the MIMIC Phase 3 BAA, "The ultimate objective of the MIMIC Phase 3 program is to demonstrate technology that has a high payoff in terms of producing MIMIC chips in a reliable, low cost manner... There is a great need to further reduce the cost of high speed testing on-wafer and at the chip and module levels."

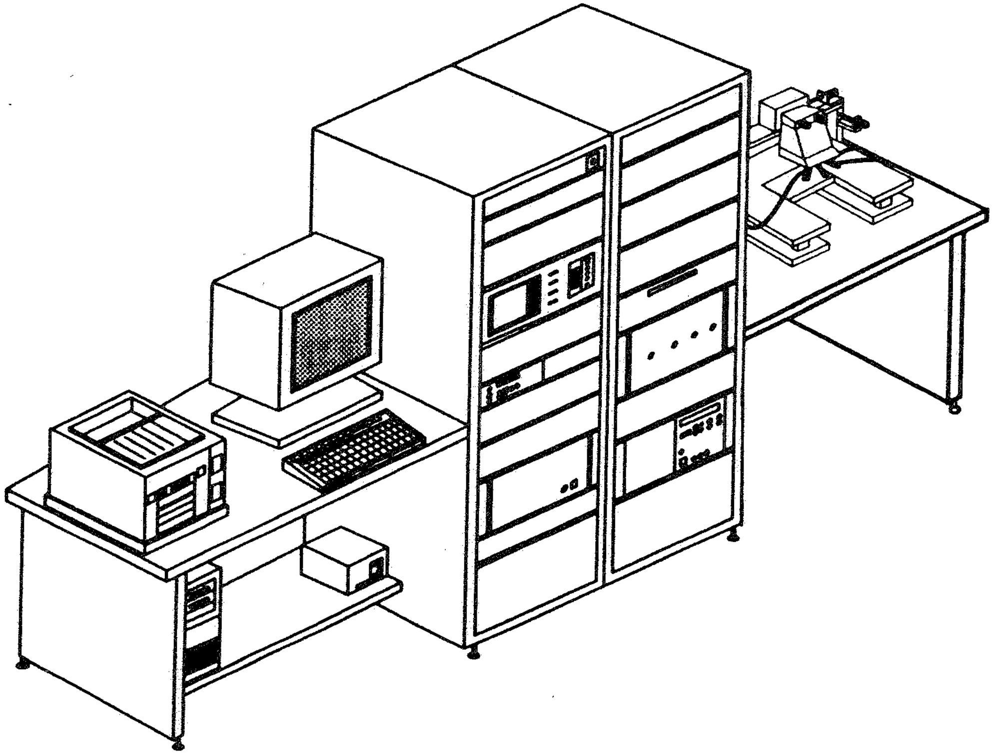
The Scientific-Atlanta MIMIC Phase 3 Test System is demonstrating that comprehensive high speed, high precision microwave and DC measurements can be reliably accomplished on-wafer with a single touchdown. The Scientific-Atlanta architecture directly reduces the cost of testing by reducing the number of test systems required for a given wafer or module throughput rate and by reducing the cost of a typical test system when compared to previous generation systems. Of particular importance is the integrated software with the MIMIC Phase 3 test system. Software costs for many systems presently in use often exceed the hardware costs.

As stated in our program objectives, the commercialization of the new test technologies developed is a primary aspect of this effort. Consequently, Scientific-Atlanta is finalizing the design and production documentation required to make the MIMIC Phase 3 Test System a commercial product. It is the second in the S-A Model 209X class of Automated Network Measurement Systems and is designated the Model 2097 MMIC Wafer Test System.

Since the MIMIC Phase 3 system has an extensive set of capabilities chosen to test virtually any chip type, The 2097 is designed to be sold in a modular format. This feature allows the users to configure a system with only the capabilities required for their current applications and keep capital equipment costs to a minimum. Upgrades for additional capabilities up to the full configuration can be made at any time.

In addition to the new Model 2097, Scientific-Atlanta will continue to develop further system extensions. Present plans include extending the Model 2097 architecture for frequency coverage below 2 GHz and for providing control interfaces and software to support packaged device handlers. Enhanced techniques for simplified calibration and verification are also being evaluated as potential product offerings based on information obtained during this program.

An Automated MIMIC Wafer RF Test System



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Outline

- Introduction
- Program Description
- System Architecture
- Phase 2 Contractor Activities
- Benefits to MIMIC Community
- Transition to Commercial Product
- Summary

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Scientific-Atlanta MIMIC Phase 3 Program

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Introduction

- Device variations and high reliability requirements will require comprehensive testing for the foreseeable future
- Multi-chip modules require high confidence components for economic production
- Comprehensive RF testing is a significant portion of the total component cost
    - Wafers
    - Chips
    - Multi Chip Modules (MCMs)
- Test costs approaching 5% of device cost are
    - Test cost reductions to less than 1% of device cost are needed
- Test throughput is the most important issue at most foundries
    - Test time reductions are vital to the commercial success of GaAs devices

Device Characterization Requires Multi-Dimensional Measurements

Test Conditions versus Device and Measurement Types

WAFER PRODUCTION MEASUREMENTS	Low Noise Amplifier	Power Amplifier	Control Circuit	Frequency Converter
Small Signal S-Parameters	Freq, Power, Temp, DC	-	State, Power, DC, Freq, Temp	Freq, Power, Temp, DC
Large Signal S-parameters	-	Freq, Power, Temp, DC	-	-
Noise Figure	Freq, Temp, DC	-	-	Freq, Temp, DC
Spurious Spectral Components	Freq, Power, Temp, DC	Freq, Power, Temp, DC	State, Power, DC, Freq, Temp	-
Non-Linear Spectral Components	Freq, Power, Temp, DC	Freq, Power, Temp, DC	State, Power, DC, Freq, Temp	Freq, Power, Temp, DC
DC Measurements	Freq, Temp, DC	Freq, Power, Temp, DC	State, Power, DC, Freq, Temp	Freq, Power, Temp, DC

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MMIC Measurement System Requirements for Low Cost Production

- High throughput for wafers, chips, multi-chip assemblies, and modules
- Long term stability and autonomous operation for large production runs
- Test system flexibility required for low and medium production runs
- No compromise in accuracy
- Lower cost of ownership than present systems
- Unified data management
    - Raw data
    - Data analysis
    - Device acceptance
    - Device data archives
    - Interfaces to CAD/CAM and DBMS

High Productivity is a Must

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Scientific-Atlanta MIMIC Phase 3 Program

Objectives

1. Develop test technologies to reduce the production cost of MIMIC chips
    - Reduce test times by a factor of 10
    - Reduce set-up time for new MMIC chips
    - Enhance data presentations
    - Provide a general purpose database interface

2. Demonstrate test technologies on MIMIC Phase 2 chips
    - Select target MIMICs for key applications
    - Establish interfaces with Phase 2 teams
    - Demonstrate capabilities in Atlanta facility and at selected foundries

3. Incorporate the advanced features into new commercial test systems
    - Instrumentation improvements concurrently funded by S-A
    - Utilize S-A product design and support capabilities

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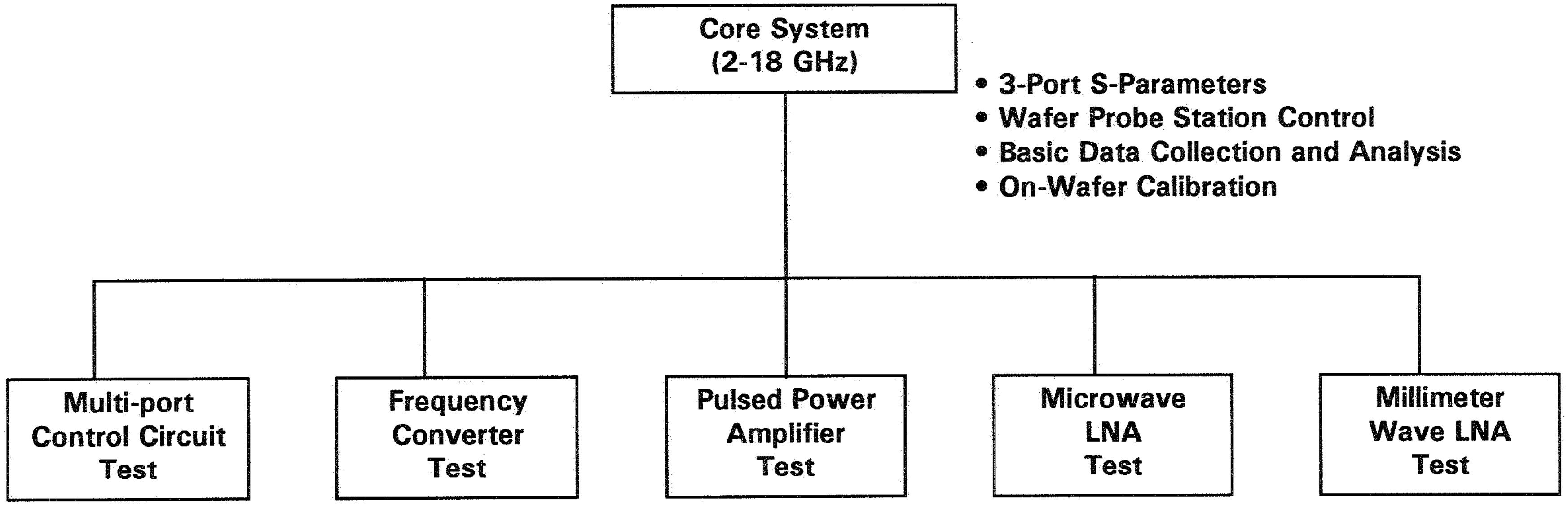
Scientific-Atlanta MIMIC Phase 3 Program
Test Mode Architecture



Core System (2-18 GHz)

- 3-Port S-Parameters
- Wafer Probe Station Control
- Basic Data Collection and Analysis
- On-Wafer Calibration

Multi-port Control Circuit Test

- 16-Bit Device Control
- Current Monitoring
- Fast Bias Control

Frequency Converter Test

- Noise Figure
- Compression Points
- Intermodulation Products
- Conversion Gain
- Isolation
- Port Match
- IF Port Flatness
- Intercept Points

Pulsed Power Amplifier Test

- Power Calibration
- Compression Points
- Efficiency
- Intercept Points
- Q-Point
- Spurs/Harmonics
- Bias Pulsing
- Large Signal S-Parameters

Microwave LNA Test

- 2-Port S-Parameters
- Noise Figure
- Spurious Signals
- Intermodulation Products
- Compression Points

Millimeter Wave LNA Test

- 2-Port S-Parameters
- Noise Figure
- Spurious Signals
- Intermodulation Products
- Compression Points

<u>Six Test Modes Address the Key Test Requirements</u>
<u>Modular Architecture Ensures Flexibility</u>

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photo of mimic room

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Scientific-Atlanta MIMIC Phase 3 System

Block Diagram

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Phase 2 Contractor Activities

- Hughes & M/A-COM
    - Pulsed power amplifier test techniques
    - Wafer handling training
- Martin-Marietta Electronic Laboratory - Syracuse
    - Millimeter wave LNA test techniques
    - Test set design consultation
    - DC bias pulser
- Site Visits & Phase 3 Briefings
    - M/A-COM
    - Hughes
    - Texas Instruments
    - TRW
    - Raytheon
    - Army Labcom
    - Westinghouse
    - Martin-Marietta
    - TriQuint
    - Alpha

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Demonstration Chip Testing

MIMIC Phase 2 Target Test Chips	
Chip Type	Foundry
7-bit Phase Shifter	Raytheon
Wideband LNA	Texas Instruments
X-Band HPA	Hughes
Ka-Band LNA	TRW
GEN-X Frequency Converter	Texas Instruments

- Demonstration chip testing activity will compare test times and test data using the MIMIC Phase 3 Test System with that obtained by the Phase 2 Contractors using existing test systems

Scientific-Atlanta MIMIC Phase 3 Test System

Typical Test Times

Test Type	Test Parameters	Test Time (seconds)
Multi-Frequency	4 s-parameters @ 15 frequencies	0.01
Multi-State Multi-Frequency	4 s-parameters @ 64 states @ 3 frequencies	0.15
Noise Figure	5 frequencies	0.65
Spurious	10 GHz sweep @ 1 MHz resolution	0.67
DC	16 Channels - Current	0.01

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Benefits of Scientific-Atlanta Phase 3 Program to the MIMIC Community

GaAs Wafer Production Cost Model

- Processed wafer cost = $1 - $2 per square mm
  $4,000 - $8,000 per 3 inch wafer
  Assume $5,000 as standard cost
- DC Yield - 80%   RF Yield - 80%

	Die Size (mm^2)	Raw Die Cost	Number of raw die	Number of DC good die	Number of RF good die
Small Signal Devices	20	$23	220	176	141
Power Devices	90	$100	50	40	32

- Production DC and RF test cost of $0.04 per second
  Based on $10/hr labor at 300% overhead
  5 year depreciation on $500,000 capital investment

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Benefits of Scientific-Atlanta Phase 3 Program to the MIMIC Community

GaAs Wafer Production Cost Analysis

- Conventional Test System
  - Based on separate instruments
    - VNA, Spectrum Analyzer, Noise Figure Meter, etc
    - Optimized GPIB interface software

	Die DC Test Time	Die RF Test Time	Number of DC Tests	Number of RF Tests	Total Wafer Cost	Unit Cost
Power Devices	0.8	160	50	40	$ 5258	$ 164
Small Signal Devices	0.8	50	220	176	$ 5359	$ 30

- Test costs approach 4% of device costs

- Test times approach 2.5 hours per wafer for small signal devices

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Benefits of Scientific-Atlanta Phase 3 Program to the MIMIC Community

GaAs Wafer Production Cost Analysis

- The Scientific-Atlanta MIMIC Phase 3 Test System

	Die DC Test Time	Die RF Test Time	Number of DC Tests	Number of RF Tests	Total Wafer Cost	Unit Cost
Power Devices	0.2	2.3	50	40	$ 5004	$ 125
Small Signal Devices	0.2	4.7	220	176	$ 5035	$ 28

- Total test time for small signal devices is <u>less than 15 minutes per wafer</u>
- S-A MIMIC Phase 3 Test System <u>reduces test time by 90%</u>
- Device <u>costs can be reduced up to 25%</u>

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Transition to Commercial Product
Model 2097 MMIC Wafer Test System

- Modular RF and DC test system for single connection on-wafer measurements
    - Vector s-parameters
    - Spectral analysis
    - Noise figure
- 2-18 GHz standard - 0.5-3 GHz and 18-40 GHz optional
- 10,000 vector or scalar measurements per second
- 2 and 3-port RF interfaces
- Modular architecture supports upgrades for additional test types
    - Pulsed power
    - Frequency conversion devices
    - Intermodulation testing
- Up to 112 dB dynamic range
- Integrated DUT state and DC bias control
- Complete interface to wafer probing equipment
- Complete test development and data management software
    - Graphical User Interface for all operations
    - Powerful plotting features for test development/diagnostics
    - ASCII data file conversion for exporting to database software
    - Fully integrated data analysis for Pass/Fail testing
- Supports testing of modules, assemblies, and multi-chip modules (MCMs)

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Model 2097 MMIC Wafer Test System

General Specifications

Characteristic	Specification
Measurement Types	Vector S-Parameter Spectral Content Noise Figure Power Intermodulation Components Gain Compression Power Added Efficiency
Peak Measurement Speed	10,000 measurements per second 100 frequencies per second - standard 10,000 frequencies per second - optional
DUT Digital Control Outputs	32 bits minimum — standard 96 bits — optional
DUT Digital Status Inputs	32 bits
DUT Test Parameter Sequencing	10 nested test parameter loops User defined order

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Model 2097 MMIC Wafer Test System

General Specifications

Characteristic	Specification
Configuration	3 Port
Frequency Range	2-18 GHz - standard 0.5-3 GHz & 18-40 GHz - optional
DUT Input Power Range	-50 to +10 dBm - standard -50 to +27 dBm - optional
DUT Maximum Output Power	+10 dBm on Ports #1 and #2 Up to +43 dBm on Port #3
RF Pulse Width	100 nsec minimum
Duty Factor	0% - 100%
PRF	0 to 1 MHz

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Model 2097 MMIC Wafer Test System

RF Measurements

Characteristic	Specification
Measurement Modes	CW, Single Pulse, Multi-Pulse Profile
Spectral Content	Resolution Bandwidth - 2 MHz to 60 kHz
Power Measurement Range	CW, Pulsed -50 to +50 dBm
Noise Figure Measurements	Y-Factor Method, 1 dB minimum
Intermodulation Products Measurement (Arbitrary Component Products)	100 kHz minimum spacing Intercept Point extrapolated from straight line fits of fundamental and intermod magnitudes as a function of input level
Gain Compression Measurement	1 dB or 3 dB Compression Point
Measurement Resolution	0.001 dB - Magnitude 0.01° - Phase
Dynamic Range	69 dB at 10,000 measurements per second 80 dB @ 2,000 measurements per second 112 dB at 100 measurements per second

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Model 2097 MMIC Wafer Test System

DC Supply/Control/Measurement

Characteristic	Specification
DUT Digital Control Line Voltage Range	0 to +5 VDC (TTL, CMOS) 0 to -7 VDC (selectable)
Control Line Current Monitoring	1 μA to 10 mA
Number of Fast Bias Voltage Lines	6
Voltage & Current Range of Fast Bias Lines	0 to +15 VDC @ 1.5 A max 0 to -15 VDC @ 1.5 A max
Number of Pulsed & High Current Bias Lines	1 - standard 2 - optional
Fast Bias/Pulsed Bias Current Monitoring	1 μA to 9.99 A
Voltage/Current Range of Pulsed Lines	0-20 V , 200 Watts maximum
DC Bias Pulse Width	10 μsec minimum

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Summary

- The Scientific-Atlanta MIMIC Phase 3 Program has extended our expertise in high speed test system applications to encompass MIMIC on-wafer test requirements for a wide variety of chip functions

- Scientific-Atlanta has commercialized the techniques developed under MIMIC Phase 3 funding in the Model 2097 MMIC Wafer Test System

- Scientific-Atlanta MMIC production test systems
    1. Reduce test times by a factor of 10-100
    2. Improve flexibility in test system configuration
        - Six basic test modes cover key RF test types
        - Simple reconfiguration of all test types via software setups
    3. Lower the cost of ownership compared to previous test systems

- Scientific-Atlanta is continuing to extend and commercialize the capabilities developed during the MIMIC Phase 3 Program with IR&D funding