ASALT

Accel-RF System for Accelerated Life Testing

for RF and Microwave Components

Technical Brief

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1.0 Introduction

The Accel-RF System for Accelerated Life Testing (ASALT), Figure 1-1, is a single system capable of performing elevated-temperature life tests on a variety of RF and microwave components, such as: field-effect transistors (FETs), monolithic microwave integrated circuits (MMICs), hybrid microwave integrated circuits (HMICs), and microwave module assemblies. The underlying architecture of the ASALT product line was an outgrowth of an SBIR program and NASA-funded effort with the *MMIC Reliability Assurance Working Group*. This effort culminated in the co-authoring of a book on GaAs MMIC Reliability Assurance Guidelines[1] with NASA.

The ASALT system consists of hardware and software used to initiate, supervise, and record temperature and electrical performance parameters automatically throughout the test duration. The thermal, RF, and DC stimulus to each device-under-test (DUT) are independently controlled. The test station is controlled through a Windows-based interface installed on a personal computer (PC). Program functions include: calibration, test configuration, data monitoring and presentation, and data post-processing.

The primary failure mechanisms in microwave and RF devices may be accelerated using elevated temperature. From a reliability analysis perspective it is important to maintain a well-defined junction temperature. The ASALT thermal controller is designed with this requirement in mind. It provides real-time monitoring, continuous control, and automatic shut-off of the DUT thermal system. The primary thermal-management system is designed to control the base-plate temperature of each DUT to within ±2ºC. Since it measures all DC and RF power into and out of the DUT, given the device thermal resistance and measured surface temperature, the junction temperature may be determined using standard thermal calculation methods. Hence, if desired, the system computer can dynamically adjust the surface temperature throughout the life test to maintain a constant junction temperature.

The ASALT DC power system is designed for flexibility and modularity. Two supplies per device provide the needed power to test the latest high-frequency devices, from HBTs and

[1] S. Kayali and G. Ponchak, and R. Shaw, *GaAs MMIC Reliability Assurance Guidelines for Space*, National Aeronautics and Space Administration Jet Propulsion Laboratory, Pasadena, CA, 1996

enhancement-mode devices to PHEMT and GaN structures. Each source is programmable through the computer user-interface, support both voltage- and current-source modes, and include voltage- and current-sensing circuits designed to shut the supply down rapidly upon over-limit settings. One supply is designed as the "controlling" source, used in such applications as the gate drive of a standard PHEMT device. This source is bi-directional and provides excellent low-voltage and current sensing. The second supply is unidirectional and can source up to 10-Amps of current (with a maximum of 150-Watts). This supply is typically used as the drain or collector supply.

The primary functions of DC and thermal control, along with signal multiplexing, are supported in a modular extensible block configuration. Each power/heater controller (PHU) block supports 4 channels. Additional PHUs may be added to the system to extend the number of channels. The number of channels is only limited by physical DUT space, available source power, and the measurement time required to cycle through every channel. 96-channel DC-only systems are available.

The third major component of any RF life test station is the RF stimulus. As with DC and thermal control, RF-drive frequency and power-levels are user-defined and controlled via the PC interface. A wide dynamic range is required to support rapid acquisition of gain-compression curves while at the same time providing a reasonable range of nominal drive levels. The ASALT architecture is designed to maximize RF stimulus options. The base RF matrix (RFM) provides a wideband frequency range at power levels up to a maximum of +15 dBm at the DUT input. As with the PHU, the RFM is modular and extensible, each block supporting up to 8 channels. Practically, the RFM system design is only limited by the residual losses associated with cascading blocks. 32-channel RF systems are available, operating from 500 MHz to 3 GHz, 900 MHz to 10 GHz, or 2 GHz to 18 GHz.

For applications requiring higher RF drive levels, a separate solid-state power amplifier module (SSPA) is available. These optional blocks are narrowband by nature, but can support drive levels up to 10-Watts. Hence, a large variety of device technologies and applications are supported with one modular system design.

The 32-channel ASALT station is rack mounted in a triple-bay configuration that is approximately 60 inches wide by 55 inches high, allowing easy access to the DUT test fixtures and the various modular components in the station. A typical block diagram of the system is shown in Figure 1-2

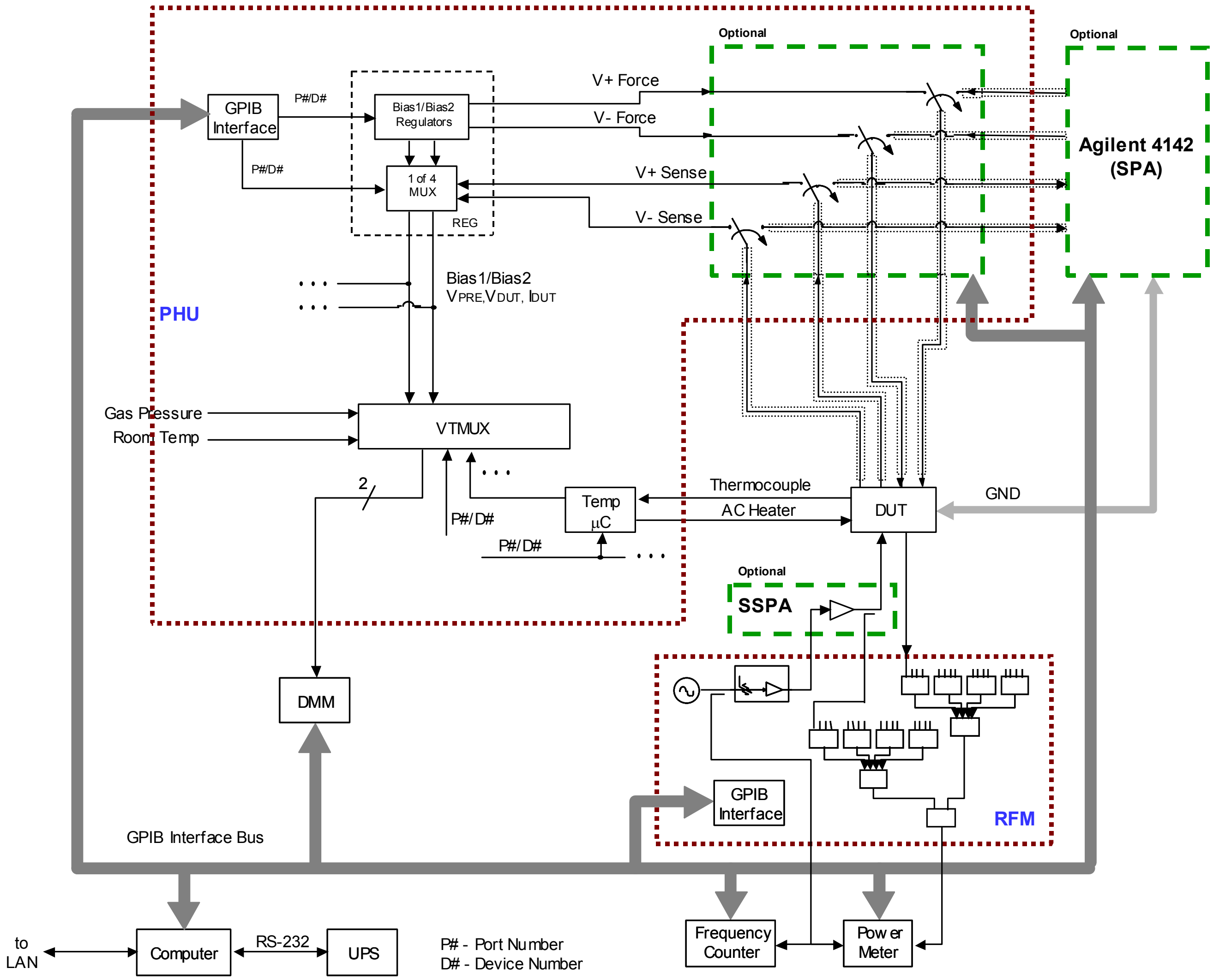


Figure 1–2: ASALT Block Diagram

2.0 Application Software

The ASALT station for RF and microwave components is controlled through the ATS application software installed on a PC "embedded" into one of the system racks. The graphical user interface operates under the Microsoft Windows 2000 environment and is designed to be user-friendly. The PC controls and gathers data from other equipment and circuits in the test station through the General Purpose Interface Bus (GPIB). Additionally, it communicates with the Uninterruptible Power Supply (UPS) that will force a soft shutdown of the ASALT station in the event of a general power failure.

The GPIB is connected to a dual RF power meter, a digital multimeter, a frequency counter, and optionally a semiconductor parameter analyzer for monitoring various parameters of interest during the reliability or burn-in test. The primary parameters being monitored include:

1) Temperature at the DUT base plate
2) DC electrical parameters (voltages, currents)
3) RF input and output power levels

The monitored parameters may be displayed on the computer screen while the test is in progress. In addition, several other calculated parameters are also displayed, including:

1) Elapsed time of the test
2) Parameter variations from test start
3) DUT gain (Pout-Pin)
4) DUT power dissipation
5) Channel temperature (based on user-specified thermal resistance information)

The ATS software is written in National Instruments Labview for maximum portability. The complete ATS package includes everything needed to control and utilize the system hardware. Additionally, virtual instrument drivers are available for each Accel-RF custom instrument, providing the technical user the ability to write custom "application wrappers" if desired.

ATS is organized by function and divided into four major categories: 1) System Setup; 2) System Calibration; 3) Special-Test/Utility modes; and 4) the Runtime mode. Typically, system configuration occurs first. This includes defining the backup directories, gas pressure warning levels, several DUT temperature parameters, etc. Special control modes exist to support RF calibration, current-sense calibration, and thermocouple calibration. Once calibration is complete and levels are set, channels are configured. Absolute and variational limits are defined along with general information such as model number, serial number, storage interval, etc. Finally, the ATS monitor routine supports continuous monitoring of device performance.

3.0 DUT Thermal Control and Fixturing

The ASALT station supports independent, accurate thermal control of each device being tested. Accelerated life testing is usually performed at an elevated temperature in order to keep the duration of the test within an acceptable time period, which is usually several weeks or months. AC heaters are mounted in each DUT fixture. The temperature is regulated by controlling the power injected into the heater. The DUT fixtures are mounted on a ventilation chamber that is cooled from forced-air, chilled-water, or liquid–gas. Each ventilation chamber holds up to twelve RF DUT fixtures - a total of thirty-two (32) DUTs in a triple-bay system. Figure 3-1 shows a typical ventilation chamber with ten DUT fixtures installed. The ventilation chamber cooling capacity is designed to maintain a DUT temperature below the lowest required level (typically 150°C) at the maximum DUT power dissipation. Conversely, the heater must be able to achieve the highest required level (typically 250°C) with a DUT that dissipates no power. The DUT fixtures are designed to optimize the tradeoff of these two performance extremes.

The ability to accurately sense the DUT temperature is a primary requirement in an elevated temperature test. ASALT is capable of monitoring and independently controlling the heater for each DUT fixture to within ±2°C of the desired value. The fixture heater is powered from a 120-volt AC supply and controlled via a digital feedback loop to achieve the accuracy required.

A typical DUT fixture is shown in Figure 3-2. The DUT is mounted on a heater block that is thermally isolated via air gaps from the remaining parts of the fixture. This keeps the temperature of the DUT from affecting the integrity of the remaining RF circuitry, connectors, and cables. Thermal isolation allows the temperature profile of the DUT to be easily controlled and consistently repeated. Figure 3-3 shows a typical temperature response of the normal DUT fixture, with the bottom plot displayed on a finer scale than the top plot.

Unfortunately, the thermal-isolation air gaps also keep the internal block from being electrically connected to the outer block of the test fixture. With respect to microwave circuit performance, this causes RF grounding problems. Accel-RF has developed several techniques to mitigate these RF discontinuity problems. The RF discontinuities of the fixture, biasing circuitry, oscillation-suppression circuitry, and the input/output impedance of the DUT must be modeled or empirically determined for proper RF performance prior to life testing. Accel-RF is a specialty microwave component design and manufacturing company, possessing a wide range of modeling and measurement experience with RF circuits. It is this experience that uniquely qualifies Accel-RF for the challenges of microwave and RF device reliability testing and burn-in.

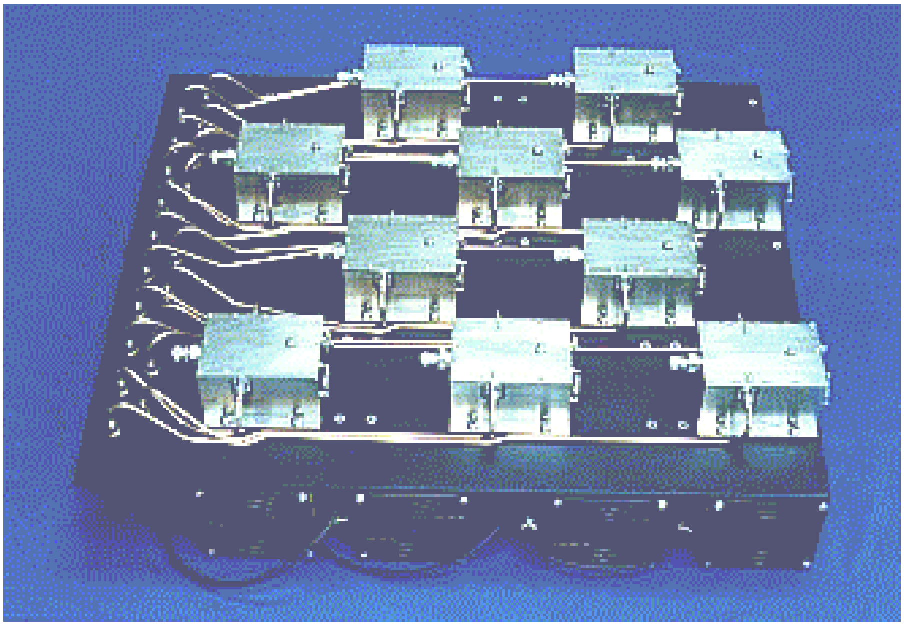


Figure 3–1: Typical Ventilation Chamber with 10 Single DUT Fixtures

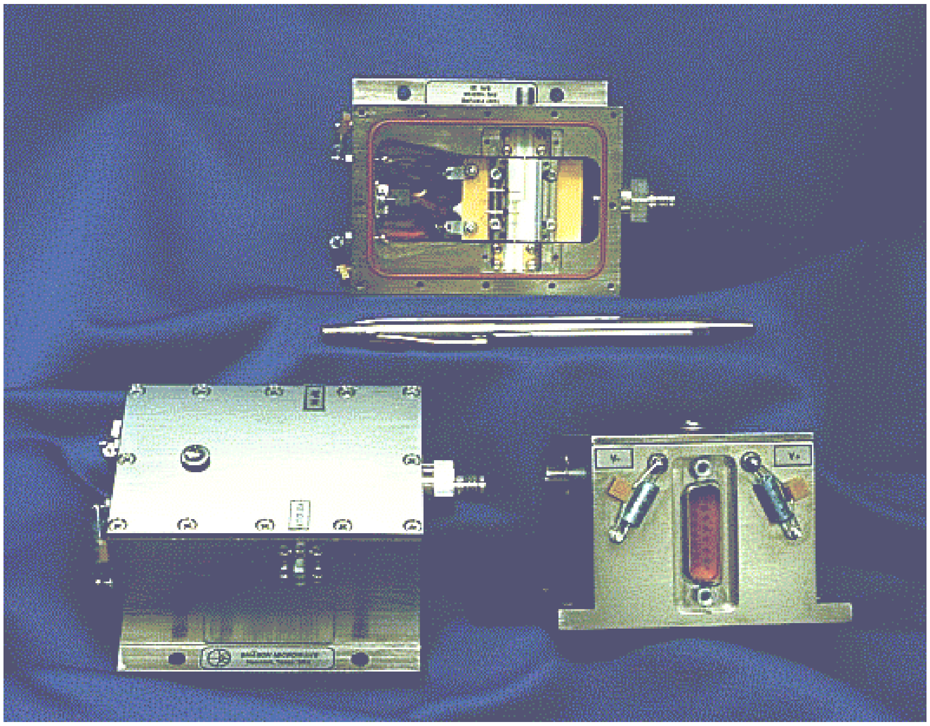
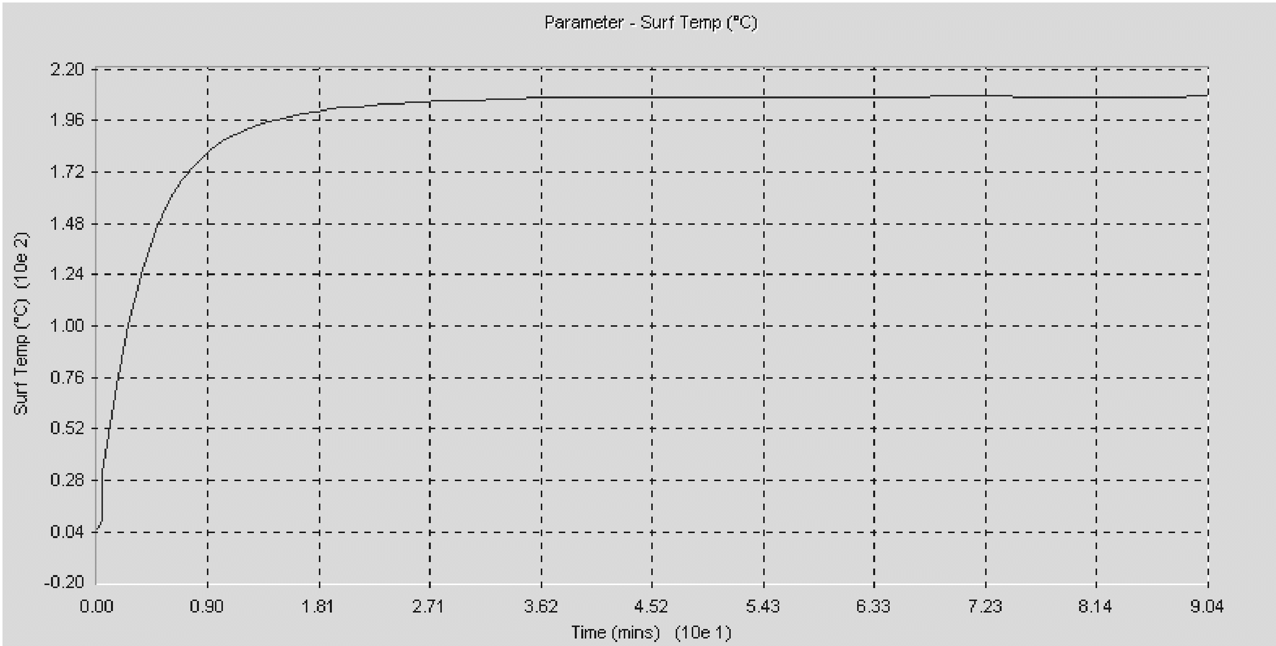


Figure 3–2: Typical DUT Fixture



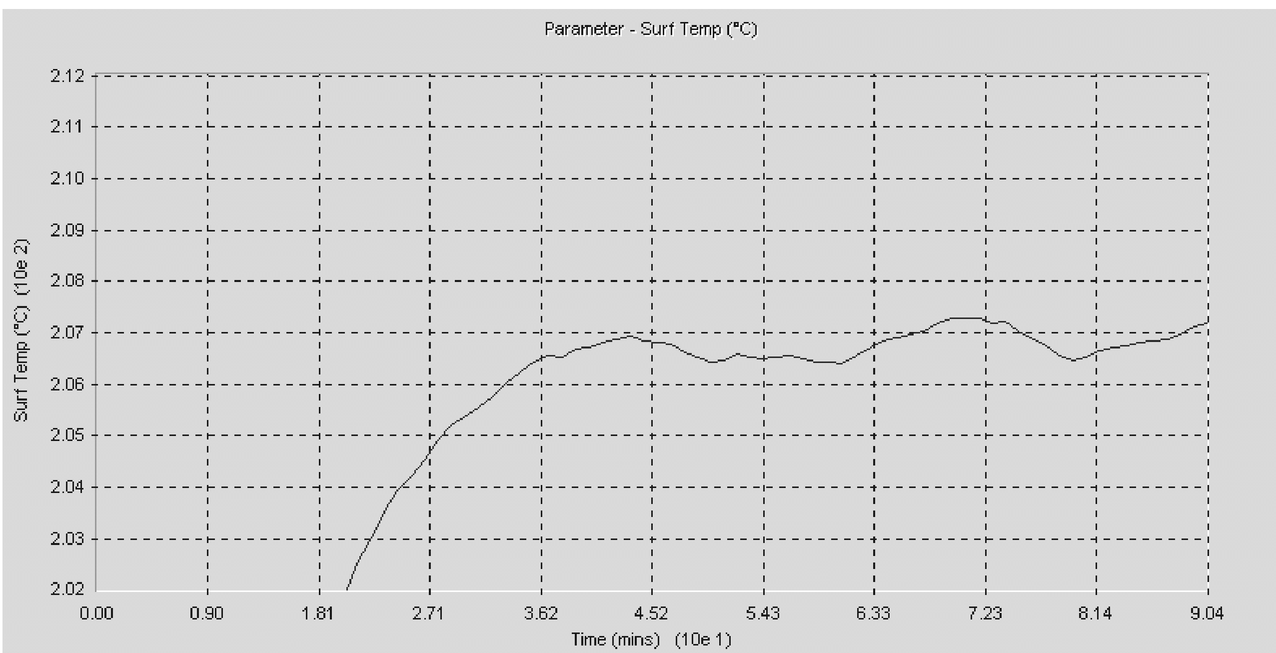


Figure 3–3: Measured Temperature Control–Loop Performance

4.0 DC Power Supply

The DC Power Supplies for the ASALT station perform supervisory, interfacing, and DC power generation for the DUT's. Each PHU controller provides independent dual-power supplies to each of four DUTs. The DC power is supplied through a distribution network controlled from the system computer.

The PHU supports biasing using custom supply designs. These boards support several key functions needed for any viable biasing scheme using microwave components: 1) current- or voltage-sourcing modes; 2) semi-active biasing; 3) bias sequencing; and 4) rapid over current (or voltage) shutdown. By supporting current- or voltage-source modes, testing of HBT (heterojunction bipolar transistor), and FET technologies may be easily supported. Two biases for each channel may be independently controlled. The primary bias may source ~1.0V to 100V at up to 10A (total power not to exceed 150W). The secondary bias operates from -14V to +14V at up to 0.1A. Semi-active biasing implies that the system can, as an example, set the gate voltage on a MESFET device to yield a target drain current. The system computer measures the drain current and iteratively changes the gate voltage to yield the result.

Bias sequencing relates to the order in which the biases are applied to the DUT. In many cases, one bias needs to be applied before the other. For example, depletion-mode MESFET devices must have their gate voltages present before the drain voltage is applied to avoid damage. Two techniques are employed that provide redundant security in bias sequencing. First, the software itself follows the prescribed sequence. Second, the PHU hardware design incorporates logic that forces the sequence definition.

Rapid over-current protection is critical to allow failure analysis to be performed on the device. The most common failure mechanisms in device junctions follow a nonlinear degradation curve. For example, drain current may initially increase slowly as the junction fails. These failures are directly related to junction temperature. The increased device power dissipation causes even greater junction heating, which can eventually precipitate a thermal-runaway condition. In some cases, the time required for the device to burn out is quite short. Once the damage has reached this point, it is often very difficult to perform meaningful failure analysis. Built into each channel's bias circuitry are comparators that trip when the current (or voltage, when operating in current-source mode) exceeds specified thresholds. This circuitry is designed to remove the bias within 1µs (depending on load capacitance), hence protecting the device against thermal runaway damage.

Finally, a timeout circuit exists that will automatically remove bias from the DUTs if no computer activity occurs within approximately 15 minutes. This avoids accruing test time on the DUTs if the computer, for any reason, is unable to continue monitoring.

5.0 RF Matrix Unit

The RF Matrix Unit (RMU) generates and controls the RF levels associated with the DUT input and output. Voltage Controlled Oscillators (VCOs) generate the stimulus signals, Variable-Gain Amplifiers (VGAs) provide RF level control, and RF switches are used to select which signals are routed to the external meters.

A first or master RMU, shown in the Figure 5-1 block diagram, supports up to eight DUTs. VCO signal generation is shown in the upper left corner. Two VCOs are required to support the multi-octave bandwidth featured in the ASALT station. A divider/switch routes these signals to output connectors. Two ports are re-injected into the RMU Master for further amplification and routing to the DUTs. At this point, an external generator may inject other stimuli (such as a CDMA generator). The two additional output ports are routed as inputs to the second or Slave unit, which does not contain any VCOs.

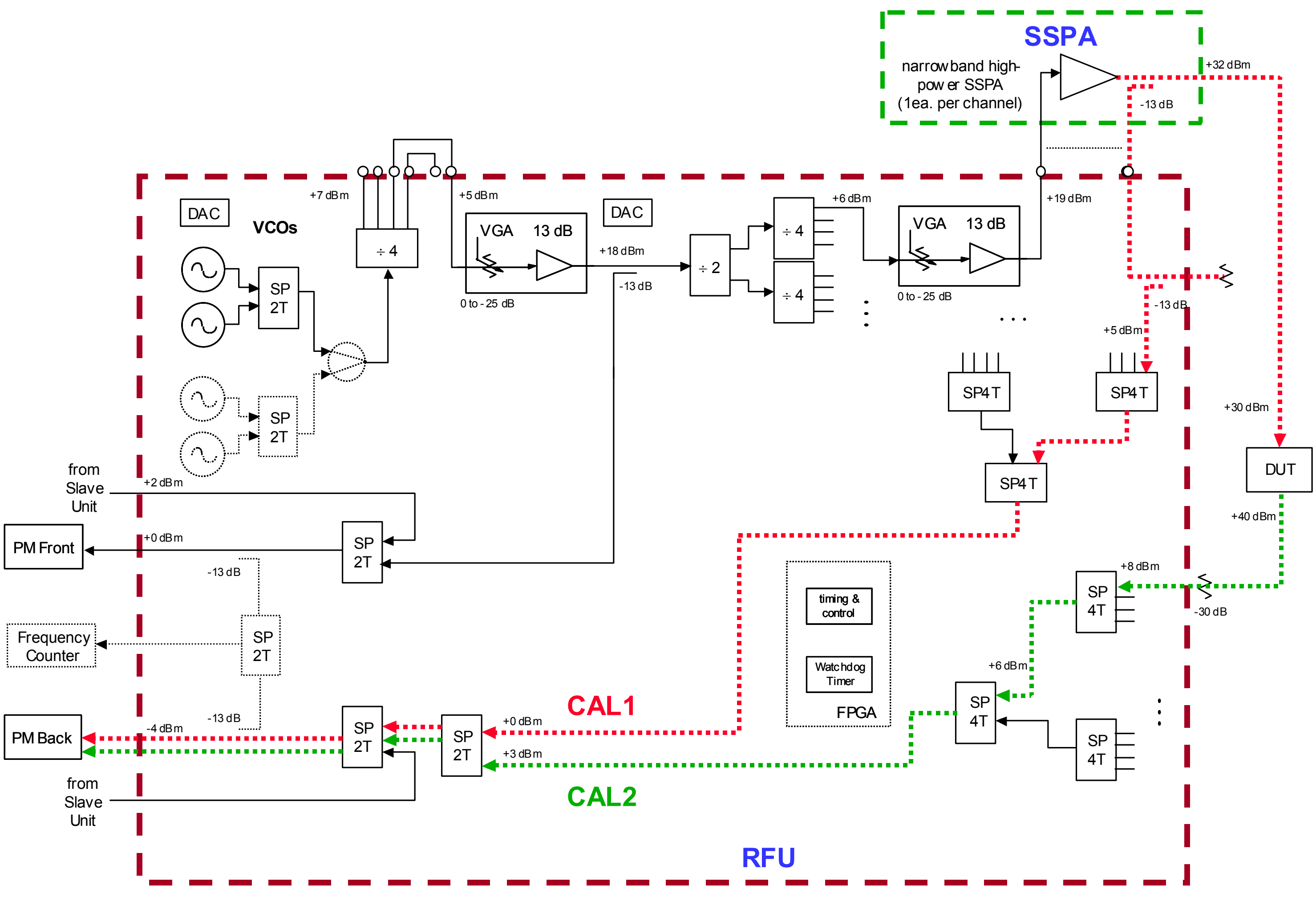


Figure 5-1: Typical RF Matrix Unit (RMU) Block Diagram

To support user-specified drive levels and gain-compression sweeps, the RF level to the DUT input must be variable. The computer controls these levels by setting the voltage at the VGA inputs. Note that the overall block of 8 channels has independent level control. Further, each channel contains its own independent VGA, providing >20 dB of dynamic range.

A tradeoff exists between RF drive power and bandwidth. Three RMU versions are designed to support operation from 500 MHz to 3 GHz, 900 MHz to 10 GHz, or 2 GHz to 18 GHz at a DUT drive level of +15 dBm. As shown in Figure 5-1, an external amplifier may be used to increase DUT drive levels. If +15 dBm is adequate for a particular application, the output signal may be directly re-injected into the RMU for distribution – eliminating the need for external amplifiers.

If higher power levels are required, an optional solid–state power amplifier (SSPA) may be injected into the RF transmit chain. SSPA designs are available to deliver up to +10 Watts at the DUT input, but only over a narrow band of frequencies – typically 5% to 10% bandwidth. Accel-RF's SSPA designs support a variety of frequencies (check with the factory for available frequency and power selections). A sample of the output signal is returned to the RMU for power monitoring.

By making the base RMU broadband, the user need only replace the SSPA box to support applications at differing frequencies and power levels. This modular design approach supports the power level and frequency requirements in a cost-effective and low-maintenance manner.

As with the PHU, a timeout circuit exists that will automatically remove RF power from the DUTs if no computer activity occurs within approximately 15 minutes. This avoids accruing test time on the DUTs if the computer, for any reason, is unable to continue monitoring.

6.0 SEMICONDUCTOR PARAMETER ANALYZER

As an optional item, the ASALT station may include an Agilent Technologies 4142 Semiconductor Parameter Analyzer (SPA). This allows the operator to more fully characterize the device under test using the many voltage and current stimulus options available in the SPA. For example, a full set of device I-V curves may be generated for each device. Further, SPA integration supports many intrinsic reliability test options, such as: hot carrier injection, time dependent dielectric breakdown, modified J–RAMP, etc.. The analyzer drives one channel at a time, but may be multiplexed into any of the available test channels as defined by the operator.

7.0 SUMMARY

The ASALT station provides a cost–effective solution to performing accelerated life testing. Accel-RF's turnkey systems maximize flexibility by providing a complete RF, DC, and thermal management solution that is seamlessly integrated with a powerful graphical user interface. Accel-RF customers benefit from years of experience in the microwave reliability-testing arena. The test set hardware and software design is based on many years of development and production, and incorporates an abundance of user-requested features.

Customers leverage Accel-RF's expertise to obtain the best cost/performance value available anywhere. The company understands the issues associated with fixture designs that support device stabilization, gain and power matching, transition design, and DC biasing. Hence, Accel-RF is a valuable resource for application support.

The keys performance parameters include:

- Temperature Range: +45ºC to +250ºC (note: colder low temperatures are available if water-or gas-cooled options are used)
- Frequency Band: 500 MHz to 18 GHz in 3 standard models
- DUT input power: ≥ +15 dBm without SSPA (up to +10W with SSPA)

Table 1 presents a list of typical capabilities and features of the complete ASALT station (note: special requirements and customization are welcome).

Table 1: ASALT Performance and Features

Parameter	Specification
Number of Channels	32 DUTs maximum
Number of Voltages per DUT	Two
Voltage Ranges	Bias #1: (+1.0 to +100 V) (Pmax = 150W) Bias #2: (-14 to +14 V)
Current Ranges	Bias #1: 10.0 A Bias #2: 100 mA
DUT Temperature Range	+45ºC to +250ºC note: low temp limited by cooling and device power dissipation. 150-W device with air-cooling minimum temp ~ 150ºC.
Temperature Accuracy	+/- 2°C
Resolution	+/- 1.0°C
Base System Frequency	2 GHz to 18 GHz 900 MHz to 10 GHz 500 MHz to 3 GHz
SSPA Bandwidth	> 5% (each frequency)
DUT RF input power	+15 dBm w/o SSPA (+10W w/ SSPA)
DUT RF output power	+100 W
Monitoring Capabilities	DC voltages, DC currents, RF power levels, elapsed time, temperature (DUT surface and channel)
Shutdown Capabilities	Limit failure, loss of prime power, and thermal runaway. A limit failure is defined as an absolute value above (or below) that defines a failure.
Continuous Monitoring	Displays the last measured values, initial values, and deviation values.
User Interface	User-set absolute limits and variation values, temperature of test, and frequency of recorded information.
Dimensions	Rack-mounted (60"W x 55"H x 36"D)

8.0 RELATED EXPERIENCE

Accel-RF Corporation was formed to provide test hardware and services to the microwave and RF community. The key personnel have over 20 years of combined experience specifically applicable to microwave reliability testing. We have participated in industry-working groups for semiconductor reliability. Roland Shaw, President of Accel-RF, co–edited the "*Gallium-Arsenide (GaAs) MMIC Reliability Assurance Guideline for Space Applications*," developed by the NASA MMIC Reliability Working Group and published by the Jet Propulsion Laboratory (JPL Publication 96–25). It is rapidly becoming the industry standard for GaAs applications. Hence, Accel-RF understands and has helped develop the standards by which microwave devices are tested and characterized.

The ASALT station leverages lessons learned from three generations of automated reliability test set designs. We know what is required and how to obtain accurate reliability data for the latest technologies, including GaN and E-mode devices. The purchase of this test capability leverages the knowledge base and proven performance of a turnkey system.

Further information regarding any aspect of the ASALT station is available from.

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