Welcome

RI 7100A Microwave Test System
On-Site Training Seminar

Test Engineer Training

Roos Instruments

Welcome to the Roos Instruments RI 7100A Microwave Test System User Training Seminar. The objective of this seminar is to provide you, the user of this system, the information you need to operate, calibrate and maintain the RI 7100A Microwave Test System.

Seminar Topic Areas

User Training Outline

- 1. System Basics
- 2. Basic Software Structure
- 3. Developing and Running Test Plans
- 4. Hands-on Lab
- 5. More Test Plans
- 6. System Data Base Tools
- 7. System Maintenance and Calibration

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This training seminar consists of 7 major topic areas. The first section introduces the system's basic hardware and discusses the basic measurements performed by the system. The second section discusses the basic software structure. The third section leads you through in detail the creation and execution of a custom test plan, the displaying of the test results and the execution of the Production Test Executive. We will then have a hands-on lab and you will have a chance to create your own test plans. After the lab we discuss more of the software features and the local SQL data base tools. The last section will describe the calibration and maintenance of the system.

Introduction

- **System Block Diagram**
- **Software Structure**
- **Basic Measurements**

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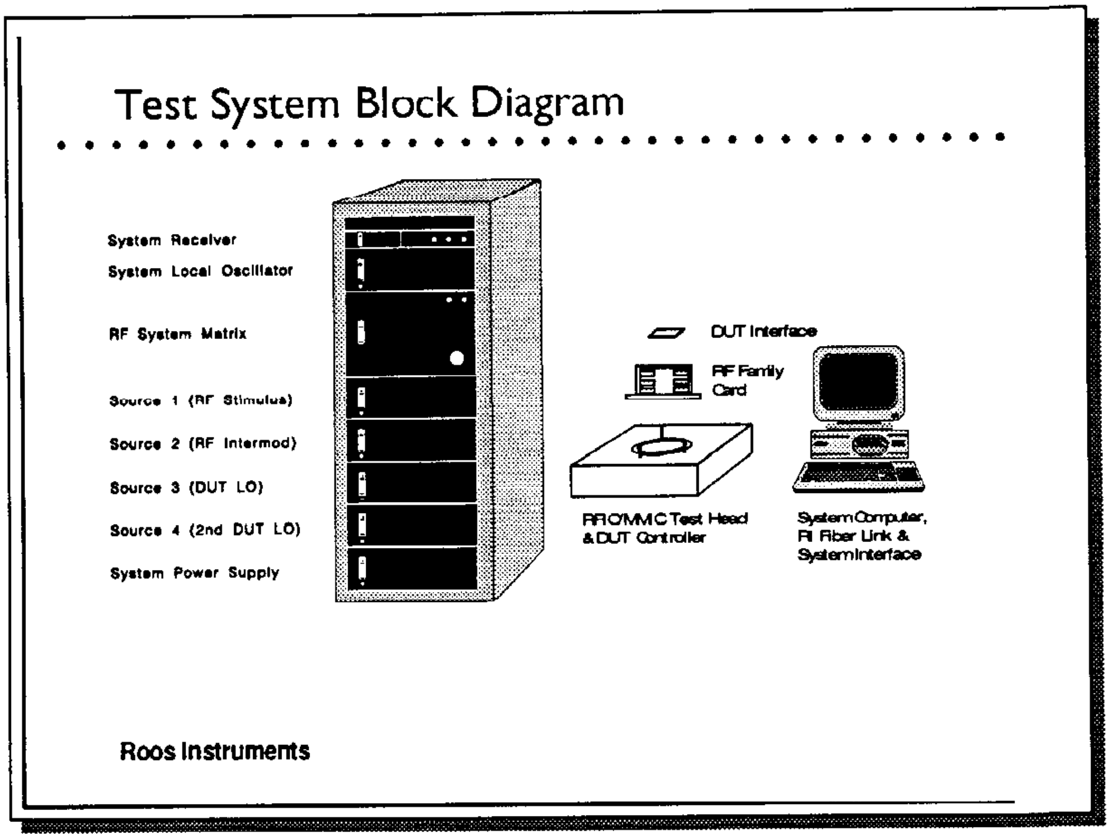
In this section we will discuss the system's overall block diagram, how the system software is structured and review the fundamental measurements the RI 7100A Microwave Test System will perform.

Test System Block Diagram



The system is based on a single channel receiver design. The system uses simple, fast, measurement hardware to perform all measurements and relies on its object-oriented system software to control the measurement process, analyze the data and provide the user interface. The measurement process is simple and direct, signals to and from the device-under-test (DUT) are provided through the wafer probes (or the device contactor assembly & DUT interface) to the RF Family Card/Test Fixture and then to the RFIC/MMIC Test Head.

System Components

System Components

- RF Family Card/Test Fixture & DUT Interface
- RFIC/MMIC Test Head & Programmable DUT Controller
- System Receiver
- RF/Microwave Stimulus Sources
- RF System Matrix & System Power Supply
- System Rack & Test Head Manipulator
- System Computer w/RIFL Interface
- System Software

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The RI 7100A Microwave Test System consists of 10 major components:

(1) RI RF Family Card/Test Fixture & DUT Interface,

(2) RI RFIC/MMIC Test Head

(3) RI Programmable DUT Controller,

(4) RI System Receiver,

(5) Synthesized Microwave Sources (System LO, DUT Stimulus, 2nd Intermod Stimulus and DUT LO),

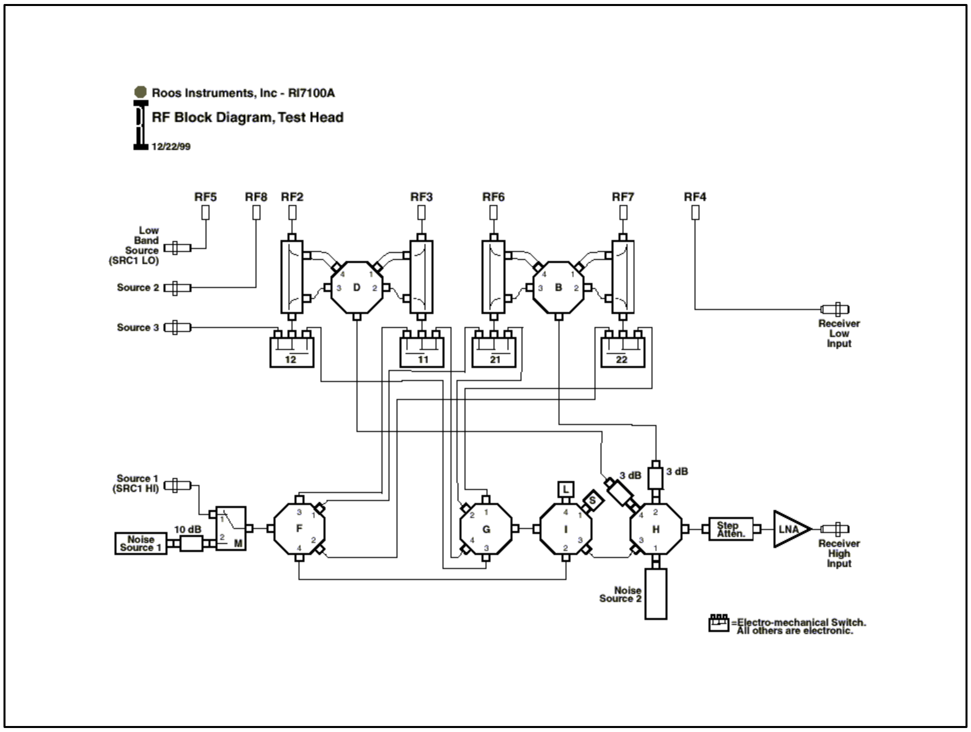
(6) RI RF System Matrix,

(7) RI System Power Supply,

(8) RI System Rack & Test Head Manipulator,

(9) RI System Computer with the RI Fiber Link (RIFL),

(10) and the RI System Software Package.

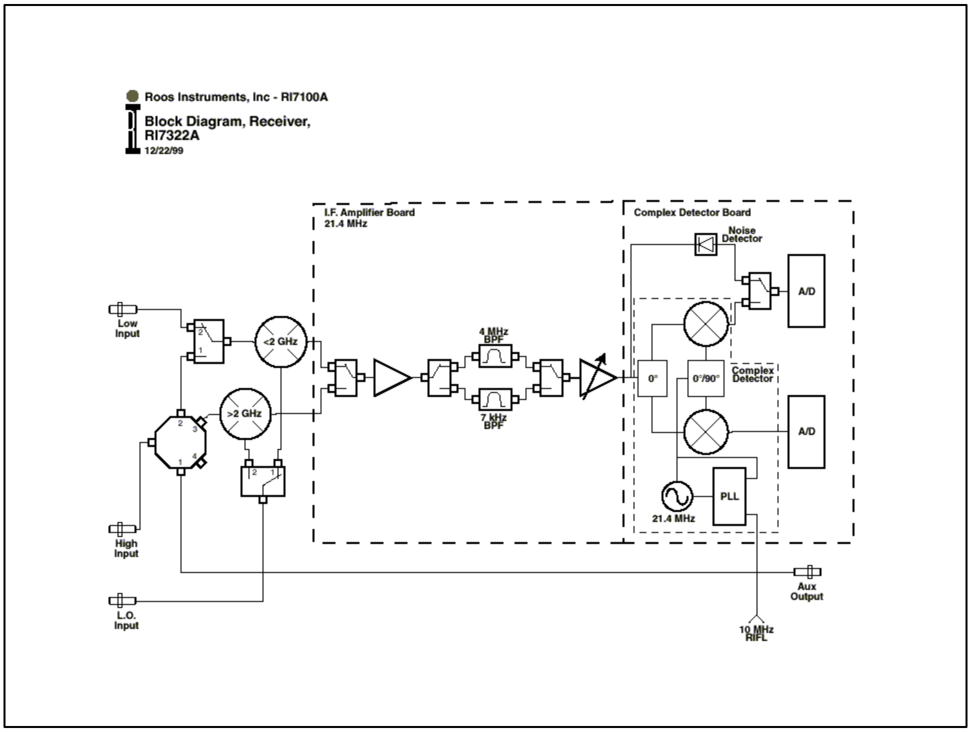


The RFICMMIC Test Head contains the couplers, microwave switches, Bi-state loads, the RFpower sensor and the noise source necessary to make multi-port S parameter, RF power and noise figure measurements.

To minimize the temperature sensitivity of the test head, all of the microwave test set components are enclosed in a proportional temperature controlled oven.

To perform a stimulus/response measurement such as forward gain (521). DUTstimulus signals (from the microwave sources) are routed through the Test Head to the device-under-test (DUT).

The RFIC/MMIC Test Head then uses high speed switches to selectively route the test signals received from the DUT to the System Receiver.



The microwave signals received by the System Receiver are down-converted to the 21.4 MHz IF frequency using the external Microwave System Local Oscillator (LO).

The IF signalmeasurements are then made by a synchronous detector slaved to the system wido 10 MHz reference.

The A to D converter digitizes the sampled I and Q signal components and sends the digitized data over the RI Fiber Link (RIFL) to the system computer.

Microwave Sources

- **RF/Microwave Synthesized Sources**
- **0.01 to 20 GHz**
- **2, 3, 4 or 5 Sources in Each System**
  System Local Oscillator
  RF Source 1 (RF Stimulus)
  RF Source 2 (Intermod Stimulus)
  RF Source 3 (DUT Local Oscillator)
  RF Source 4 (2nd DUT Local Oscillator)

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The RI 7100A Microwave Test System uses Synthesized Microwave Sources with broad frequency coverage (0.01 to 20 GHz), low phase noise and spurious performance and fast switching speed. The system is configured with 2, 3, 4 or 5 microwave sources. A minimum of 2 sources are required. One source is needed for the system local oscillator and one source is used for the device-under-test RF stimulus. To perform two tone intermodulation distortion and/or third order intercept measurements, a third source is required. A third source is also required if the device under test requires an external local oscillator (such as mixers and up/down converters.) A fourth source is required to perform two tone intermodulation distortion and/or third order intercept measurements on a DUT which also requires an external local oscillator. A fifth source can be added if the DUT requires two external LOs.

RF System Matrix

RF System Matrix

- **Functions:**
  - **RF Signal Conditioning**
  - **Combine RF Intermod Tones**
- **Contains:**
  - **Six Plug-in RF Slots**
  - **High Power RF Amplifier Modules**
    - **0.5-1, 1-2, 2-3 GHz; Up to +36 dBm**
  - **Attenuator/Amplifier/Combiner Modules**
    - **0.1-4 GHz; Up to +27 dBm**
  - **Thru Modules**

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The RF Stimulus signals can be amplified and/or combined by the RF System Matrix before the signals are routed to the DUT. The RF System Matrix contains 6 plug-in slots. Each RF Matrix is custom configured to the user's specific needs. The plug-in modules currently offered include: three High Power RF Amplifier Modules (≤+37 dBm outputs, 0.5 to 1, 1 to 2 & 2 to 3 GHz), one Amplifier/Combiner Module (1 or 2 tones, ≤+30 dBm outputs from 0.1 to 4 GHz) and one Attenuator/Combiner Module (1 or 2 tones, ≤10 dBm outputs from 0.01 to 20 GHz). Multiple modules of each type can be added to the System Matrix.

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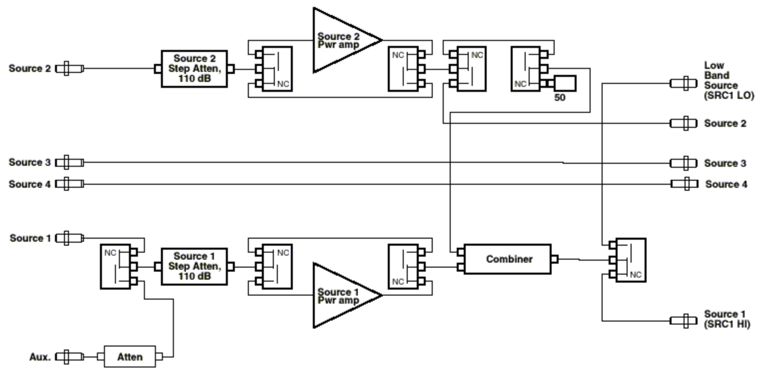
Block Diagram, Source 1/2 Output Module
RI726XA
12/22/99



Notes:

7266A: No pwr amps, no aux atten.
7267A: No aux atten.
7268A: No pwr amps
7269A: Fully loaded

Programmable DUT Controller

- **Functions:**
  - **DC & Pulsed Bias (Force & Sense)**
  - **Analog Stimulus & Measurement (Including I & Q Tones)**
  - **DUT Digital Control (Serial & Parallel)**
  - **DC Measurement**

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The RI Programmable DUT Controller provides the DC & pulsed bias, analog stimulus & measurement and the digital interface between the DUT and the test system. The RI DUT Controller is custom configured to each user's specific needs. Roos Instruments offers several plug-in application functions including:

- High Current Bias Supply Lines: 2 to 12 Vdc; 3.0 Amps max. per line, 35 us min pulse width.
- Medium Current Bias Supply Lines: $\leq \pm$ 12 Vdc; 200 mA max. per line.
- Dual Power Buffer Outputs: $\leq \pm$ 12 Vdc; 200 mA max.
- Device Power Lines: 8 lines to 2 Medium Current Bias Supplies.
- Low Current Parametric Measurement Lines: VI Force & Sense, 15 mA max.
- DUT Control Lines: Bi-State Levels, $\leq \pm$ 10 Vdc.
- DC Voltage Measurement Lines: 12 bit Resolution.
- DC Switch Matrix: 1 Input and 8 Outputs.
- Divide By 64 Capability: Divides RF Input Signal by 64, Buffers & Outputs the Resulting Signal.
- Base Band Analyzer: Measures S/N, SINAD, Distortion, Rise/Fall, Timing, etc.
- Arbitrary Waveform Synthesis: 2 Analog & 2 Digital Outputs, DC to 10 MHz.

Multiple lines/pins of each type can be added to the DUT Controller. Additional functions and features can be easily added to the DUT Controller in the future as new capabilities become available.

System Computer

System Computer

- **Functions:**
  - User Interface
  - System Management
  - Test Plan Generation & Execution
  - Measurement Control and Signal Processing
  - Data Analysis
- **Contains:**
  - IBM Compatible Personal Computer
  - OS/2 Operating System
  - RI System Software & SQL Relational Data Base
  - System/RIFL Interface

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All of the user interface, system management, test plan generation & execution, measurement control and data analysis is performed by the System Computer. The test system uses an IBM compatible System Computer and IBM's multi-tasking operating system, OS/2. The system software contains more than 2 MBytes of high level executable software written in SMALL TALK. Less than 1% of the software is written in assembly language for vector math and RI Fiber Link (RIFL) control.

System Interface & RI Fiber Link

- System Communication and Control
- Fiber Optic Communication Link
- Interface Card Plugs into System Computer
- RI Instrument Control thru RIFL Decoder Module
- RI Receiver Contains RIFL to GPIB Interface
- Scheduled Timing and Event Control

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The RI System Interface and the RI Fiber Link (RIFL) provide the test system's internal fiber optic communication and instrumentation control link. The RI System Interface is a plug-in card in the System Computer with a RIFL interface connection. The RI Fiber Link uses dual unidirectional plastic fiber cables in a simple ring pattern to connect the System Interface to the RI instrumentation.

Each RI instrument contains a RIFL interface connection and a RIFL Decoder Module. RI instrumentation in the test system do not contain microprocessors for control. Control of all functions is provided by the System Computer through the RI Fiber Link to the RIFL Decoder in each RI instrument.

Each RIFL Decoder Module is an independent node on the RI Fiber Link. Each node on the RI Fiber Link can be up to 15 meters apart. To control the GPIB instruments in the system, the RI System Receiver contains a second RIFL Decoder Module, a RIFL to GPIB Interface Module and a rear panel GPIB connector for connecting GPIB cables between the RI System Receiver and any GPIB instruments.

The RI fiber communication link is a self addressing interface. The RIFL interface transfers serial data, and provides the system with both precise scheduled timing and event control.

RI System Software Packages

System Software

- **Graphical User Interfaces**
- **Test Panels & Buttons**
- **Copy & Paste Buttons to Create Test Plans**
- **On Screen Help**

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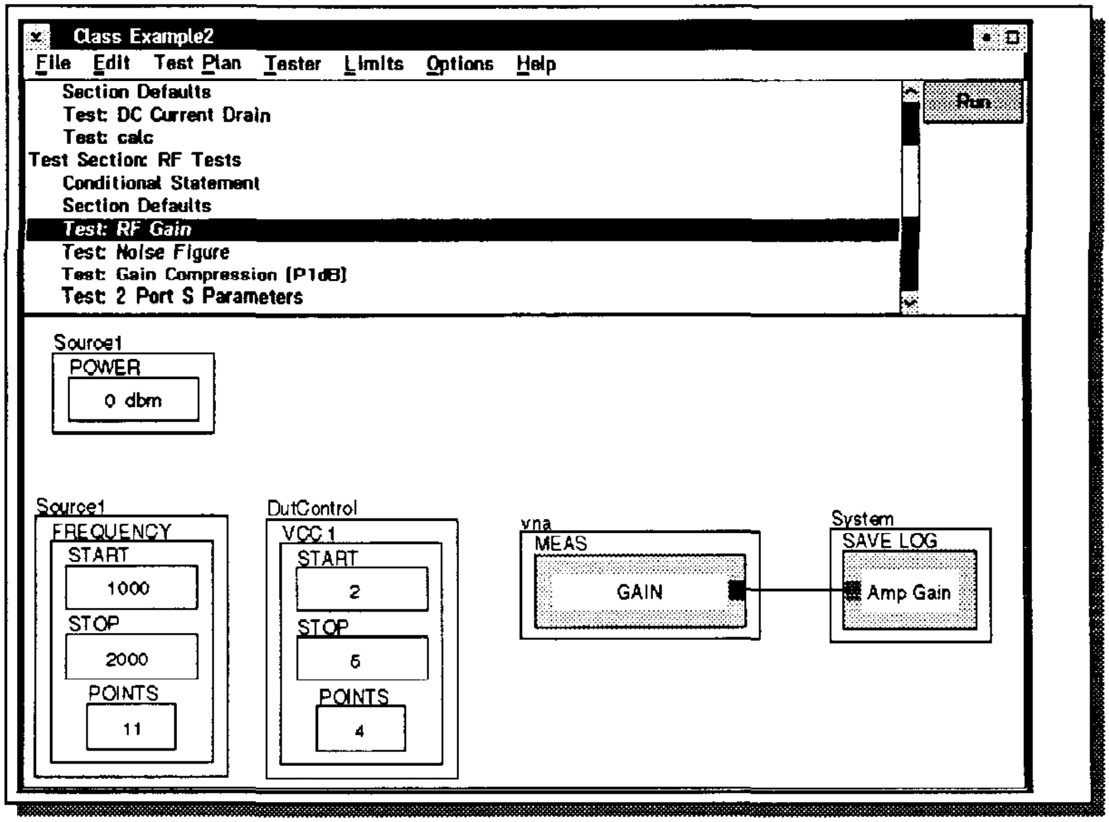
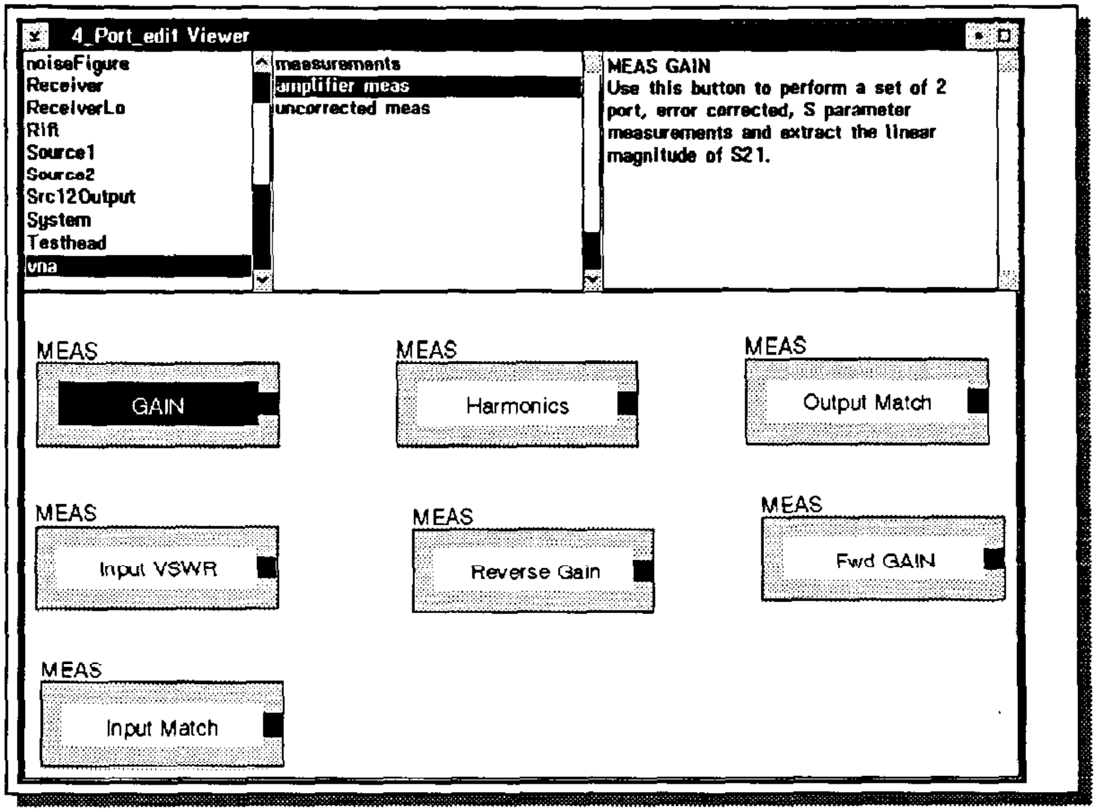
The RI 7100A Microwave Test System uses a graphical based, object oriented Test Executive and User Interface to create and run test plans, store and analyze test results and to interact with the test system's instrumentation and networked peripherals. Test procedures are displayed graphically as Test Plan Panels. Measurements and measurement states are represented in the test plan as graphical objects which we call buttons. You create test plans by copying buttons from other panels and pasting the buttons into the test panels you are creating. The System Software provides extensive On screen help for both the novice user and the experienced test engineer.

Typical Test Plan



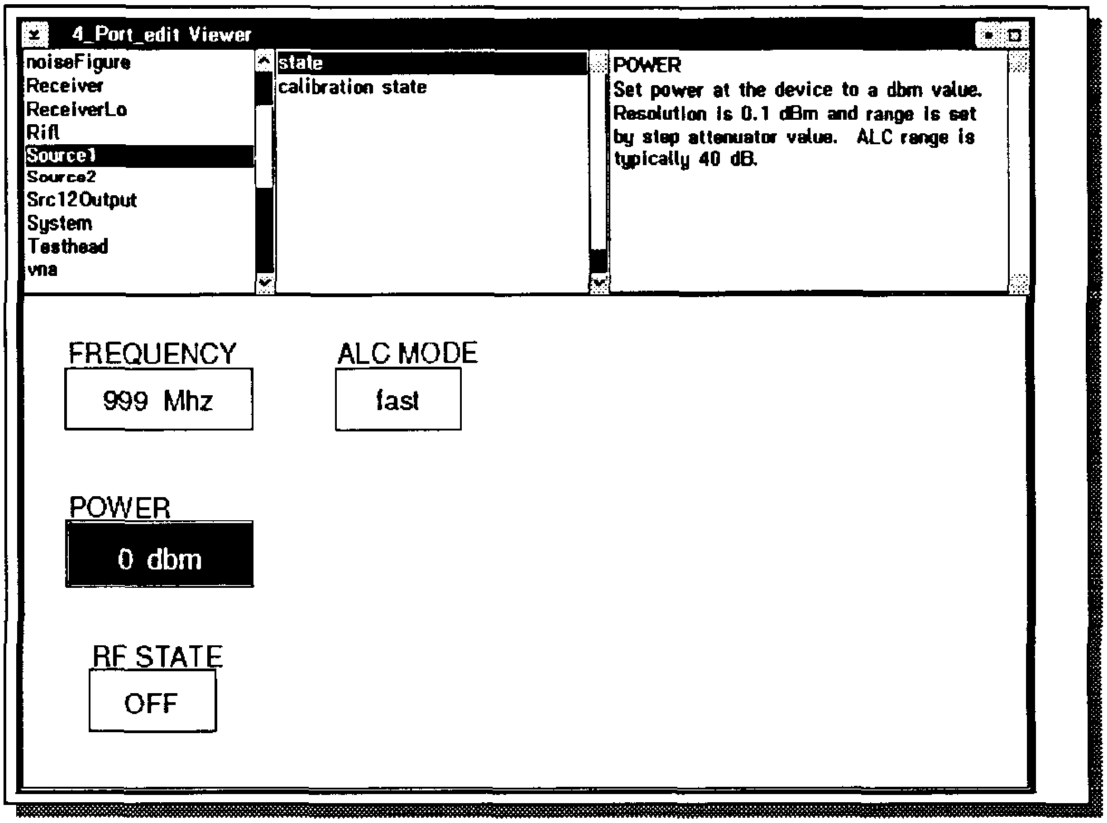
A typical test plan panel is shown above. The measurement state buttons on the left side of the test plan tell the system the conditions at which the measurements are to be made. In this example the measurements are to be made from 1000 MHz to 2000 MHz in 11 steps and at bias levels from 2 to 5 Vdc in 4 steps (a total of 44 measurement states). The GAIN measurement button (shown in the middle of the test panel) tells the system to perform the gain measurements at each measurement state. The **Amp Gain** (Save Data to Data Base) button connected to the measurement button tells the system to save the test results in the Local SQL Data Base using **Amp Gain** as the column label. This simple data flow structure also instructs the system to save into the data base the complete measurement state/status, event time, the unique part number associated with each part, the operator's name/ID number and the site location ID name/ ID number. Later we will see Data Flow Diagrams which also contain Calculation buttons and Local Variable Save buttons.

Test System Viewer Window



You create test plans, as previously shown, by copying buttons from other test plan panels (or from the Test Instrument Panels) and adding the buttons to a new test plan panel. For example to add the GAIN measurement button you select the **vna** instrument and the **amplifier meas** button types (shown above), select the **MEAS GAIN** button (highlight the button), and add the button to the test plan. The process takes just a few seconds. It is that simple and easy to create tests.

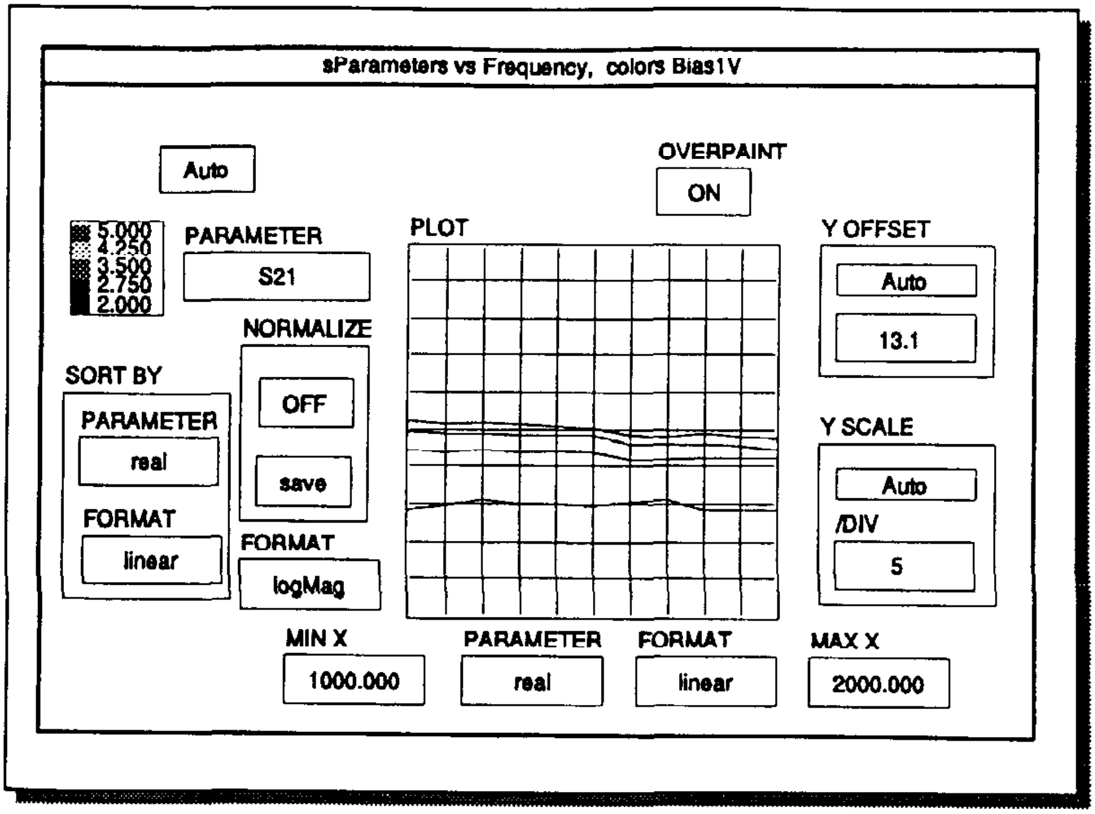
Measurement State Buttons



The Test System Viewer panels also provide the measurement state buttons. For example to select the source power state button in the previous example, you select the **Source1** instrument and the **state** button types (shown above), select the **POWER** state button (highlight the button), and add the button to the test plan.

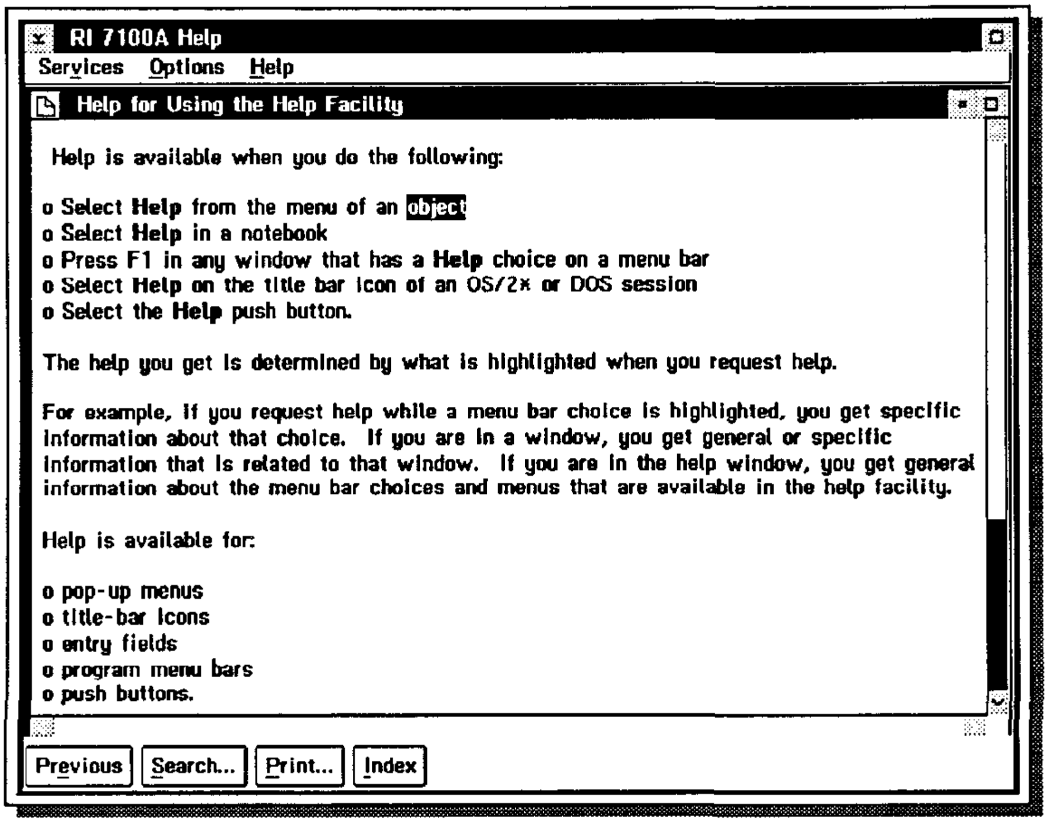
The test system software provides Test Instrument panels for each physical instrument in the system (such as the RI Test Head, RI System Receiver and the Microwave Sources) and each virtual instrument defined by the system (such as the noise figure meter, vector network analyzer, gain compression meter, etc.)

Data Viewer



The test system displays the test results using one of several different data viewers. The rectangular data viewer above displays the test results for a test plan measuring forward gain (S21) of a 2 port LNA from 1 to 2 GHz in 11 frequency steps and at 5 different DC bias levels from 2 to 5 volts. Each colored trace represents a different bias level as shown in the legend on the left. The x axis is frequency from 1 to 2 GHz with linear scaling. The Y axis is S21 (Log magnitude) with the Y axis center line at 13.1 dB and the Y axis scaling of 5 dB per division. The data viewers will be described in detail later.

On-Screen Help



On-screen help is provided through out the system software. There are several ways to request help. You can:

1) Select the **Help** menu bar choice,

2) Place the mouse pointer on the object, press and hold the **Left** mouse button and select the **F1** key on the keyboard.

3) Place the mouse pointer on an object, click the **Right** mouse button and select the pop-up menu choice: **Help**.

Physical Instruments

Physical vs. Virtual Instruments

- **Physical Instruments**
  - **RF Family Card/Test Fixture**
  - **RFIC/MMIC Test Head & Programmable DUT Controller**
  - **System Receiver**
  - **Microwave Sources**
- **Basic Measurement Functions**
  - **I & Q Voltage**
  - **DC Voltage & DC Current**

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Basic Measurements

As you will see many of the measurement instruments/functions do not physically exist, except in software as virtual instruments which can be easily reconfigured to create new instruments and measurement functions. To perform the complex measurement functions represented by the virtual instruments, the test system very quickly performs many, simple, low level measurements (I & Q voltage, and DC current & voltage) and uses the processing speed and power of the system computer to calculate the test results desired (S parameters, RF power, noise figure, harmonics, intermodulation distortion, DC current and voltage, etc.)

Physical vs. Virtual Instruments

- Virtual Instruments
  - Vector Network Analyzer
  - RF Power Meter
  - Noise Figure Meter
  - Gain Compression Meter
  - Spectral Analysis Meter
  - Intermod Distortion and TOI Meters
- Easily Reconfigured to Create New Instruments

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Listed above are examples of virtual instruments which have been created.

Basic Measurement Capability

- S Parameters
- RF Power
- Noise Figure & Noise Power
- Spectral Purity
- Gain Compression
- Conversion Gain
- Intermod Distortion
- 3rd Order Output Intercept
- Isolation
- DC Voltage & DC Current
- DC to RF Efficiency
- I & Q Amplitude & Phase

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The RI 7100A Microwave Test System will perform all of the basic measurements listed above, very quickly. Each of these fundamental measurements will now be discussed in detail.

S Parameters

- Definition of Scattering Parameters
- Measurement Concept
- Flow Graphs
- RF 7100A Measurement Hardware
- Error Correction
- Two Port Error Model

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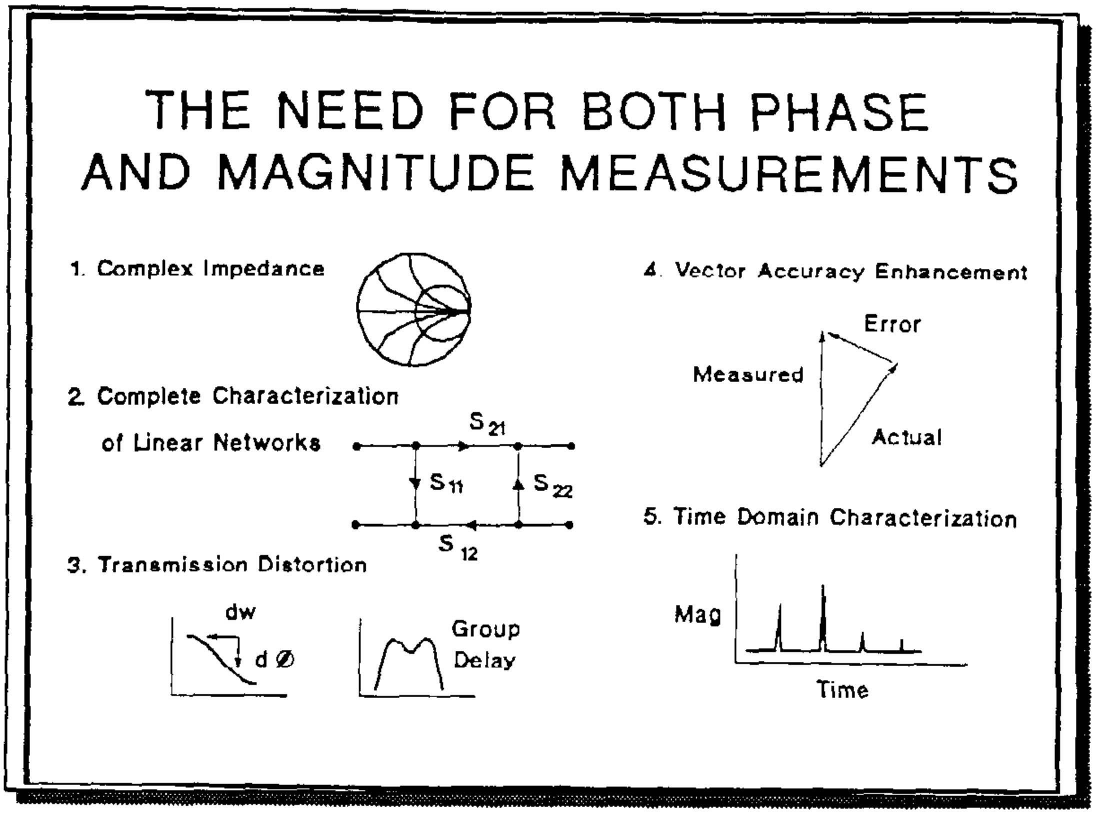
Introduction

S parameters (or more specifically Scattering parameters) are fundamental RF parameters for characterizing RF/microwave devices and RF/microwave signal networks. The following slides will define S parameters, describe the measurement process and concepts associated with S parameter measurements, describe how the Test System performs S parameter measurements and discuss 2 port error correction of systematic errors.

Why Measure Phase and Magnitude

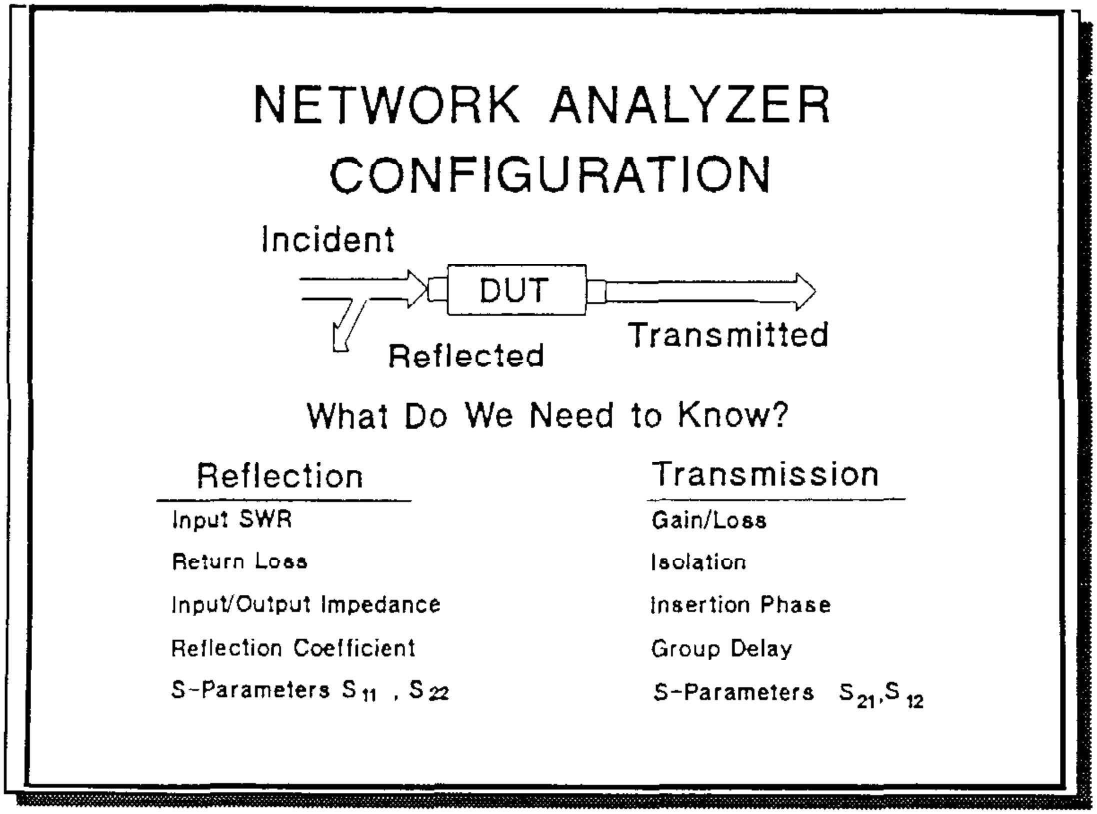


Before we discuss S parameters in detail, it may be useful to understand why we need to measure S parameters of an RF device and why phase information is useful. S parameter measurements (both amplitude and phase) are used to characterize the transfer characteristics (input to output response) of an RF device and to determine the complex impedance (both resistive and reactive components) of the device's RF inputs and outputs.

S parameter measurements are also useful for characterizing the device's transmission errors such as signal distortion thru the device due to non-linear changes in phase and group delay. With S parameter data (both magnitude and phase) you can carefully monitor the impact of small changes in the manufacturing process on the device's RF performance (in order to improve the manufacturing process) and improve the RF CAD models used to design the devices.

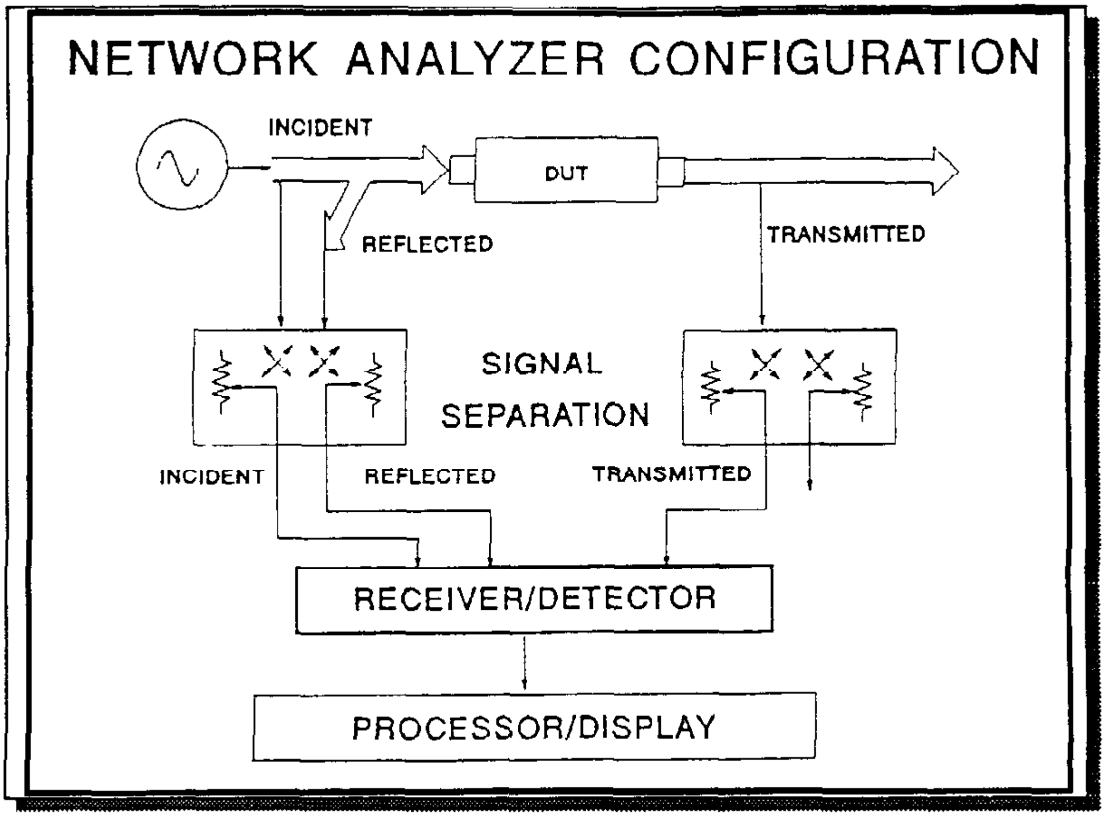
Another benefit of measuring both amplitude and phase is the ability to characterize and mathematically eliminate several system measurement errors (due to cable\connection\switch losses and impedance mismatches, changes in coupler directivity over frequency, and source & load mismatch errors) and thereby significantly improve both amplitude and phase measurement accuracy when compared to scalar (magnitude only) measurement systems.

Systems capable of measuring both the magnitude and phase response of a device are referred to as vector network measurement systems or vector network analyzers (VNAs). Systems only capable of measuring amplitude are referred to as scalar measurement systems or scalar network analyzers.



To fully analyze the magnitude and phase characteristics of a typical 2 port device (device with 2 RF connections), may require looking at the data in different ways. A vector network analyzer system provides you the flexibility to present the data in many different formats as shown in the slide.

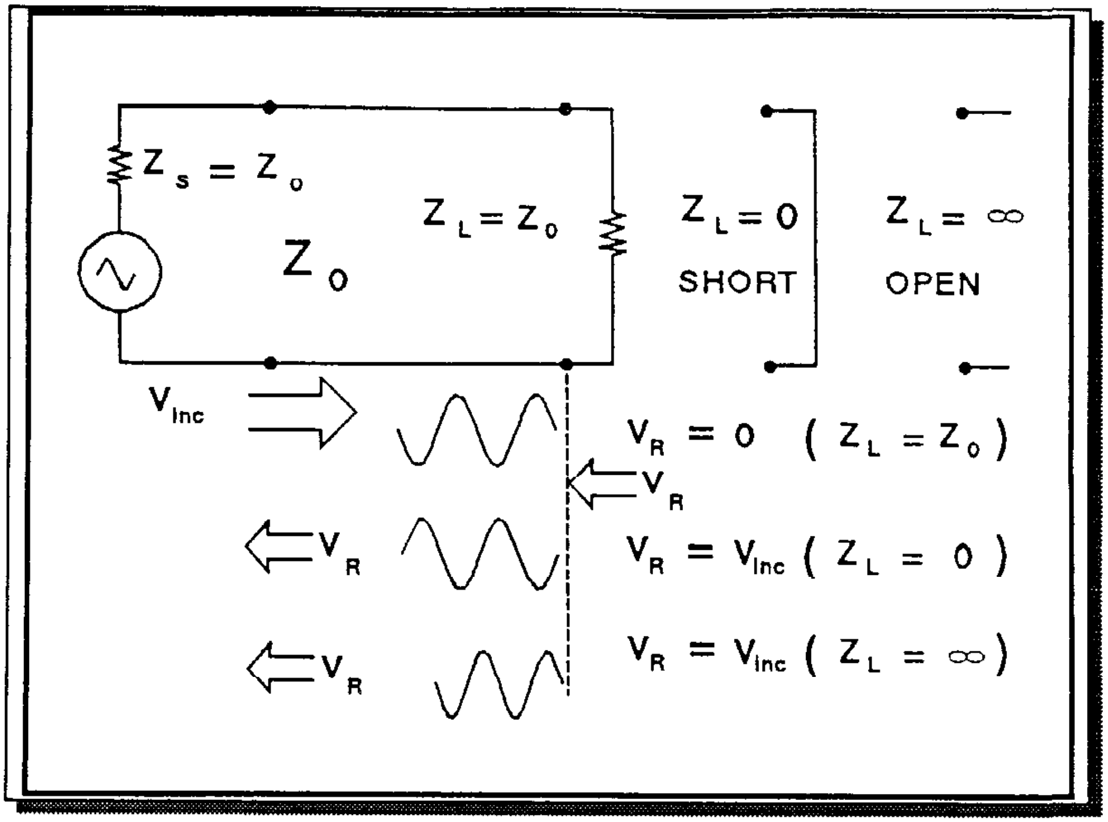
Vector Network Analyzer



A typical vector network analyzer (VNA) system consists of 4 major parts: the Stimulus Source which provides the incident signal; the S parameter Test Set which provides the signal separation of the incident, reflected and transmitted signals; the System Receiver which converts the microwave signals to lower intermediate frequency (IF) signals, measures the signals with a complex demodulator (I & Q demodulator) and digitizes the I (in phase) and Q (quadrature) signal components; and a Signal Processor/System Computer which processes the digitized signal data and displays the test results on a CRT screen.

What are these signals that the S parameter Test Set provides to the System Receiver? The Incident and transmitted signals are fairly intuitive. The incident signal is the signal applied to the RF input of the device-under-test. The signal transmitted through the device to the output of the device-under-test is the transmitted signal. We can measure and compare the amplitude and phase of the incident signal applied with the transmitted signal received to determine the transmission parameters. For example the ratio of the transmitted signal's amplitude to the incident signal's amplitude is the gain or loss through the device.

RF Reflected Signals



The reflected signals are more complex to understand. To help explain what is meant by reflected signals and how they are generated let us look at three transmission line examples . In each example we have an incident signal of RF or microwave energy from a source with an output impedance of 50 ohms. We know that the signal will deliver maximum power to a transmission line if the transmission line's impedance is the same or equal to the source impedance (i.e. 50 ohm impedance transmission line with infinite length.)

In the first example we terminate the transmission line with a 50 ohm termination. All of the energy flowing from the source will be absorbed by the termination (i.e. the incident signal cannot distinguish between a Zo load and a Zo transmission line of infinite length.)

In the second example we terminate the transmission line with a short circuit. The short circuit has 0 ohms and can not dissipate any power and the energy is reflected back towards the source. Since the short circuit can not support any voltage (Vshort= 0 volts), the reflected voltage wave must be equal in magnitude and 180 degrees out of phase with the incident voltage wave in order for the voltage sum at the short to be equal to zero.

Similarly, in the third example we terminate the transmission line with an open. The open circuit has infinite impedance and can not support any current and thus can not dissipate any power. The energy is reflected back towards the source in phase and of the same magnitude as the incident wave at the open.

Reflection Coefficient, Return Loss & SWR

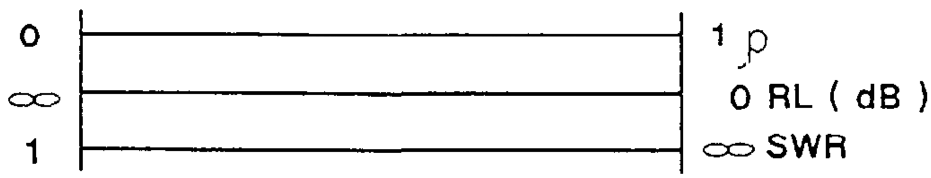
REFLECTION TERMINOLOGY

Reflection Coefficient $\Gamma = \frac{V_R}{V_{INC}} = \frac{Z_L - Z_O}{Z_L + Z_O} = \rho \angle \phi$

$$\rho = |\Gamma|$$

$$\text{Return Loss} = -20 \text{ Log } \rho$$

$$\text{SWR} = \frac{1+\rho}{1-\rho}$$

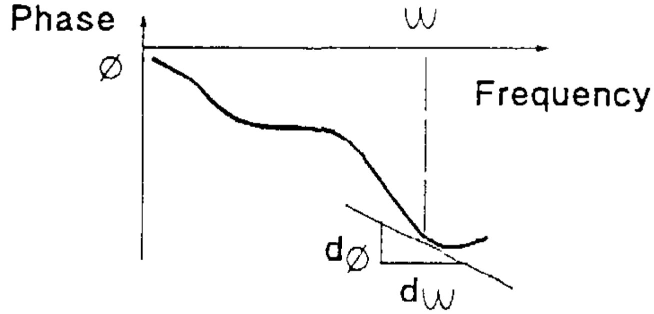


We have established that the reflected signal is a function of both the load impedance and the characteristic impedance of the incident signal. The ratio of the reflected voltage to the incident voltage (as shown in the slide) is defined as the reflection coefficient, gamma (Γ).

The reflection coefficient has both a magnitude and a phase term. The magnitude of the reflection coefficient is defined as rho (ρ) and varies between the values of 0 and 1. Return loss in dB is defined as -20 log ρ. This results in a positive dB number between 0 dB (ρ=1) to infinite dB (ρ=0). Standing Wave Ratio (SWR) is defined as the ratio of the maximum standing wave voltage to the minimum standing wave voltage (Emax/Emin). It is also related to ρ by the equation shown. SWR varies between 1 and infinity.

Group Delay

GROUP DELAY



$$\text{Group Delay} = t_g = \frac{-d\phi}{d\omega}$$

ϕ In Radians

ω In Radians/Sec

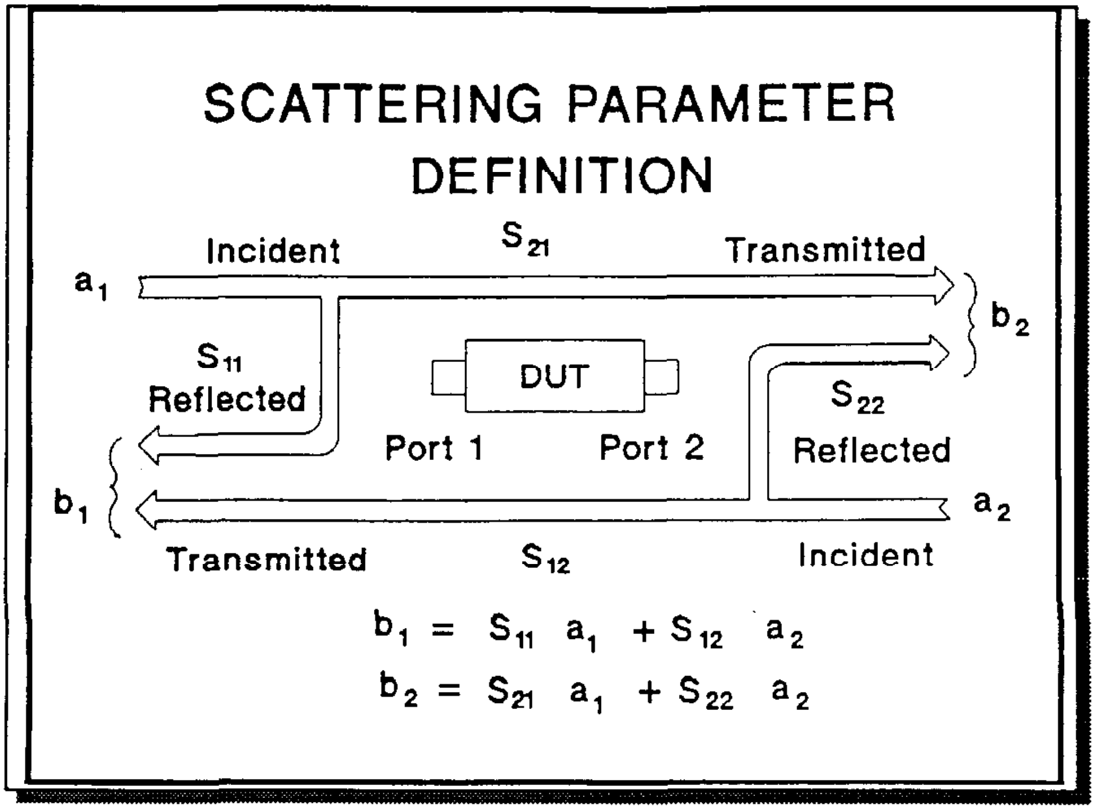
$$= \frac{-1}{360°} \cdot \frac{d\phi}{d_f}$$

ϕ In degrees

f In Hz ($\omega = 2\pi f$)

Another useful parameter is Group Delay. Group Delay is defined as the negative rate of change in the transmission phase response (dϕ) of a device with respect to the change in the RF frequency (dw or df). This is equal to the derivative of the phase response with respect to frequency. For example a device with a linear phase shift vs RF frequency would have a constant rate of change with respect to frequency and therefore a constant group delay. The units for group delay are seconds which indicates that group delay is a measure of transit time through the device-under-test for a particular frequency.

S Parameter Definition



S parameters or Scattering parameters (S11, S12, S21, S22) define the relationship between the incident, transmitted and reflected signals at the inputs and outputs of the device under test. The examples and equations shown are for a 2 port RF device. a1, a2, b1 and b2 are defined below:

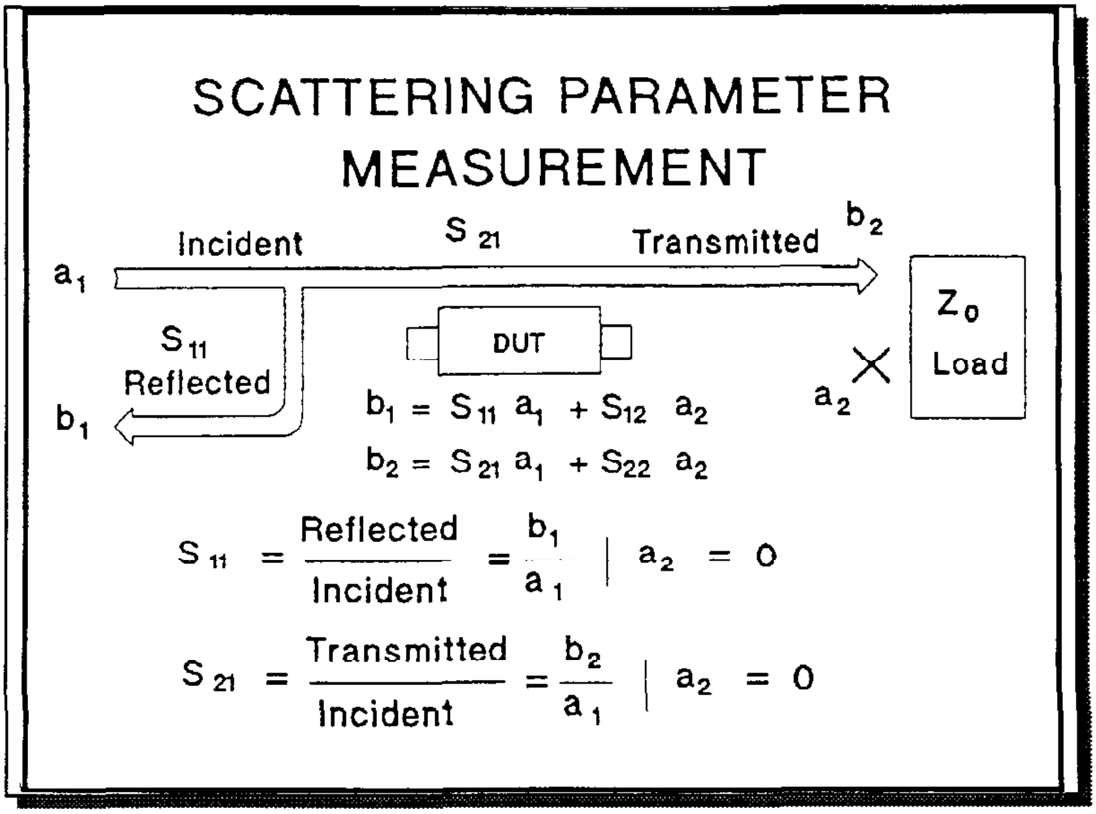
a1 is the incident signal applied in the forward direction to the input port (port 1).

a2 is the incident signal applied in the reverse direction to the output port (port 2).

b1 is the energy out of port 1. b1 is equal to the sum of the reflected energy from the a1 signal applied to port 1 and the energy transmitted through the device from the a2 signal applied to port 2.

b2 is the energy out of port 2. b2 is equal to the sum of the reflected energy from the a2 signal applied to port 2 and the energy transmitted through the device from the a1 signal applied to port 1.

Measuring 2 Port S Parameters



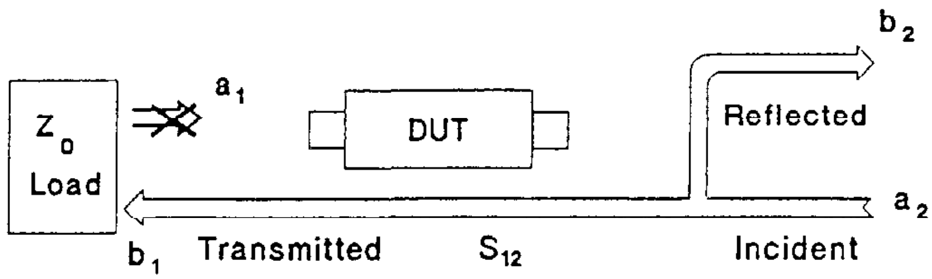
Forward Measurements

To determine the four S parameters we first terminate port 2 with a Zo load eliminating the a2 signal. The resulting equations yield S11 and S21. S11 is the ratio of b1/a1 and S21 is the ratio of b2/a1, when a2 is zero. S11 is equivalent to the reflection coefficient, gamma (Γ). Please notice that gamma (Γ) is defined as Vinc/Vrefl = b1/a1. Similarly, S21 is equal to the forward transmission coefficient.

S parameters use a numbering convention that the first number represents the RF port where the energy emerged from the device and the second number is the RF port where the incident energy is applied to the device. Thus, S21 Is the ratio of the energy emerging from port 2 to the energy incident at port 1. Gain or loss is indicated by values greater or less than unity.

Measuring 2 Port S Parameters

REVERSE MEASUREMENT



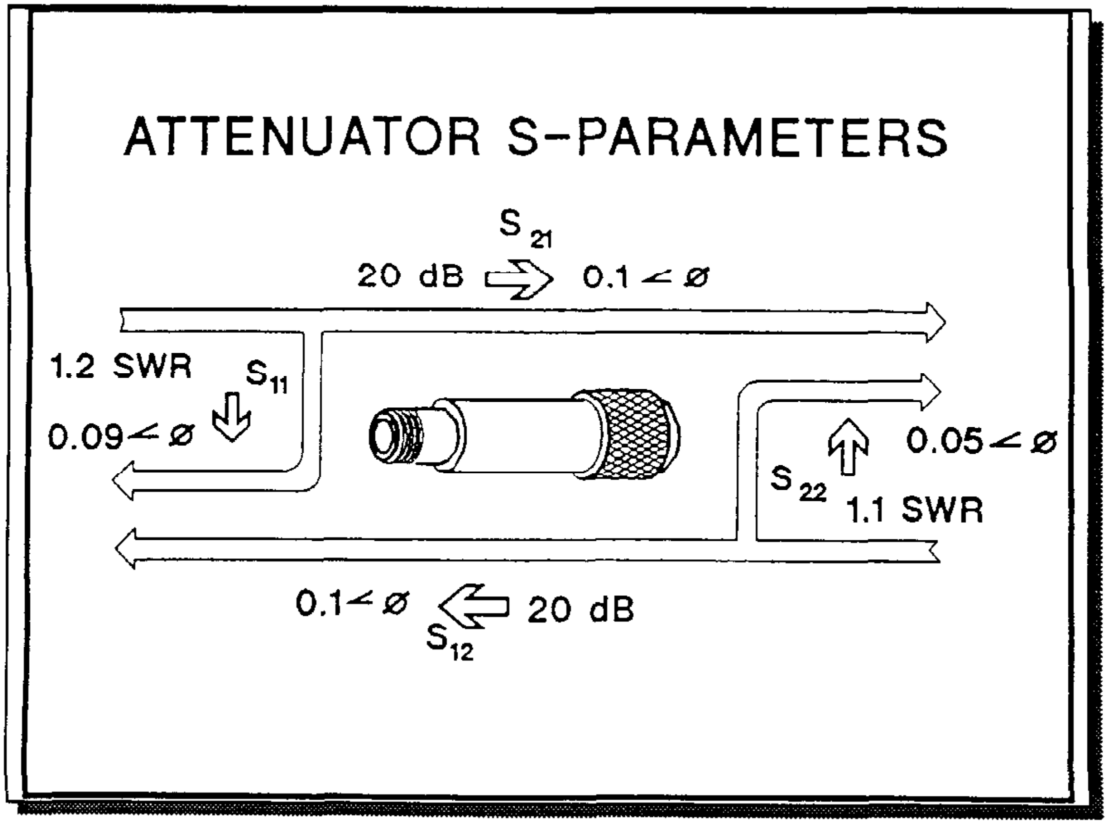
$$S_{22} = \frac{b_2}{a_2} \quad \Big| \quad a_1 = 0$$

$$S_{12} = \frac{b_1}{a_2} \quad \Big| \quad a_1 = 0$$

Reverse Measurements

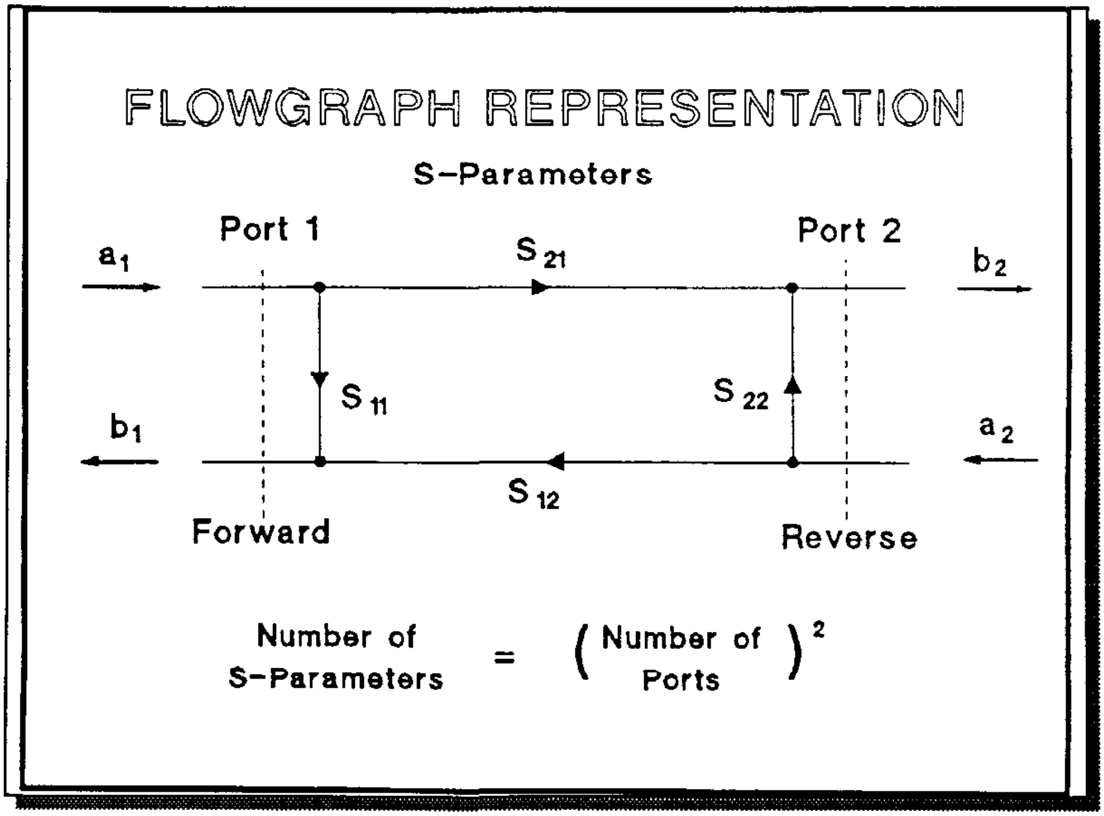
By placing the source at port 2 and terminating the input with a Zo load, the a1 term is now zero and S22 and S12 can be determined. Notice that the S parameters are referenced to the Zo impedance of the network analyzer (typically 50 ohms.)

Testing a Attenuator



One of the advantages of S parameters is that they are intuitive. S21 is simply the forward gain or loss of the device in linear units. For the 20 dB attenuator shown, we see that the loss through the attenuator is equal to an S parameter voltage ratio of 0.1. Since S parameters are complex parameters, there is a phase angle term (ϕ) as well as a magnitude term associated with each S parameter. The SWR of the device is equivalent to the S11 or input voltage reflection coefficient of 0.09.

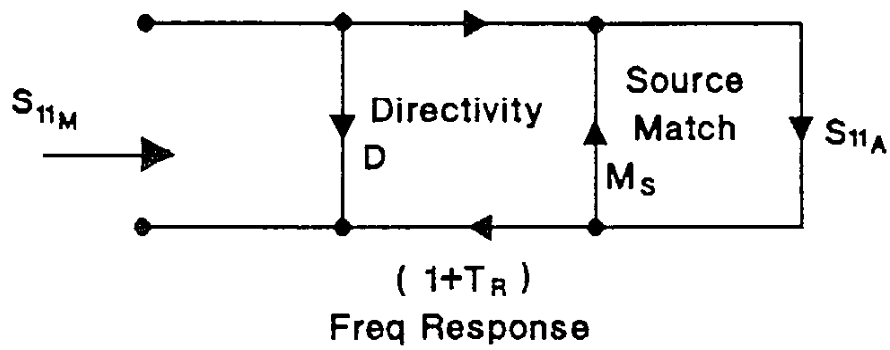
S Parameter Flow Graphs



This is a flow graph representation of a two port device, such as the attenuator from the previous slide. The input port has two nodes: one representing the incident or **a** wave and one for the emerging **b** wave. Lines that connect nodes are called branches. Each branch has an arrow and a value corresponding to an S parameter. Energy will only flow in the direction of an arrow.

One Port S Parameter Measurement Model

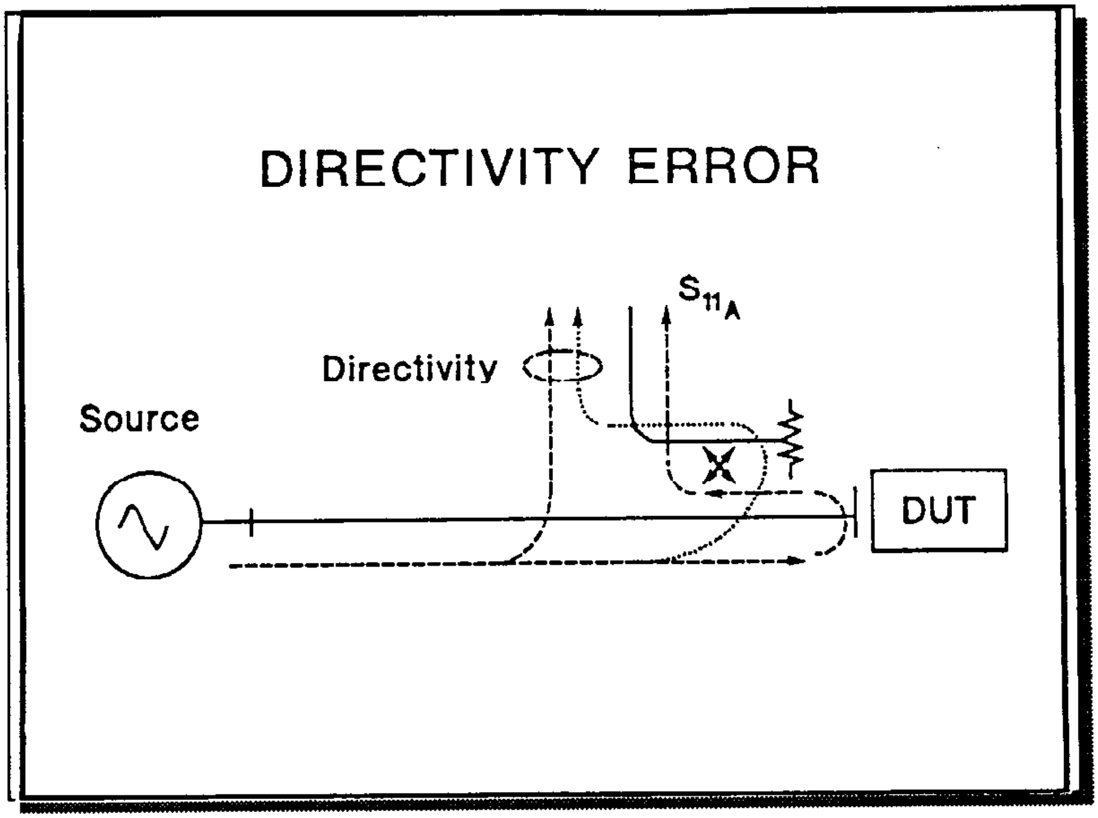
"ONE PORT" MEASUREMENT MODEL



$$S_{11_M} = D + \frac{S_{11_A}\ (1+T_R)}{1 - M_S\, S_{11_A}}$$

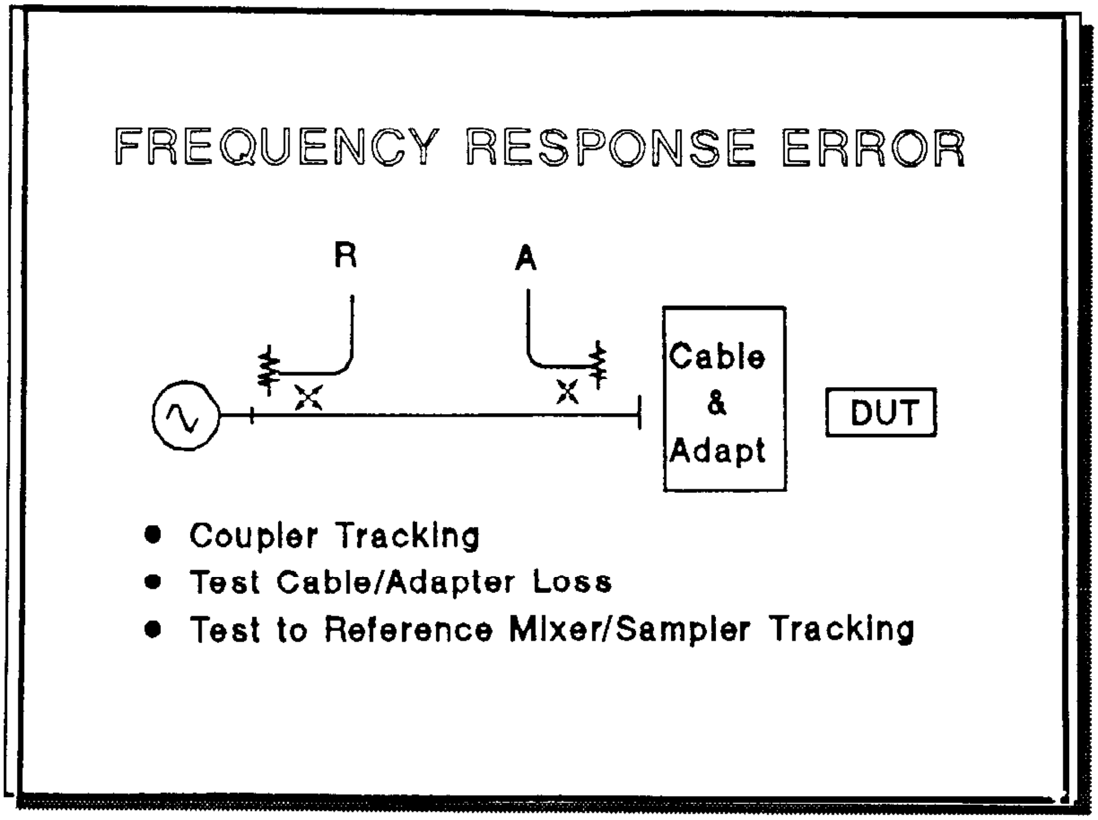
By applying well defined calibration techniques, we can characterize the measurement system's systematic errors (errors which are stable and repeatable) and mathematically remove these errors from the measurement process and there by improve the system's overall measurement performance. This process is often referred to as S parameter error correction. The one port measurement model shown identifies the three major systematic errors associated with one port measurements. D represents directivity errors, TR represents tracking errors and MS represents source match errors. (A complete two port model will be presented later.)

Directivity Errors



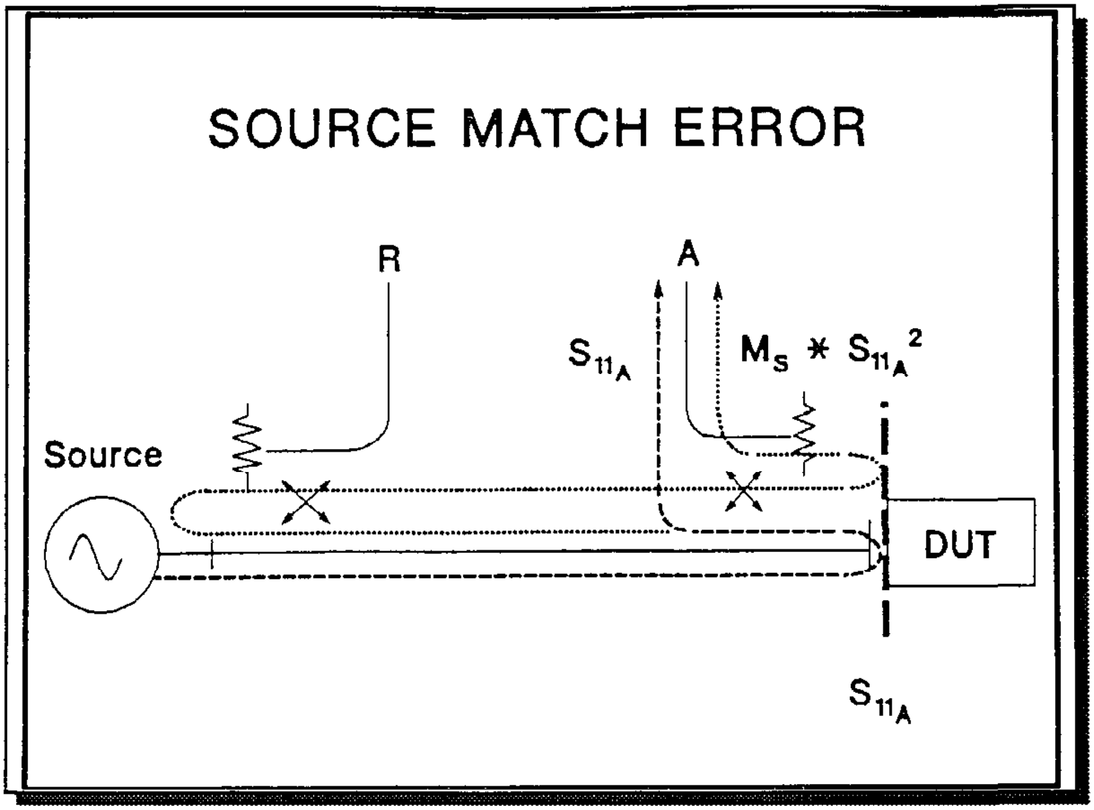
Directivity errors are caused by signals, other than the signal reflected off of the DUT, which are detected at the coupled arms of the directional couplers in the S parameter test set. These error signals are caused by imperfections in the directional couplers used in the test set and impedance mismatches of the adapters or test cables that physically connect the device under test to the S parameter test set. These errors combine vectorally with the true reflection coefficient (S11A) to yield an inaccurate value for the measured data S11M. We call the combined errors: Overall Directivity.

Reflection Tracking Errors



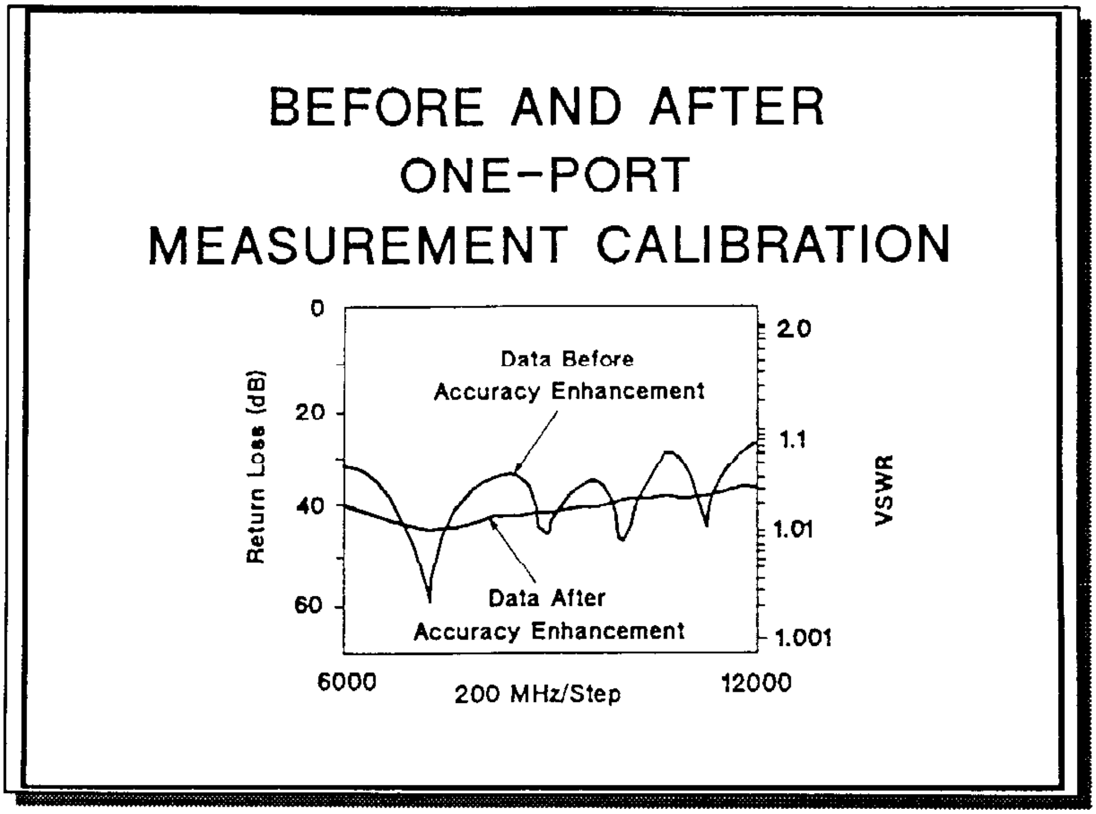
Reflection tracking errors are a composite of the frequency response of the couplers (coupler tracking), the test cables and the microwave mixer in the System Receiver.

Source Match Errors



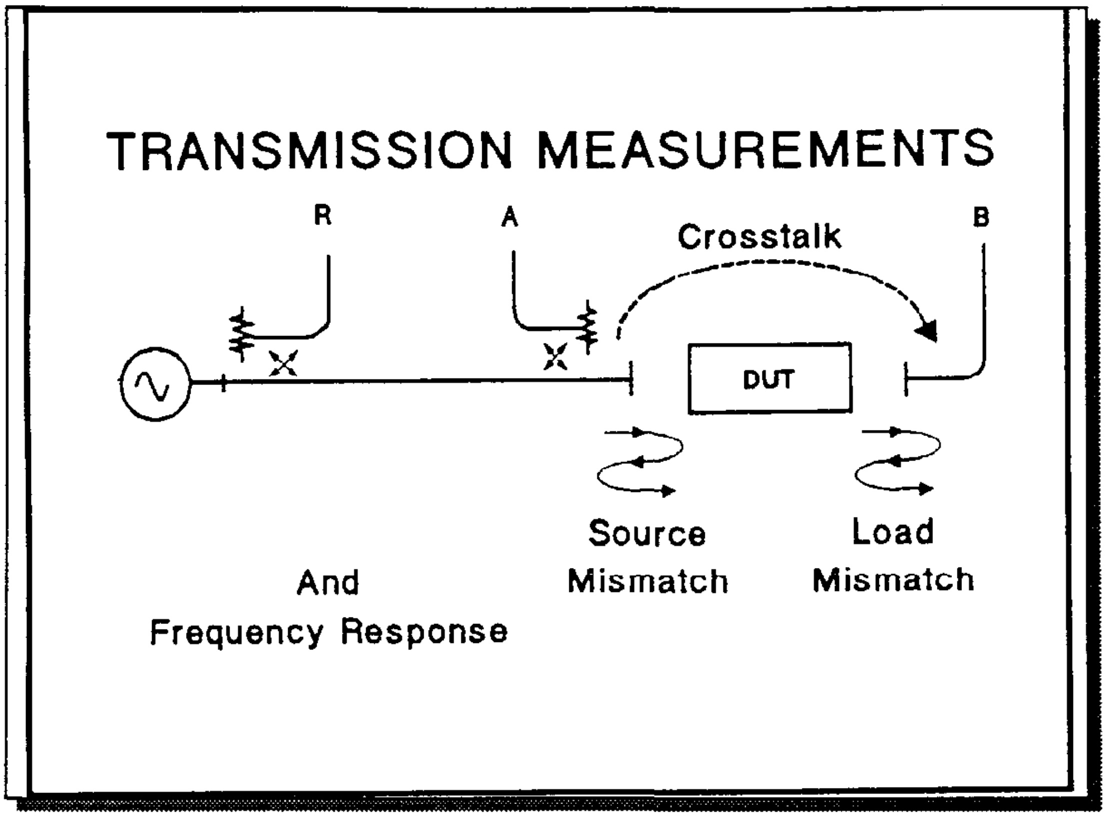
When a signal is reflected back off the test device into the test system, the signal does not see a ideal load due to all of the small mismatches errors caused by imperfect connections, transitions, etc. in the system. An error loop is formed with the signal bouncing back and forth (as shown in the slide.) This error is related to the product of mismatch terms and it is only a major factor when the test device has a large mismatch.

1 Port Calibration & Vector Error Correction



The impact of performing calibration and vector error correction to mathematically eliminate systematic errors (even for one port devices) is significant as you can see. The importance of vector error correction for multi port devices is even more critical.

Two Port Error Models



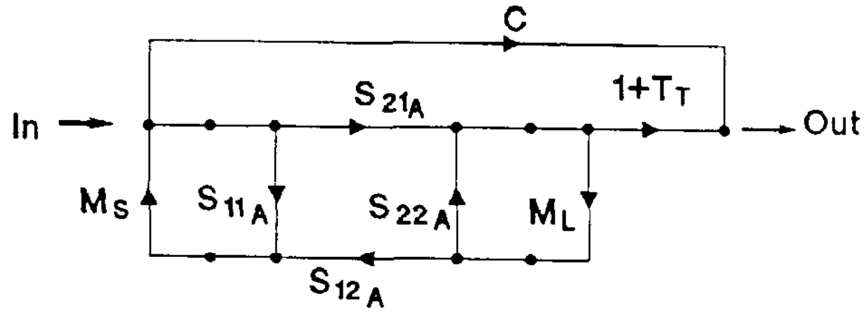
Transmission Measurements

The two port transmission measurement model identifies four major systematic errors: crosstalk (C), source match (MS), load match (ML) and transmission frequency response (Tt). The crosstalk (C) error term is due to signals leaking around the DUT. The leakage error may become significant when the transmitted signal level is reduced substantially by the test device (i.e. high loss devices.)

We can also see that any load mismatch at the output of our test device has the potential of adding errors to our input port reflection measurement by causing signals to be reflected back through the device. The error contribution is a function of both the forward and reverse transmission characteristics of the device under test and the load match presented to the DUT. We will refer to this term as the load match of our test system.

Two Port Error Model

TRANSMISSION MEASUREMENT MODEL



$$S_{21_M} = C + \frac{S_{21_A}\,(1 + T_T)}{1 - M_S\,S_{11_A} - M_L S_{22_A} - M_S M_L S_{21_A} S_{12_A}}$$

Flow Graph

The transmission measurement model is shown above. Notice the interaction of the source match (MS) with S11A, the load match (ML) with S22A, the transmission frequency response error (Tt) with S21A and the source match and load match with S12A. This model shows that in order to accurately extract S21A data, we need to also know accurately S11, S12 and S22.

2 PORT S PARAMETER MEASUREMENT CALIBRATION

- Traditional Calibration Approach
  - Characterize Systematic Errors
  - Remove Systematic Errors from Measurement
  - Reflection Cal M_S, D, T_R
  - Thru Connection T_T, M_L
  - Isolation Measurement C
- Newer Approach TRL (Thru, Reflect & Line)
  - Relies on Characteristic Impedance of Line
  - RI 7100A Supports TRL and its Variants

TRL Calibration

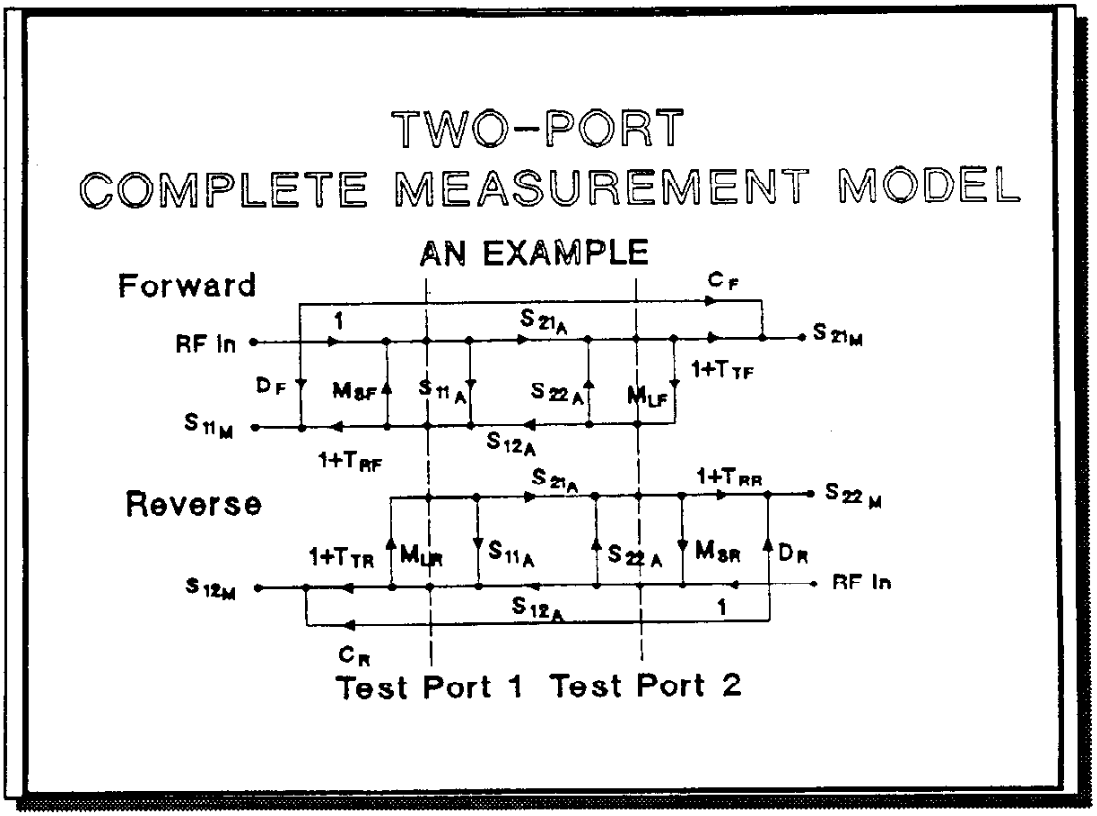
By performing a full two port S parameter measurement calibration, we can characterize and mathematically remove the effects of the systematic errors. The traditional two port calibration approach is to perform a one-port reflection calibration to determine source match, use a through connection to characterize transmission frequency response and load match, and to perform an isolation calibration to determine transmission leakage or crosstalk. The RI 7100A Microwave Test System uses a newer approach TRL (Thru, Reflect and Line) and its variants to calibrate the system. This newer calibration approach relies only on the characteristic impedance of a short transmission line. From two sets of 2 port measurements that differ by this short length of transmission line and two reflection measurements, the full error correction can be determined. The three basic steps in the calibration process are:

Thru - connection of port 1 and port 2, directly or with a short length of transmission line.

Reflect - connect identical one-port high reflection coefficient devices to each port

Line - insert a short length of transmission line between port 1 and port 2 (different line lengths are required for the Thru and the Line)

Complete Two Port Error Model



Flow Graph

A complete full two port measurement model is shown above. Notice that it contains both a forward and reverse measurement model.

TRANSMISSION CORRECTION COMPLETE MODEL

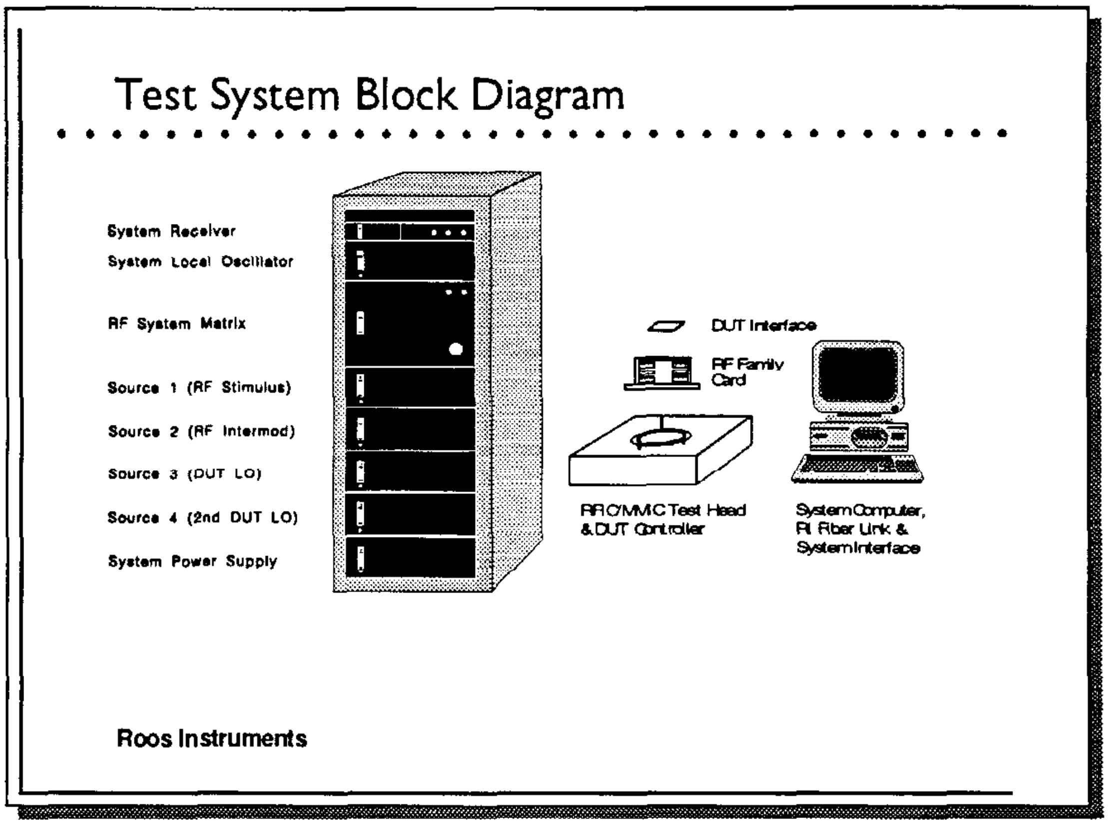
$$S_{21A} = \frac{\left[\dfrac{(S_{21M} - E_{XF})}{E_{TF}}\right]\left[\left(1 + \dfrac{(S_{22M} - E_{DR})}{E_{RR}}\right)(E_{SR} - E_{LF})\right]}{\left[\left(1 + \dfrac{(S_{11M} - E_{DF})}{E_{RF}}\right)E_{SF}\right]\left[\left(1 + \dfrac{(S_{22M} - E_{DR})}{E_{RR}}\right)E_{SR}\right] - \left[\left(\dfrac{S_{21M} - E_{XF}}{E_{TF}}\right)\left(\dfrac{S_{12M} - E_{XR}}{E_{TR}}\right)E_{LR}E_{LF}\right]}$$

- **Requires measuring all four s-parameters.**

Mathematical Model

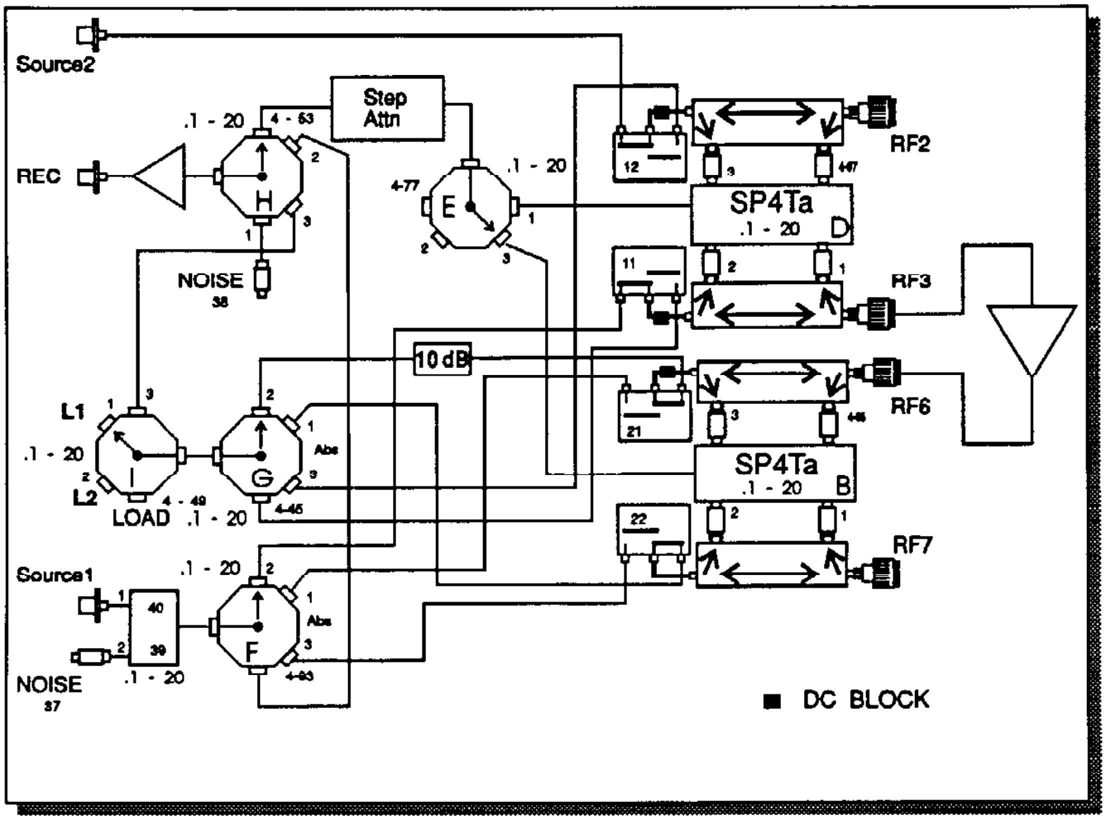
The equation for extracting one S parameter (S21A) is shown above. Notice that all 4 measured S parameters terms are in the equation. This is true for all four S parameter terms. You must measure all four S parameters (both magnitude and phase) in order to determine any of the actual S parameter values.

Test System Block Diagram



Typical Test System

RI RFIC/MMIC Test Head

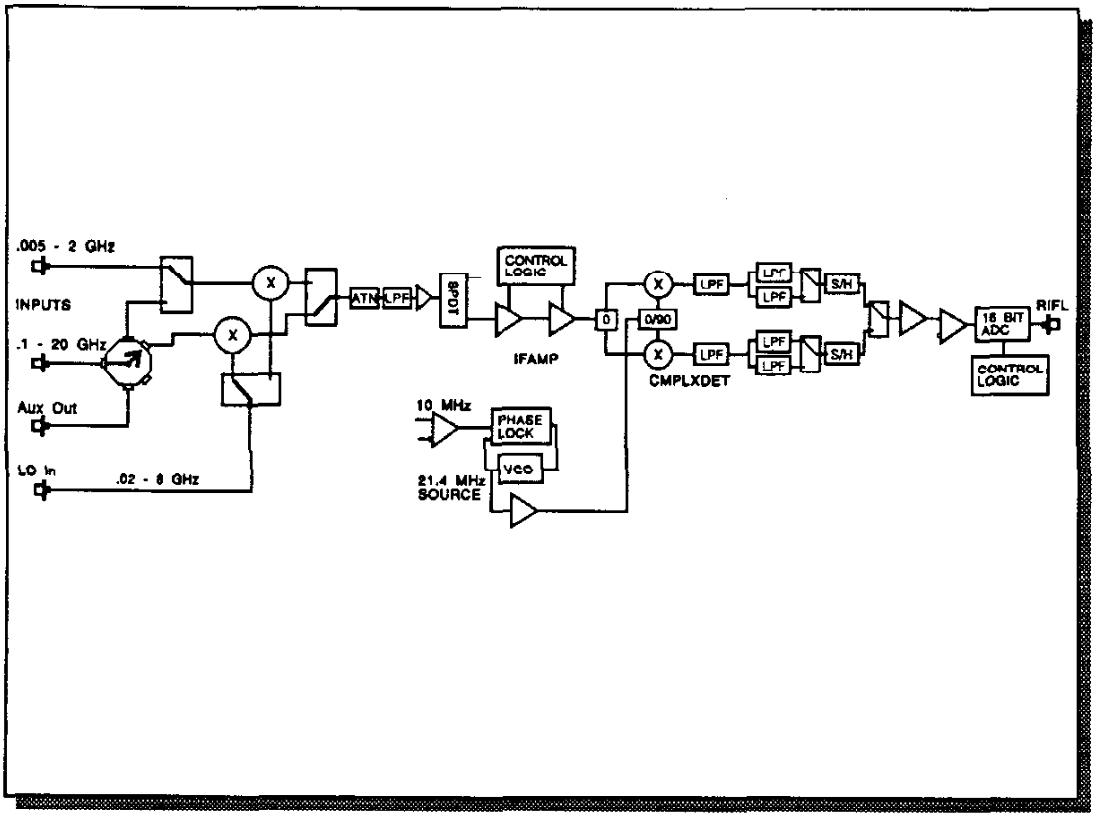


4 Port Test Configuration for S Parameters

The block diagram and test configuration presented is a typical two port S parameter measurement configuration for the RI Test Head. The two port device under test (DUT) is shown connected to RF ports 3 & 6. The RF stimulus source (Source1) is connected to the Source1 input port. The RF stimulus signal is routed through the Test Head to the DUT's RF input connected to RF port 3. The resulting incident and reflected signals at port 3 and transmitted and reflected signals at port 6 are separated by the directional couplers connected to port 3 and port 6. The electronic switches (connected to the fixed attenuators on the coupled arms of the port 3 & 6 directional couplers) individually route these coupled signals through a second switch, a RF step attenuator, a third electronic switch and a RF preamplifier to the REC port which sends the signals to the single channel System Receiver for signal processing.

The RI 7100A test system uses a Bi-state load pull approach, instead of reversing the DUT or reversing the RF stimulus signal's direction to measure the S22 and S12 terms. This unidirectional S parameter measurement approach is especially useful for characterizing unidirectional active devices such as power amplifiers at high RF signal levels. To create the Bi-state loads the RFIC/MMIC Test Head uses custom, high speed, electronic switch loads. These loads are connected to the thru path of each of the directional couplers. (Follow the thru path of the directional couplers, through the mechanical switch, the 10 dB attenuator and an electronic switch to the bi-state loads L1 & L2.)

RI System Receiver



Measurement Configuration for S Parameters

The signals received by the System Receiver (at its 0.005 - 2 GHz or 0.1 - 20 GHz INPUT port) are down converted to the 21.4 MHz IF frequency using the external System Local Oscillator connected to the LO In port. The IF signals are conditioned (attenuated, filtered &/or amplified) and sent to the complex/synchronous detector. The complex detector splits the received signal into two equal amplitude and equal phase signals and mixes one signal with a 21.4 MHz signal in phase with the System Receiver's internal 21.4 MHz SOURCE to create the I (in phase) signal component and mixes the other signal with a 21.4 MHz signal which is 90 degrees out of phase with the 21.4 MHz SOURCE to create the Q (quadrature) signal component. The resulting signals are low pass filtered and sampled by high speed sample & hold circuits. The high speed A to D converter digitizes the sampled I and Q signal components and sends the digitized data over the RI Fiber Link (RIFL) to the System Computer for processing. The 21.4 MHz SOURCE signals are generated from (and slaved to) to the system wide 10 MHz frequency reference/time base.

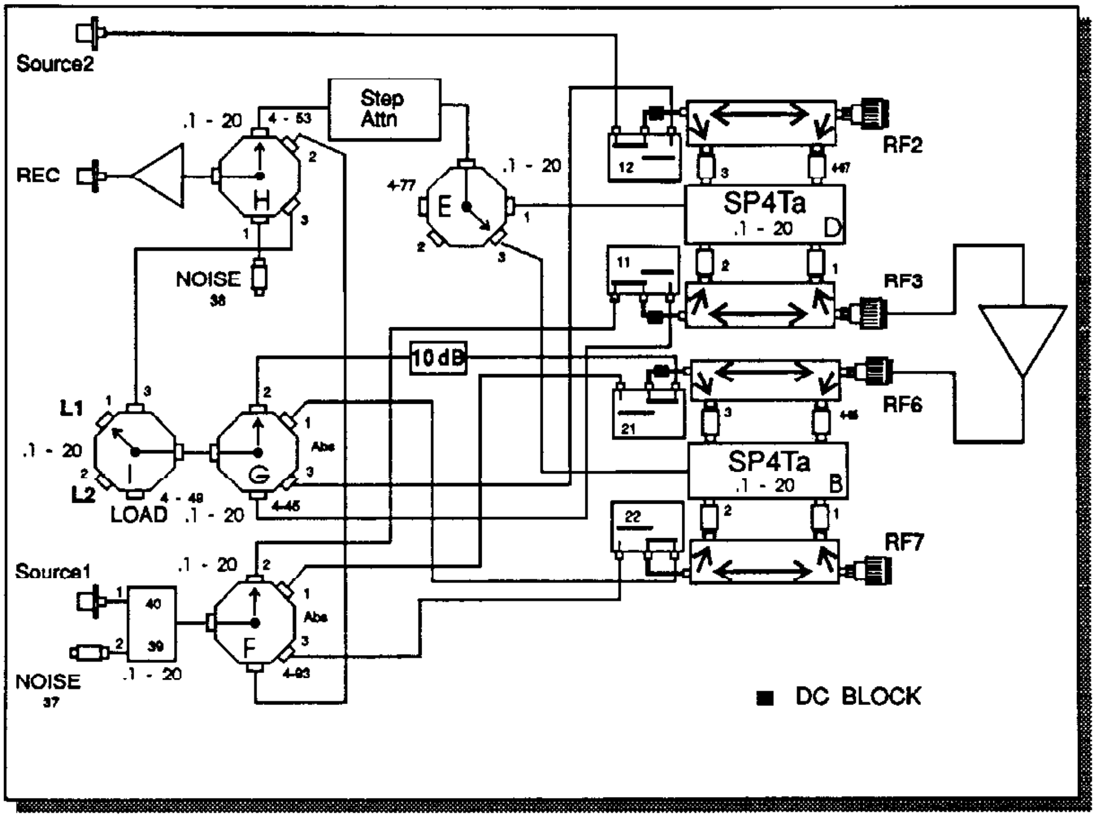
The RI 7100A Microwave Test System provides high speed, high accuracy S parameter measurements, measuring all four S parameters in less than 250 usec with approximately 34 dB of residual directivity and tracking errors less than $\pm$0.1 dB and $\pm$1.0 degree at the RF port connections. This performance may degrade as a function of the connector interfacing required by the DUT.

RF POWER

- RI 7100A RF Power Measurements
- Absolute Power (dbm, watts, etc.)
- S Parameter Detection Hardware
  - Amplitude Only Measurement
  - IF Measurement
  - Wide Dynamic Range
  - Automatically Corrects for Signal Path Losses

The RI 7100A Microwave Test System provides high performance absolute power measurement capability using the S parameter measurement hardware previously discussed and displays the results in the units desired including dBm and watts. By performing the measurements at IF frequencies the system offers very fast measurement rates (less than 100 usec per measurement) over the entire frequency range of the system and over a broad dynamic range (from RF levels less than -70 dBm to RF levels greater than +40 dBm.) Using sophisticated error correction algorithms, the system automatically compensates for changes in the insertion loss through the system.

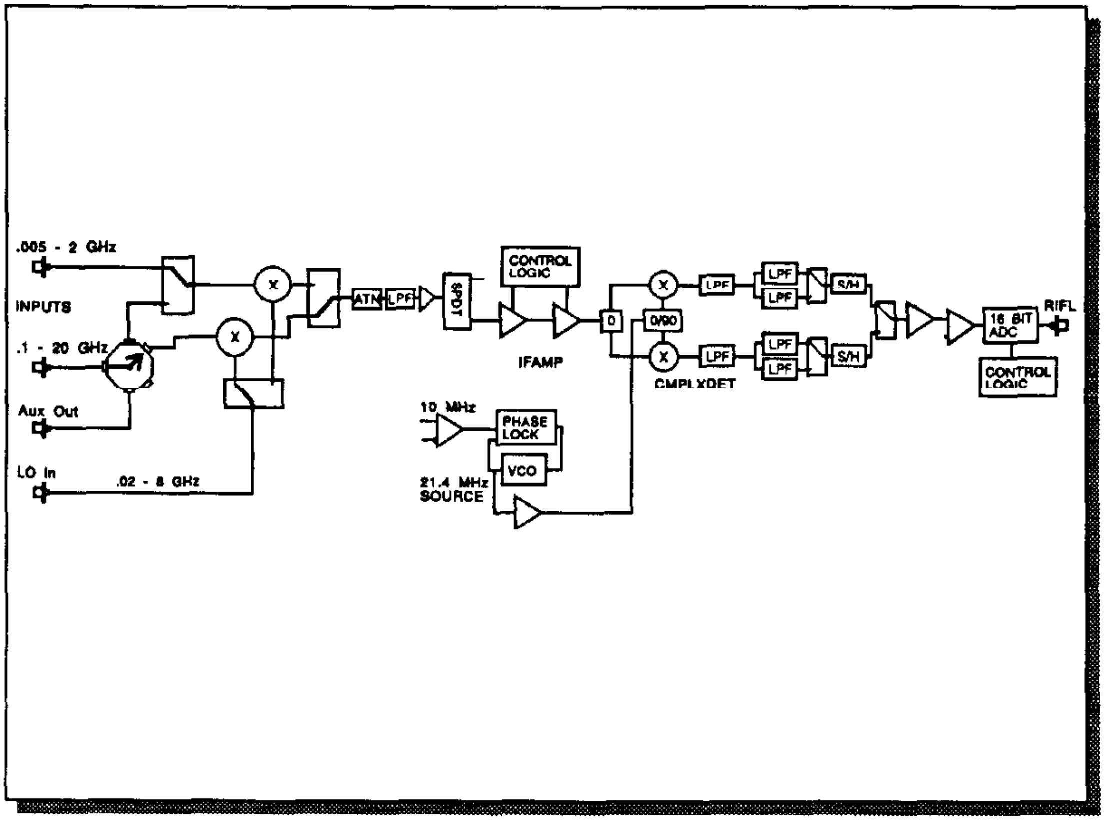
RI RFIC/MMIC Test Head



4 Port Test Configuration for RF Power

The test configuration shown is a typical RF power measurement configuration for the RI 7100A's RFIC/MMIC Test Head. Please notice that the test configuration is the same as for making two port S parameter measurements. To measure the RF output power of the two port device-under-test (DUT) shown, the system needs to measure the level of the transmitted signal into RF port 6 from the DUT. The transmitted signal is routed (as shown above) through the incident arm of the RF port 6 directional coupler, a fixed attenuator, the electronic switch which selects the incident arm, another electronic switch, a step attenuator, a third electronic switch and a RF preamplifier to the single channel System Receiver (connected to port REC) for signal processing. All of the signal paths through the RFIC/MMIC Test Head are individually characterized and calibration factors are maintained for each of these paths.

RI System Receiver



Measurement Configuration for RF Power

The measurement process for RF power measurements by the System Receiver is the same as the measurement process for S parameter measurements except only one signal is measured instead of all four of the coupled signals. The signal received by the System Receiver (at its 0.005 - 2 GHz or 0.1 - 20 GHz INPUT port) is down converted to the 21.4 MHz IF frequency using the external System Local Oscillator connected to the LO In port. The IF signal is conditioned (attenuated, filtered &/or amplified) and sent to the complex/synchronous detector.

The complex detector splits the received signal into two equal amplitude and equal phase signals and mixes one signal with a 21.4 MHz signal in phase with the System Receiver's internal 21.4 MHz SOURCE to create the I (in phase) signal component and mixes the other signal with a 21.4 MHz signal which is 90 degrees out of phase with the 21.4 MHz SOURCE to create the Q (quadrature) signal component.

The resulting signals are low pass filtered and sampled by high speed sample & hold circuits. The high speed A to D converter digitizes the sampled I and Q signal components and sends the digitized data over the RI Fiber Link (RIFL) to the System Computer for processing. The System Software then calculates the amplitude component of the signal measured.

The 21.4 MHz SOURCE signals are generated from (and slaved to) to the system wide 10 MHz frequency reference/time base.

NOISE FIGURE

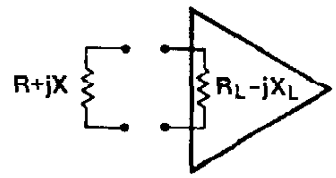
- Definitions
- Y Factor Measurements
- Second Stage Error Correction
- Mismatch Effects
- System Noise Figure Effects
- RI 7100A Noise Figure Measurements

Introduction

The RI 7100A Microwave Test System performs high performance noise figure measurements using the S parameter measurement hardware previously discussed and the built-in electronic noise source in the RFIC/MMIC Test Head. The following slides will define noise figure, describe the Y factor measurement process, describe the importance of second stage noise correction and mismatch errors and discuss how the RI 7100A Microwave Test System performs noise figure measurements.

Available Noise Power

AVAILABLE NOISE POWER (THERMAL)



$P_{av} = kTB$ = Power Delivered to a Conjugate Load, i.e. $R_L = R$, $X_L = X$.

k = Boltzmann's constant (1.38×10^{-23} Joule/K)

T = Temperature (K)

B = Bandwidth (Hz)

Note: At Standard Temperature T_o (=290K):

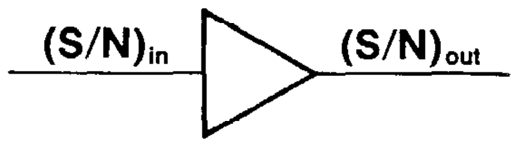
$kT_o = 4 \times 10^{-21}$ W/Hz = -174 dBm/Hz

Definition

Before we define noise figure we need to first define thermal noise power available from a passive device such as a resistor using the theoretical work performed by Nyquist and Johnson. The thermal noise power delivered to a conjugate load at temperature T and in a Bandwidth B is equal to kTB where k is Boltzmann's constant.

Noise Figure

**WHAT IS NOISE FIGURE
(ORIGINAL DEFINITION)**



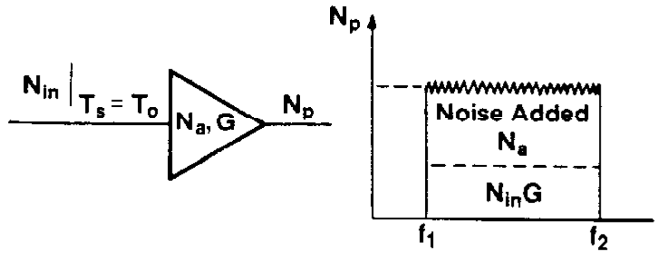
$$F \equiv \left. \frac{(S/N)_{in}}{(S/N)_{out}} \right|_{T_s = 290K}$$

$$F\ (dB) \equiv 10 \log \left. \frac{(S/N)_{in}}{(S/N)_{out}} \right|_{T_s = 290K}$$

<u>Original Definition</u>

The noise figure of a two port device (a device with two RF ports) is a measure of how the thermal noise and the shot noise generated in a device degrades the S/N (signal to noise ratio) from the input to the output of the device. The current definition for noise figure applies to both the linear and log units. (Previously, Noise figure was defined as 10 log (Noise Factor) and Noise Factor was defined as (S/N)in/(S/N)out at 290K.)

AN EQUIVALENT DEFINITION OF NOISE FIGURE (IRE)



Noise Figure: $F \equiv \left. \frac{N_a + N_{in}G}{N_{in}G} \right|_{T_s = T_o = 290K}$

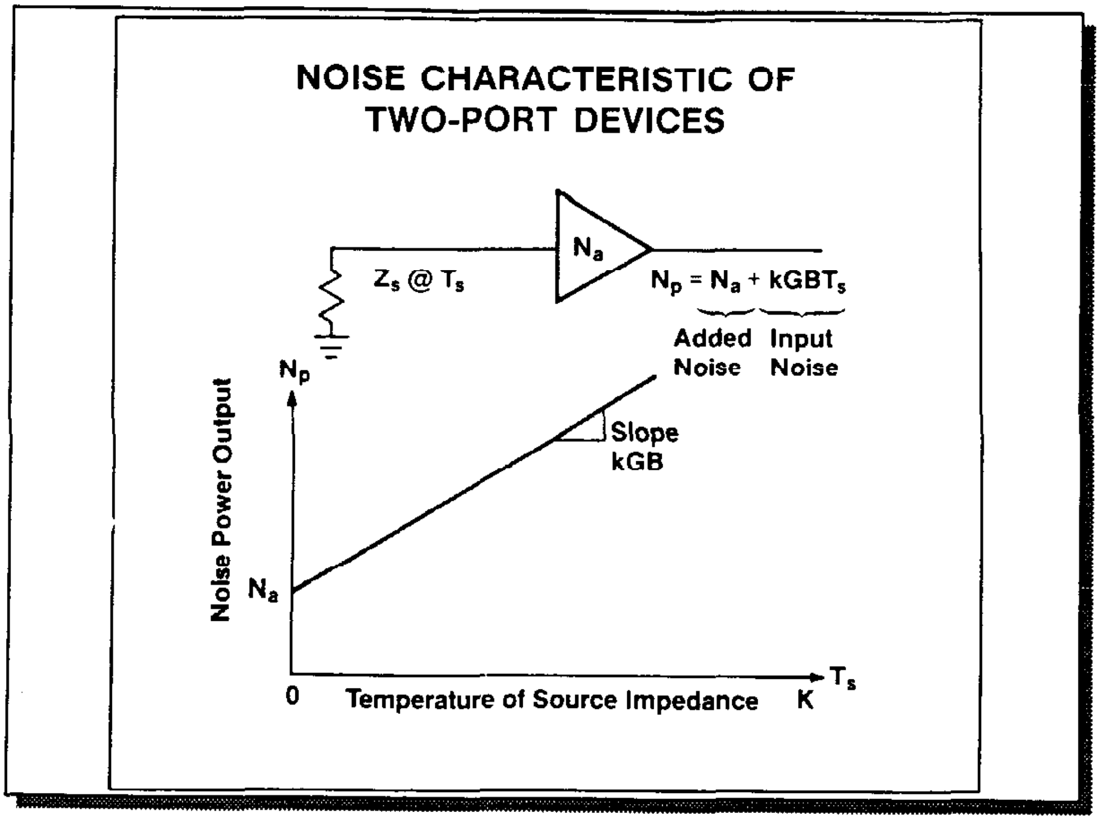
Where

- N_{in} = P_{av} From the Source When at 290K i.e., $N_{in} = kT_oB$
- G = Available Gain
- B = Bandwidth
- T_o = Temperature of Source Resistance (290K)

Note: $N_a = kT_oBG\,(F-1)$

Another Definition

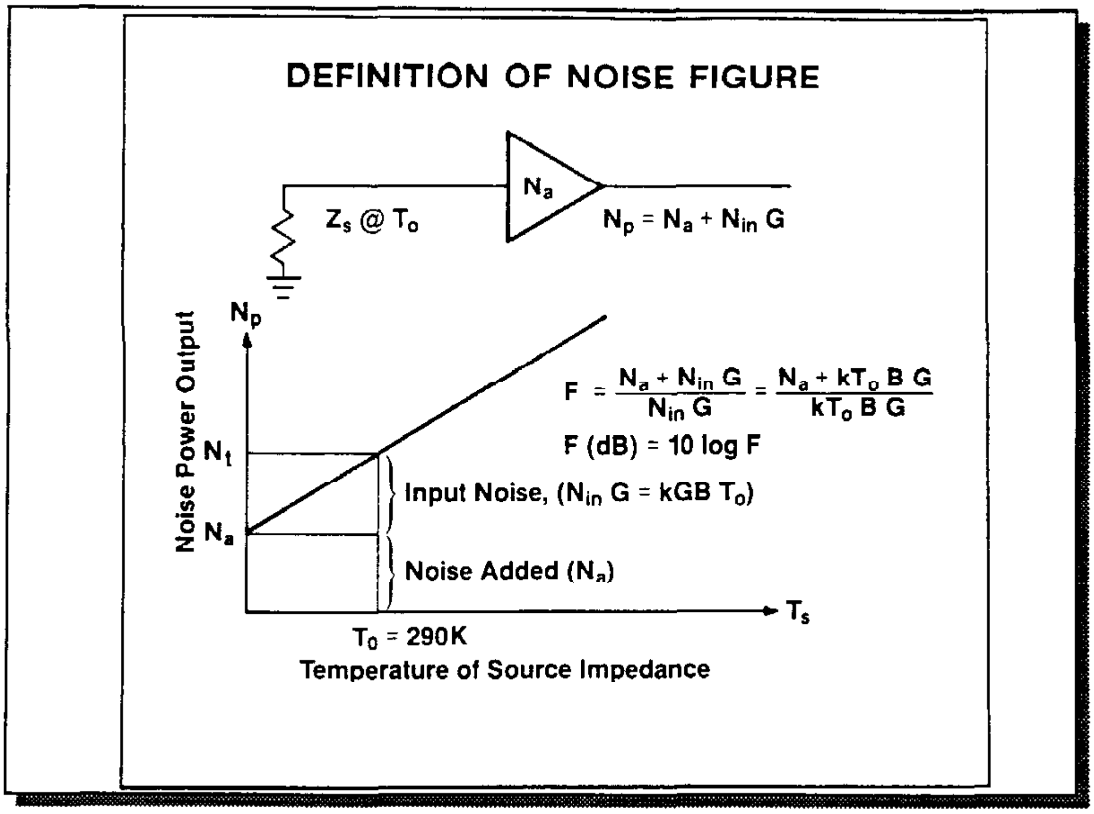
To measure noise figure, we need to understand the additive properties of uncorrelated noise. The noise power at the output of a two-port device is the sum of the noise present at the device's input (Nin) which is amplified by the device's gain (G), plus the noise contributed by the device (Na). Specifically Nout=Nin x G + Na. If we substitute Nout into the equation from the previous slide and solve for F again we obtain the equation shown above.



Two Port Devices

If we terminate the input of a two port device with a load Zs at a temperature Ts, the noise power present using our original equation would be Nin=K x Ts x B. We see that the noise power present in a bandwidth B is a linear function of the temperature of the source impedance Zs. Note that if the temperature of the load (Ts) is equal to 0K then the noise power at the output of the device (Np) would be equal to the noise power contributed by the device (Na).

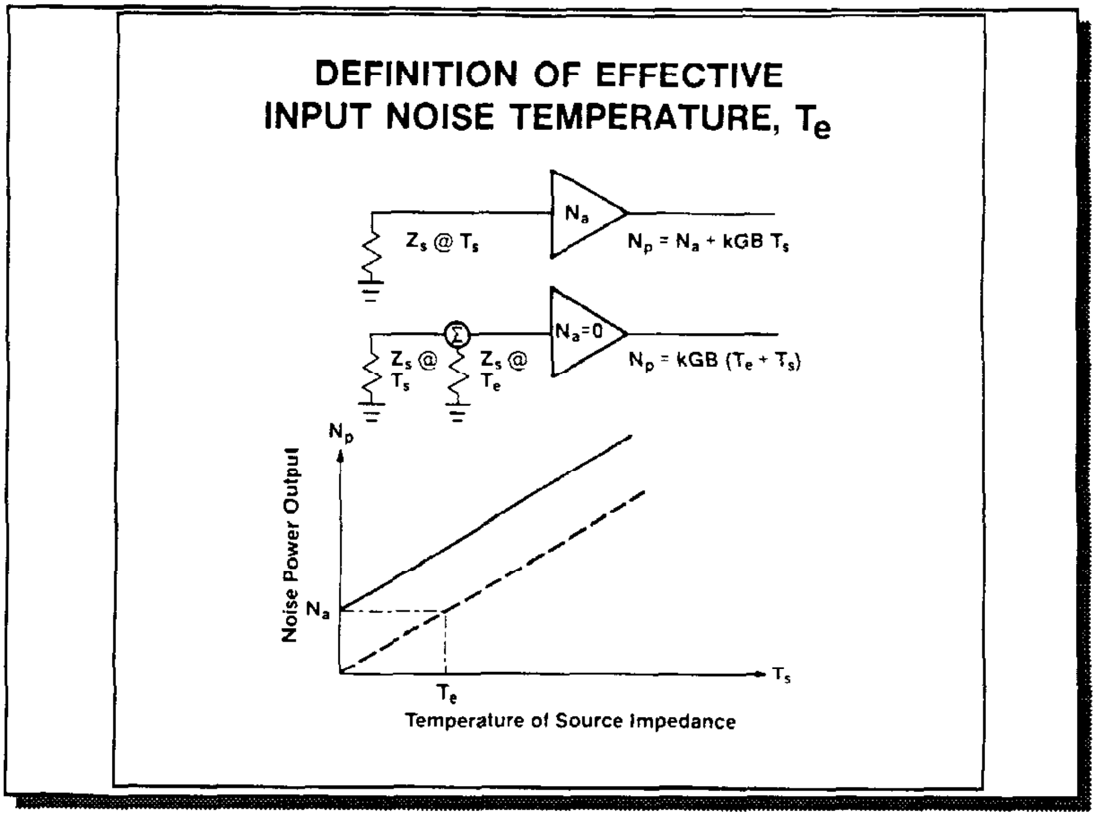
Noise Figure



Current Definition

Noise figure is equal to the total noise power out of the DUT divided by (the input noise to the DUT times the gain of the device), all at 290K.

Effective Input Noise Temperature, Te

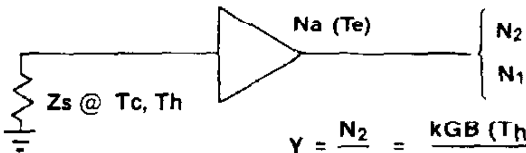


Definition

Sometimes the noise properties of a two port device are described in terms of its effective input noise temperature, Te. This parameter is much more useful for low noise devices because it is a more sensitive indicator of changes in the noise figure performance of the device. Te is the temperature of a fictitious source resistor added to the input of a noise free two port device that produces the same output noise power as the two port DUT being tested (without the additional source resistor). Te does not require the 290K temperature reference.

Noise Figure Measurements

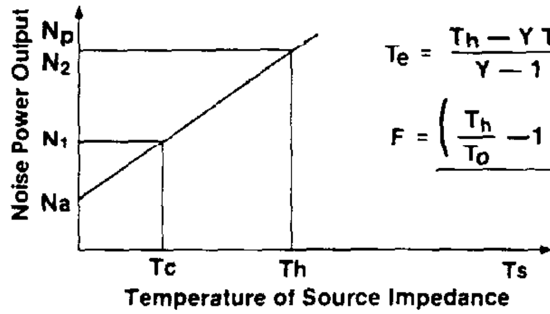
MEASUREMENT OF NOISE



$$Y = \frac{N_2}{N_1} = \frac{kGB\,(T_h + T_e)}{kGB\,(T_c + T_e)}$$

$$T_e = \frac{T_h - Y\,T_c}{Y - 1}\ , \quad F = \frac{T_e + T_o}{T_o}$$

$$F = \frac{\left(\frac{T_h}{T_o} - 1\right) - Y\left(\frac{T_c}{T_o} - 1\right)}{Y - 1}$$

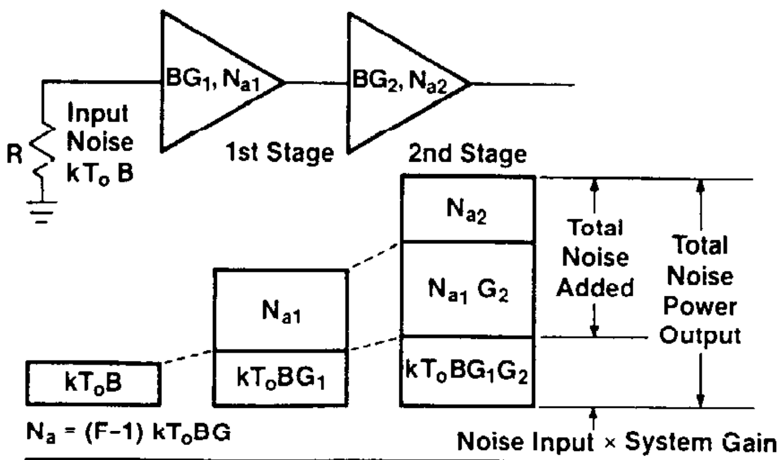


<u>Y Factor Noise Figure Measurements</u>

Y factor noise figure measurements are the most common method for determining a device's noise figure and the standard approach used by the RI 7100A Microwave Test System. This approach requires applying two known levels of thermal noise (k x Th x B & k x Tc x B) to the input of the DUT and measuring the resulting levels of output noise power (N2 & N1) in a known measurement bandwidth, B. The two noise levels are generated by turning on (k x Th x B) and off (k x Tc x B) an electronic noise source. These two noise levels are referred as the hot (noise source on) and cold (noise source off) noise levels, respectively. Th and Tc are referred to as the hot and cold noise temperatures, respectively. The ratio of the two resulting output noise levels N2/N1 is referred to as the Y factor. The noise figure (F) and the effective input noise (Te) can be calculated using the equations shown.

Second Stage Noise Contribution

EFFECT OF SECOND STAGE CONTRIBUTION



$$F_{total} = F_1 + \frac{F_2 - 1}{G_1} + \cdots\cdots\cdots \frac{F_n - 1}{G_1 G_2 \ldots G_n - 1}$$

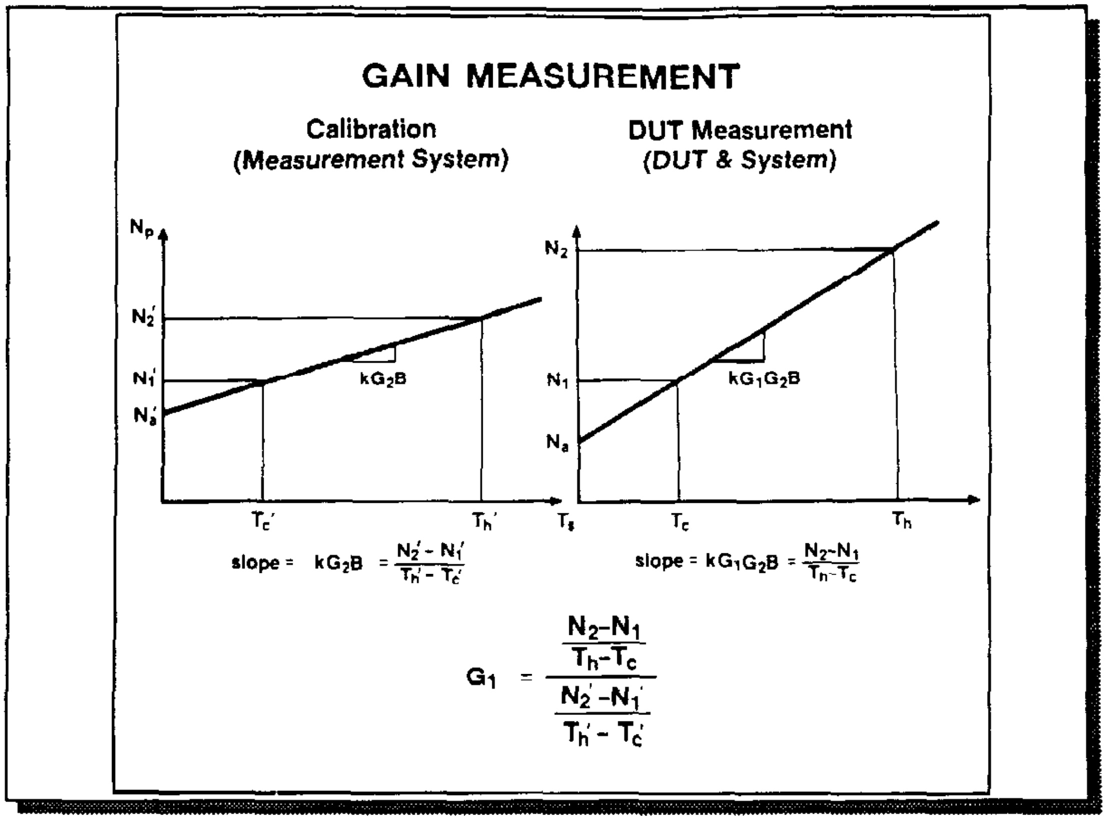
$$F_{12} = F_1 + \frac{F_2 - 1}{G_1}$$

Calculating the Second Stage Noise Contribution

The equation for calculating the total noise figure (FTotal) for a series of cascaded devices is shown above. This equation is called the cascade noise equation. This equation consists of a series of linear terms. Each term represents the noise contribution for each stage of the network. As you can see the contribution to the total noise figure of each succeeding stage/device is reduced by the gain product of the preceding stages or devices. The noise contribution after the second stage can be generally ignored if the first stage has appreciable gain.

When making noise figure measurements the first stage represents the DUT and the second stage represents the noise figure of the test hardware. To correct for the second stage noise contribution of the test system, the noise figure of the test system must be measured and applied to the equations shown.

Second Stage Noise Contribution



Calculating the Second Stage Noise Contribution (Continued)

To separate the first and second stage noise contributions, we need to determine the gain of the first stage. Fortunately, this information is included in the slope of the noise power vs source temperature graphs. Specifically, the difference in the slopes for the two noise power vs source temperature graphs shown is the gain of the DUT. Thus we can determine the gain and noise figure for the DUT by first measuring the noise figure and gain of the test system (through system calibration), next measuring the noise figure and gain of the DUT and the test system together, and then calculating the DUT's gain using the equation shown and calculating the noise figure using the equation on the previous slide.

Excess Noise Ratio

EXCESS NOISE RATIO

FREQUENCY	ENR (dB)
XXX	AAA
YYY	BBB
ZZZ	CCC

Excess Noise Ratio or ENR (dB)

$$\text{ENR (dB)} = 10 \log_{10} \left(\frac{T_h - 290}{290}\right)$$

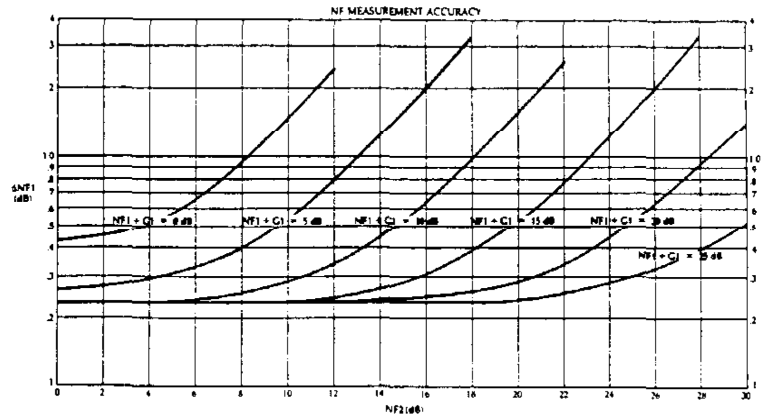
$$\text{or} \quad T_h = \left[10^{\frac{\text{ENR (dB)}}{10}} + 1\right] \cdot 290$$

Definition

Electronic noise sources used for Y factor noise figure measurements are furnished with a calibration report which characterizes the output noise power of the noise source in terms of excess noise ratio vs frequency. The mathematical relationship between excess noise ratio and the hot noise temperature, Th, of the electronic noise source is shown above. Tc, the cold noise temperature of the electronic load and the temperature of the noise source's output pad is assumed to be 290 Kelvin.

Noise Figure

NOISE FIGURE
MEASUREMENT UNCERTAINTY vs
MEASUREMENT SYSTEM NOISE FIGURE

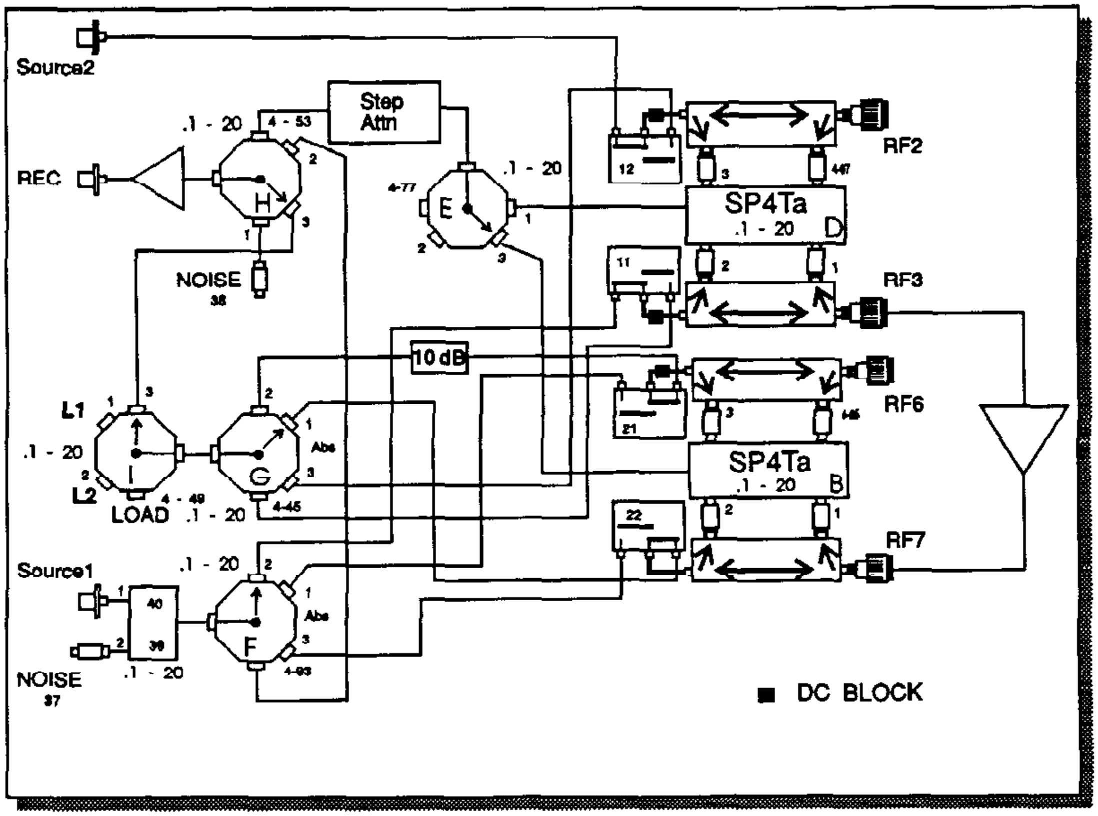


Measurement Uncertainty vs System Noise Figure

As you can see from the plot, the accuracy of the test system is a function of the DUT's noise figure & gain, and the noise figure of the measurement system. The lower the measurement system's noise figure, the lower the measurement uncertainties. The noise figure of the RI 7100A Microwave Test System is approximately 8 dB. Please note, the curves are offset from 0 dB by the uncertainty of the NIST traceable standards currently available.

The RI 7100A Microwave Test System provides high speed, high accuracy noise figure measurements, performing Y factor noise figure measurements in less than 75 msec with better than 0.125 dBrms repeatability. Better repeatability can be obtained by just selecting more averaging.

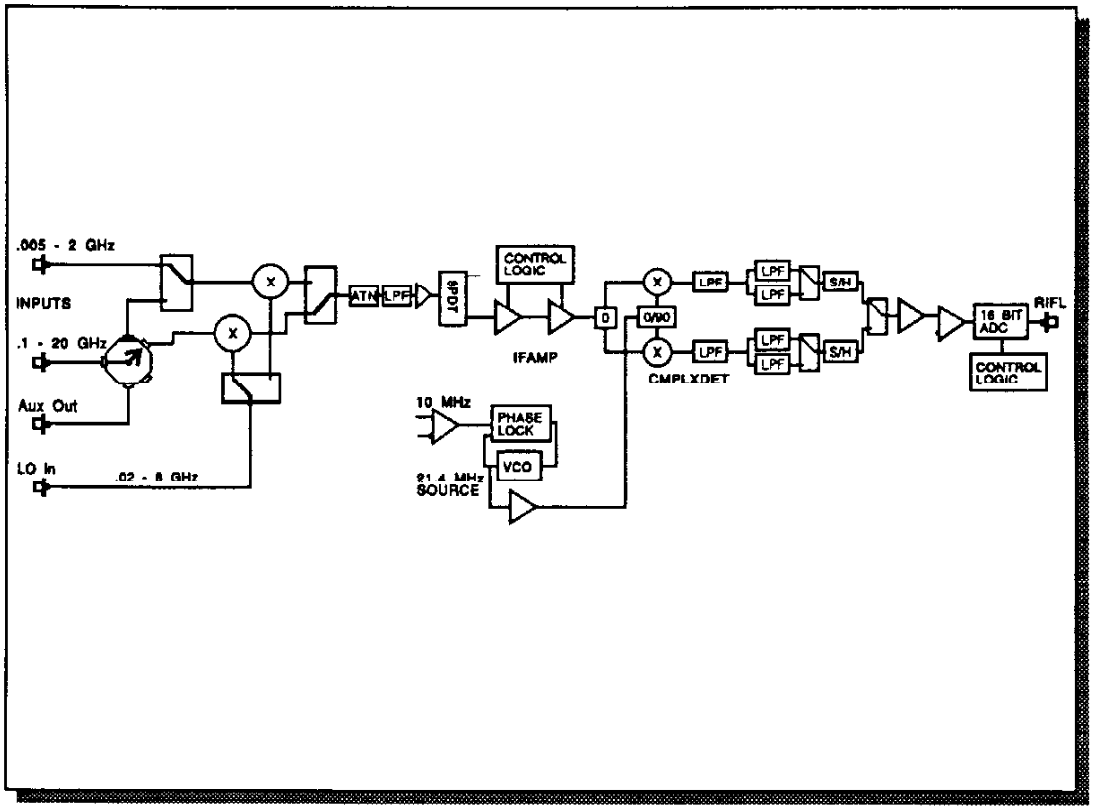
RI RFIC/MMIC Test Head



4 Port Test Configuration for Noise Figure

The test configuration shown is a typical noise figure measurement configuration for the RI 7100A's RFIC/MMIC Test Head. The noise source is switched into the port 3 source path in place of Source1. The noise source is turned on and off and the noise energy is routed through the Test Head to the device-under-test's (DUT's) RF input connected to RF port 3. To measure the noise figure of the DUT shown, the system needs to measure the noise power of the transmitted signal into RF port 7 from the DUT. The transmitted signal is routed (as shown above) through the "thru path" of the RF port 7 directional coupler, through a mechanical switch, three electronic switches and a RF preamplifier to the single channel System Receiver (connected to port REC) for signal processing.

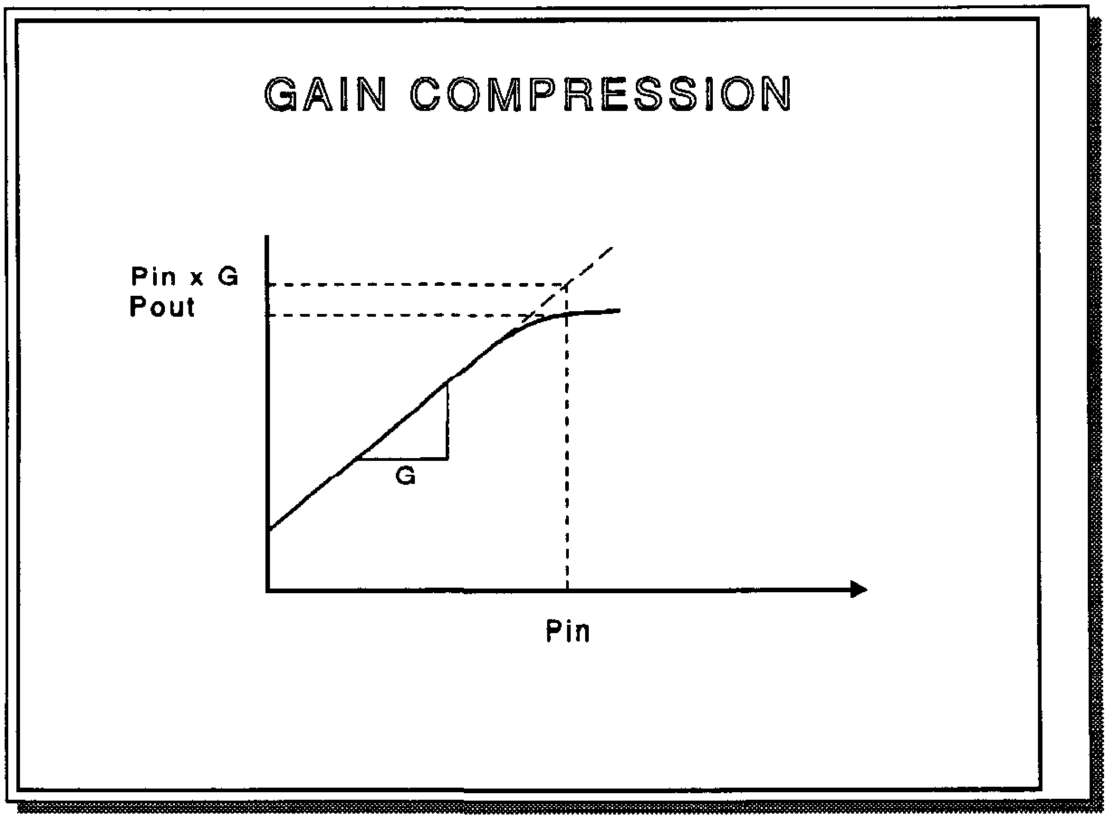
RI System Receiver



Measurement Configuration for Noise Figure

The noise signal received by the System Receiver is down converted to the 21.4 MHz IF frequency using the external System Local Oscillator connected to the LO In port. The IF signal is amplified and sent to the complex/synchronous detector. The complex detector splits the received signal into two equal amplitude and equal phase signals and mixes one signal with a 21.4 MHz signal in phase with the System Receiver's internal 21.4 MHz SOURCE to create the I (in phase) signal component and mixes the other signal with a 21.4 MHz signal which is 90 degrees out of phase with the 21.4 MHz SOURCE to create the Q (quadrature) signal component. The resulting signals are filtered, conditioned and sampled by high speed sample & hold circuits. The high speed A to D converter digitizes the sampled signals and sends the digitized data over the RI Fiber Link (RIFL) to the System Computer for processing.

Gain Compression



Pin vs Pout

The input to output level characteristics of a typical active device (such as a two port RF amplifier) is shown above. As the RF input level is increased, the output level should increase at a linear rate, following the change in the input signal level. At some point, as the input signal level continues to increase, the output level will begin to increase at a lower rate (start to compress the signal) until the output level reaches a fairly constant level (maximum output power.) The **N** dB gain compression point is the RF input level (Pin) for which the output level deviates from linearity by **N** dB.

Gain Compression

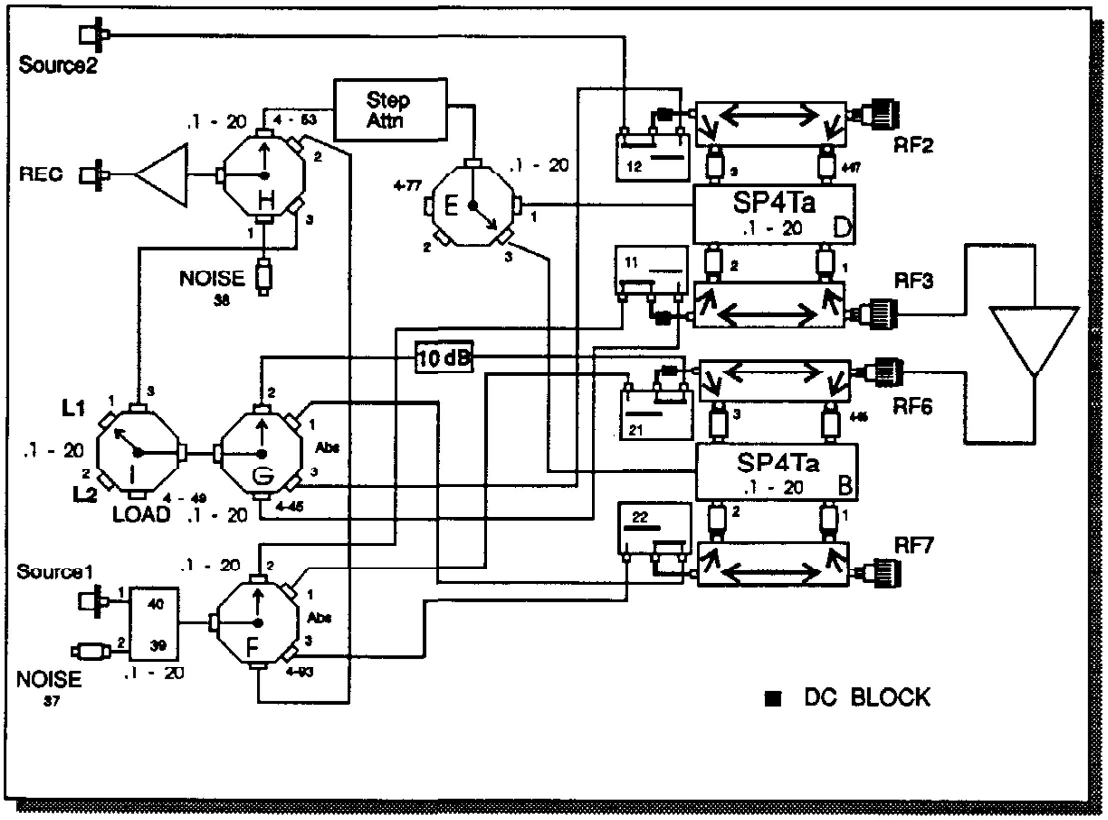
GAIN COMPRESSION

- RI 7100A Measurement Approach
  - S Parameter Detection Hardware
  - Relative RF Level Measurements
- Stimulus
  - Single RF Tone
  - *User Specifies Compression Level: N dB*
  - User Specifies RF Levels Applied to DUT
- Measure: Pout vs Pin
- Calculate: 10 Log(Pout/Pin)-G = N dB point
  Where: G = Small Signal Gain

Measurement Process

The RI 7100A Microwave Test System performs compression measurements very quickly (less than 20 msec) by varying the level of the input signal into the DUT and measuring both the DUT's RF input and output levels using the S parameter detection hardware. The user selects the RF frequency of the Stimulus Source, the compression level desired (in dB) and the start, stop & number of RF power levels to be applied to the DUT to find the compression point. The system does not iterate to find the compression point, instead it performs a fast sweep over the power range selected and calculates the actual compression point (in dBm) from the large number of measurements taken.

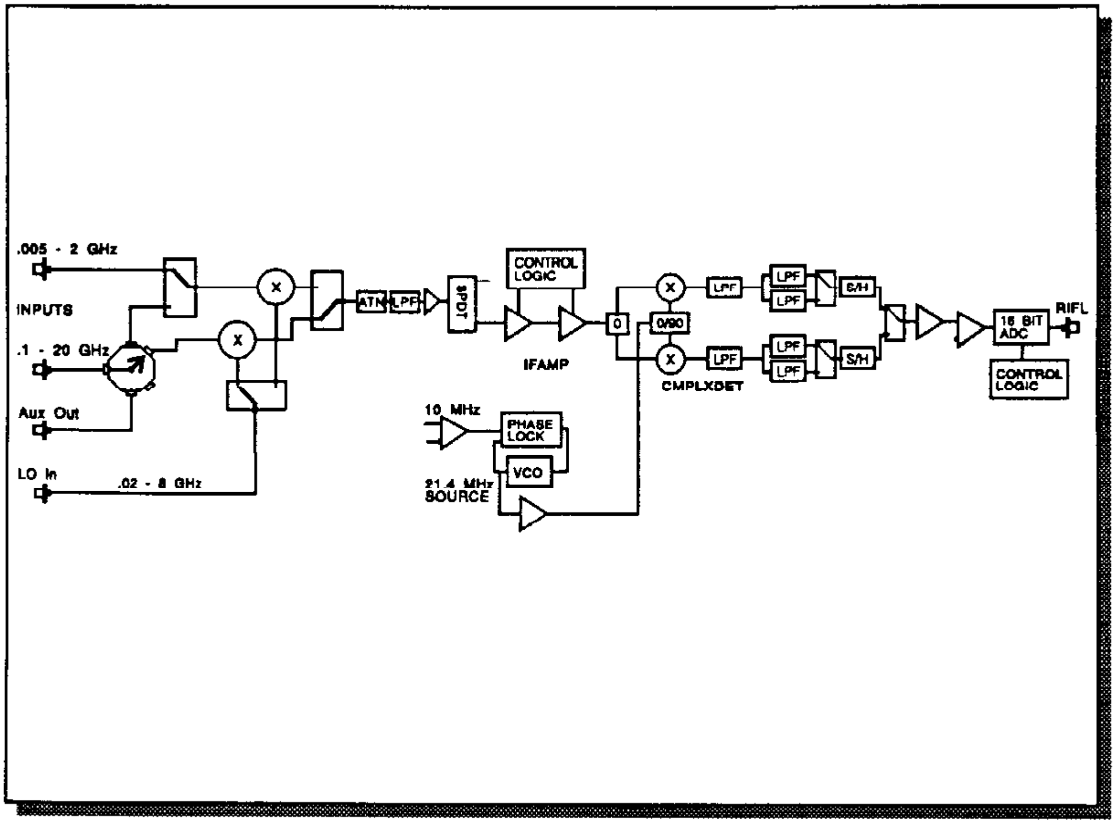
RI RFIC/MMIC Test Head



4 Port Test Configuration for Gain Compression

The test configuration shown is a typical gain compression measurement configuration for the RI 7100A's RFIC/MMIC Test Head. Please notice that the test configuration is the same as for making two port S parameter measurements. The RF stimulus source (Source1) is connected to the Source1 input port. The RF stimulus signal from the source is routed through the Test Head to the DUT's RF input connected to RF port 3. The resulting transmitted signal at port 6 is routed through the coupler connected to port 6, through a second switch, a RF step attenuator, a third electronic switch and a RF preamplifier to the REC port which sends the signals to the single channel System Receiver for signal processing. All of the signal paths through the RFIC/MMIC Test Head are individually characterized and calibration factors are maintained for each of these paths. Only the transmitted signal from the DUT must be measured. The incident signal at RF port 1 is known precisely using the calibration factors for Source1 and the calibration factors for the signal path from Source1 to the DUT input at RF port 3. The RI 7100A Microwave Test System also offers an alternative approach for measuring the DUT's gain compression point which measures both signals (the input signal to the device and the transmitted signal from the device).

RI System Receiver



Measurement Configuration for Gain Compression

The measurement process for gain compression measurements by the System Receiver is the same as the measurement process for S parameter measurements except only one signal is measured. The received signal is down converted to the 21.4 MHz IF frequency using the external System Local Oscillator connected to the LO In port. The IF signal is amplified/filtered and sent to the complex/synchronous detector. The complex detector splits the received signal into two equal amplitude and equal phase signals and mixes one signal with a 21.4 MHz signal in phase with the System Receiver's internal 21.4 MHz SOURCE to create the I (in phase) signal component and mixes the other signal with a 21.4 MHz signal which is 90 degrees out of phase with the 21.4 MHz SOURCE to create the Q (quadrature) signal component. The resulting signals are low pass filtered and sampled by high speed sample & hold circuits. The high speed A to D converter digitizes the sampled I and Q signal components and sends the digitized data over the RI Fiber Link (RIFL) to the System Computer for processing. The System Software then calculates the gain (S21).

Conversion Gain/Loss Measurements

CONVERSION GAIN/LOSS

- RI 7100A Measurement Approach
  - Multi-Port S Parameter Detection Hardware
  - Requires 3rd RF Source for DUT LO
- Stimulus
  - RF Stimulus Source: RF Input
  - DUT LO Source: LO Input
  - Maintain Constant IF Freq
  - Sweep RF & DUT LO Frequency
  - Requires 3 RF Sources to be at Different Frequencies

Measurement Process

The RI 7100A Microwave Test System performs conversion gain/loss measurements as a series of scalar (absolute amplitude) S parameter measurements between multiple RF ports. In addition to the System Local Oscillator and the DUT Stimulus Source (Source1), these measurements require a third RF source for the DUT's local oscillator (Source2, 3 or 4). The RI Microwave Test System can test devices with many RF ports. (Devices with as many as 12 RF ports have been tested. Devices with many more RF ports can be tested using external switching in the test fixture.) The user selects the RF stimulus frequencies and the DUT's IF frequency. The test system step sweeps Source1 and the DUT LO frequencies and holds the DUT IF frequency constant during the measurements. All three RF sources must be set independently to different frequencies in order to make the measurements. The order in which the measurements are performed is controlled by the test plan optimizer.

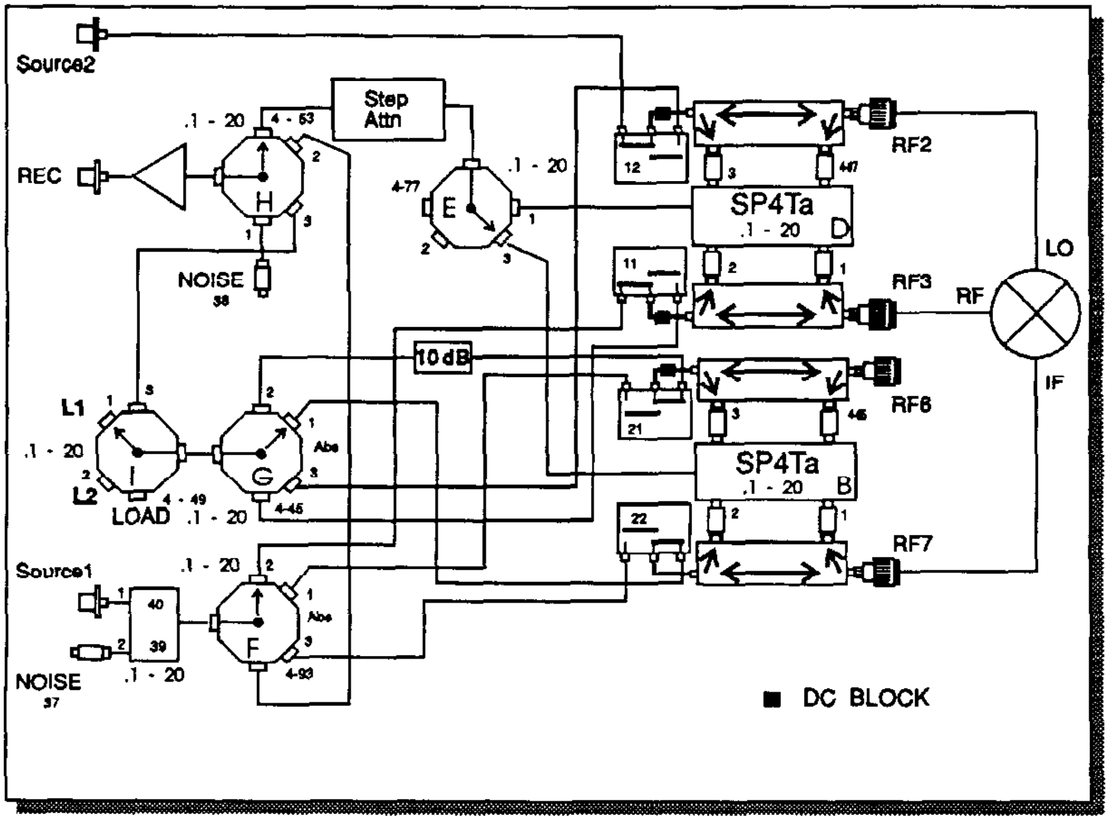
Conversion Gain/Loss Measurements

CONVERSION GAIN/LOSS

- Measure: Pin(RF) and Pout(IF)
- Calculate: Conversion Gain/Loss=Pout(IF)/Pin(RF)
- Test Plan Optimizer Determines the Measurement Sequence

<u>Measurement Process (Continued)</u>

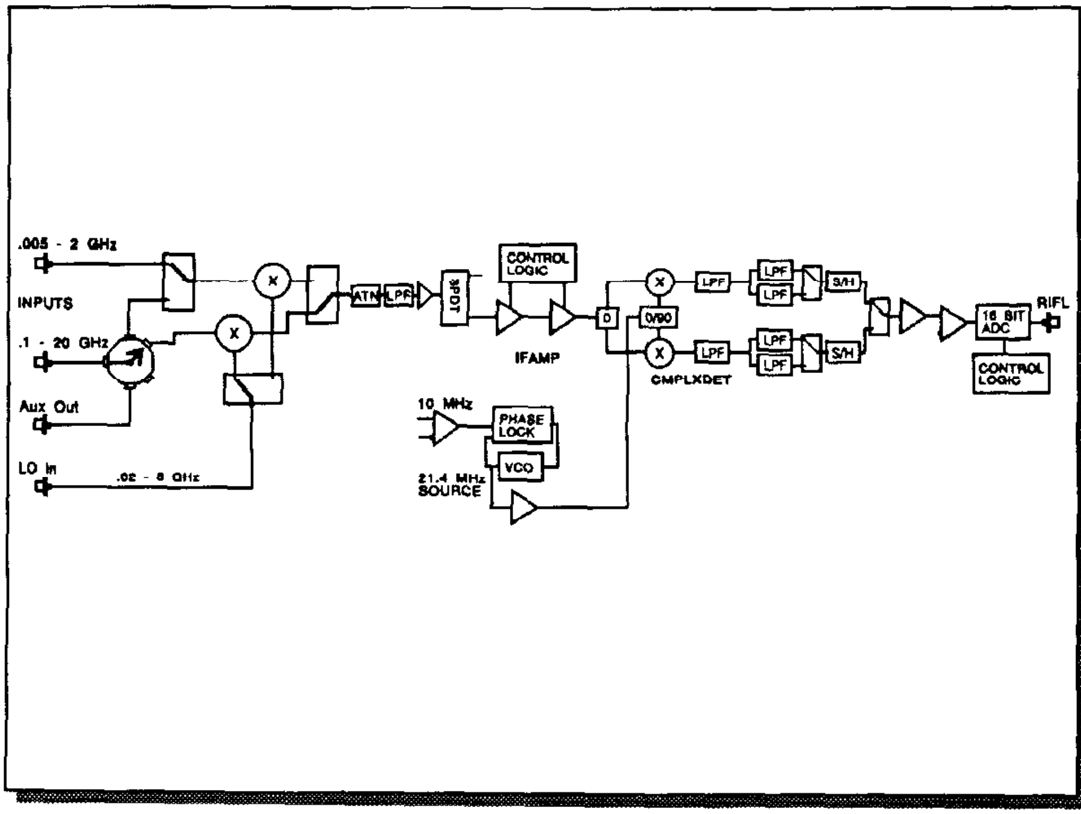
RI RFIC/MMIC Test Head



4 RF Port Test Configuration for Conversion Gain/Loss

The test configuration shown is a typical mixer conversion gain/loss measurement configuration for the RI 7100A's RFIC/MMIC Test Head. The RF stimulus source (Source1) is connected to the Source1 input port and the RF stimulus signal is routed through the Test Head to the DUT's RF input connected to RF port 3. Source2 is connected to the Source2 input port and the RF signal from Source2 is routed through the Test Head to the DUT's LO input connected to RF port 2. The mixer's IF output port is connected to RF port 7. The incident signal at port 3 and the transmitted signal at port 7 are separated and individually routed through the couplers connected to port 3 and 7, through the electronic switches (connected to the fixed attenuators on the coupled arms), another electronic switch, a RF step attenuator, a third electronic switch and a RF preamplifier to the single channel System Receiver at port REC for signal processing. All of the signal paths through the RFIC/MMIC Test Head are individually characterized and calibration factors are maintained for each of these paths.

RI System Receiver



Measurement Configuration for Conversion Gain/Loss

The measurement process for conversion gain/loss measurements by the System Receiver is the same as the measurement process for S parameter measurements. Each received signal is down converted to the 21.4 MHz IF frequency using the external System Local Oscillator connected to the LO In port. The IF signal is amplified/filtered and sent to the complex/synchronous detector. The complex detector splits the received signal into two equal amplitude and equal phase signals and mixes one signal with a 21.4 MHz signal in phase with the System Receiver's internal 21.4 MHz SOURCE to create the I (in phase) signal component and mixes the other signal with a 21.4 MHz signal which is 90 degrees out of phase with the 21.4 MHz SOURCE to create the Q (quadrature) signal component. The resulting signals are low pass filtered and sampled by the high speed sample & hold circuits. The high speed A to D converter digitizes the sampled I and Q signal components and sends the digitized data over the RI Fiber Link (RIFL) to the System Computer for processing. The System Software then calculates the conversion gain/loss (S21 magnitude only).

Spectral Purity [Harmonics] Measurements

SPECTRAL PURITY: HARMONICS

- RI 7100A Measurement Approach

  S Parameter Detection Hardware

  Relative RF Level Measurements

- Stimulus

  Single RF Tone at F1

  User Specifies Harmonic Number, N

- Measure: Pout(F1) and Pout(F1xN)

- Calculate: Pout(F1) - Pout(F1xN))
  Where Pout(F) = DUT Output Signal Level in dBm at Frequency F

Measurement Process

The RI 7100A Microwave Test System provides high performance spectral purity measurement capability using the S parameter measurement hardware previously discussed. The RI 7100A Microwave Test System performs spectral purity measurements very quickly (less than 20 msec) with the S parameter detection hardware. The user selects the RF frequency of the RF Stimulus Source (Source1) and the harmonic number to be measured. (The harmonic number is entered as a **System Scale Factor.** We will be discussing System Scale Factors later in the presentation.) The system measures the signal level of both the transmitted fundamental tone and harmonic signal (at the output of the DUT) by quickly tuning the System LO for one signal, making an absolute power measurement, then tuning to the other signal and making another absolute power measurement. (The order in which these measurements is performed is controlled by the test plan optimizer.) The difference in the signal levels is the harmonic performance and the units displayed are dBc.

Spectral Purity [Spurious] Measurements

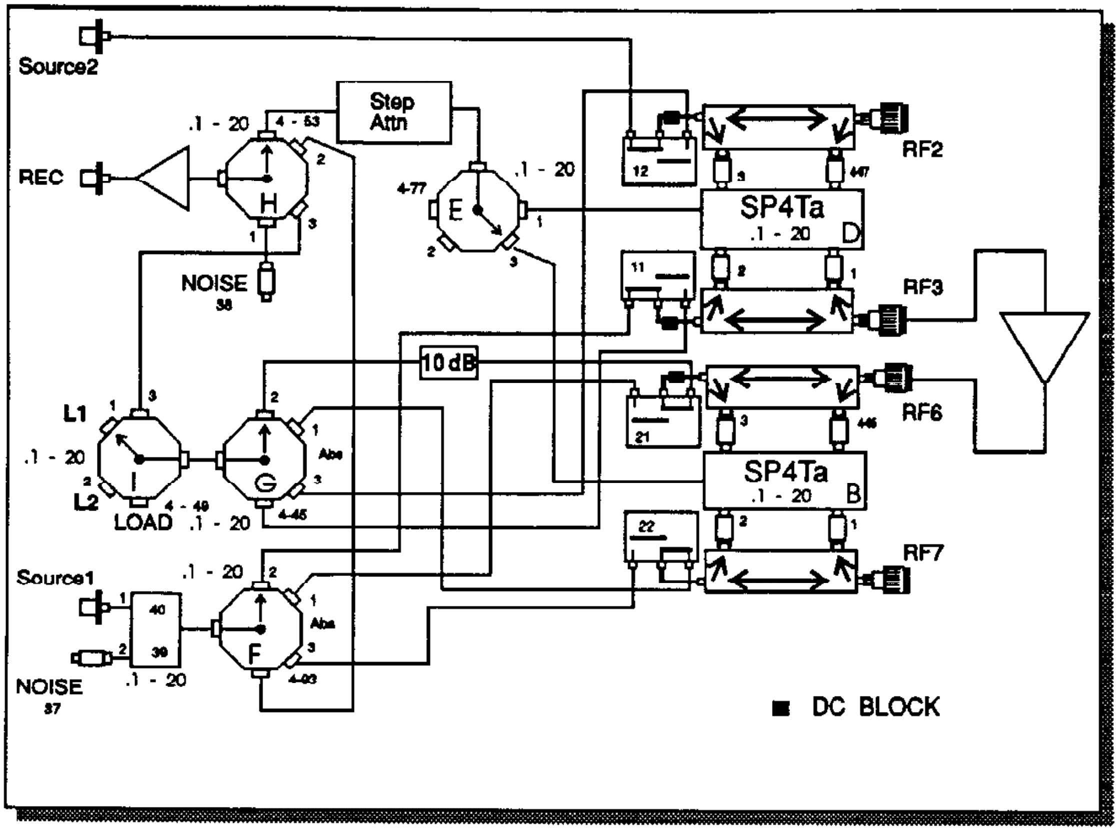
SPECTRAL PURITY: SPURIOUS

- RI 7100A Measurement Approach
  - S Parameter Detection Hardware
  - Relative RF Level Measurements
- Stimulus
  - Single RF Tone at F1
  - User Specifies Spur Frequency, F2
- Measure: Pout(F1) and Pout(F2)
- Calculate: Pout(F1) - Pout(F2))
  Where Pout(F) = DUT Output Signal Level in dBm at Frequency F

Measurement Process

The process for measuring known spurious signals is the same as for harmonics except the user selects the spur frequency to be measured, and the spurious signal's level is measured instead of the harmonic signal's level. (The spur frequency will be entered as a Frequency **Offset** from the source input signal. We will be discussing Frequency Offsets later in the presentation.)

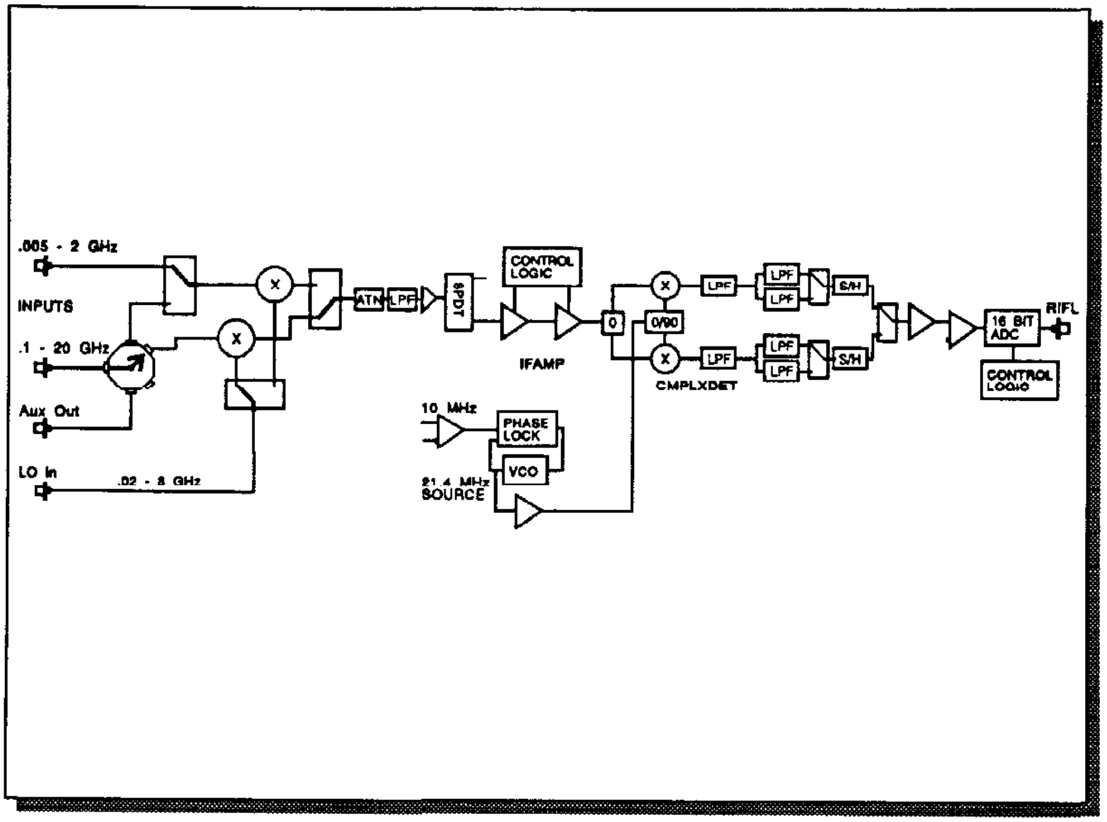
RI RFIC/MMIC Test Head



Test Configuration for Spectral Purity Measurements

The test configuration shown is a typical spectral purity measurement configuration for the RI 7100A's RFIC/MMIC Test Head. Please notice that the test configuration is the same as for making two port S parameter measurements. To measure the spectral purity of the DUT shown, the system needs to measure the levels of the DUT's transmitted signals into RF port 6 at both the fundamental frequency and the harmonic frequency (or spur frequency). Both the transmitted fundamental and harmonic/spur signals are routed (as shown above) through the incident arm of the RF port 6 directional coupler, a fixed attenuator, the electronic switch which selects the incident arm, another switch, a step attenuator, a third electronic switch and a RF preamplifier to the single channel System Receiver (connected to port REC) for signal processing.

RI System Receiver



Measurement Configuration for Spectral Purity

The measurement process for spectral purity measurements by the System Receiver is the same as the measurement process for RF power measurements except the system LO frequency will be tuned for one signal, the signal will be conditioned, sampled, digitized and the digitized data will be sent to the System Computer, and then the system LO will be tuned for the other signal and the same process will be repeated. The System Software then calculates the difference of the signal levels in dBc.

Intermodulation Distortion Measurements

INTERMODULATION DISTORTION

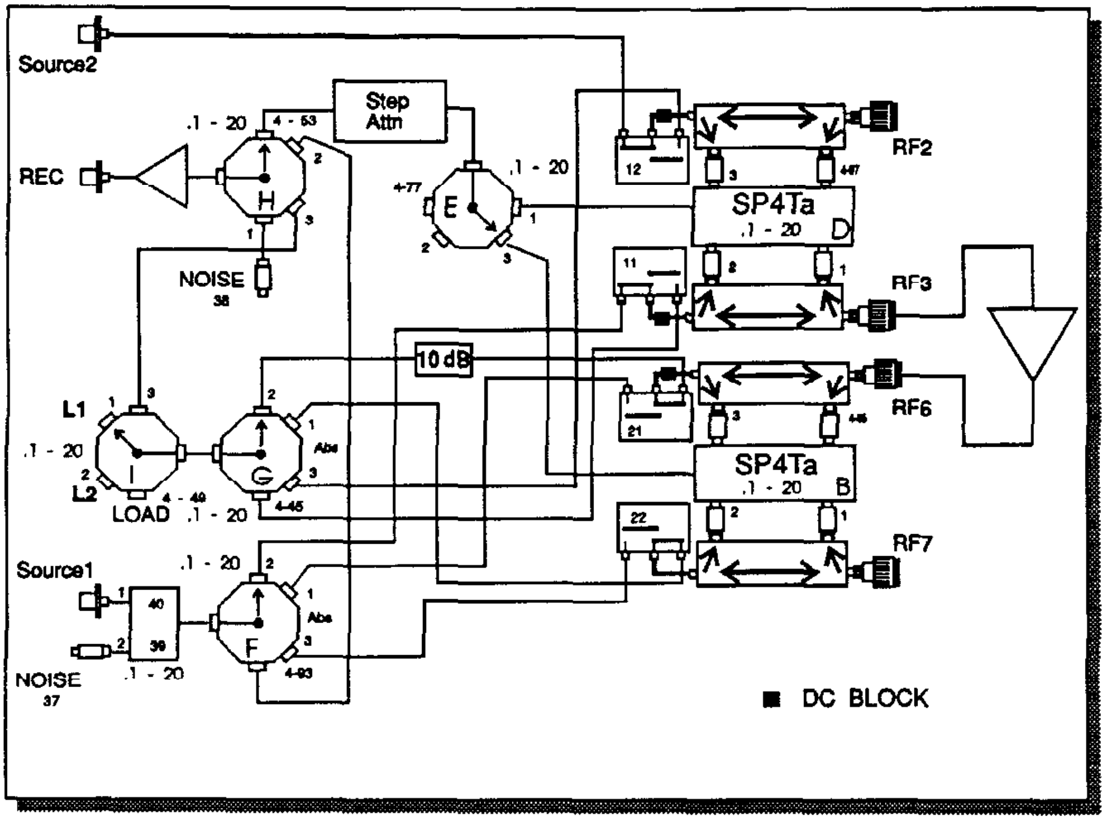
- RI 7100A Measurement Approach
  - S Parameter Detection Hardware
  - RF Level Measurements
- Stimulus
  - Two Equal Amplitude RF Tones
  - Specify RF Level, Center Freq (F1) and Spacing
  - 2nd RF Tone: F2 = F1-Spacing
- Measure: 3rd Order Distortion Product Term
  - Pout(2xF1-F2)

Measurement Process

The measurement process for performing intermodulation distortion measurements is very similar to spectral purity measurements. The RI 7100A Microwave Test System applies two RF stimulus signals to the DUT and uses the S parameter measurement hardware previously discussed to make the measurements. The user specifies the RF level applied by both signals, the RF frequency (F1) of the RF Stimulus Source (Source1) and the spacing between RF tones. The system will set the RF frequency of the second RF Stimulus Source to:
F2 = F1 - spacing selected.

The RI 7100A Microwave Test System will measure the third order distortion product of the DUT's output signal at the frequency shown above. (The order in which these measurements is performed is controlled by the test plan optimizer.)

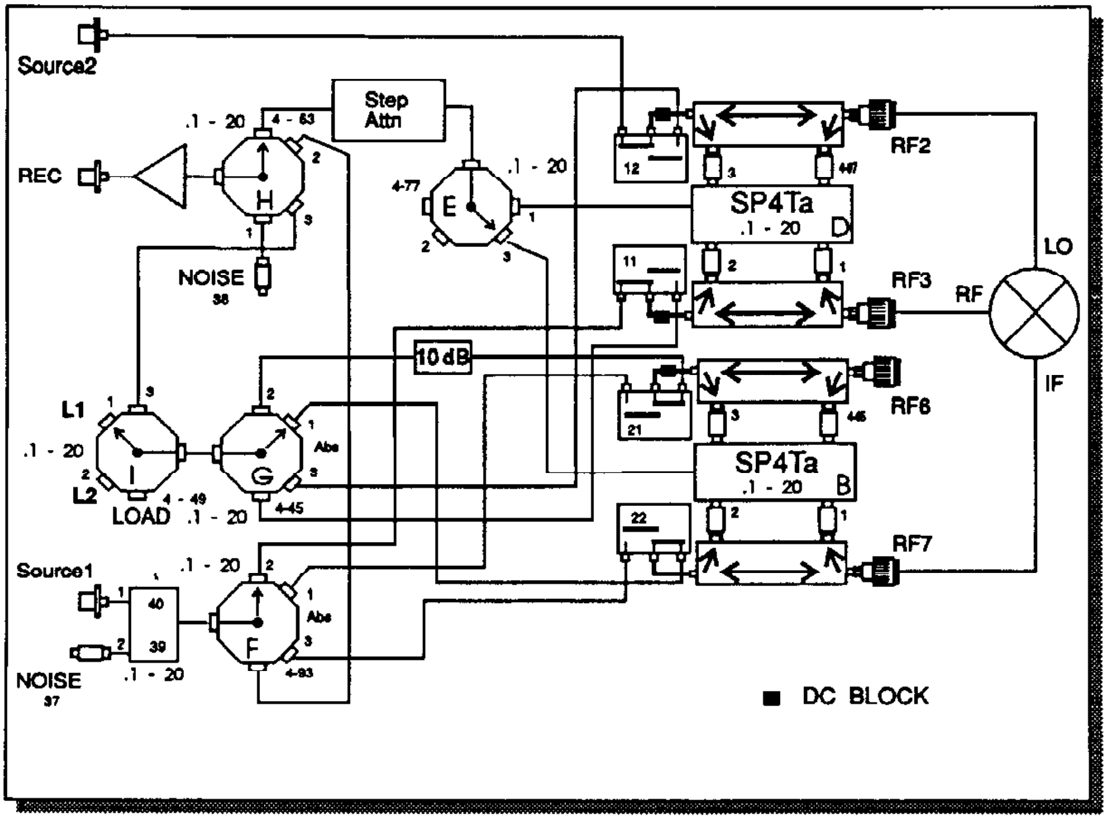
RI RFIC/MMIC Test Head



Test Configuration for Intermodulation Distortion

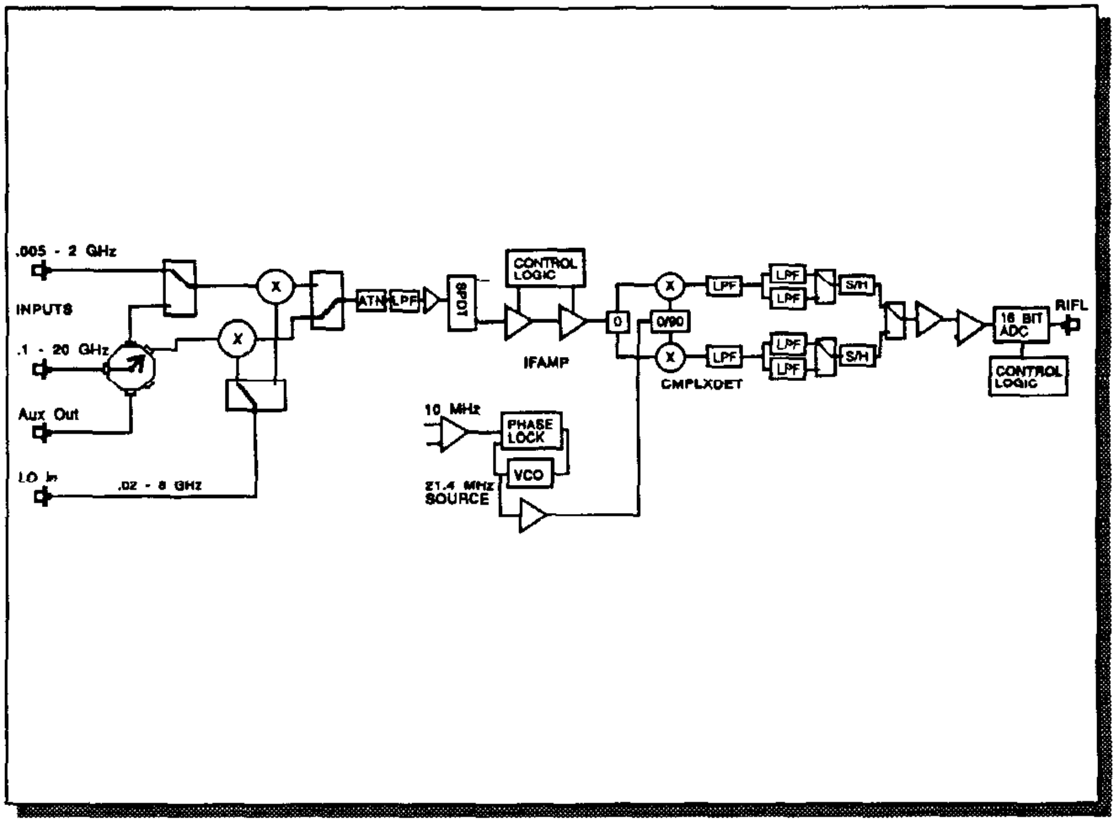
The test configuration shown is a typical intermodulation distortion measurement configuration for the RI 7100A's RFIC/MMIC Test Head. The stimulus signals from both RF stimulus sources are combined and applied to the RFIC/MMIC Test Head at the Source1 input port and the signals are routed through the Test Head to the DUT's RF input connected to RF port 3. To measure the intermodulation distortion performance of the DUT shown, the system needs to measure the levels of two DUT transmitted signals, the signal at the fundamental frequency (F1) and the intermodulation distortion product at frequency 2xF1-F2. These signals are routed through the incident arm of the RF port 6 directional coupler, a fixed attenuator, the electronic switch which selects the incident arm, another switch, a step attenuator, a third switch and a RF preamplifier to the single channel System Receiver (connected to port REC) for signal processing.

Intermodulation Distortion Measurements



4 Port Test Configuration for Intermodulation Distortion of Mixers

RI System Receiver



Measurement Configuration for Intermodulation Distortion

The measurement process for intermodulation distortion measurements by the System Receiver is the same as the measurement process for RF power measurements except the system LO frequency will be tuned for one of the two signals, the signal will be conditioned, sampled, digitized and the digitized data will be sent to the System Computer, and then this process will be repeated for the other signal. The System Software then calculates the relative level of the intermodulation product with respect to the level of the fundamental signal in dBc.

THIRD ORDER OUTPUT INTERCEPT

- RI 7100A Measurement Approach
  - S Parameter Detection Hardware
  - RF Level Measurements
- Stimulus
  - Two Equal Amplitude RF Tones
  - Specify RF Level, Center Freq (F1) and Spacing
  - 2nd RF Tone: F2 = F1-Spacing

Measurement Process

The measurement configuration and the measurement process for performing third order output intercept is exactly the same as for intermodulation distortion except the system performs the IP3 calculation shown.

THIRD ORDER OUTPUT INTERCEPT

- Measure: 3rd Order Intermodulation Product Term

  Pout(2xF1-F2)

- Calculate: IP3 out in dBm = Pout(F1)+A/2

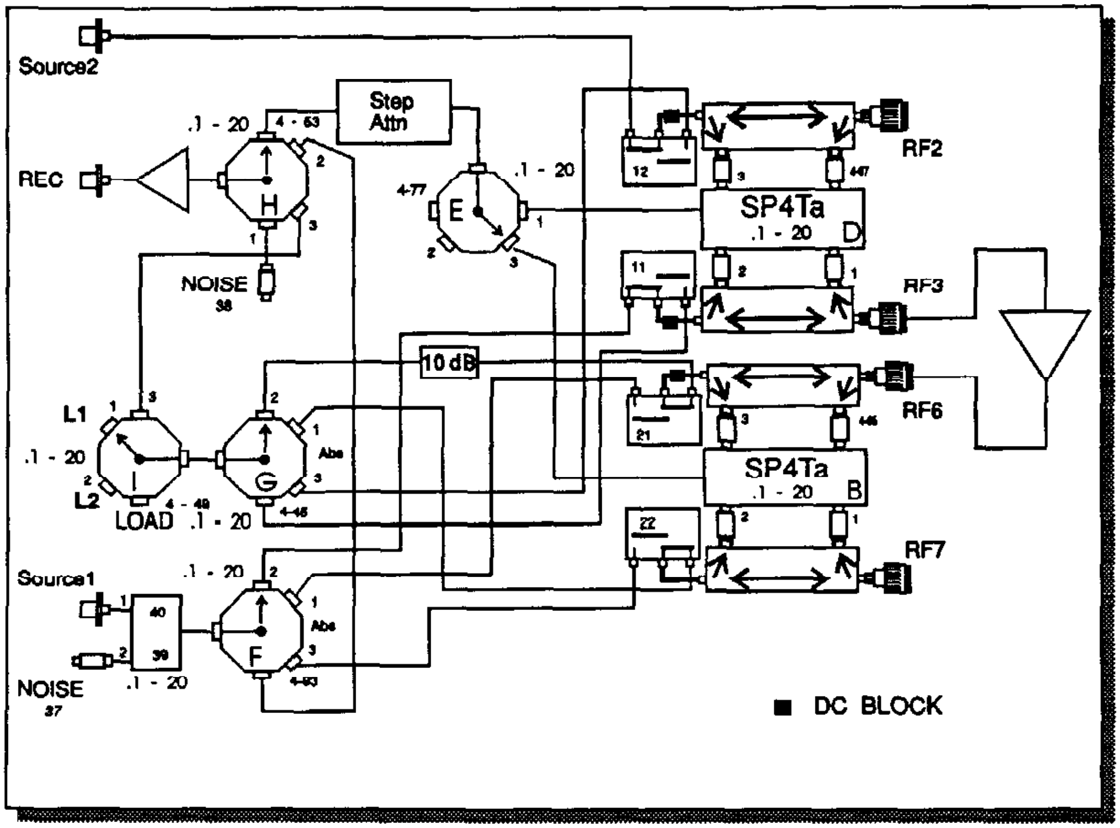
  Pout(F) = DUT Output Level(dBm) at Frequency F

  A = Pout(F1) - Pout(2xF1-F2)

- Example:
  F1=1 GHz, F2= 0.99 GHz,
  Pout(1GHz) = -5 dBm,
  Pout(1.01 GHz) = -25 dBm
  Then IP3 = +5 dBm

Measurement Process (Continued)

RI RFIC/MMIC Test Head



Test Configuration for Third Order Intercept

Mixer Isolation Measurements (LO in to Mixer out)

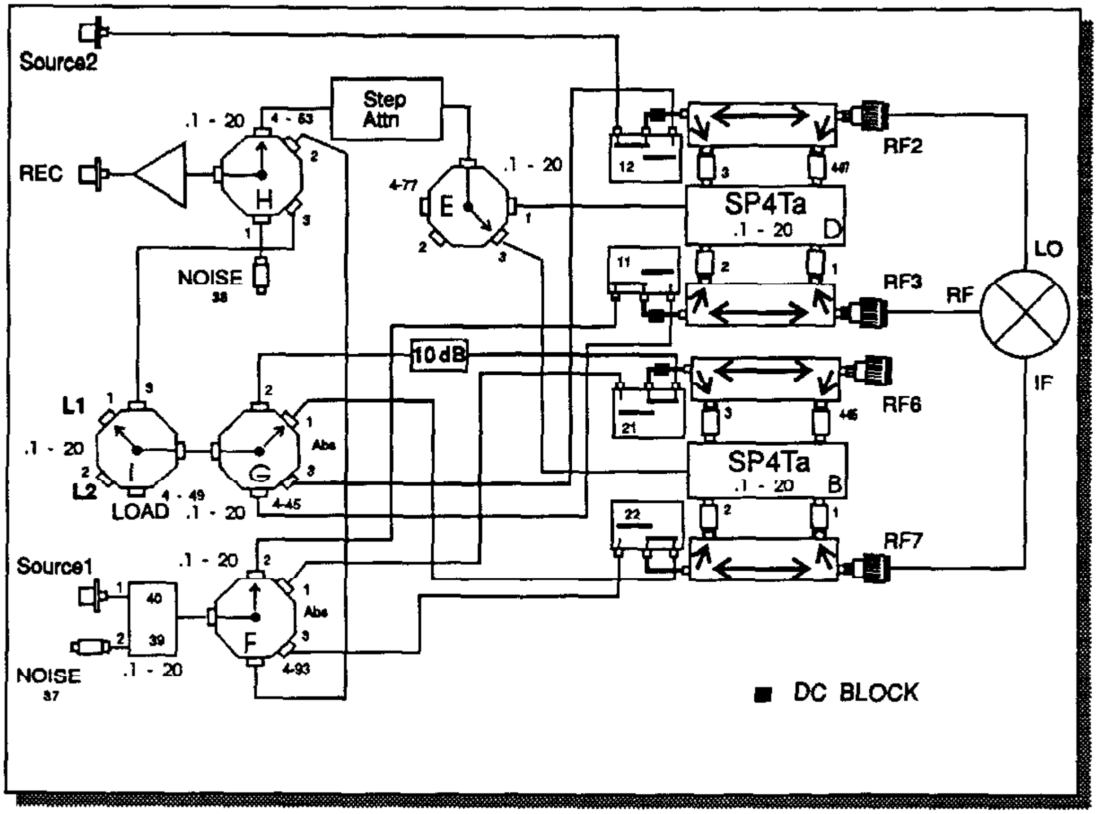
ISOLATION (LO in to MIXER out)

- RI 7100A Measurement Approach
  - S Parameter Detection Hardware
  - DUT LO Source Required
  - Terminate DUT RF Input into 50 ohms
  - RF Stimulus Source Not Required
- Stimulus
  - Single RF Tone into DUT LO Input
  - Sweep DUT LO Source Frequency
- Measure: Pin at DUT LO in & Pout at DUT IF out
- Calculate: Isolation(dB)=Pout(dBm)-Pin(dBm)

Measurement Process

The RI 7100A Microwave Test System performs mixer isolation (LO in to Mixer out) measurements as a series of scalar (absolute amplitude) S parameter measurements using the S parameter detection hardware. These measurements will require an RF signal applied to the DUT's LO input port. The RF input of the device under test will be terminated into a 50 ohm load and the DUT Stimulus Source (Source1) will be turned off. The user selects the DUT's LO source frequencies (start, stop & number of points) and the signal level. The test system will measure the signal level of the DUT's IF output at each LO frequency selected. The order in which the DUT LO Source frequencies are swept and the measurements are performed, is controlled by the test plan optimizer. Isolation is calculated as shown.

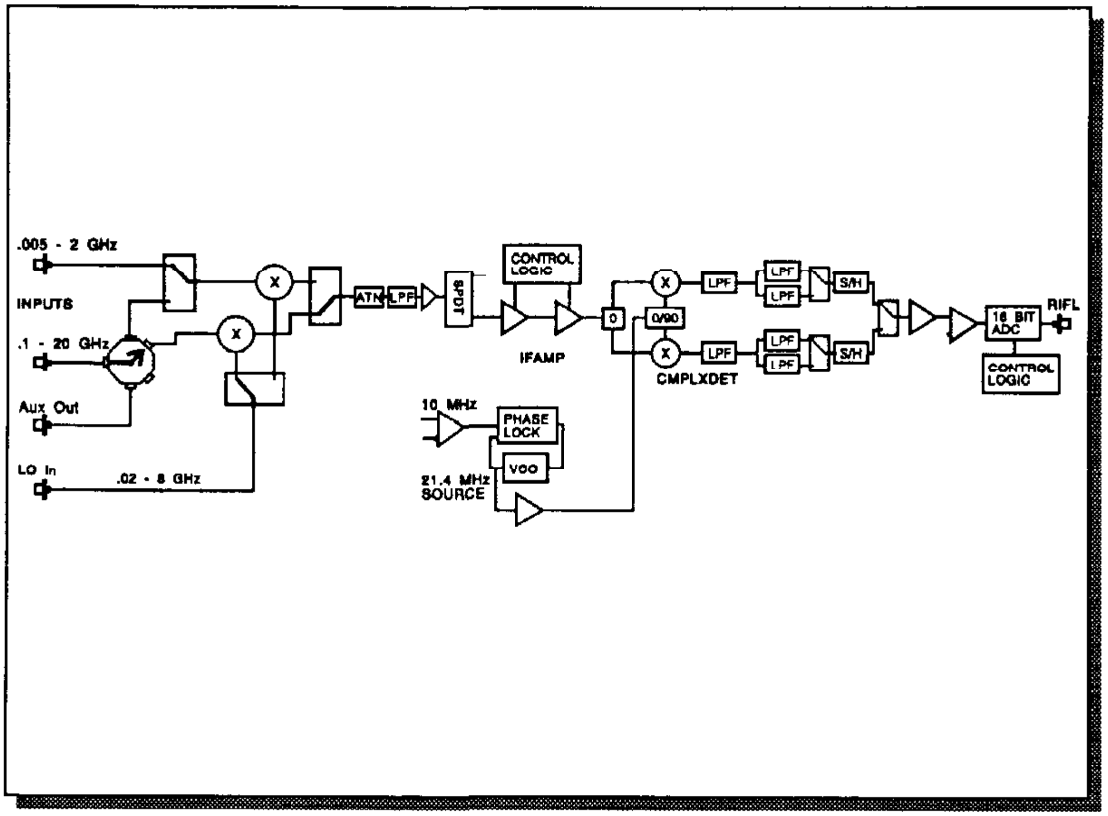
RI RFIC/MMIC Test Head



Test Configuration for Mixer Isolation

The test configuration shown is a typical mixer isolation measurement configuration for the RI 7100A's RFIC/MMIC Test Head. The RF port 3 is terminated into a 50 ohm load. The RF stimulus source (Source1) is turned off and isolated from the DUT's RF input by the mechanical RF switch connected to the directional coupler. The DUT LO source is connected to the Source2 input port and the DUT LO stimulus signal is routed through the Test Head to the DUT's LO input connected to RF port 2. The mixer's IF output port is connected to RF port 7. The transmitted signal at port 7 is routed through the directional coupler connected to port 7, through the electronic switch (connected to the fixed attenuator on the coupled arm), another switch, a step attenuator, a third electronic switch and a RF preamplifier to the single channel System Receiver at port REC for signal processing. All of the signal paths through the RFIC/MMIC Test Head are individually characterized and calibration factors are maintained for each of these paths.

RI System Receiver



Measurement Configuration for Mixer Isolation

The measurement process for mixer isolation measurements by the System Receiver is the same as the measurement process for S parameter measurements except only one signal is measured at each frequency. The signal is conditioned, sampled, digitized and the digitized data is sent to the System Computer, and then this process is repeated for the other DUT LO signal frequencies. The System Software then calculates the relative level (in dB) of each LO leakage signal with respect to the level of the LO signal applied to the DUT.

Mixer Isolation Measurements (LO in to RF in)

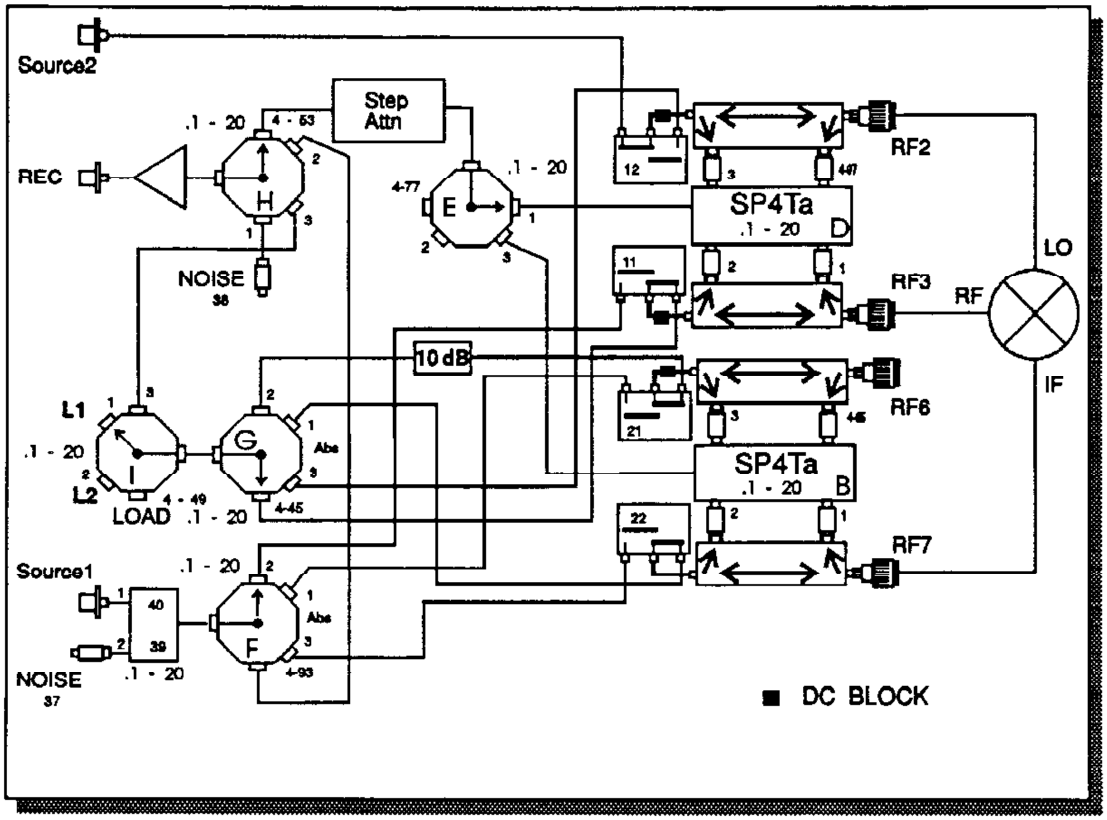
ISOLATION (LO in to RF in)

- RI 7100A Measurement Approach
  - S Parameter Detection Hardware
  - DUT LO Source Required
  - Terminate DUT IF Output into 50 ohms
  - RF Stimulus Source Not Required
- Stimulus
  - Single RF Tone into DUT LO Input
  - Sweep DUT LO Source Frequency
- Measure: Pin at DUT LO in & Pout at DUT RF in
- Calculate: Isolation(dB)=Pout(dBm)-Pin(dBm)

Measurement Process

The measurement process for mixer isolation (LO in to RF in) measurements is the same as for mixer isolation (LO in to IF out) measurements except that the DUT's IF port is terminated instead of the DUT's RF input port and the scalar S parameter measurements are performed at the DUT's RF input. The DUT LO Source is required and the DUT Stimulus Source will be turned off. The user selects the DUT's LO source frequencies (start, stop & number of points) and the signal level. The test system will measure the signal level of the DUT's RF input at each LO frequency selected. The order in which the DUT LO Source frequencies are swept and the measurements are performed, is controlled by the test plan optimizer. Isolation is calculated as shown.

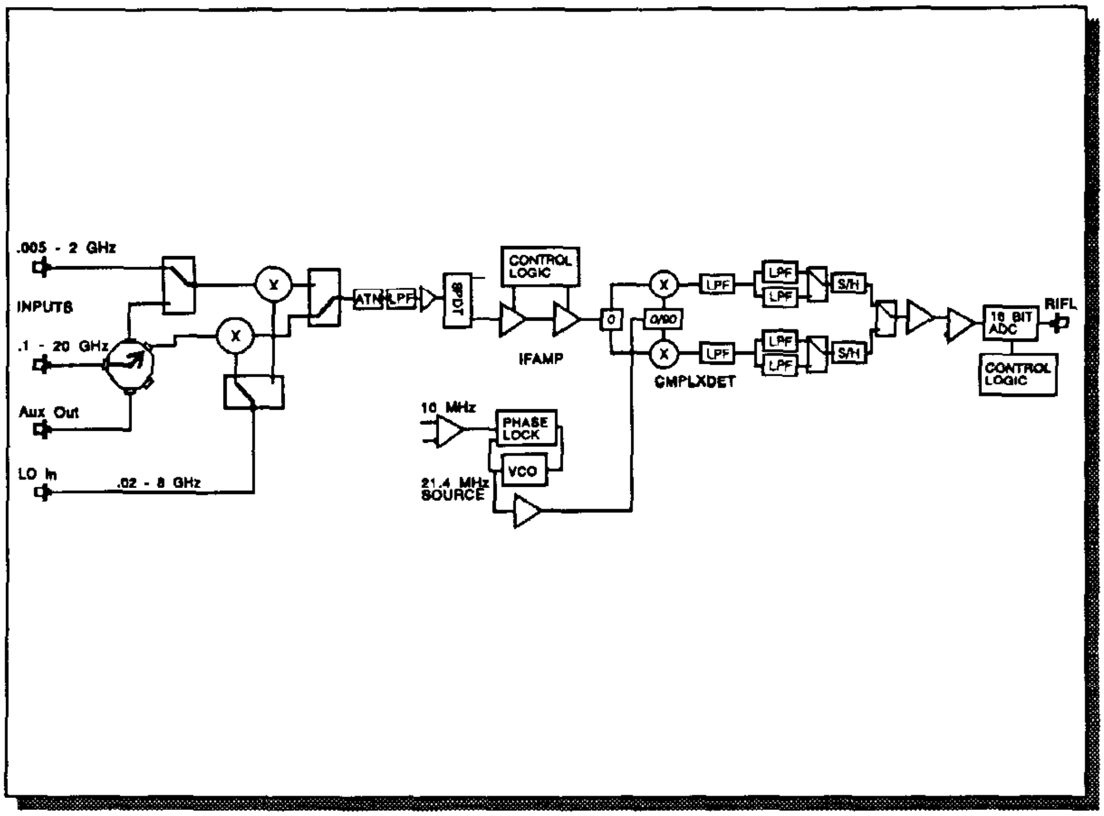
RI RFIC/MMIC Test Head



Test Configuration for Mixer Isolation

The test configuration shown is a typical mixer isolation measurement configuration for the RI 7100A's RFIC/MMIC Test Head. The DUT's IF output (connected to RF port 7) is terminated into a 50 ohm load. The RF stimulus source (Source1) is turned off and isolated from the DUT's RF input by a mechanical RF switch connected to the port 3 directional coupler. The DUT LO source is connected to the Source2 input port and the DUT LO stimulus signal is routed through the Test Head to the DUT's LO input connected to RF port 2. The mixer's RF Input port is connected to RF port 3. The transmitted signal at port 3 is routed through the directional coupler connected to port 3, through the electronic switch (connected to the fixed attenuator on the coupled arm), another switch, a step attenuator, a third electronic switch and a RF preamplifier to the single channel System Receiver at port REC for signal processing. All of the signal paths through the RFIC/MMIC Test Head are individually characterized and calibration factors are maintained for each of these paths.

RI System Receiver



Measurement Configuration for Mixer Isolation

The measurement process for mixer isolation (LO in to RF in) measurements by the System Receiver is the same as the measurement process for mixer isolation (LO in to IF out) and is the same as the measurement process for S parameter measurements in general except only one signal is measured at each frequency. The signal is conditioned, sampled, digitized and the digitized data is sent to the System Computer, and then this process is repeated for the other DUT LO signal frequencies. The System Software calculates the relative level (in dB) of each LO leakage signal with respect to the level of the LO signal applied to the DUT.