

Building a Probe for an HP4815A Vector Impedance Meter



The HP4815A Vector Impedance Meter

What is the HP4815A?

This meter measures the magnitude and phase of any impedance from 1 ohm to 100 Kohms and the phase from 0 to 360 degrees. HP built these meters back in the sixties, with entirely analog discrettes. This makes them valuable in a mostly digital world. It also makes them quite fixable if something goes wrong. However, most of the machines are missing there detachable probes. HP does not sell replacement probes, and to buy one professionally made, you will have to spend around US\$1000. So, the question is, how hard is it to make a replacement probe? This is what we set out to do. And, no, it is not easy, but can be done by those who have professional experience in the field of electrical engineering. The hope of this paper is to guide one through the process and hopefully eliminate many of the pitfalls associated with their construction.

Overview of the HP4815A Operation

The HP4815A probe has a voltage sampling section and a current sampling section, which uses a current sense

transformer. There are two main signals sent through the test load: an oscillator frequency, set by the user from .5 MHz to 108 MHz, and five nanosecond sampling pulses spaced 1.1 microseconds apart. The below pictures show what would be seen looking at the load with an oscilloscope if the two signals are separated:



[Scope of the project](#)

Most of the design work is making the current transformer work over the broad 0.5 MHz - 108 MHz Frequency range. The magnitude needs to be constant and the phase must be linear with frequency. Other problems are dealing with HP's proprietary connector for the probe. Our solution was to hard wire back into the machine. This is a long and tedious job, since the length must not vary by more than a few millimeters. Isolation and parasitics are also an issue, so good grounding and separate housings for the current and voltage senses must be carefully done. Also, many of the meters haven't been used for a while, and are out of calibration. This can be tough, because you need to test whether your probe is the problem, or if something needs to be calibrated internally. Other potential problems include burned out transistors or capacitors.

[More information on individual sections of the probe:](#)

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Current Transformer

The current transformer is the most difficult part of the design. The operating frequency is between 0.5 MHz to 108 MHz. The attached magnitude and phase plot shows what was used in the design.

For cores, we tried nanocrystalline, powdered iron, and ferrite. Ferrite produced the best results for a broad frequency range. Nanocrystalline cores were excellent at low frequencies, but at the higher frequencies they were not linear enough. Powdered iron cores did not go low enough in frequency.

Ferrite beads worked the best. The data for our core is as follows:

Material: #43

Part: #2643021801

Inside Diameter: 1.45 mm

Outside Diameter: 4.83 mm

Length: 10.72 mm

μ : 3000 max

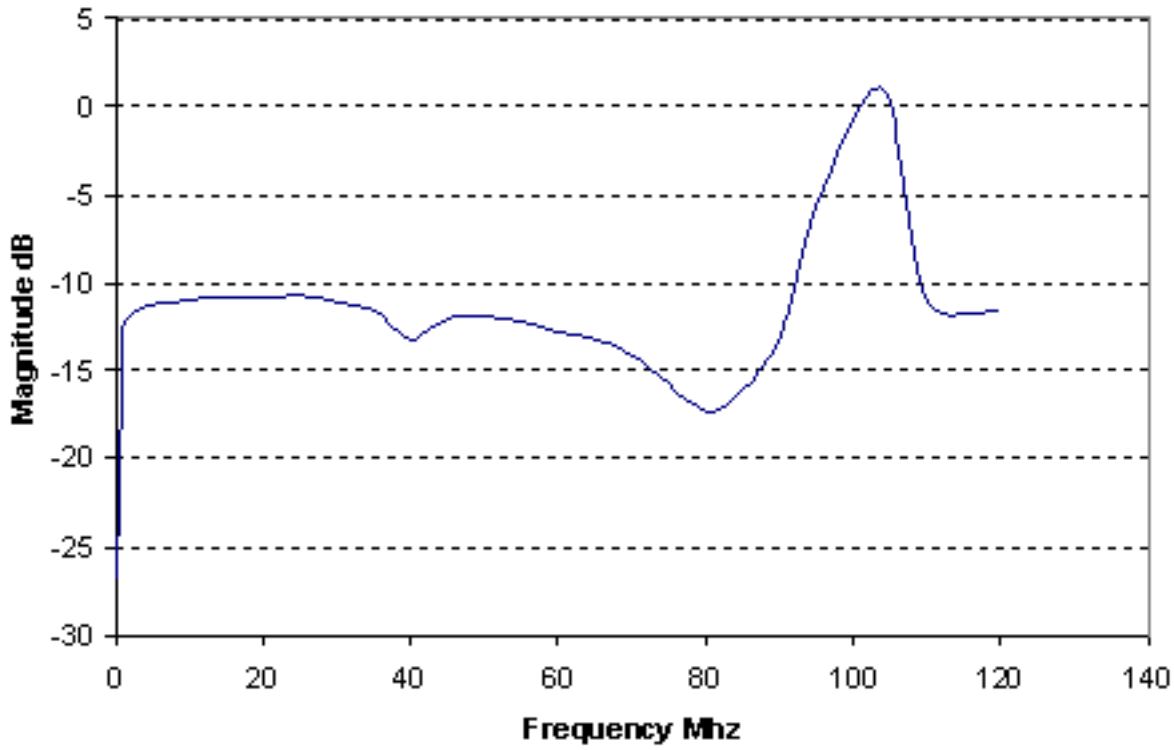
Fewer turns improved the frequency response considerably. Two turns seemed to be a good compromise. Cascading two cores in series also made the response better. Below is a picture of the core we used:



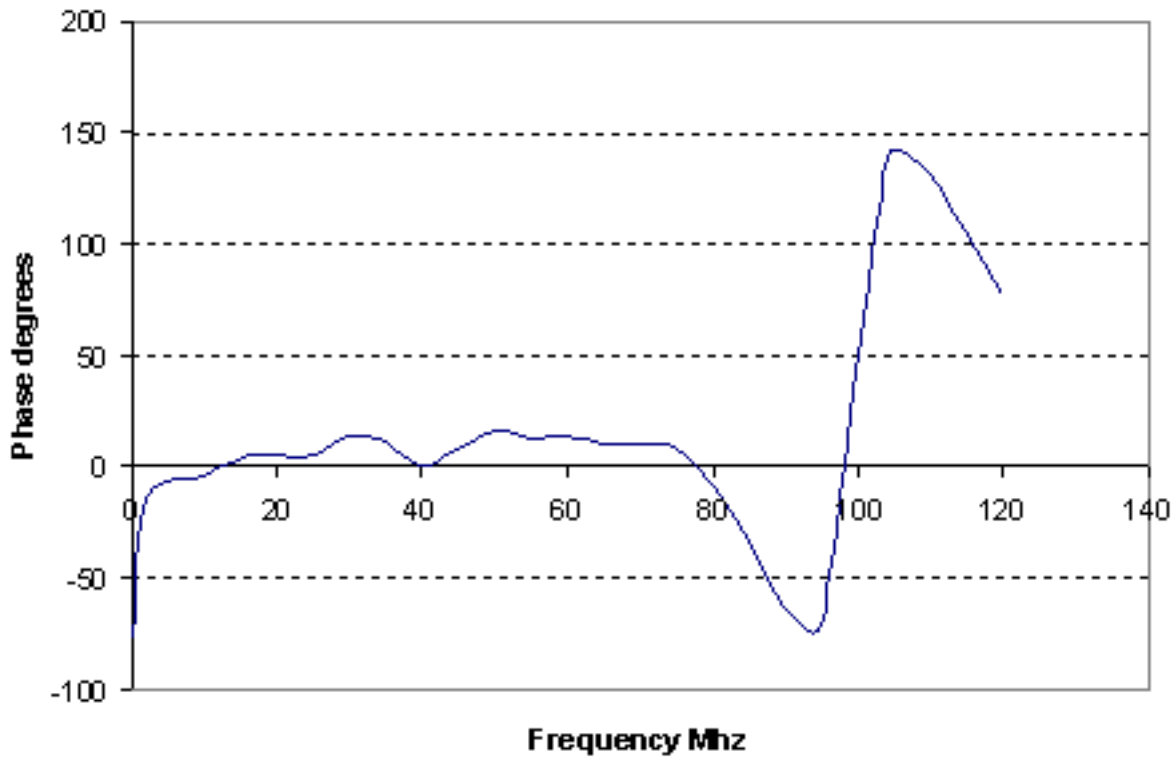
Notice that the voltage sense wire runs right through the cores. The other two turns are for the current sensing.

Here is the magnitude and phase response of our current transformer:

Mag dB



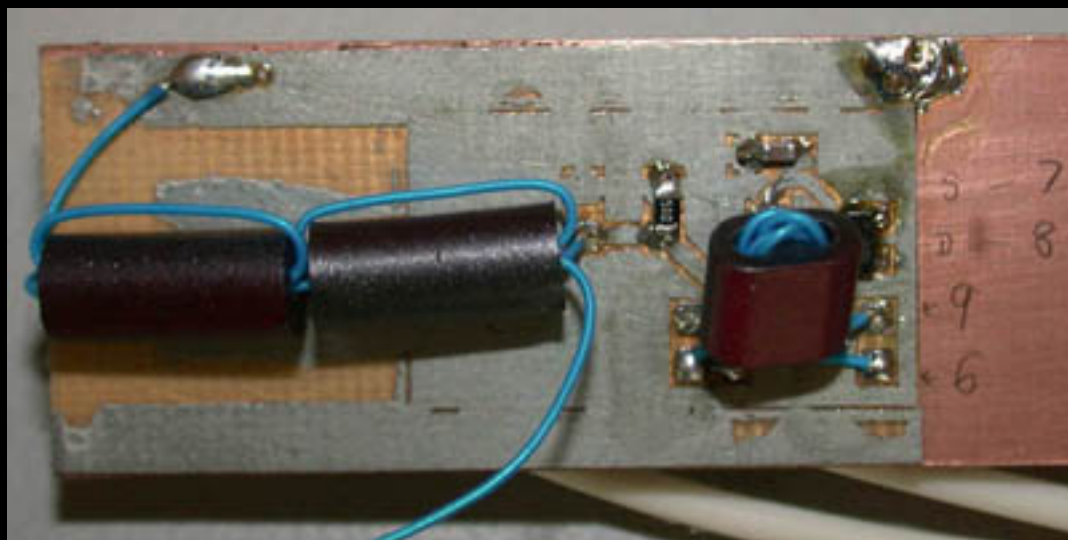
Phase



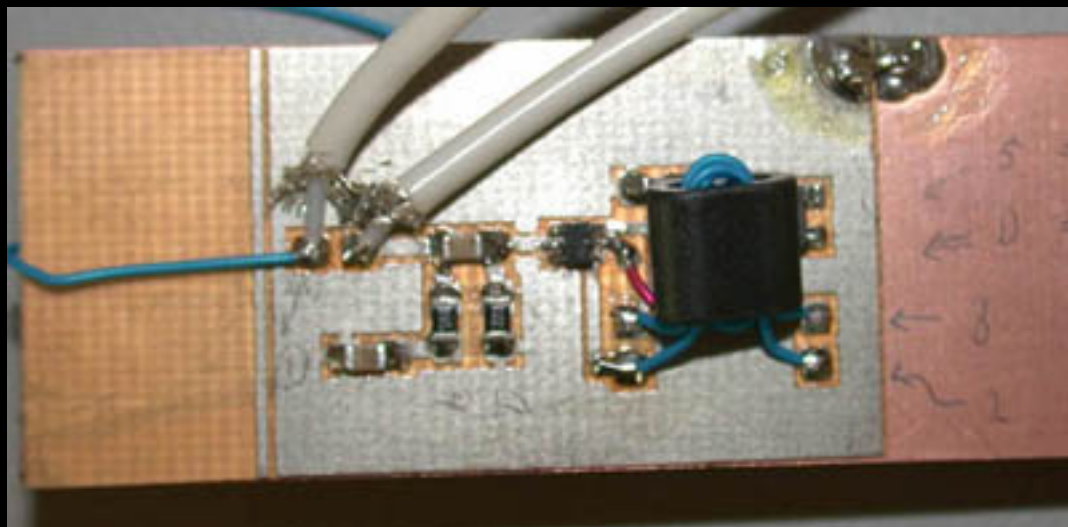


Board Design

The board design is very critical. There are nine coaxial cables that must be connected to the probe, four on the current sense and five on the voltage sense. The shielding needs to be well connected to ground, and good use of ground planes will help to prevent noise. The traces should also have a characteristic impedance of around 50 ohms, especially for the sampling pulse traces (lines 2, 3, 6, and 9). Surface mount components should be used as much as possible.



A picture of our current board:



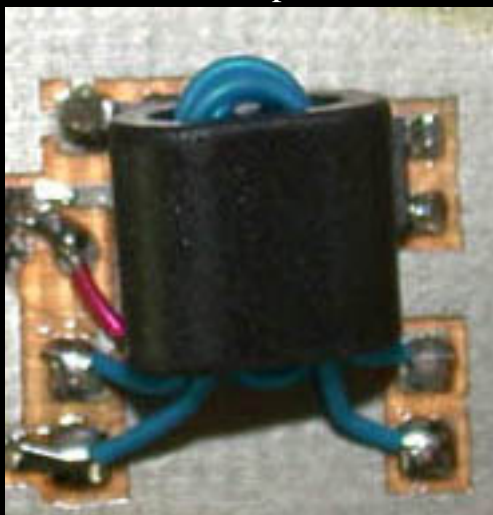
And our voltage board:

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Ballun Design

The ballun goes across the two balanced input lines for the sampling pulses. It insures that the lines are truly balanced. This is one of the easiest parts to build. Only a few turns are needed, and any ferrite core will work fine. A picture of our ballun is below:



Here is a list of the specs on the core we used:

$\mu_i=250$

$\mu =3000$

#43 Material, type 6

Ferrite

two turns of 30 gauge wirewrap

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[Routing the Coaxial cable into the machine](#)

For connecting the probe to the meter, we couldn't just use the connector on the front, because HP used a proprietary connector. Therefore, we routed the cable back to the origin inside the meter. This takes some time, and must be done carefully. All but one of the cables goes to the same part of the meter, and there is plenty of room to solder the coax directly to the boards. Each coax should be cut to precisely the same length as what was in it. After removing all the old coax, we measured each line, and added five feet to it. This should be done to within a millimeter or two (see equation below). Also, the coax should have a characteristic impedance of around 50 ohms, and a velocity factor of 0.66.

Here is a picture of where the coax goes:



$$\Delta \phi = \frac{360^\circ}{\frac{1}{f_o}} \Delta t$$

$$\Delta t = \Delta \phi \frac{1}{360^\circ f_o} = 1^\circ \frac{1}{360^\circ \cdot 108 \text{ Mhz}} = 25.7 \text{ ps}$$

$$\Delta l = .66 \cdot c \cdot \Delta t = 5.1 \text{ mm}$$

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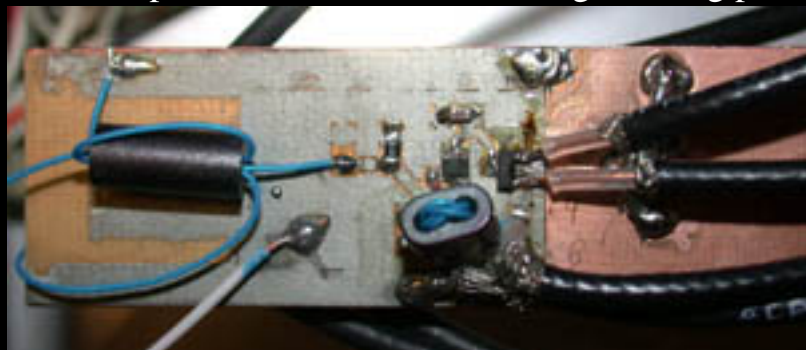
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Probe Housing

A good housing for the probe must be constructed. A conducting metal tube works best, with a good connection to ground. We divided the tube into two sections, with the top being the voltage board, and the bottom for the current board, with a grounding plane between. This provides excellent isolation, which we need for the phase measurements.

Here is a picture of our boards on the grounding plane separating them:



Current board



Voltage board

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Calibration issues

Calibration is probably the most difficult part of the project. The magnitude should be done first, then the phase.

The magnitude can be calibrated in several ways. One is to change the number of turns on the current transformer, the other by internally calibrating the meter. The phase can be adjusted by changing the length of the delay line on the voltage board (discussed later).

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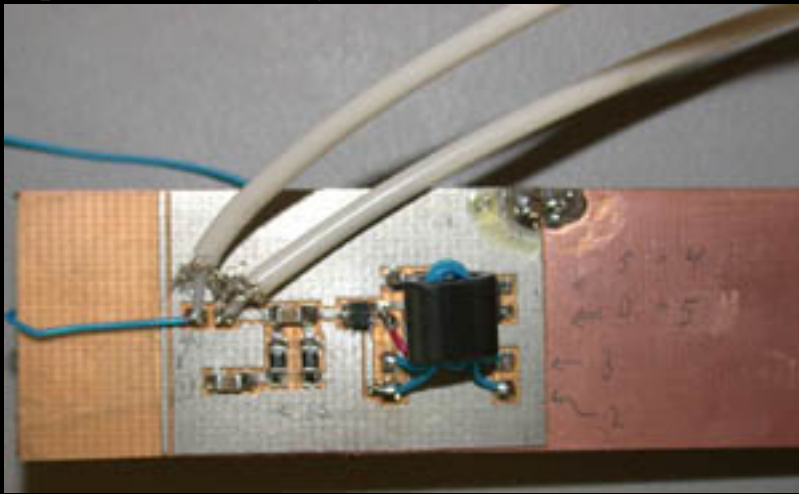
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The Delay Line for the Voltage Board

The pulses sent to the voltage board lead the sampling pulses to the current board by approximately 1.55 ns. This must be measured, as each instrument varies slightly. The best way to make a delay line is to cut a peice of coax to about 15", then connecting it to a TDR (Time Domain Relfectometer) to determine the exact length. One can assume a velocity of approximately .66c to get close to the right length.

A picture of our delay line:



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Parts used/data sheets

Most of the parts used in our design are readily available. However, here is a list of what we used:

T1 = Current Transformer:

#43 Material, Type 6 Ferrite Core Bead

$\mu = 3000$ max

Inside Diameter = 1.45mm

Outside Diameter = 4.83mm

Length = 10.72mm

T2 and T3 = Ballun:

#43 Material, Type 6 Ferrite Ballun

Capacitors and Resistors:

All 1/10 watt surface mount

Diodes:

HSMS-282x Quad Bridge Schottky Diodes

[Data Sheet](#)

Q1 and Q2 = J-Fet:

MMBF5461

[Data Sheet](#)

PCB:

permittivity = 4.0

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Surface Mount RF Schottky Barrier Diodes

Technical Data

HSMS-282x Series

Features

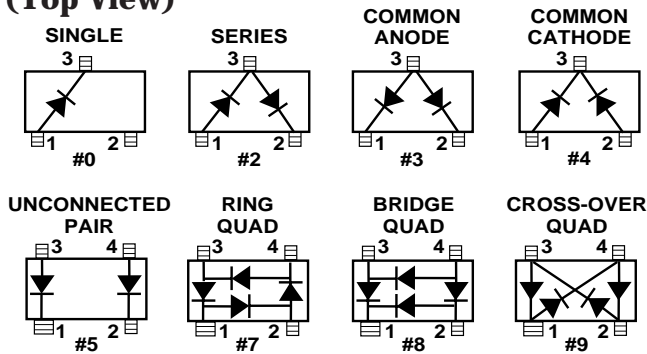
- **Low Turn-On Voltage**
(As Low as 0.34 V at 1 mA)
- **Low FIT (Failure in Time) Rate***
- **Six-sigma Quality Level**
- **Single, Dual and Quad Versions**
- **Unique Configurations in Surface Mount SOT-363 Package**
 - increase flexibility
 - save board space
 - reduce cost
- **HSMS-282K Grounded Center Leads Provide up to 10 dB Higher Isolation**
- **Matched Diodes for Consistent Performance**
- **Better Thermal Conductivity for Higher Power Dissipation**

* For more information see the Surface Mount Schottky Reliability Data Sheet.

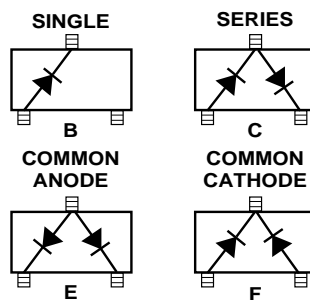
Description/Applications

These Schottky diodes are specifically designed for both analog and digital applications. This series offers a wide range of specifications and package configurations to give the designer wide flexibility. Typical applications of these Schottky diodes are mixing, detecting, switching, sampling, clamping, and wave shaping. The HSMS-282x series of diodes is the

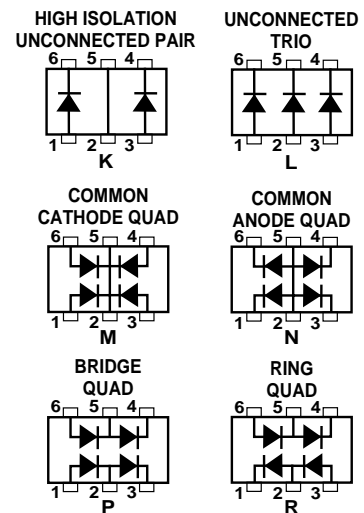
Package Lead Code Identification, SOT-23/SOT-143 (Top View)



Package Lead Code Identification, SOT-323 (Top View)



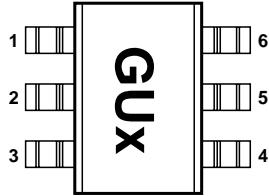
Package Lead Code Identification, SOT-363 (Top View)



best all-around choice for most applications, featuring low series resistance, low forward voltage at all current levels and good RF characteristics.

Note that Agilent's manufacturing techniques assure that dice found in pairs and quads are taken from adjacent sites on the wafer, assuring the highest degree of match.

Pin Connections and Package Marking



Notes:

1. Package marking provides orientation and identification.
2. See "Electrical Specifications" for appropriate package marking.

Absolute Maximum Ratings^[1] $T_C = 25^\circ\text{C}$

Symbol	Parameter	Unit	SOT-23/SOT-143	SOT-323/SOT-363
I_F	Forward Current (1 μs Pulse)	Amp	1	1
P_{IV}	Peak Inverse Voltage	V	15	15
T_j	Junction Temperature	$^\circ\text{C}$	150	150
T_{stg}	Storage Temperature	$^\circ\text{C}$	-65 to 150	-65 to 150
θ_{jc}	Thermal Resistance ^[2]	$^\circ\text{C}/\text{W}$	500	150

Notes:

1. Operation in excess of any one of these conditions may result in permanent damage to the device.
2. $T_C = +25^\circ\text{C}$, where T_C is defined to be the temperature at the package pins where contact is made to the circuit board.

Electrical Specifications $T_C = 25^\circ\text{C}$, Single Diode^[4]

Part Number HSMS ^[5]	Package Marking Code	Lead Code	Configuration	Minimum Breakdown Voltage V_{BR} (V)	Maximum Forward Voltage V_F (mV)	Maximum Forward Voltage V_F (V) @ I_F (mA)	Maximum Reverse Leakage I_R (nA) @ V_R (V)	Maximum Capacitance C_T (pF)	Typical Dynamic Resistance R_D (Ω) ^[6]						
2820	C0 ^[3]	0	Single	15	340	0.5 10	100 1	1.0	12						
2822	C2 ^[3]	2	Series												
2823	C3 ^[3]	3	Common Anode												
2824	C4 ^[3]	4	Common Cathode												
2825	C5 ^[3]	5	Unconnected Pair												
2827	C7 ^[3]	7	Ring Quad ^[5]												
2828	C8 ^[3]	8	Bridge Quad ^[5]												
2829	C9 ^[3]	9	Cross-over Quad												
282B	C0 ^[7]	B	Single												
282C	C2 ^[7]	C	Series												
282E	C3 ^[7]	E	Common Anode												
282F	C4 ^[7]	F	Common Cathode												
282K	CK ^[7]	K	High Isolation Unconnected Pair												
282L	CL ^[7]	L	Unconnected Trio												
282M	HH ^[7]	M	Common Cathode Quad												
282N	NN ^[7]	N	Common Anode Quad												
282P	CP ^[7]	P	Bridge Quad												
282R	OO ^[7]	R	Ring Quad												
Test Conditions										$I_R = 100 \mu\text{A}$	$I_F = 1 \text{ mA}$ ^[1]			$V_F = 0 \text{ V}$ $f = 1 \text{ MHz}$ ^[2]	$I_F = 5 \text{ mA}$

Notes:

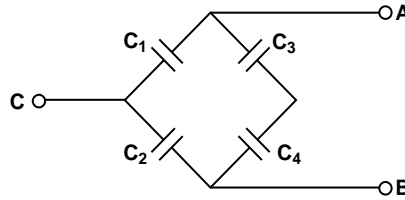
1. ΔV_F for diodes in pairs and quads in 15 mV maximum at 1 mA.
2. ΔC_{TO} for diodes in pairs and quads is 0.2 pF maximum.
3. Package marking code is in white.
4. Effective Carrier Lifetime (τ) for all these diodes is 100 ps maximum measured with Krakauer method at 5 mA.
5. See section titled "Quad Capacitance."
6. $R_D = R_S + 5.2 \Omega$ at 25°C and $I_F = 5 \text{ mA}$.
7. Package marking code is laser marked.

Quad Capacitance

Capacitance of Schottky diode quads is measured using an HP4271 LCR meter. This instrument effectively isolates individual diode branches from the others, allowing accurate capacitance measurement of each branch or each diode. The conditions are: 20 mV R.M.S. voltage at 1 MHz. Agilent defines this measurement as “CM”, and it is equivalent to the capacitance of the diode by itself. The equivalent diagonal and adjacent capacitances can then be calculated by the formulas given below.

In a quad, the diagonal capacitance is the capacitance between points A and B as shown in the figure below. The diagonal capacitance is calculated using the following formula

$$C_{\text{DIAGONAL}} = \frac{C_1 \times C_2}{C_1 + C_2} + \frac{C_3 \times C_4}{C_3 + C_4}$$

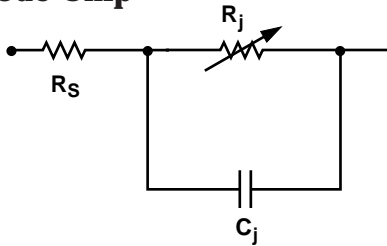


The equivalent adjacent capacitance is the capacitance between points A and C in the figure below. This capacitance is calculated using the following formula

$$C_{\text{ADJACENT}} = C_1 + \frac{1}{\frac{1}{C_2} + \frac{1}{C_3} + \frac{1}{C_4}}$$

This information does not apply to cross-over quad diodes.

Linear Equivalent Circuit Model Diode Chip



R_S = series resistance (see Table of SPICE parameters)

C_j = junction capacitance (see Table of SPICE parameters)

$$R_j = \frac{8.33 \times 10^{-5} \text{ nT}}{I_b + I_s}$$

where

I_b = externally applied bias current in amps

I_s = saturation current (see table of SPICE parameters)

T = temperature, °K

n = ideality factor (see table of SPICE parameters)

Note:

To effectively model the packaged HSMS-282x product, please refer to Application Note AN1124.

ESD WARNING:

Handling Precautions Should Be Taken To Avoid Static Discharge.

SPICE Parameters

Parameter	Units	HSMS-282x
B_V	V	15
C_{J0}	pF	0.7
E_G	eV	0.69
I_{BV}	A	1E-4
I_S	A	2.2E-8
N		1.08
R_S	Ω	6.0
P_B	V	0.65
P_T		2
M		0.5

Typical Performance, $T_C = 25^\circ\text{C}$ (unless otherwise noted), Single Diode

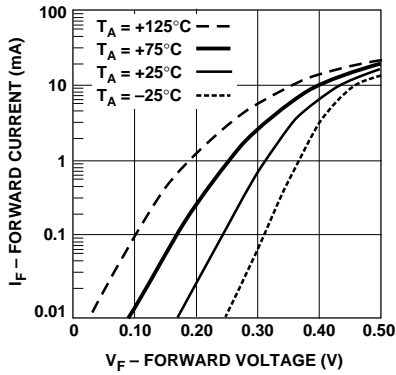


Figure 1. Forward Current vs. Forward Voltage at Temperatures.

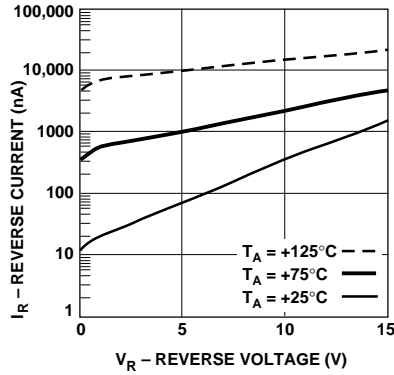


Figure 2. Reverse Current vs. Reverse Voltage at Temperatures.

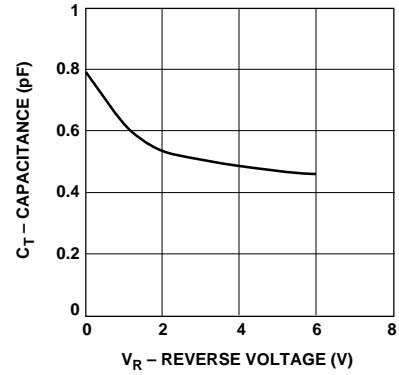


Figure 3. Total Capacitance vs. Reverse Voltage.

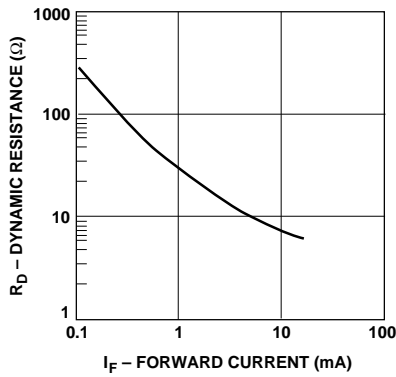


Figure 4. Dynamic Resistance vs. Forward Current.

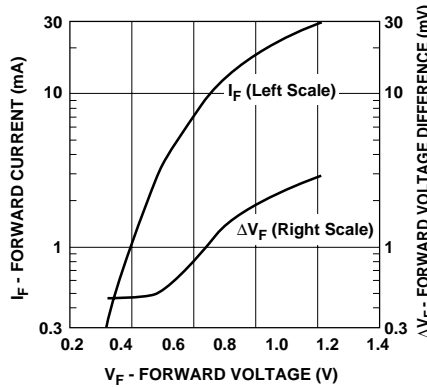


Figure 5. Typical V_f Match, Series Pairs and Quads at Mixer Bias Levels.

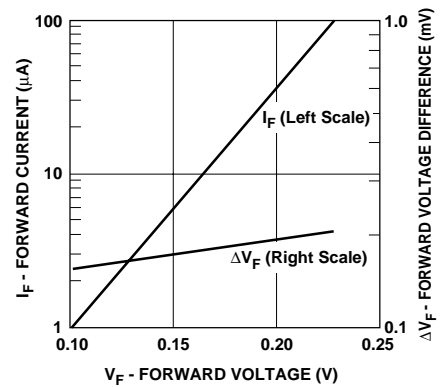


Figure 6. Typical V_f Match, Series Pairs and Quads at Detector Bias Levels.

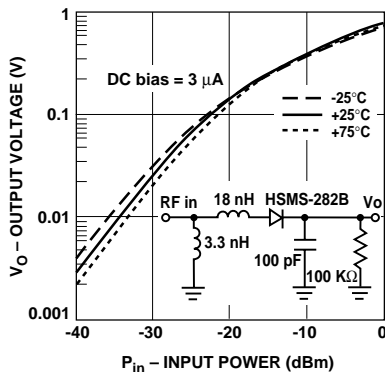


Figure 7. Typical Output Voltage vs. Input Power, Small Signal Detector Operating at 850 MHz.

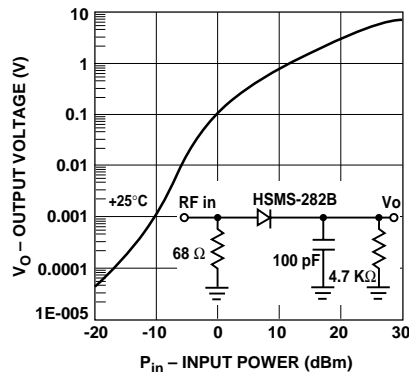


Figure 8. Typical Output Voltage vs. Input Power, Large Signal Detector Operating at 915 MHz.

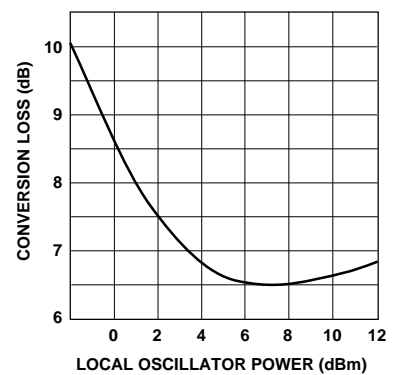


Figure 9. Typical Conversion Loss vs. L.O. Drive, 2.0 GHz (Ref AN997).

Applications Information Product Selection

Agilent's family of surface mount Schottky diodes provide unique solutions to many design problems. Each is optimized for certain applications.

The first step in choosing the right product is to select the diode type. All of the products in the HSMS-282x family use the same diode chip—they differ only in package configuration. The same is true of the HSMS-280x, -281x, 285x, -286x and -270x families. Each family has a different set of characteristics, which can be compared most easily by consulting the SPICE parameters given on each data sheet.

The HSMS-282x family has been optimized for use in RF applications, such as

- ✓ DC biased small signal detectors to 1.5 GHz.
- ✓ Biased or unbiased large signal detectors (AGC or power monitors) to 4 GHz.
- ✓ Mixers and frequency multipliers to 6 GHz.

The other feature of the HSMS-282x family is its unit-to-unit and lot-to-lot consistency. The silicon chip used in this series has been designed to use the fewest possible processing steps to minimize variations in diode characteristics. Statistical data on the consistency of this product, in terms of SPICE parameters, is available from Agilent.

For those applications requiring very high breakdown voltage, use the HSMS-280x family of diodes. Turn to the HSMS-281x when you

need very low flicker noise. The HSMS-285x is a family of zero bias detector diodes for small signal applications. For high frequency detector or mixer applications, use the HSMS-286x family. The HSMS-270x is a series of specialty diodes for ultra high speed clipping and clamping in digital circuits.

Schottky Barrier Diode Characteristics

Stripped of its package, a Schottky barrier diode chip consists of a metal-semiconductor barrier formed by deposition of a metal layer on a semiconductor. The most common of several different types, the passivated diode, is shown in Figure 10, along with its equivalent circuit.

R_S is the parasitic series resistance of the diode, the sum of the bondwire and leadframe resistance, the resistance of the bulk layer of silicon, etc. RF energy coupled into R_S is lost as heat—it does not contribute to the rectified output of the diode. C_J is parasitic junction capacitance of the diode, controlled by the thickness of the epitaxial layer and the diameter of the Schottky contact. R_J is the junction resistance of the diode, a function of the total current flowing through it.

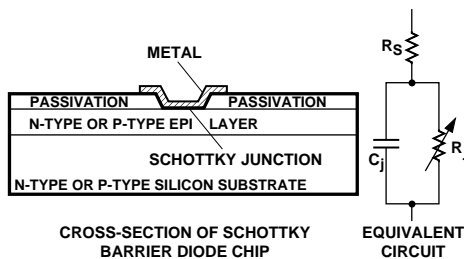


Figure 10. Schottky Diode Chip.

$$R_j = \frac{8.33 \times 10^{-5} n T}{I_S + I_b} = R_V - R_S$$

$$\approx \frac{0.026}{I_S + I_b} \text{ at } 25^\circ\text{C}$$

where

- n = ideality factor (see table of SPICE parameters)
- T = temperature in $^\circ\text{K}$
- I_S = saturation current (see table of SPICE parameters)
- I_b = externally applied bias current in amps
- R_V = sum of junction and series resistance, the slope of the V-I curve

I_S is a function of diode barrier height, and can range from picoamps for high barrier diodes to as much as $5 \mu\text{A}$ for very low barrier diodes.

The Height of the Schottky Barrier

The current-voltage characteristic of a Schottky barrier diode at room temperature is described by the following equation:

$$I = I_S \left(e^{\frac{V - IR_S}{0.026}} - 1 \right)$$

On a semi-log plot (as shown in the Agilent catalog) the current graph will be a straight line with inverse slope $2.3 \times 0.026 = 0.060$ volts per cycle (until the effect of

R_S is seen in a curve that droops at high current). All Schottky diode curves have the same slope, but not necessarily the same value of current for a given voltage. This is determined by the saturation current, I_S , and is related to the barrier height of the diode.

Through the choice of p-type or n-type silicon, and the selection of metal, one can tailor the characteristics of a Schottky diode. Barrier height will be altered, and at the same time C_j and R_S will be changed. In general, very low barrier height diodes (with high values of I_S , suitable for zero bias applications) are realized on p-type silicon. Such diodes suffer from higher values of R_S than do the n-type. Thus, p-type diodes are generally reserved for detector applications (where very high values of R_V swamp out high R_S) and n-type diodes such as the HSMS-282x are used for mixer applications (where high L.O. drive levels keep R_V low). DC biased detectors and self-biased detectors used in gain or power control circuits.

Detector Applications

Detector circuits can be divided into two types, large signal ($P_{in} > -20$ dBm) and small signal ($P_{in} < -20$ dBm). In general, the former use resistive impedance matching at the input to improve flatness over frequency—this is possible since the input signal levels are high enough to produce adequate output voltages without the need for a high Q reactive input matching network. These circuits are self-biased (no external DC bias) and are used for gain and power control of amplifiers.

Small signal detectors are used as very low cost receivers, and require a reactive input impedance matching network to achieve adequate sensitivity and output voltage. Those operating with zero bias utilize the HSMS-285x family of detector diodes. However, superior performance over temperature can be achieved with the use of 3 to 30 μ A of DC bias. Such circuits will use the HSMS-282x family of diodes if the operating frequency is 1.5 GHz or lower.

Typical performance of single diode detectors (using HSMS-2820 or HSMS-282B) can be seen in the transfer curves given in Figures 7 and 8. Such detectors can be realized either as series or shunt circuits, as shown in Figure 11.

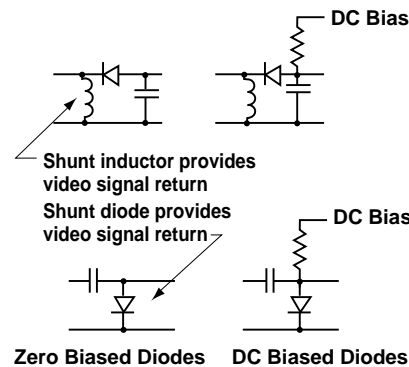


Figure 11. Single Diode Detectors.

The series and shunt circuits can be combined into a voltage doubler^[1], as shown in Figure 12. The doubler offers three advantages over the single diode circuit.

- ✓ The two diodes are in parallel in the RF circuit, lowering the input impedance and making the design of the RF matching network easier.
- ✓ The two diodes are in series in the output (video) circuit, doubling the output voltage.
- ✓ Some cancellation of even-order harmonics takes place at the input.

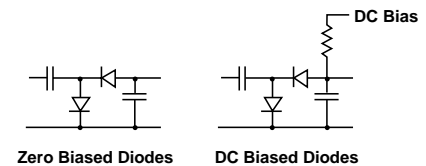


Figure 12. Voltage Doubler.

The most compact and lowest cost form of the doubler is achieved when the HSMS-2822 or HSMS-282C series pair is used.

Both the detection sensitivity and the DC forward voltage of a biased Schottky detector are temperature sensitive. Where both must be compensated over a wide range of temperatures, the differential detector^[2] is often used. Such a circuit requires that the detector diode and the reference diode exhibit identical characteristics at all DC bias levels and at all temperatures. This is accomplished through the use of two diodes in one package, for example the HSMS-2825 in Figure 13. In the Agilent assembly facility, the two dice in a surface mount package are taken from adjacent sites on the wafer (as illustrated in Figure 14). This

^[1] Agilent Application Note 956-4, "Schottky Diode Voltage Doubler."

^[2] Raymond W. Waugh, "Designing Large-Signal Detectors for Handsets and Base Stations," *Wireless Systems Design*, Vol. 2, No. 7, July 1997, pp 42 – 48.

assures that the characteristics of the two diodes are more highly matched than would be possible through individual testing and hand matching.

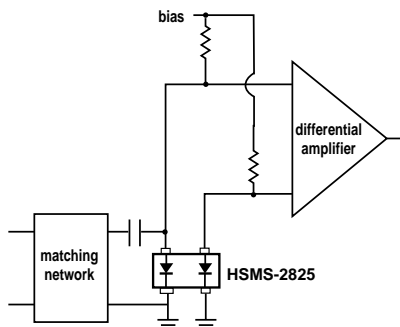


Figure 13. Differential Detector.

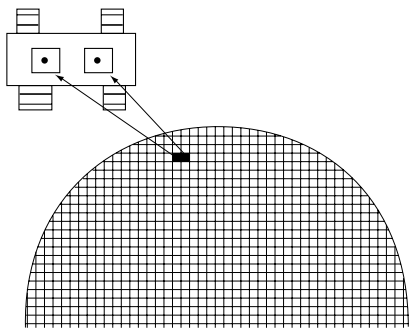


Figure 14. Fabrication of Agilent Diode Pairs.

In high power applications, coupling of RF energy from the detector diode to the reference diode can introduce error in the differential detector. The HSMS-282K diode pair, in the six lead SOT-363 package, has a copper bar between the diodes that adds 10 dB of additional isolation between them. As this part is manufactured in the SOT-363 package it also provides the benefit of being 40% smaller than larger SOT-143 devices. The HSMS-282K is illustrated in Figure 15 — note that the ground connections must be made as close to the package as possible to minimize stray inductance to ground.

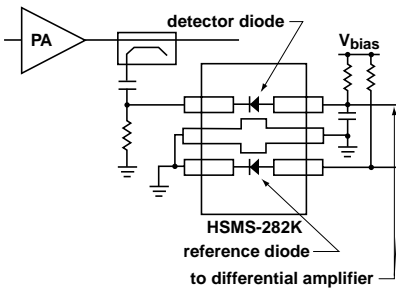


Figure 15. High Power Differential Detector.

The concept of the voltage doubler can be applied to the differential detector, permitting twice the output voltage for a given input power (as well as improving input impedance and suppressing second harmonics).

However, care must be taken to assure that the two reference diodes closely match the two detector diodes. One possible configuration is given in Figure 16, using two HSMS-2825. Board space can be saved through the use of the HSMS-282P open bridge quad, as shown in Figure 17.

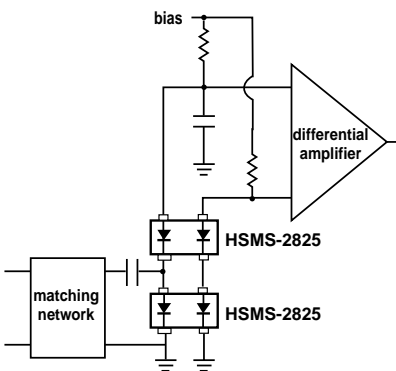


Figure 16. Voltage Doubler Differential Detector.

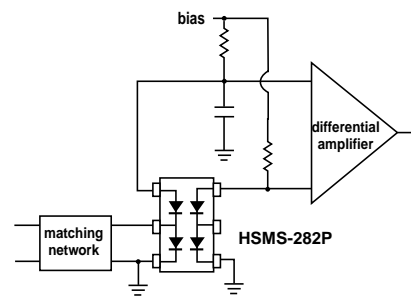


Figure 17. Voltage Doubler Differential Detector.

While the differential detector works well over temperature, another design approach^[3] works well for large signal detectors. See Figure 18 for the schematic and a physical layout of the circuit. In this design, the two 4.7 K Ω resistors and diode D2 act as a variable power divider, assuring constant output voltage over temperature and improving output linearity.

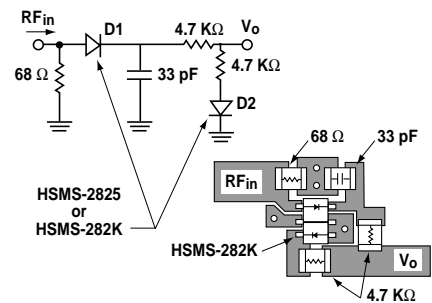


Figure 18. Temperature Compensated Detector.

In certain applications, such as a dual-band cellphone handset operating at both 900 and 1800 MHz, the second harmonics generated in the power control output detector when the handset is working at 900 MHz can cause problems. A filter at the output can reduce unwanted emissions at 1800 MHz in this case, but a

^[3] Hans Eriksson and Raymond W. Waugh, "A Temperature Compensated Linear Diode Detector," to be published.

lower cost solution is available^[4]. Illustrated schematically in Figure 19, this circuit uses diode D2 and its associated passive components to cancel all even order harmonics at the detector's RF input. Diodes D3 and D4 provide temperature compensation as described above. All four diodes are contained in a single HSMS-282R package, as illustrated in the layout shown in Figure 20.

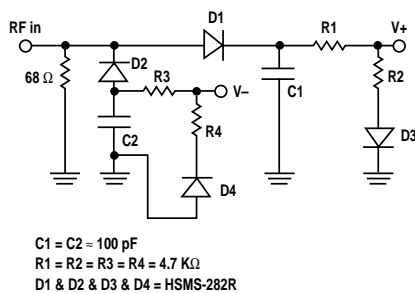


Figure 19. Schematic of Suppressed Harmonic Detector.

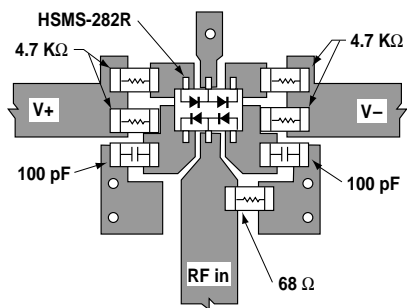


Figure 20. Layout of Suppressed Harmonic Detector.

Note that the forgoing discussion refers to the output voltage being extracted at point V+ with respect to ground. If a differential output is taken at V+ with respect to V-, the circuit acts as a voltage doubler.

Mixer applications

The HSMS-282x family, with its wide variety of packaging, can be used to make excellent mixers at frequencies up to 6 GHz.

The HSMS-2827 ring quad of matched diodes (in the SOT-143 package) has been designed for double balanced mixers. The smaller (SOT-363) HSMS-282R ring quad can similarly be used, if the quad is closed with external connections as shown in Figure 21.

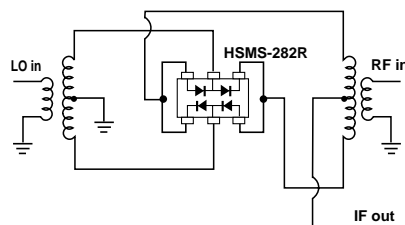


Figure 21. Double Balanced Mixer.

Both of these networks require a crossover or a three dimensional circuit. A planar mixer can be made using the SOT-143 crossover quad, HSMS-2829, as shown in Figure 22. In this product, a special lead frame permits the crossover to be placed inside the plastic package itself, eliminating the need for via holes (or other measures) in the RF portion of the circuit itself.

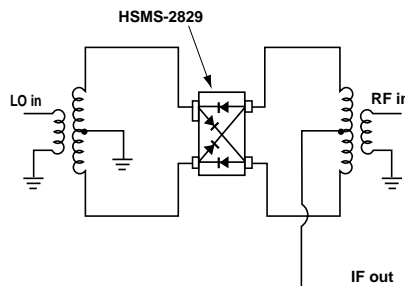


Figure 22. Planar Double Balanced Mixer.

A review of Figure 21 may lead to the question as to why the HSMS-282R ring quad is open on the ends. Distortion in double balanced mixers can be reduced if LO drive is increased, up to the point where the Schottky diodes are driven into saturation. Above this point, increased LO drive will not result in improvements in distortion. The use of expensive high barrier diodes (such as those fabricated on GaAs) can take advantage of higher LO drive power, but a lower cost solution is to use a eight (or twelve) diode ring quad. The open design of the HSMS-282R permits this to easily be done, as shown in Figure 23.

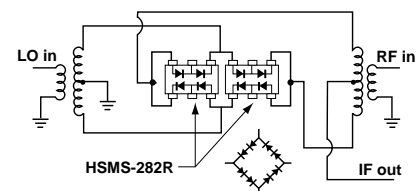


Figure 23. Low Distortion Double Balanced Mixer.

This same technique can be used in the single-balanced mixer. Figure 24 shows such a mixer, with two diodes in each spot normally occupied by one. This mixer, with a sufficiently high LO drive level, will display low distortion.

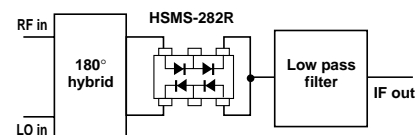


Figure 24. Low Distortion Balanced Mixer.

^[4] Alan Rixon and Raymond W. Waugh, "A Suppressed Harmonic Power Detector for Dual Band 'Phones," to be published.

Sampling Applications

The six lead HSMS-282P can be used in a sampling circuit, as shown in Figure 25. As was the case with the six lead HSMS-282R in the mixer, the open bridge quad is closed with traces on the circuit board. The quad was not closed internally so that it could be used in other applications, such as illustrated in Figure 17.

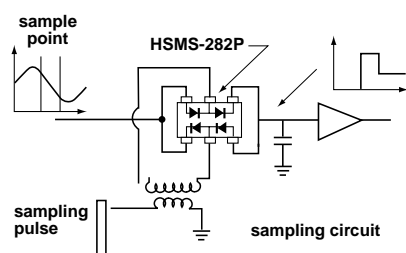


Figure 25. Sampling Circuit.

Thermal Considerations

The obvious advantage of the SOT-323 and SOT-363 over the SOT-23 and SOT-142 is combination of smaller size and extra leads. However, the copper leadframe in the SOT-3x3 has a thermal conductivity four times higher than the Alloy 42 leadframe of the SOT-23 and SOT-143, which enables the smaller packages to dissipate more power.

The maximum junction temperature for these three families of Schottky diodes is 150°C under all operating conditions. The following equation applies to the thermal analysis of diodes:

$$T_j = (V_f I_f + P_{RF}) \theta_{jc} + T_a \quad (1)$$

where

- T_j = junction temperature
- T_a = diode case temperature
- θ_{jc} = thermal resistance
- $V_f I_f$ = DC power dissipated
- P_{RF} = RF power dissipated

Note that θ_{jc} , the thermal resistance from diode junction to the foot of the leads, is the sum of two component resistances,

$$\theta_{jc} = \theta_{pkg} + \theta_{chip} \quad (2)$$

Package thermal resistance for the SOT-3x3 package is approximately 100°C/W, and the chip thermal resistance for the HSMS-282x family of diodes is approximately 40°C/W. The designer will have to add in the thermal resistance from diode case to ambient — a poor choice of circuit board material or heat sink design can make this number very high.

Equation (1) would be straightforward to solve but for the fact that diode forward voltage is a function of temperature as well as forward current. The equation for V_f is:

$$I_f = I_s \left[e^{\frac{11600 (V_f - I_f R_s)}{nT}} - 1 \right] \quad (3)$$

where n = ideality factor
 T = temperature in °K
 R_s = diode series resistance

and I_s (diode saturation current) is given by

$$I_s = I_0 \left(\frac{T}{298} \right)^{\frac{2}{n}} e^{-4060 \left(\frac{1}{T} - \frac{1}{298} \right)} \quad (4)$$

Equation (4) is substituted into equation (3), and equations (1) and (3) are solved simultaneously to obtain the value of junction temperature for given values of diode case temperature, DC power dissipation and RF power dissipation.

Diode Burnout

Any Schottky junction, be it an RF diode or the gate of a MESFET, is relatively delicate and can be burned out with excessive RF power. Many crystal video receivers used in RFID (tag) applications find themselves in poorly controlled environments where high power sources may be present. Examples are the areas around airport and FAA radars, nearby ham radio operators, the vicinity of a broadcast band transmitter, etc. In such environments, the Schottky diodes of the receiver can be protected by a device known as a limiter diode.^[5] Formerly available only in radar warning receivers and other high cost electronic warfare applications, these diodes have been adapted to commercial and consumer circuits.

Agilent offers a complete line of surface mountable PIN limiter diodes. Most notably, our HSMP-4820 (SOT-23) can act as a very fast (nanosecond) power-sensitive switch when placed between the antenna and the Schottky diode, shorting out the RF circuit temporarily and reflecting the excessive RF energy back out the antenna.

^[5] Agilent Application Note 1050, "Low Cost, Surface Mount Power Limiters."

Assembly Instructions SOT-3x3 PCB Footprint

Recommended PCB pad layouts for the miniature SOT-3x3 (SC-70) packages are shown in Figures 26 and 27 (dimensions are in inches). These layouts provide ample allowance for package placement by automated assembly equipment without adding parasitics that could impair the performance.

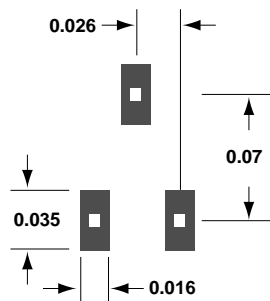


Figure 26. PCB Pad Layout, SOT-323 (dimensions in inches).

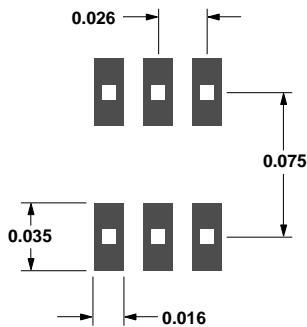


Figure 27. PCB Pad Layout, SOT-363 (dimensions in inches).

SMT Assembly

Reliable assembly of surface mount components is a complex process that involves many material, process, and equipment factors, including: method of heating (e.g., IR or vapor phase reflow, wave soldering, etc.) circuit board material, conductor thickness and pattern, type of solder alloy, and the thermal conductivity and thermal mass of components. Components with a low mass, such as the SOT packages, will reach solder reflow temperatures faster than those with a greater mass.

Agilent's diodes have been qualified to the time-temperature profile shown in Figure 28. This profile is representative of an IR reflow type of surface mount assembly process.

After ramping up from room temperature, the circuit board with components attached to it (held in place with solder paste)

passes through one or more preheat zones. The preheat zones increase the temperature of the board and components to prevent thermal shock and begin evaporating solvents from the solder paste. The reflow zone briefly elevates the temperature sufficiently to produce a reflow of the solder.

The rates of change of temperature for the ramp-up and cool-down zones are chosen to be low enough to not cause deformation of the board or damage to components due to thermal shock. The maximum temperature in the reflow zone (T_{MAX}) should not exceed 235°C.

These parameters are typical for a surface mount assembly process for Agilent diodes. As a general guideline, the circuit board and components should be exposed only to the minimum temperatures and times necessary to achieve a uniform reflow of solder.

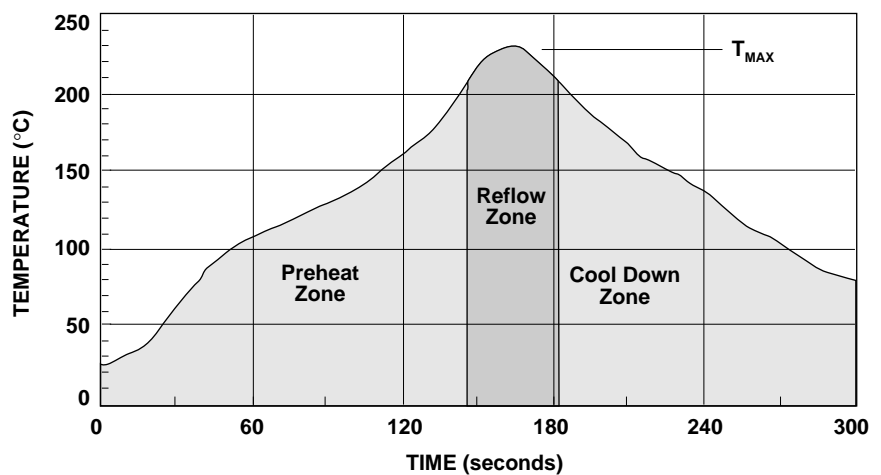


Figure 28. Surface Mount Assembly Profile.

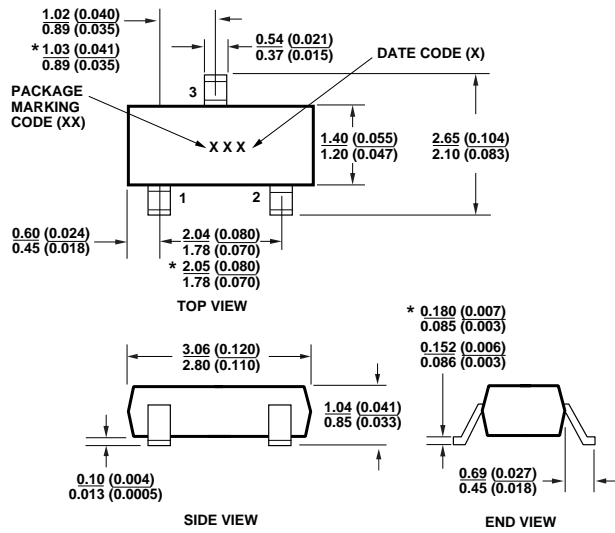
Part Number Ordering Information

Part Number	No. of Devices	Container
HSMS-282x-TR2 *	10000	13" Reel
HSMS-282x-TR1 *	3000	7" Reel
HSMS-282x-BLK *	100	antistatic bag

x = 0, 2, 3, 4, 5, 7, 8, 9, B, C, E, F, K, L, M, N, P or R

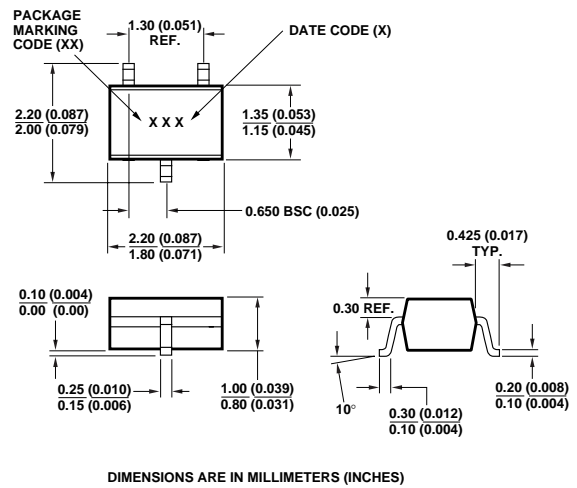
Package Dimensions

Outline 23 (SOT-23)



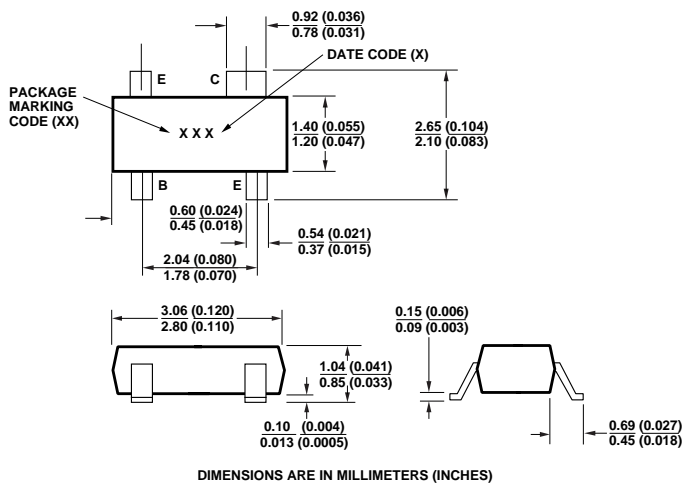
* THESE DIMENSIONS FOR HSMS-280X AND -281X FAMILIES ONLY.
DIMENSIONS ARE IN MILLIMETERS (INCHES)

Outline SOT-323 (SC-70 3 Lead)



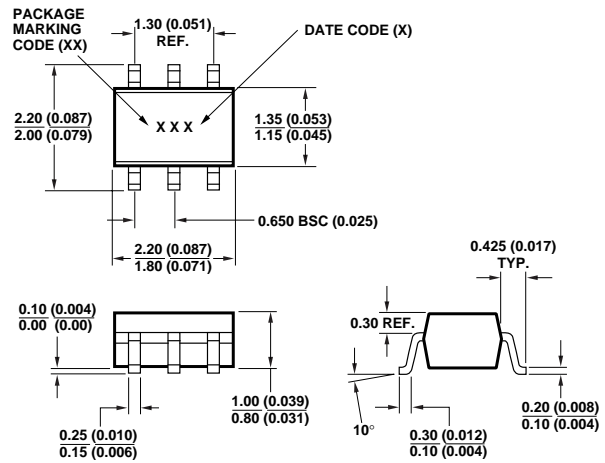
DIMENSIONS ARE IN MILLIMETERS (INCHES)

Outline 143 (SOT-143)



DIMENSIONS ARE IN MILLIMETERS (INCHES)

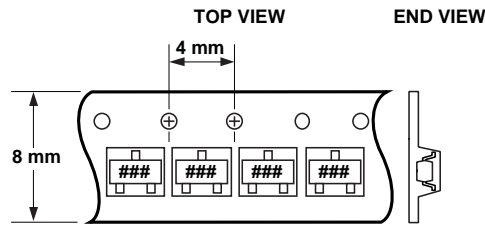
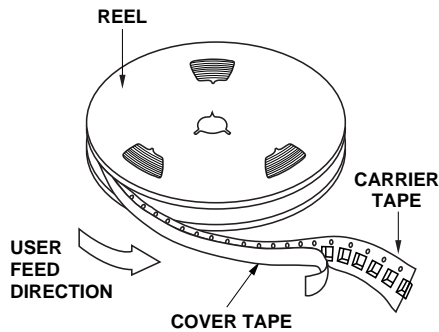
Outline SOT-363 (SC-70 6 Lead)



DIMENSIONS ARE IN MILLIMETERS (INCHES)

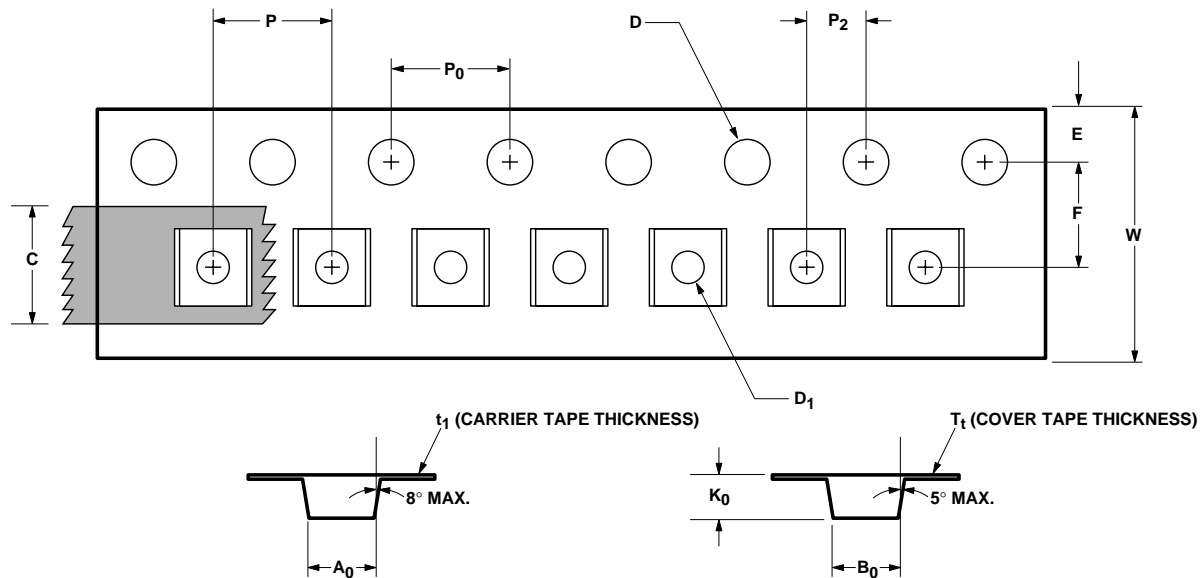


Device Orientation



Note: "###" represents Package Marking Code. Package marking is right side up with carrier tape perforations at top. Conforms to Electronic Industries RS-481, "Taping of Surface Mounted Components for Automated Placement." Standard quantity is 3,000 devices per reel.

Tape Dimensions and Product Orientation For Outline SOT-323 (SC-70 3 Lead)



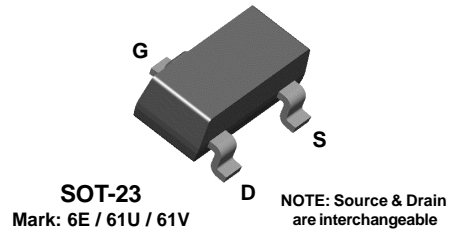
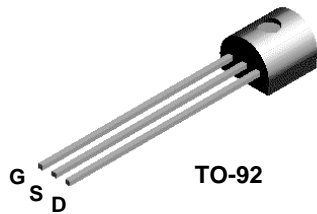
DESCRIPTION		SYMBOL	SIZE (mm)	SIZE (INCHES)
CAVITY	LENGTH	A ₀	2.24 ± 0.10	0.088 ± 0.004
	WIDTH	B ₀	2.34 ± 0.10	0.092 ± 0.004
	DEPTH	K ₀	1.22 ± 0.10	0.048 ± 0.004
	PITCH	P	4.00 ± 0.10	0.157 ± 0.004
	BOTTOM HOLE DIAMETER	D ₁	1.00 + 0.25	0.039 + 0.010
PERFORATION	DIAMETER	D	1.55 ± 0.05	0.061 ± 0.002
	PITCH	P ₀	4.00 ± 0.10	0.157 ± 0.004
	POSITION	E	1.75 ± 0.10	0.069 ± 0.004
CARRIER TAPE	WIDTH	W	8.00 ± 0.30	0.315 ± 0.012
	THICKNESS	t ₁	0.255 ± 0.013	0.010 ± 0.0005
COVER TAPE	WIDTH	C	5.4 ± 0.10	0.205 ± 0.004
	TAPE THICKNESS	T _t	0.062 ± 0.001	0.0025 ± 0.00004
DISTANCE	CAVITY TO PERFORATION (WIDTH DIRECTION)	F	3.50 ± 0.05	0.138 ± 0.002
	CAVITY TO PERFORATION (LENGTH DIRECTION)	P ₂	2.00 ± 0.05	0.079 ± 0.002

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Data subject to change.
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Obsoletes 5968-2356E, 5968-5934E
5968-8014E (1/00)

**2N5460
2N5461
2N5462**

**MMBF5460
MMBF5461
MMBF5462**



P-Channel General Purpose Amplifier

This device is designed primarily for low level audio and general purpose applications with high impedance signal sources. Sourced from Process 89.

Absolute Maximum Ratings* TA = 25°C unless otherwise noted

Symbol	Parameter	Value	Units
V_{DG}	Drain-Gate Voltage	- 40	V
V_{GS}	Gate-Source Voltage	40	V
I_{GF}	Forward Gate Current	10	mA
T_J, T_{stg}	Operating and Storage Junction Temperature Range	-55 to +150	°C

*These ratings are limiting values above which the serviceability of any semiconductor device may be impaired.

NOTES:

- 1) These ratings are based on a maximum junction temperature of 150 degrees C.
- 2) These are steady state limits. The factory should be consulted on applications involving pulsed or low duty cycle operations.

Thermal Characteristics TA = 25°C unless otherwise noted

Symbol	Characteristic	Max		Units
		2N5460-5462	*MMBF5460-5462	
P_D	Total Device Dissipation Derate above 25°C	350	225	mW
		2.8	1.8	mW/°C
$R_{\theta JC}$	Thermal Resistance, Junction to Case	125		°C/W
$R_{\theta JA}$	Thermal Resistance, Junction to Ambient	357	556	°C/W

*Device mounted on FR-4 PCB 1.6" X 1.6" X 0.06."

2N5460 / 5461 / 5462 / MMBF5460 / MMBF5461 / MMBF5462

P-Channel General Purpose Amplifier

(continued)

Electrical Characteristics

TA = 25°C unless otherwise noted

Symbol	Parameter	Test Conditions	Min	Typ	Max	Units
--------	-----------	-----------------	-----	-----	-----	-------

OFF CHARACTERISTICS

$V_{(BR)GSS}$	Gate-Source Breakdown Voltage	$I_G = 10 \mu A, V_{DS} = 0$	40			V
I_{GSS}	Gate Reverse Current	$V_{GS} = 20 V, V_{DS} = 0$			5.0	nA
		$V_{GS} = 20 V, V_{DS} = 0, T_A = 100^\circ C$			1.0	μA
$V_{GS(off)}$	Gate-Source Cutoff Voltage	$V_{DS} = 15 V, I_D = 1.0 \mu A$	5460	0.75	6.0	V
			5461	1.0	7.5	V
			5462	1.8	9.0	V
V_{GS}	Gate-Source Voltage	$V_{DS} = 15 V, I_D = 0.1 mA$	5460	0.5	4.0	V
			5461	0.8	4.5	V
			5462	1.5	6.0	V

ON CHARACTERISTICS

I_{DSS}	Zero-Gate Voltage Drain Current*	$V_{DS} = 15 V, V_{GS} = 0$	5460	- 1.0	- 5.0	mA
			5461	- 2.0	- 9.0	mA
			5462	- 4.0	- 16	mA

SMALL SIGNAL CHARACTERISTICS

g_{fs}	Forward Transfer Conductance	$V_{DS} = 15 V, V_{GS} = 0, f = 1.0 kHz$				
		5460	1000		4000	$\mu mhos$
		5461	1500		5000	$\mu mhos$
		5462	2000		6000	$\mu mhos$
g_{os}	Output Conductance	$V_{DS} = 15 V, V_{GS} = 0, f = 1.0 kHz$			75	$\mu mhos$
C_{iss}	Input Capacitance	$V_{DS} = 15 V, V_{GS} = 0, f = 1.0 MHz$		5.0	7.0	pF
C_{rss}	Reverse Transfer Capacitance	$V_{DS} = 15 V, V_{GS} = 0, f = 1.0 MHz$		1.0	2.0	pF
NF	Noise Figure	$V_{DS} = 15 V, V_{GS} = 0,$ $R_G = 1.0 megohm, f = 100 Hz,$ $BW = 1.0 Hz$		1.0	2.5	dB
e_n	Equivalent Short-Circuit Input Noise Voltage	$V_{DS} = 15 V, V_{GS} = 0, f = 100 Hz,$ $BW = 1.0 Hz$		60	115	nV/\sqrt{Hz}

*Pulse Test: Pulse Width $\leq 300 ms$, Duty Cycle $\leq 2\%$

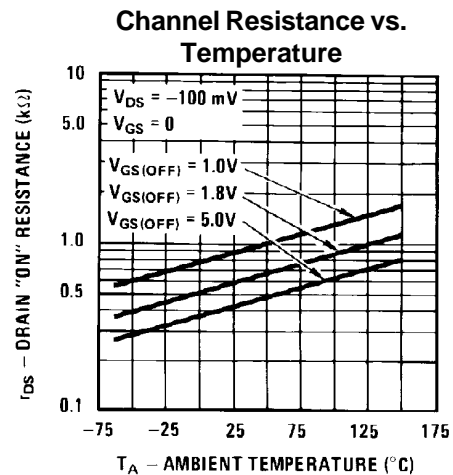
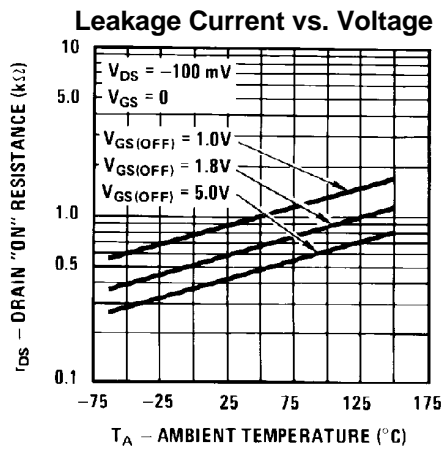
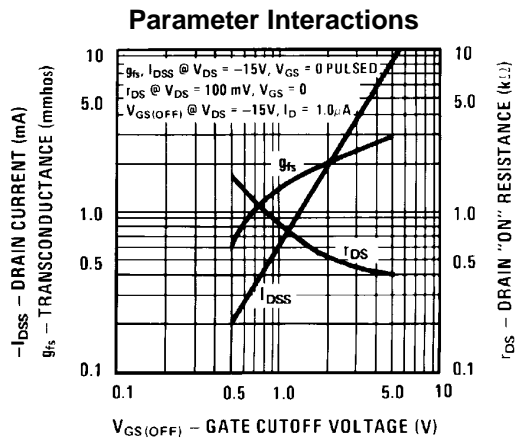
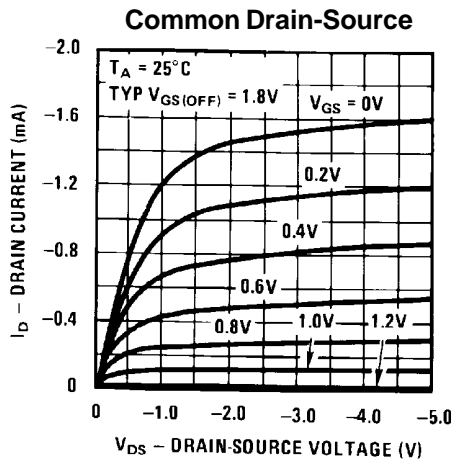
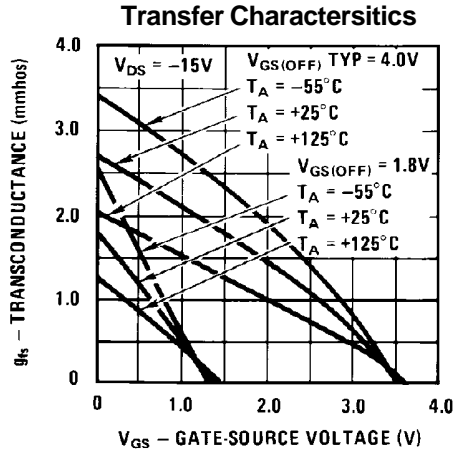
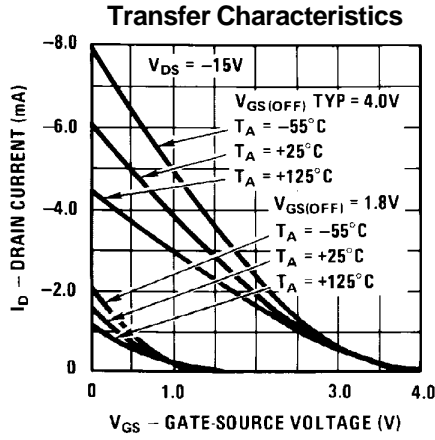
2N5460 / 5461 / 5462 / MMBF5460 / MMBF5461 / MMBF5462

P-Channel General Purpose Amplifier

(continued)

2N5460 / 5461 / 5462 / MMBF5460 / MMBF5461 / MMBF5462

Typical Characteristics (continued)



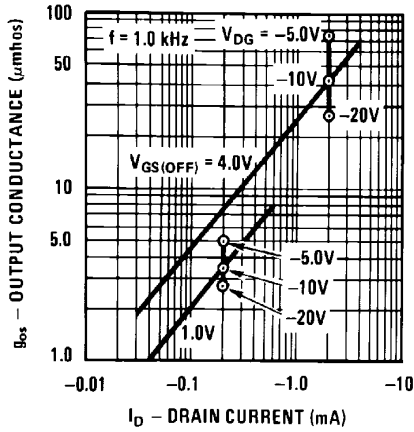
P-Channel General Purpose Amplifier

(continued)

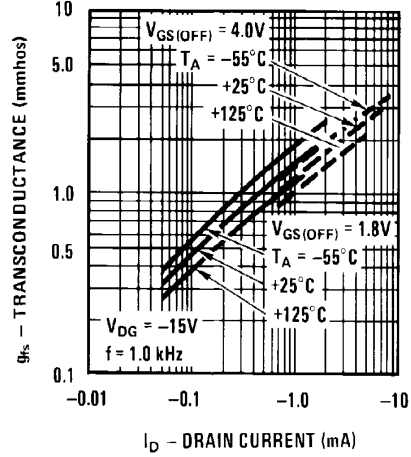
2N5460 / 5461 / 5462 / MMBF5460 / MMBF5461 / MMBF5462

Typical Characteristics (continued)

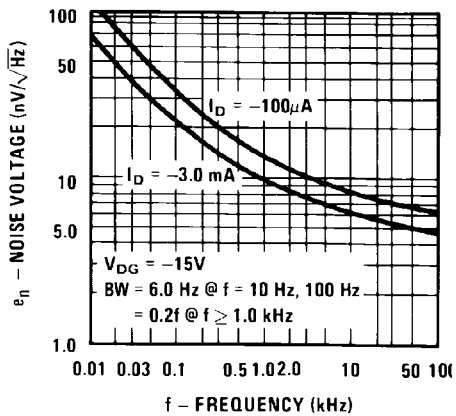
Output Conductance vs. Drain Current



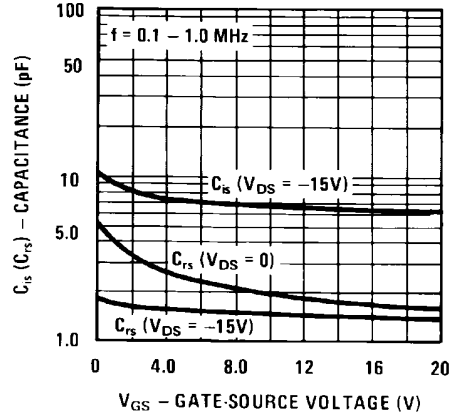
Transconductance vs. Drain Current



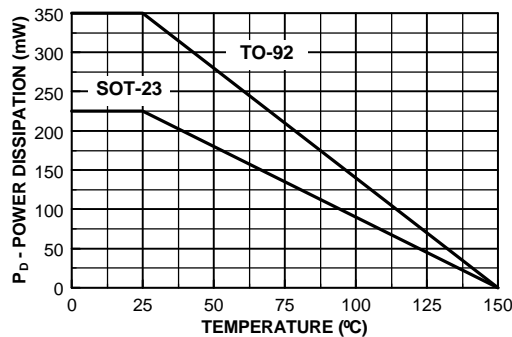
Noise Voltage vs. Frequency



Capacitance vs. Voltage



Power Dissipation vs. Ambient Temperature



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Bottomless TM	FAST _r TM	PACMAN TM	SuperSOT TM -6
CoolFET TM	FRFET TM	POP TM	SuperSOT TM -8
CROSSVOLT TM	GlobalOptoisolator TM	PowerTrench [®]	SyncFET TM
DenseTrench TM	GTO TM	QFET TM	TinyLogic TM
DOMET TM	HiSeC TM	QS TM	UHC TM
EcoSPARK TM	ISOPLANAR TM	QT Optoelectronics TM	UltraFET [®]
E ² CMOS TM	LittleFET TM	Quiet Series TM	VCX TM
EnSigna TM	MicroFET TM	SILENT SWITCHER [®]	
FACT TM	MICROWIRE TM	SMART START TM	
FACT Quiet Series TM	OPTOLOGIC TM	Stealth TM	

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2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

PRODUCT STATUS DEFINITIONS

Definition of Terms

Datasheet Identification	Product Status	Definition
Advance Information	Formative or In Design	This datasheet contains the design specifications for product development. Specifications may change in any manner without notice.
Preliminary	First Production	This datasheet contains preliminary data, and supplementary data will be published at a later date. Fairchild Semiconductor reserves the right to make changes at any time without notice in order to improve design.
No Identification Needed	Full Production	This datasheet contains final specifications. Fairchild Semiconductor reserves the right to make changes at any time without notice in order to improve design.
Obsolete	Not In Production	This datasheet contains specifications on a product that has been discontinued by Fairchild semiconductor. The datasheet is printed for reference information only.



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[HP 4815A Manual](#)

HP has a good manual, which can be downloaded in PDF format here:

[HP 4815A Manual](#)

[HP4815A-probe section](#)

Rev. 1

March 18, 2004

WALLA WALLA COLLEGE

KittDa@wwc.edu



OPERATING AND SERVICE MANUAL

MODEL 4815A
RF VECTOR IMPEDANCE METER

SERIALS PREFIXED 631

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Green Pond Road Rockaway, New Jersey, U. S. A.

Table 1-1. Specifications

FREQUENCY	RECORDER OUTPUTS
<p>Range: 500 kHz to 108 MHz in five bands: 500 kHz to 1.5 MHz, 1.5 to 4.5 MHz, 4.5 to 14 MHz, 14 to 35 MHz, 35 to 108 MHz.</p> <p>Accuracy: ±2% of reading, ±1% of reading at 1.592 and 15.92 MHz.</p> <p>RF monitor output: 150 mV minimum into 50 ohms.</p>	<p>Frequency: 0 to 1 volt from 0 to 1K ohm source, proportional to dial rotation.</p> <p>Impedance magnitude: 0 to 1 volt from 1K ohm source.</p> <p>Phase angle: 0 ± 0.9 volt from 1K ohm source.</p>
IMPEDANCE MAGNITUDE MEASUREMENT	ACCESSORIES FURNISHED:
<p>Range: 1 ohm to 100K ohms; full-scale ranges: 10, 30, 100, 300, 1K, 3K, 10K, 30K, 100K ohms.</p> <p>Accuracy: ±4% of full scale ± $(\frac{f}{30 \text{ MHz}} + \frac{Z}{25 \text{ K}\Omega})\%$ of reading, where f = frequency in MHz and Z in ohms; reading includes probe residual impedance.</p> <p>Calibration: linear meter scale with increments 2% of full scale.</p>	<ol style="list-style-type: none"> 00600A Accessory Kit. Rack Mounting Kit. Plugin board extender.
PHASE ANGLE MEASUREMENT	DIMENSIONS:
<p>Range: 0 to 360° in two ranges: 0 ± 90°, 180° ± 90°.</p> <p>Accuracy: ± $(3 + \frac{f}{30 \text{ MHz}} + \frac{Z}{25 \text{ K}\Omega})$ degrees; where f = frequency in MHz and Z is in ohms.</p> <p>Calibration: increments of 2°.</p> <p>Adjustments: front panel screwdriver adjustments for Magnitude and Phase Zero.</p>	<p>NOTES: (A) DIMENSIONS IN INCHES AND (MILLIMETERS). (B) REAR APRON RECESS. (C) DETACHABLE POWER CABLE. (D) RECOMMENDED CABLE CLEARANCE.</p>
	<p>WEIGHT: net 39 lbs. (17,6 kg), shipping 50 lbs. (22,5 kg).</p> <p>POWER: 105 to 125 v or 210 to 250 v, 50 to 400 Hz, 50 w.</p>

Table 1-2. Additional Information

MEASURING TERMINAL CHARACTERISTICS	RFI CHARACTERISTICS
<p>Configuration: Both excitation and measuring circuits are contained in a single sampling probe attached to instrument by a cable. Measurement is made between probe center pin and ground pin on probe case.</p> <p>Residuals: indicated impedance includes approximately 0.5 ohm resistance and 8 nH inductance in series with the unknown, and 0.3 pF capacitance in parallel with the unknown.</p> <p>Impedance: 25 ohms in series with 0.01 μF, looking into probe. Probe is constant-current driving source to circuit being measured.</p>	<p>External oscillator input: Rear BNC connector accepts excitation signal, 100 mV ±10% into 50 ohms; maximum instantaneous rate of change 1 MHz/s.</p>
TEST SIGNAL CHARACTERISTICS	SELF-CONTAINED CALIBRATION
<p>Waveshape: sinusoidal.</p> <p>Level: approximately 4 μA on all ranges except 10-ohm scale where it is approximately 13 μA.</p>	<p>Probe check: 100 ohms ±.5% at phase angle of 0° ± 2°.</p>

SECTION I

GENERAL INFORMATION

1-1. DESCRIPTION.

1-2. The Model 4815A RF Vector Impedance Meter (Figure 1-1) is a general purpose, self-contained instrument for measuring complex impedance in a wide variety of laboratory applications as well as production testing of circuits and components. The frequency range is 0.5 to 108 MHz; impedance magnitude is measured in 9 ranges from 10 Ω to 100 K Ω full scale; and phase angle between 0° and 360° is indicated on two ranges.

1-3. Impedance measurement is made at the tip of a probe that is at the end of a 5 ft. cable, with rf test signal and measuring circuits brought close to the probe tip to reduce residual impedances.

1-4. An internal rf oscillator, 0.5 to 108 MHz supplies a test signal to the unknown impedance, 12.6 μ a on the 10 ohm range and 4 μ a on all other ranges. Provision is made for using an external rf source, particularly useful when measuring quartz crystals and other high Q devices.

1-5. Dc voltages proportional to magnitude, phase and frequency are available at the rear panel for recording equipment.

1-6. Complete specifications are given in Table 1-1.

1-7. Additional information on the Model 4815A is given in Table 1-2. The characteristics are general design parameters that are useful in the application of the Impedance Meter.

1-8. ACCESSORIES FURNISHED.

1-9. Accessory kit number 00600A is supplied with the 4815A. The kit consists of adapters for probe to BNC and Type N connectors, a probe socket for use on circuit boards, a component mounting adapter, probe holder, probe ground assembly and center pins. The probe accessories are described in detail in Paragraphs 1-9 to 1-16 and shown in Figure 1-1 and 1-2. Also supplied is a rack mounting kit with hardware (-hp- Stock No. 5060-0776) and a circuit board extender for servicing.

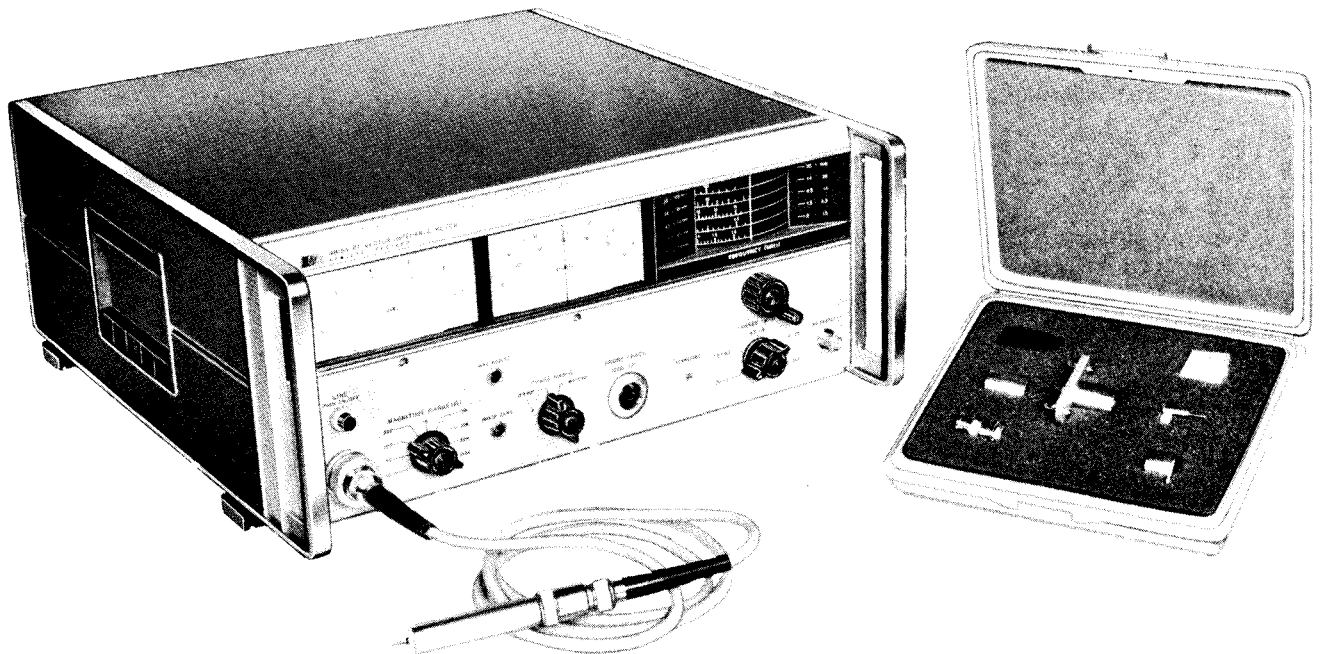


Figure 1-1. Model 4815A RF Vector Impedance Meter with 00600A Probe Accessory Kit

Paragraphs 1-10 to 1-21

1-10. **PROBE ADAPTER.** This adapter converts the probe tip to a male type N connector and is available under accessory number 10206A.

1-11. **PROBE TO BNC ADAPTER.** With the use of the 10207A accessory, this adapter converts the probe tip to a male BNC connector and is available under accessory number 10207A.

1-12. **PROBE SOCKET.** This socket supports the probe and guides the center pin to the test point. An excellent ground return is obtained with the socket, which is available under accessory number 10210A.

1-13. **COMPONENT MOUNTING ADAPTER.** This adapter allows many types of components to be measured with minimum addition of residual impedance to affect measurements, and is separately available as accessory number 00601A.

1-14. **PROBE GROUND ASSEMBLY** is a grounding device that may be positioned at a convenient point on the probe barrel. A spring-loaded pin makes ground contact. This accessory is available as -hp- Stock No. 187B-21A-8.

1-15. **PROBE CENTER PINS.** Six additional center pins are supplied against possible damage or loss. The small-diameter end of the center pin is inserted into the mating jack in the probe tip.

1-16. **PROBE HOLDER.** This accessory clips onto the front handle of the 4815A to hold the probe when not in use, and is available separately as -hp- Stock No. 5040-0404

1-17. ACCESSORIES AVAILABLE.

1-18. **SHIELDED BANANA PLUGS TO FEMALE BNC.** This adapter converts banana post inputs to shielded BNC, and is available as accessory 10111A. The adapter has approximately 10 pF shunt capacity.

1-19. INSTRUMENT IDENTIFICATION.

1-20. Each Model 4815A is identified by an eight-digit (000-00000) serial number on the rear panel. The five digit number is an identification number unique to each instrument and the three digit number is a serial prefix number used to document changes.

1-21. All instruments with the same serial prefix are the same. The group of instruments to which this manual applies directly is identified on the title page. For instruments with serial numbers higher than those listed on the title page, a Manual Change sheet describing the changes is included with the manual. The manual for an instrument having special electrical modifications will include an insert sheet describing that modification. If a change sheet or special information sheet is missing, the information can be supplied by any Hewlett-Packard Sales and Service Office listed at the back of this manual.

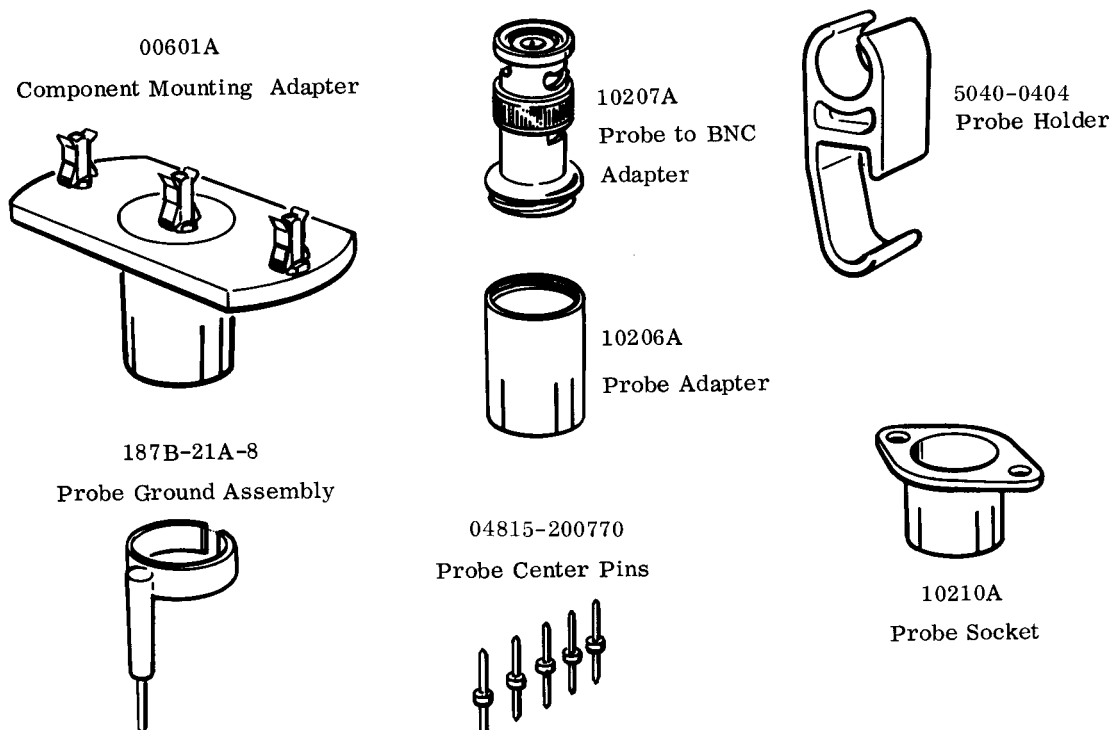


Figure 1-2. Probe Accessories

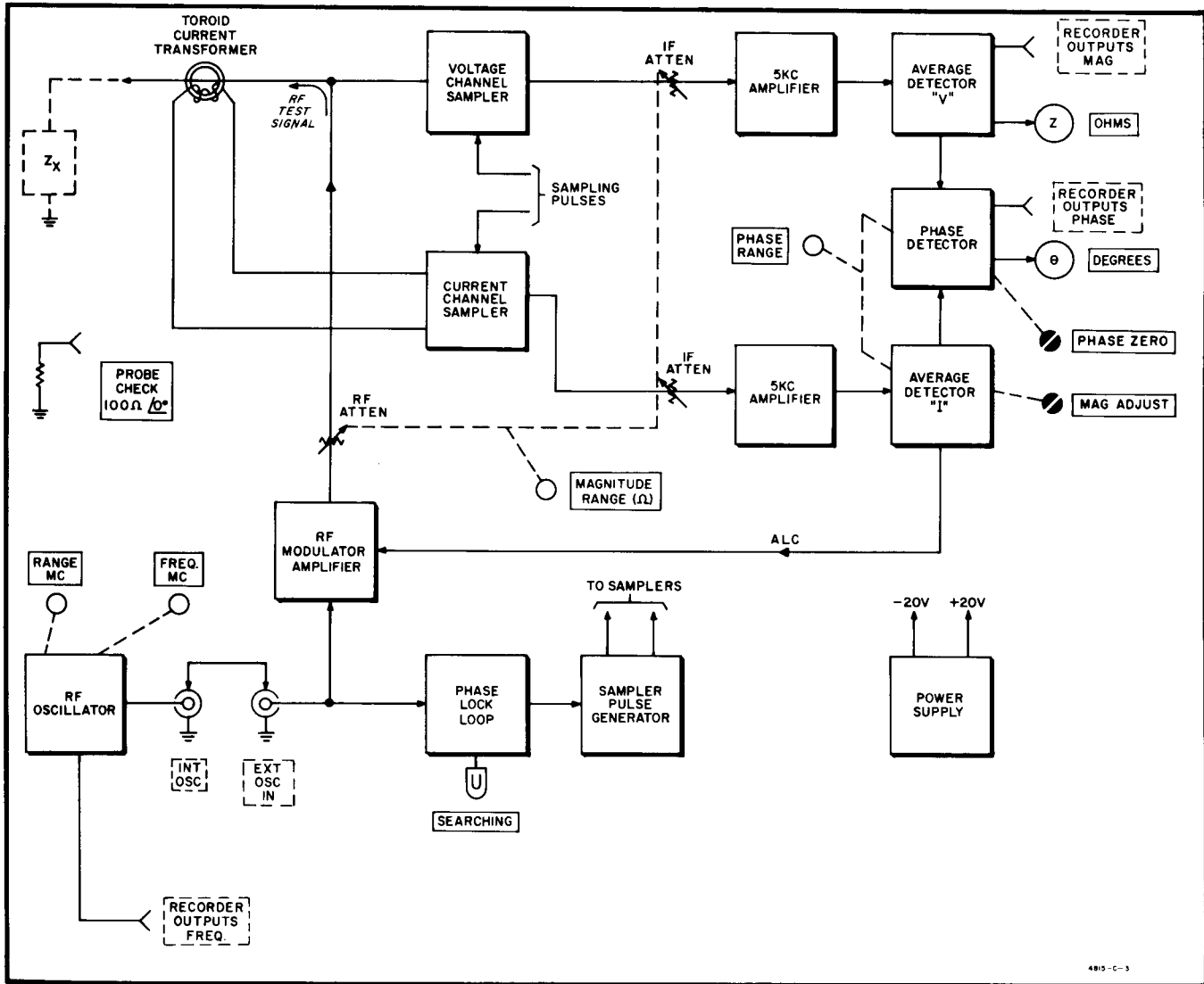
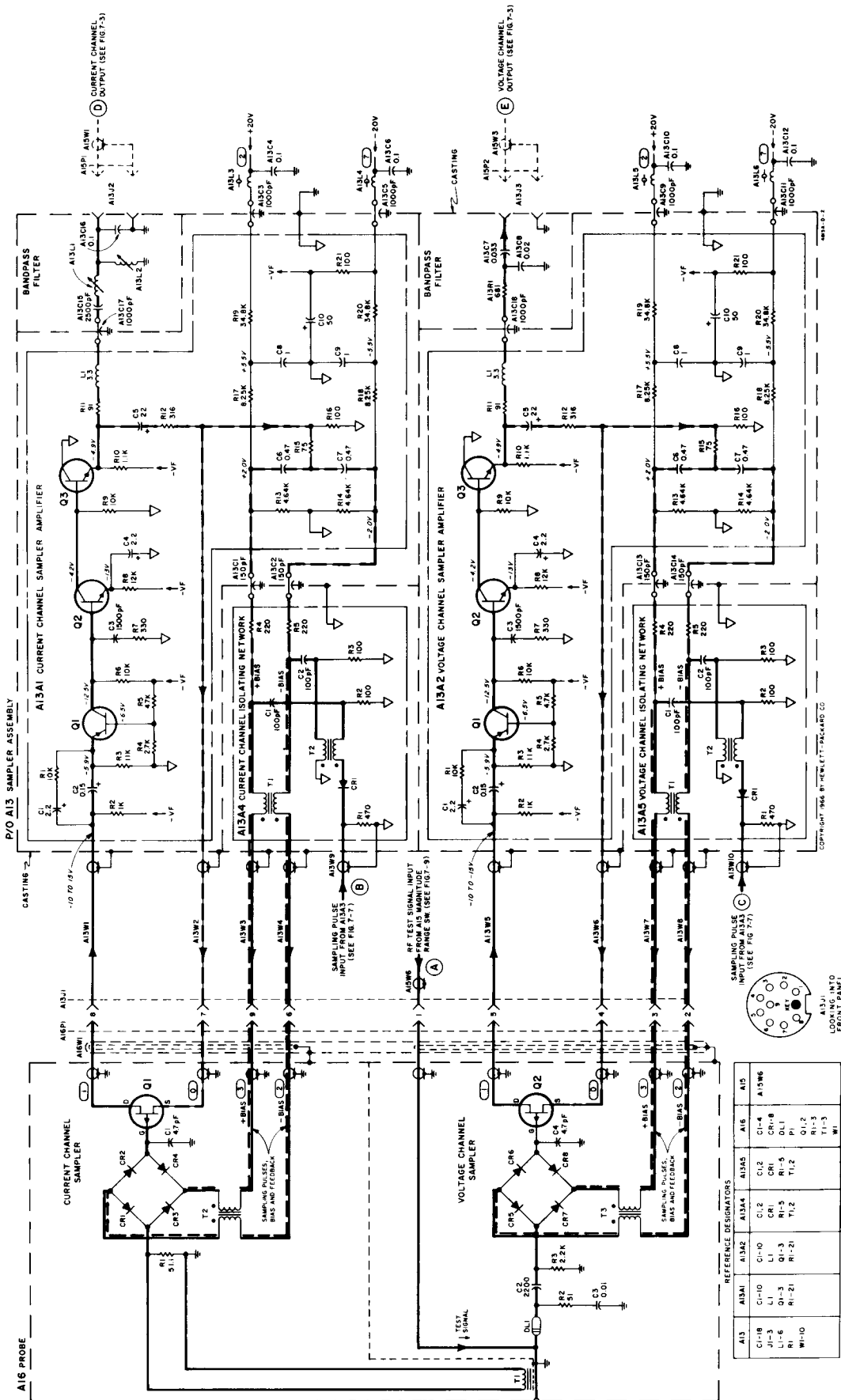


Figure 4-1. Simplified Overall Block Diagram.



4815A - PROBE & SAMPLER AMPS

Figure 4-3. Probe and Sampler Circuits (sheet 2 of 2)



Results

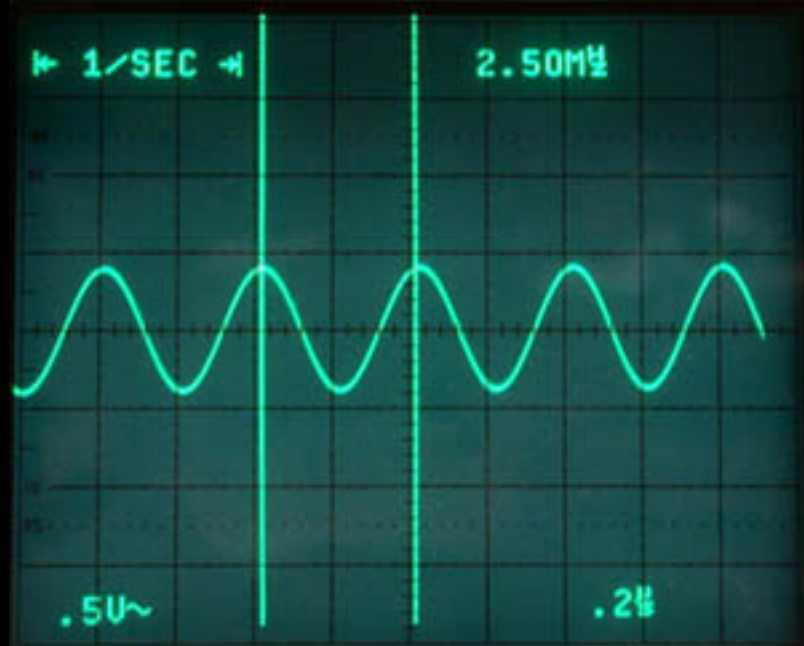
We didn't complete the project, but we did get some promising results from our work. Our magnitude measurements came out fairly well, being off by a constant. Our phase was also quite constant, being off by 60 degrees.

The magnitude and phase, as output by the HP4815A were:

At 0.5 MHz:

Resistor Value	Meter Reading	Phase
100 kohms	21 kohms	-60 °
10 kohms	2.1 kohms	-60 °
1 kohms	200 ohms	-60 °
100 ohms	21 ohms	-60 °

Here are some picuters of our output through the load:



Oscillator Output



Sampling Pulses



Current sampling board



Voltage sampling board

Notice the significant number of coax coming off the board

Advice: make a bigger board with better connections

Rev. 1
March 18, 2004

