3 cup

MASTER

**Kansas City
Division**

REPRODUCTION OF THIS DOCUMENT IS PROHIBITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

UC-38

MASTER

HIGH FREQUENCY
PARAMETER
TECHNIQUES

BDX-613-347

March, 1971

Prepared by:
Dennis C. Martin
Department 863

PDO 6984496
Final Report

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Technical Communications

**Kansas City
Division**

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

leg

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

This report was

Prepared by:

Dennis C. Martin

Dennis C. Martin
D/863

Approved by:

Donald D. Peterson

Donald D. Peterson
D/863

Contributor:

E. R. Elmer
D/863

THE BENDIX CORPORATION
KANSAS CITY DIVISION
KANSAS CITY, MISSOURI

A prime contractor for the Atomic Energy Commission
Contract Number AT(29-1)-613 USAEC

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

ABSTRACT

This report discusses the theory, the conversion factors, and operating procedures involved in measuring the scattering parameters for high frequency representation of transistors. The Hewlett-Packard test system is discussed as a potential s-parameter measurement tool.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

CONTENTS

Section	Page
SUMMARY	11
DISCUSSION	13
HYBRID PARAMETERS	13
TWO-PORT S-PARAMETERS	16
CONVERSION OF S-PARAMETERS TO h-PARAMETERS	25
EVALUATION OF SOME ACTUAL DEVICES	25
BIBLIOGRAPHY	27
APPENDICES	
A. THE HEWLETT-PACKARD MEASUREMENT SYSTEM . .	A-1
B. COMPUTER PROGRAM FOR CONVERTING S-PARAMETERS TO h-PARAMETERS	B-1
C. COMPUTER PRINTOUT SHOWING SOME OF THE VALUES MEASURED ON TWO DEVICES	C-1
D. HISTOGRAMS OF h_{fe} MEASUREMENTS FOR 2N918 AND GRAPHS OF h-PARAMETER MEASUREMENTS FOR 2N5913	D-1
DISTRIBUTION	D-7

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

ILLUSTRATIONS

Figure		Page
1	Common Emitter Equivalent Circuit	14
2	Measurement of h_{fe} and h_{oe} From Transistor Characteristics	17
3	Representation of the Measurement of S-Parameters	22
A-1	Representation of the Measurement System of the Hewlett-Packard 8745A	A-2

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

SUMMARY

Hybrid (h) parameters cannot be accurately measured at frequencies above 100 megahertz (MHZ) since effective opens and shorts are hard to obtain and short circuits frequently cause oscillation in the device being measured. A different set of parameters developed for high frequency measurements can be used to represent a transistor. These are known as scattering or s-parameters. Direct mathematical relationships exist between scattering and hybrid parameters so that hybrid values can be calculated from measurable scattering values.¹

The purpose of this project was to develop the theory, conversion factors, and operating procedures involved in determining the h-parameters of transistors by measuring their scattering or s-parameters. The Hewlett-Packard s-parameter measurement system was used.

¹"Transistor Parameter Measurements," Hewlett-Packard Application Note 77-1, February 1, 1967, p. 2.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

DISCUSSION

HYBRID PARAMETERS

Hybrid parameters and scattering parameters are both derived from the representation of a transistor as a two-port device. Hybrid parameters are the coefficients of two equations: one equation representing the voltage at the input port written as a function of the input current and output voltage; the other equation representing the current at the output port as a function of input current and output voltage. These equations are expressed below in matrix form. The coefficient matrix is called the [h] matrix.

$$\begin{bmatrix} V_{in} \\ I_{out} \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} I_{in} \\ V_{out} \end{bmatrix}$$

The four h-parameters are:

1. h_{11} = Short Circuit Input Impedance
2. h_{12} = Open Circuit Reverse Voltage Transfer Ratio
3. h_{21} = Short Circuit Forward Current Transfer Ratio
4. h_{22} = Open Circuit Output Admittance

Proper convention is to subscript the coefficients, or h-parameters, with an i, r, f, or o for input, reverse, forward, or output; with an e for common emitter configuration; a c for common collector; or a b for common base. The most commonly used hybrid parameters are common emitter and these will be considered here.

The two equations are represented in Figure 1 by a common emitter equivalent circuit composed of direct current components.

Figure 1. Common Emitter Equivalent Circuit

The two equations are written as below for the common emitter case.

$$\begin{bmatrix} V_{be} \\ I_c \end{bmatrix} = \begin{bmatrix} h_{ie} & h_{re} \\ h_{fe} & h_{oe} \end{bmatrix} \begin{bmatrix} I_b \\ V_{ce} \end{bmatrix}$$

Hybrid parameter values are functions of both dc bias point and frequency. Values are measured by varying the respective driving parameter over small excursions from the dc bias point while holding another driving parameter constant and at the same time monitoring a third driving parameter. The procedure can be illustrated by differentiating the defining equations for the h-parameters while holding one parameter constant:

From the above matrix,

$$V_{be} = h_{ie} I_b + h_{re} V_{ce}$$

$$I_c = h_{fe} I_b + h_{oe} V_{ce} ;$$

If $V_{ce} = \text{Constant}$, then

$$dV_{be} = h_{ie} dI_b + 0$$

$$dI_c = h_{fe} dI_b + 0 .$$

If $I_b = \text{Constant}$, then

$$dV_{be} = 0 + h_{re} dV_{ce}$$

$$dI_c = 0 + h_{oe} dV_{ce}$$

Hence:

$$h_{ie} = \left. \frac{dV_{be}}{dI_b} \right|_{V_{ce} = \text{Constant}} \quad (\text{Effectively Shorting the Output})$$

$$h_{re} = \left. \frac{dV_{be}}{dV_{ce}} \right|_{I_b = \text{Constant}} \quad (\text{Effectively Opening the Input})$$

$$h_{fe} = \left. \frac{dI_c}{dI_b} \right|_{V_{ce} = \text{Constant}} \quad (\text{Effectively Shorting the Output})$$

and,

$$h_{oe} = \left. \frac{dI_c}{dV_{ce}} \right|_{I_b = \text{Constant}} \quad (\text{Effectively Opening the Input}).$$

These expressions are represented in Figure 2 on typical operating curves at some frequency of interest $[f]$.

Reactive devices are used to obtain well defined opens and shorts at certain frequencies of interest; however, this becomes increasingly difficult to accomplish at frequencies above 100 MHz. Another difficulty at higher frequencies is that some transistors tend to oscillate when short circuited.

TWO-PORT S-PARAMETERS

Scattering parameters above 1 GHz are desirable since the measurement system overcomes the following basic difficulties.²

1. Tuning and dc bias networks may be reactive in nature and tend to oscillate. The use of slide-screw tuners and characterization of the device in terms of the s-parameters alleviates the problem.
2. Direct broadband measurement of hybrid parameters is difficult since the resonant circuits which produce the effective short and open conditions are very sensitive to frequency and make broadband sweep measurements impossible. Broadband 50 Ω systems incorporating standard components are available and s-parameters are measured with these systems.
3. The sources of error above 1 GHz are multiplied and measurement systems must aid the operator in consistent and accurate calibration. The s-parameter test set-up provides consistently accurate measurements.

Figure 3 illustrates the transistor as a two-port device and shows a simplified measurement system.

² Julius Lange, "Microwave Transistor Characterization Including S-Parameters," S-Parameters: Circuit Analysis and Design, Hewlett-Packard Application Note 95, September, 1968, pp. 1-1 through 1-13.

From Transistor's Input Characteristics

$$h_{ie} = \left. \frac{\Delta V_{BEi}}{\Delta I_{Bi}} \right|_{V_{CE} = \text{Constant} = V_{CE3}}$$

$$h_{re} = \left. \frac{\Delta V_{BEr}}{\Delta V_{CEr}} \right|_{I_B = \text{Constant}} = \left. \frac{\Delta V_{BEr}}{V_{CE4} - V_{CE2}} \right|_{I_B = I_{Br}}$$

Figure 2. Measurement of h_{fe} and h_{oe} From Transistor Characteristics

From Transistor's Output Characteristics

$$h_{fe} = \left. \frac{\Delta I_{Cf}}{\Delta I_{Bf}} \right|_{V_{CE} = \text{Constant}} = \left. \frac{\Delta I_{Cf}}{I_{B4} - I_{B2}} \right|_{V_{CE} = V_{CEf}}$$

$$h_{oe} = \frac{\Delta I_{Co}}{\Delta V_{CEo}} \quad I_B = \text{Constant} = I_{B3}$$

Figure 2 Continued. Measurement of h_{fe} and h_{oe} From Transistor Characteristics

Z = Characteristic Line Impedance = 50Ω

V_{in} = Input Voltage at Input Port

I_{in} = Input Current at Input Port

V_{out} = Output Voltage at Output Port

I_{out} = Output Current at Output Port

The four transmission parameters are defined below:³

a_{in} = Incident Wave at Input Port

$$= 1/2 \left(\frac{V_{in}}{\sqrt{Z_o}} + \sqrt{Z_o} I_{in} \right)$$

b_{in} = Reflected Wave at Input Port

$$= 1/2 \left(\frac{V_{in}}{\sqrt{Z_o}} - \sqrt{Z_o} I_{in} \right)$$

a_{out} = Incident Wave at Output Port

$$= 1/2 \left(\frac{V_{out}}{\sqrt{Z_o}} + \sqrt{Z_o} I_{out} \right)$$

b_{out} = Reflected Wave at Output Port

$$= 1/2 \left(\frac{V_{out}}{\sqrt{Z_o}} - \sqrt{Z_o} I_{out} \right)$$

From these transmission parameters, the s-parameters, or coefficients of the equations representing the transistor as a two-port network, can be defined.

³Fritz K. Weinert, "Scattering Parameters Speed Design of High Frequency Transistor Circuits," Electronics, September 5, 1966.

The two equations representing the network are:

$$\begin{bmatrix} b_{in} \\ b_{out} \end{bmatrix} = \begin{bmatrix} s_{11} & s_{12} \\ s_{21} & s_{22} \end{bmatrix} \begin{bmatrix} a_{in} \\ a_{out} \end{bmatrix}$$

Scattering parameters are dimensionless, complex number quantities. They have both magnitude and phase.

Therefore:

MAGNITUDE

PHASE

$$\begin{aligned} \left| s_{11} \right| &= \left| \frac{b_{in}}{a_{in}} \right| \quad a_{out} = 0; & \text{ARG}(s_{11}) &= \text{ARG} \left(\frac{b_{in}}{a_{in}} \right) \quad a_{out} = 0 \\ \left| s_{12} \right| &= \left| \frac{b_{in}}{a_{out}} \right| \quad a_{in} = 0; & \text{ARG}(s_{12}) &= \text{ARG} \left(\frac{b_{in}}{a_{out}} \right) \quad a_{in} = 0 \\ \left| s_{21} \right| &= \left| \frac{b_{out}}{a_{in}} \right| \quad a_{out} = 0; & \text{ARG}(s_{21}) &= \text{ARG} \left(\frac{b_{out}}{a_{in}} \right) \quad a_{out} = 0 \\ \left| s_{22} \right| &= \left| \frac{b_{out}}{a_{out}} \right| \quad a_{in} = 0; & \text{ARG}(s_{22}) &= \text{ARG} \left(\frac{b_{out}}{a_{out}} \right) \quad a_{in} = 0 \end{aligned}$$

The coefficient matrix is called the [s] matrix. The four s-parameters are:

1. s_{11} = Input Reflection Coefficient
2. s_{12} = Reverse Transmission Coefficient
3. s_{21} = Forward Transmission Coefficient
4. s_{22} = Output Reflection Coefficient

Scattering parameters are measured with the following mathematical interpretation. The driving point impedances can be represented as:

$$Z_{in} = \frac{V_{in}}{I_{in}} ; \quad Z_{out} = \frac{V_{out}}{I_{out}} .$$

Where the source and load impedances are made equal to Z_o (50Ω) as shown in Figure 3, $a_{out} = 0$ and $a_{in} = 0$.

Then, with switches at A in Figure 3,

$$s_{11} = \left. \frac{b_{in}}{a_{in}} \right|_{a_{out} = 0} = \frac{1/2 [(V_{in} / \sqrt{Z_o}) - \sqrt{Z_o} I_{in}]}{1/2 [(V_{in} / \sqrt{Z_o}) + \sqrt{Z_o} I_{in}]} \\ = \left| \frac{Z_{in} - Z_o}{Z_{in} + Z_o} \right| \frac{\left(\frac{Z_{out} - Z_o}{Z_{in} + Z_o} \right)}{\angle \text{ARG} \left(\frac{Z_{out} - Z_o}{Z_{in} + Z_o} \right)}$$

and, with switches at B in Figure 3,

$$s_{22} = \left. \frac{b_{out}}{a_{out}} \right|_{a_{in} = 0} = \frac{1/2 [(V_{out} / \sqrt{Z_o}) - \sqrt{Z_o} I_{out}]}{1/2 [(V_{out} / \sqrt{Z_o}) + \sqrt{Z_o} I_{out}]} \\ = \left| \frac{Z_{out} - Z_o}{Z_{out} + Z_o} \right| \frac{\left(\frac{Z_{out} - Z_o}{Z_{out} + Z_o} \right)}{\angle \text{ARG} \left(\frac{Z_{out} - Z_o}{Z_{out} + Z_o} \right)}$$

With the switches thrown at A, $a_{out} = 0$, while a_{in} is found as follows:

By Kirchhoff's Voltage Law (KVL), $E_{g1} = I_{in} Z_o$

$$\text{and, } a_{in} = 1/2 \left(\frac{V_{in}}{\sqrt{Z_o}} + \sqrt{Z_o} I_{in} \right) = \frac{1}{2\sqrt{Z_o}} (V_{in} + Z_o I_{in})$$

$$a_{in} = \frac{E_{g1}}{2\sqrt{Z_o}} .$$

b_{out} is found as follows:

$$a_{out} = 0 = 1/2 \left(\frac{V_{out}}{\sqrt{Z_o}} + \sqrt{Z_o} I_{out} \right) .$$

Figure 3. Representation of the Measurement of S-Parameters

Then,

$$\frac{V_{out}}{\sqrt{Z_o}} = -\sqrt{Z_o} I_{out}$$

and,

$$b_{out} = 1/2 \left(\frac{V_{out}}{\sqrt{Z_o}} - \sqrt{Z_o} I_{out} \right)$$

$$b_{out} = \frac{V_{out}}{\sqrt{Z_o}} .$$

Then s_{21} becomes

$$s_{21} = \left. \frac{b_{out}}{a_{in}} \right|_{a_{out} = 0} = \frac{V_{out} / \sqrt{Z_o}}{E_{g1} / 2\sqrt{Z_o}} = \left| \frac{V_{out}}{2E_{g1}} \right| \angle \text{ARG} \left(\frac{V_{out}}{2E_{g1}} \right) .$$

With the switches thrown at B, $a_{in} = 0$, while a_{out} is found as follows:

By KVL, $E_{g2} = V_{out} + I_{out} Z_o$

$$a_{out} = 1/2 \left(\frac{V_{out}}{\sqrt{Z_o}} + \sqrt{Z_o} I_{out} \right) = 1/2 \sqrt{Z_o} (V_{out} + I_{out} Z_o)$$

$$a_{out} = \frac{E_{g2}}{2 \sqrt{Z_o}} .$$

b_{in} is found as follows:

$$a_{in} = 0 = 1/2 \left(\frac{V_{in}}{\sqrt{Z_o}} + \sqrt{Z_o} I_{in} \right) .$$

Then,

$$\frac{V_{in}}{\sqrt{Z_o}} = -\sqrt{Z_o} I_{in}$$

and,

$$b_{in} = 1/2 \left(\frac{V_{in}}{\sqrt{Z_o}} - \sqrt{Z_o} I_{in} \right)$$

$$b_{in} = \frac{V_{in}}{\sqrt{Z_o}} .$$

Then s_{12} becomes

$$s_{12} = \left. \frac{b_{in}}{a_{out}} \right|_{a_{in} = 0} = \frac{V_{in} / \sqrt{Z_o}}{E_{g2} / 2\sqrt{Z_o}} = \frac{V_{in}}{2E_{g2}} \frac{1}{\text{ARG} \left(\frac{V_{in}}{2E_{g2}} \right)} .$$

Scattering parameter measurements can be outlined as follows:

1. s_{11} and s_{22} are equal to the voltage reflection coefficients when line, source, and load impedances are equal. They are actually the power reflection coefficients.
2. s_{12} and s_{21} become a voltage ratio when line, source, and load impedances are equal. They are actually the square roots of the power absorbed in the load divided by the source power available (square roots of transducer power gain).
3. The measurement system consists of transmission lines used to connect the two ports of the device to matched load and source impedances and equipment for recording the voltage reflection and voltage ratios.

CONVERSION OF S-PARAMETERS TO h-PARAMETERS

The equations of h-parameters and s-parameters can be solved simultaneously to yield the following relationships:⁴

$$h_{11} = \frac{(1 + s_{11})(1 + s_{22}) - s_{12}s_{21}}{(1 - s_{11})(1 + s_{22}) + s_{12}s_{21}} \times Z_o$$

$$h_{12} = \frac{2s_{12}}{(1 - s_{11})(1 + s_{22}) + s_{12}s_{21}}$$

$$h_{21} = \frac{-2s_{21}}{(1 - s_{11})(1 + s_{22}) + s_{12}s_{21}}$$

$$h_{22} = \frac{(1 - s_{22})(1 - s_{11}) - s_{12}s_{21}}{Z_o [(1 - s_{11})(1 + s_{22}) + s_{12}s_{21}]}$$

All variables are complex and mathematical solution by hand is time consuming. Therefore, a computer program was written to perform the above computations (Appendix B). Not only does this program perform the above computations, it converts the inputs from decibels and degrees into the proper units to make the computations possible. This means that readings from the Hewlett-Packard measurement system (Appendix A) may be fed into the computer without change. Output from this program includes a holerith printout for each type of configuration (common emitter, base, or collector), device name, serial number, frequency, s-parameters in both polar and rectangular forms, and the corresponding h-parameters, with proper units where applicable, in both polar and rectangular forms.

EVALUATION OF SOME ACTUAL DEVICES

Several types of devices were used in the evaluation of the Hewlett-Packard measurement system discussed in Appendix A: the 2N5913 (RCA) NPN and

⁴"S-Parameter Techniques for Faster, More Accurate Network Design," Hewlett-Packard Journal, Volume 18, No. 6, February, 1967.

the 2N918 (Fairchild) NPN. Both transistors are designed for use at frequencies in the kilomegahertz region. Typical results (Appendices C and D) were obtained from tests of these devices at several frequencies.

Bias conditions for the two devices were as follows.

2N5913 $V_{ce} = +12.5$ volts

$I_c = +100$ milliamps

2N918 $V_{ce} = +5$ volts

$I_c = +10$ milliamps

Bias and RF levels were kept as nearly consistent as possible. Placement in the test socket was consistent and device lead contacts were made as short as possible.

Major sources of error in the system are impedance mismatches between elements, coupler directivity, and variations in coupling coefficient tracking. Some of these errors may be reduced by calibrating at specific frequencies and applying correction factors. For the tests conducted, calibration was accomplished at several frequencies in the range, but no correction factors were applied.

Appendix A*

THE HEWLETT-PACKARD MEASUREMENT SYSTEM

The Hewlett-Packard (HP) measurement system enables the user to make measurements in a few hours which would normally take days or weeks. The system is easy to calibrate, it enables the user to switch measurements from one parameter to another with pushbutton ease, and it features direct readout of the s-parameters in magnitude and phase.

SYSTEM COMPONENTS

The system used here was constructed of the following test equipment.

1. The HP 8745A S-PARAMETER TEST SET/0.1-2.0 GHZ. This is a composite unit that replaces open bench set-ups. A block diagram of the HP 8745A is shown in Figure A-1.
2. The HP 11600B TRANSISTOR FIXTURE for TO 18 (TO 72, TO 46, etc.) devices, or the HP 11602B for TO 5 (TO 12, etc.) devices, and SHORT and THRU terminations for calibration. These are compatible with the HP 8745A. If the HP 11599A QUICK CONNECT ADAPTOR is used, the transistor fixtures can be attached to the HP 8745A with the movement of a single lever.
3. The HP 8717A TRANSISTOR BIAS SUPPLY. This supply is compatible with both the 8745A and the transistor fixtures. Connection is made in the rear from the 8717A to the 8745A using a special HP 08717-60022 CABLE ASSEMBLY.
4. The HP 8690B SWEEP OSCILLATOR with the HP 8699B POWER LEVEL OUTPUT/0.1 to 4.0 GHZ UNIT. This signal source lets the operator observe the s-parameters throughout a range of frequencies or at one particular frequency either with marker designators or with manual sweep. A standard RG9 B/U cable is used to connect the 8745A to the 8717A.

*The material in this section is based on information presented in S-Parameter Test Set Training Manual 8745A, Hewlett-Packard, January, 1969.

Set-up for Measuring s_{11} and s_{21}

Set-up for Measuring s_{12} and s_{22}

Figure A-1. Representation of the Measurement System of the Hewlett-Packard 8745A

Reference and Test Channels During Measurement

Figure A-1 Continued. Representation of the Measurement System of the Hewlett-Packard 8745A

Reference and Test Channels During Measurement

Figure A-1 Continued. Representation of the Measurement System of the Hewlett-Packard 8745A*

*Adapted from a Hewlett-Packard Drawing

5. The HP 8410A NETWORK ANALYZER with the HP 8414A POLAR DISPLAY with overlays. This measurement source gives direct readout in magnitude and phase. Magnitude is expressed in decibels. Readings are taken using the 8414A or the 8413A PHASE GAIN INDICATOR. The 8413A has a meter-type readout.
6. Interconnection between the 8410A and the 8745A/8717A is made via the HP 8411A HARMONIC FREQUENCY CONVERTER/0.11-12.4 GHZ.
7. Other cable connections include connecting the SWEEP REFERENCE OUTPUT of the 8699B to the SWEEP REFERENCE INPUT of the 8410A and connecting the MARKER and BLANKING outputs to the 8414A or the 8413A as desired. Connections are available on both the 8414A and the 8413A for use with external oscilloscopes or X-Y recorders. Reference manuals supply information about the load limits and other capacities of these connections.

CALIBRATION PROCEDURE

This calibration procedure should be followed before measurements can be made on this system.

1. Supply power to the units and allow approximately 30 minutes warm-up time.
2. Set the REFERENCE PLANE EXTENSION on the s-parameter test set at zero.
3. Insert the polar display into the network analyzer, allow 30 minutes for warm-up, and turn the intensity very low.
4. Adjust the power level on the POWER LEVEL UNIT (8699B) to zero.
5. Attach either the TO 18 or the TO 5 transistor fixture to the 8745A. Snap on one of the dials and rotate the dial so that the HP symbol is at the bottom.
6. Depress pushbutton A or B at the INPUT PORT selection on the 8745A, depending on which colored line on the snap-on dial lines up with A or B on the transistor fixture.
7. Depress pushbutton s_{11} or s_{22} .
8. Increase the power level by rotating the knob on the 8699B unit until the reference channel meter on the network analyzer is just to the left of the operate zone. Adjust the intensity of the polar display to see the

trace. Center the trace by depressing the BEAM CTR pushbutton and adjusting the horizontal and vertical positioning controls.

9. Adjust START/CW to 250 MHZ and STOP/ Δ F to 500 MHZ on the white scales on the sweep oscillator. Set the SWEEP TIME/(SEC) to the 0.1-0.01 range and adjust the vernier of this control all the way clockwise, but not to the LINE SYNC position. Sweep time is now equal to 0.01 second.
10. Adjust the test channel gain on the network analyzer to around 20, set the sweep stability control for the range 0.25 to 0.50 GHZ, and adjust the sweep stability vernier for maximum stability on the polar display.
11. The trace which now shows up on the polar display should be arc-like. Adjust the REFERENCE PLANE EXTENSION on the s-parameter test set until the trace on the polar display goes to a dot--or nearest in appearance to a dot--for both s_{11} and s_{22} .
12. Use the phase and magnitude verniers and the test channel gain to adjust the trace so that $s_{11} = s_{22} = 1.0 \angle 0^\circ$. This means that the dot trace should lie on the outermost concentric circle and on the zero degree radial line. If s_{11} and s_{22} differ greatly, repeat steps 8 through 12 of this procedure.
13. Plug the SHORT termination into the transistor fixture which comes with the fixture so that the arrow is pointing up. Depress the s_{11} and s_{22} pushbuttons. The polar display should read $s_{11} = s_{22} \approx 1.0 \angle 180^\circ$. The OPEN and SHORT termination will agree fairly well for frequencies below 500 MHZ.
14. Reset START/CW to 750 MHZ and STOP/ Δ F to 1.5 GHZ on the 8410A. If necessary, readjust the power level on the 8699B plug-in so the needle is positioned as in Step 8. Readjust stability if necessary.
15. Adjust the REFERENCE PLANE EXTENSION slightly as in Step 11.
16. Readjust the phase and amplitude verniers if necessary for $s_{11} = s_{22} = 1 \angle 180^\circ$.
17. Remove the SHORT termination and plug in the THRU termination, which also comes with the fixture, so that the arrow is pointing up. Depress the s_{12} and s_{21} pushbuttons on the s-parameter test set. The polar display should read $s_{12} = s_{21} = 1 \angle 0^\circ$. If it does not, repeat steps 8 through 17.
18. The measurement system is now calibrated for readings on the polar display. If the 8413A PHASE GAIN INDICATOR is to be used, remove

the polar display unit and replace it with the 8413A. Repeat calibration procedure steps 12 through 18. The 6 degree and 3 decibel ranges are very sensitive; therefore, adjustments to 1 $\angle 0^\circ$ and 1 $\angle 180^\circ$ should be made as close as possible by using these ranges. Start step 12 with an open socket, and plug terminations into the fixtures as needed.

19. After calibration, the SHORT and THRU terminations are no longer needed except when recalibrating. The measurement system is now ready for use.

If any of these steps cannot be completed, check all the individual test units, cables, and connections for malfunction.

MEASUREMENT OF DEVICES

The following steps in actually measuring a device are based on measurements taken of one of the devices under consideration in this project.

Device:

Fairchild 2N918, NPN, TO 18 package.

Bias Conditions:

$V_{ce} = +5$ volts

$I_c = +10$ milliamps

Frequency = 100 megahertz

EBC base

Measurement Procedure:

1. Choose the proper snap-on dial if different from the dial used in calibration of the system. The proper dial is the EBC bipolar base which fits the TO 18 transistor fixture (which should have been chosen in the calibration procedure in anticipation of testing TO 18 devices). Snap the dial onto the fixture and rotate the letters CE to the top for measurement of common emitter parameters.
2. Push the INPUT PORT A or B button, depending on which colored line on the snap-on dial lines up with A or B on the transistor fixture. In this case the red line lines up with the A on the transistor fixture; therefore, the input port becomes A and the A button is depressed.

3. Set the transistor bias supply. In this case the controls were set as follows:

<u>Control</u>	<u>Setting</u>
TRANSISTOR	BIPOLAR NPN
OUTPUTS	NORMAL
FIXTURE CONFIGURATION	CE
LEAD CONFIGURATION	EBC
I_E -S LIMIT (MA)	50 Milliamps
METER FUNCTION (Left)	V_{CE}
RANGE (V)	10
METER FUNCTION (Right)	I_C
RANGE (MA)	10
RANGE (MA)	0.1 to 10
V_{CE} -DS AMPLIFIER	Rotated until 5 volts read on (left) meter.
BIAS ON/OFF	Depressed ON (Button illuminates in the ON position.)
I_E -S AMPLIFIER	Placed the first device to be measured in the fixture and rotated until 10 milliamps read on the (right) meter.

When changing devices, the BIAS ON/OFF button should be turned off until the next device is inserted into the fixture to avoid damaging transients.

4. Depress the s_{11} pushbutton, decrease the power level on the 8699B unit until the NETWORK ANALYZER has just enough power to operate. This will ensure that small signal parameters will be measured. Note the position of the needle on the reference CHANNEL LEVEL INDICATOR METER and make sure this position is consistent while measuring all four s-parameters.
5. Set a frequency range of interest. In START-STOP mode, the sweep generator will cause the polar display to display a trace equal to the locus of s-parameter values over the frequency range between the START/CW and STOP/ ΔF limits. Similarly, the ΔF mode will display a locus of s-parameter values. In this case, only one point, or frequency, on the locus of values is of concern. Therefore, the sweep generator was set in the START-STOP mode, with limits of 100 MHZ to 250 MHZ, for the 100 MHZ frequency under consideration. This range is compatible with, and was set for, the stability range of 0.1 to 0.25 GHZ on the NETWORK ANALYZER. The stability vernier was adjusted for maximum stability.

6. From this point, either the markers or the MANUAL mode can be used. For accuracy, an Eldorado 985 FREQUENCY COUNTER was used to set the frequency output in the MANUAL mode to 100 MHZ. The marker frequency could also have been set to 100 MHZ using the counter. These settings can be accomplished by placing the sweep generator in MANUAL mode and rotating the manual vernier control to the frequency of interest, or, if using the markers, by placing the sweep generator in AUTO mode, depressing one of the marker push-buttons, and adjusting that marker's vernier control to the frequency of interest. The counter was connected to the power level unit output on the front of the sweep generator to monitor the frequency in MANUAL mode. Connection would have been made in the rear of the sweep generator for setting the marker.

7. Either the POLAR DISPLAY or PHASE GAIN INDICATOR can be used. In this case, the MANUAL mode was used so that the PHASE GAIN INDICATOR could be used. Measurement is very simple from this point. Just depress the s_{11} , s_{12} , s_{21} , or s_{22} pushbutton and the range pushbuttons on the PHASE GAIN INDICATOR, and then read each parameter directly. If the polar display is used, it will be necessary to change the test channel gain from the setting found in calibration of the measurement system. This setting is the unity gain or zero decibel (db) level. In the case of the 2N918 transistor, this setting was 24 decibels. As an example, to read s_{12} it became necessary to increase this gain setting to 32 decibels or up 8 decibels to read the polar display with some accuracy. This means that the outermost concentric circle was moved from a value of 1.0 to a new value of 0.4 full scale ($-8 \text{ db} = 20 \text{ Log [Gain]}$. $\therefore \text{Gain} = \text{Antilog} [-0.4] = 10^{-0.4} = 10^{-1} \times 10^{0.6} = 0.1 \times 4 = 0.4$). In short, increasing the test channel gain increases sensitivity. As a second example, in order to see s_{21} on the polar display at all ($|s_{21}| > 1.0$) the setting was reduced to 10 db or down 14 db. Full scale is now 5.0 ($+14 \text{ db} = 20 \text{ Log [Gain]}$ $\therefore \text{Gain} = \text{Antilog} [0.7] = 10^{0.7} = 5.0$).

8. The readings from either the POLAR DISPLAY or PHASE GAIN INDICATOR must be converted into units of gain from decibels, and degrees must be converted to radians before the h-parameters can be calculated from the expressions relating s- and h-parameters.

In this report, the computer program was written to make the necessary conversions and calculate the h-parameters from the s-parameters in decibel-degree form data. The program is written in the XTRAN language for use with COM-SHARE terminals.

Appendix B

COMPUTER PROGRAM FOR CONVERTING S-PARAMETERS TO h-PARAMETERS (COM-SHARE TIME-SHARING, X-TRAN LANGUAGE)

```
*S-PARAMETER TO H-PARAMETER CONVERSION
DIMENSION S(100),A(100),R(100),H(100),P(100),RE(100),GM(100),FREQ(25)
DIMENSION NSER(25),X(100),Y(100),XX(100)
DISPLAY SENTER TYPE OF CONFIGURATION CODES
DISPLAY SCOMMON COLLECTOR IS CODE 1$
DISPLAY SCOMMON BASE IS CODE 2$
DISPLAY SCOMMON EMITTER IS CODE 3$
ACCEPT NC
DISPLAY SENTER LAST FOUR NUMBERS OF THE DEVICE NAMES
ACCEPT NU
DISPLAY SENTER NUMBER OF DEVICES$
ACCEPT N0
N=N0*4
DISPLAY SENTER S IN DECIBELS(FLOATING PT.),A IN DEGREES(FLOATING PT.)$
D0 40 I=1,N
40 ACCEPT S(I), A(I)
DISPLAY SENTER FREQUENCIES IN MEGAHERTZ$
D0 45 I=1,N0
45 ACCEPT FREQ(I)
DISPLAY SENTER SERIAL NUMBERS$
D0 46 I=1,N0
46 ACCEPT NSER(I)
DISPLAY SENTER THE BIAS CONDITIONS - VOLTS(FLOATING PT.),MA(FLOATING PT$
ACCEPT VOLT,AMP
DISPLAY SENTER AMBIENT TEMPERATURE IN CENTIGRADES
ACCEPT TEMP
D0 11 I=1,N
CP=S(I)/20.0
11 XX(I)=10.0**CP
D0 10 I=1,N
R(I)=A(I)*0.017453
X(I)=XX(I)*COS(R(I))
10 Y(I)=XX(I)*SIN(R(I))
K=N-3
JJ=0
D0 30 I=1,K,4
JJ=JJ+1
AA=1.0+X(I)
BB=ATAN(Y(I)/AA)
IF(AA) 12,13,13
12 BB=BB+180.*0.017453
13 CC=SQRT((AA**2)+(Y(I)**2))
DD=1.0-X(I)
EE=ATAN(-Y(I)/DD)
IF(DD) 14,15,15
14 EE=EE+180.*0.017453
15 FF=SQRT((DD**2)+(Y(I)**2))
GG=1.0+X(I+3)
HH=ATAN(Y(I+3)/GG)
IF(GG) 16,17,17
16 HH=HH+180.*0.017453
17 PP=SQRT((GG**2)+(Y(I+3)**2))
```

```

QQ=1.0-X(I+3)
RR=ATAN(-Y(I+3)/QQ)
IF(QQ) 18, 19, 19
18 RR=RR+180.*0.017453
19 SS=SQRT((QQ**2)+(Y(I+3)**2))
TT=X(I+1)*X(I+2)-Y(I+1)*Y(I+2)
UU=Y(I+1)*X(I+2)+X(I+1)*Y(I+2)
VV=CC*PP
WW=BB+HH
X0=FF*SS
YY=EE+RR
ZZ=FF*PP
AB=EE+HH
AC=VV*COS(WW)
AD=VV*SIN(WW)
AE=X0*COS(YY)
AF=X0*SIN(YY)
AG=ZZ*COS(AB)
AH=ZZ*SIN(AB)
AI=AG+TT
AJ=AH+UU
AK=ATAN(AJ/AI)
IF(AI) 33, 34, 34
33 AK=AK+180.*0.017453
34 AL=SQRT((AI**2)+(AJ**2))
AM=AC-TT
AN=AD-UU
A0=ATAN(AN/AM)
IF(AM) 35, 36, 36
35 A0=A0+180.*0.017453
36 AP=SQRT((AM**2)+(AN**2))
AQ=2.0*XX(I+1)
AR=R(I+1)
AS= 2.0*XX(I+2)
AT=R(I+2)+180.*0.017453
AU=AE-TT
AV=AF-UU
AW=ATAN(AV/AU)
IF(AU) 37, 38, 38
37 AW=AW+180.*0.017453
38 AX=SQRT((AU**2)+(AV**2))
H(I)=(AP/AL)*50.0
H(I+1)=AQ/AL
H(I+2)=AS/AL
H(I+3)=AX/(AL*50.0)
P(I)=(A0-AK)/0.017453
P(I+1)=(AR-AK)/0.017453
P(I+2)=(AT-AK)/0.017453
P(I+3)=(AW-AK)/0.017453
L=1
M=I+3
DO 50 J=L,M
RE(J)=H(J)*COS(P(J)*0.017453)
50 GM(J)=H(J)*SIN(P(J)*0.017453)
WRITE(1,400)
400 FORMAT(////////////////////)
WRITE(1,900) NSER(JJ)
900 FORMAT(IX,'SERIAL# ',I4)
WRITE(1,800) FREQ(JJ)
800 FORMAT(IX,'FREQUENCY=',I4,' MHZ')
WRITE(1,1111) TEMP

```



```

1111 FORMAT(1X, 'TEMPERATURE =', F5.1, ' DEGREES CENTIGRADE')
WRITE(1,1001) VOLT,AMP
1001 FORMAT(1X, 'BIAS CONDITIONS ARE ', F5.1, ' VOLTS AND ', F6.1, ' MILLIAMPS
WRITE(1,700) NU
700 FORMAT(1X, 'HIGH FREQUENCY SCATTERING PARAMETERS FOR A 2N',14/)
WRITE(1,600) XX(1),A(1)
600 FORMAT(1X, 'S11=', F6.3, ' AT ', F8.3, ' DEGREES')
WRITE(1,601) X(1),Y(1)
601 FORMAT(1X, 'REAL PART=', F7.3, ' IMAG PART=', F7.3//)
WRITE(1,602) XX(I+1),A(I+1)
602 FORMAT(1X, 'S12=', F6.3, ' AT ', F8.3, ' DEGREES')
WRITE(1,601) X(I+1),Y(I+1)
WRITE(1,603) XX(I+2),A(I+2)
603 FORMAT(1X, 'S21=', F6.3, ' AT ', F8.3, ' DEGREES')
WRITE(1,601) X(I+2),Y(I+2)
WRITE(1,604) XX(I+3),A(I+3)
604 FORMAT(1X, 'S22=', F6.3, ' AT ', F8.3, ' DEGREES')
WRITE(1,601) X(I+3),Y(I+3)
WRITE(1,500) NU
500 FORMAT(1X, 'HIGH FREQUENCY HYBRID PARAMETERS FOR A 2N',14/)
26 IF(NC -1)20,21,22
22 IF(NC -2)20,23,24
24 IF(NC -3)20,25,20
20 DISPLAY $RE-ENTER CONFIGURATION CODES
ACCEPT NER
NC =NER
G0 TO 26
21 WRITE(1,100) H(1),P(1)
WRITE(1,101) RE(1),GM(1)
WRITE(1,102) H(I+1),P(I+1)
WRITE(1,103) RE(I+1),GM(I+1)
WRITE(1,104) H(I+2),P(I+2)
WRITE(1,105) RE(I+2),P(I+2)
WRITE(1,106) H(I+3),P(I+3)
WRITE(1,107) RE(I+3),GM(I+3)
G0 TO 30
23 WRITE(1,200) H(1),P(1)
WRITE(1,201) RE(1),GM(1)
WRITE(1,202) H(I+1),P(I+1)
WRITE(1,203) RE(I+1),GM(I+1)
WRITE(1,204) H(I+2),P(I+2)
WRITE(1,205) RE(I+2),GM(I+2)
WRITE(1,206) H(I+3),P(I+3)
WRITE(1,207) RE(I+3),GM(I+3)
G0 TO 30
25 WRITE(1,300) H(1),P(1)
WRITE(1,301) RE(1),GM(1)
WRITE(1,302) H(I+1),P(I+1)
WRITE(1,303) RE(I+1),GM(I+1)
WRITE(1,304) H(I+2),P(I+2)
WRITE(1,305) RE(I+2),GM(I+2)
WRITE(1,306) H(I+3),P(I+3)
WRITE(1,307) RE(I+3),GM(I+3)
WRITE(1,1000)
1000 FORMAT(//////////)
30 CONTINUE
100 FORMAT(1X, 'HIC=', F7.3, ' OHMS AT ', F8.3, ' DEGREES')
101 FORMAT(1X, 'REAL(HIC)=', F7.3, ' IMAG(HIC)=', F7.3//)
102 FORMAT(1X, 'HRC=', F6.3, ' AT ', F8.3, ' DEGREES')
103 FORMAT(1X, 'REAL(HRC)=', F7.3, ' IMAG(HRC)=', F7.3//)
104 FORMAT(1X, 'HFC=', F6.3, ' AT ', F8.3, ' DEGREES')

```

```

105 FORMAT(1X,'REAL(HFC)=',F7.3,'    IMAG(HFC)=',F7.3//)
106 FORMAT(1X,'H0C=',F6.3,' MH0S AT ',F8.3,' DEGREES')
107 FORMAT(1X,'REAL(H0C)=',F7.3,'    IMAG(H0C)=',F7.3//)
200 FORMAT(1X,'HIB=',F7.3,' 0HMS AT ',F8.3,' DEGREES')
201 FORMAT(1X,'REAL(HIB)=',F7.3,'    IMAG(HIB)=',F7.3//)
202 FORMAT(1X,'HRB=',F6.3,' AT ',F8.3,' DEGREES')
203 FORMAT(1X,'REAL(HRB)=',F7.3,'    IMAG(HRB)=',F7.3//)
204 FORMAT(1X,'HFB=',F6.3,' AT ',F8.3,' DEGREES')
205 FORMAT(1X,'REAL(HFB)=',F7.3,'    IMAG(HFB)=',F7.3//)
206 FORMAT(1X,'H0B=',F6.3,' MH0S AT ',F8.3,' DEGREES')
207 FORMAT(1X,'REAL(H0B)=',F7.3,'    IMAG(H0B)=',F7.3//)
300 FORMAT(1X,'HIE=',F7.3,' 0HMS AT ',F8.3,' DEGREES')
301 FORMAT(1X,'REAL(HIE)=',F7.3,'    IMAG(HIE)=',F7.3//)
302 FORMAT(1X,'HRE=',F6.3,' AT ',F8.3,' DEGREES')
303 FORMAT(1X,'REAL(HRE)=',F7.3,'    IMAG(HRE)=',F7.3//)
304 FORMAT(1X,'HFE=',F6.3,' AT ',F8.3,' DEGREES')
305 FORMAT(1X,'REAL(HFE)=',F7.3,'    IMAG(HFE)=',F7.3//)
306 FORMAT(1X,'H0E=',F6.3,' MH0S AT ',F8.3,' DEGREES')
307 FORMAT(1X,'REAL(H0E)=',F7.3,'    IMAG(H0E)=',F7.3//)
STOP
END
*
```

Appendix C

COMPUTER PRINTOUT SHOWING SOME OF THE VALUES MEASURED ON TWO DEVICES

SERIAL# 1
FREQUENCY= 100 MHZ
TEMPERATURE = 25.0 DEGREES CENTIGRADE

BIAS CONDITIONS ARE 5.0 VOLTS AND 10.0 MILLIAMPERES

HIGH FREQUENCY SCATTERING PARAMETERS FOR A 2N 918

S11= 0.343 AT -68.800 DEGREES
REAL PART= 0.124 IMAG PART= -0.320

S12= 0.030 AT 69.000 DEGREES
REAL PART= 0.011 IMAG PART= 0.028

S21= 5.957 AT 102.500 DEGREES
REAL PART= -1.289 IMAG PART= 5.815

S22= 0.861 AT -6.000 DEGREES
REAL PART= 0.856 IMAG PART= -0.090

HIGH FREQUENCY HYBRID PARAMETERS FOR A 2N 918

H1E= 74.514 OHMS AT -37.963 DEGREES
REAL(H1E)= 58.748 IMAG(H1E)= -45.837

HRE= 0.038 AT 48.920 DEGREES
REAL(HRE)= 0.025 IMAG(HRE)= 0.029

HFE= 7.565 AT 262.420 DEGREES
REAL(HFE)= -0.998 IMAG(HFE)= -7.499

H0E= 0.004 MH0S AT -0.245 DEGREES
REAL(H0E)= 0.004 IMAG(H0E)= -0.000

SERIAL# 2
FREQUENCY=1000 MHZ
TEMPERATURE = 25.0 DEGREES CENTIGRADE

BIAS CONDITIONS ARE 12.5 VOLTS AND 100.0 MILLIAMPERES

HIGH FREQUENCY SCATTERING PARAMETERS FOR A 2N5913

S11= 0.767 AT 134.500 DEGREES
REAL PART= -0.538 IMAG PART= 0.547

S12= 0.363 AT 56.000 DEGREES
REAL PART= 0.203 IMAG PART= 0.301

S21= 0.923 AT 29.500 DEGREES
REAL PART= 0.803 IMAG PART= 0.454

S22= 0.432 AT -168.000 DEGREES
REAL PART= -0.422 IMAG PART= -0.090

HIGH FREQUENCY HYBRID PARAMETERS FOR A 2N5913

H1E= 16.922 OHMS AT -3.605 DEGREES
REAL(H1E)= 16.889 IMAG(H1E)= -1.064

HRE= 0.831 AT 63.915 DEGREES
REAL(HRE)= 0.365 IMAG(HRE)= 0.746

HFE= 2.111 AT 217.415 DEGREES
REAL(HFE)= -1.676 IMAG(HFE)= -1.282

H0E= 0.055 MH0S AT -15.878 DEGREES
REAL(H0E)= 0.053 IMAG(H0E)= -0.015

SERIAL# 4
FREQUENCY= 100 MHZ
TEMPERATURE = 25.0 DEGREES CENTIGRADE

BIAS CONDITIONS ARE 5.0 VOLTS AND 10.0 MILLIAMPERES

HIGH FREQUENCY SCATTERING PARAMETERS FOR A 2N 918

S11= 0.462 AT -44.000 DEGREES
REAL PART= 0.333 IMAG PART= -0.321

S12= 0.032 AT 71.000 DEGREES
REAL PART= 0.010 IMAG PART= 0.030

S21= 6.310 AT 107.000 DEGREES
REAL PART= -1.845 IMAG PART= 6.034

S22= 0.851 AT -6.500 DEGREES
REAL PART= 0.846 IMAG PART= -0.096

HIGH FREQUENCY HYBRID PARAMETERS FOR A 2N 918

H1E= 114.529 OHMS AT -42.218 DEGREES
REAL(H1E)= 84.821 IMAG(H1E)= -76.957

HRE= 0.053 AT 44.270 DEGREES
REAL(HRE)= 0.038 IMAG(HRE)= 0.037

HFE=10.600 AT 260.270 DEGREES
REAL(HFE)= -1.792 IMAG(HFE)=-10.447

H0E= 0.005 MH0S AT -5.235 DEGREES
REAL(H0E)= 0.005 IMAG(H0E)= -0.000

SERIAL# 5
FREQUENCY= 100 MHZ
TEMPERATURE = 25.0 DEGREES CENTIGRADE

BIAS CONDITIONS ARE 5.0 VOLTS AND 10.0 MILLIAMPERES

HIGH FREQUENCY SCATTERING PARAMETERS FOR A 2N 918

S11= 0.501 AT -42.000 DEGREES
REAL PART= 0.372 IMAG PART= -0.335

S12= 0.032 AT 70.000 DEGREES
REAL PART= 0.011 IMAG PART= 0.030

S21= 6.310 AT 108.500 DEGREES
REAL PART= -2.002 IMAG PART= 5.984

S22= 0.832 AT -7.000 DEGREES
REAL PART= 0.826 IMAG PART= -0.101

HIGH FREQUENCY HYBRID PARAMETERS FOR A 2N 918

H1E=123.292 0HMS AT -45.284 DEGREES
REAL(H1E)= 86.748 IMAG(H1E)=-87.611

HRE= 0.056 AT 40.531 DEGREES
REAL(HRE)= 0.043 IMAG(HRE)= 0.037

HFE=11.209 AT 259.031 DEGREES
REAL(HFE)= -2.134 IMAG(HFE)=-11.004

H0E= 0.005 MH0S AT -6.438 DEGREES
REAL(H0E)= 0.005 IMAG(H0E)= -0.001

SERIAL# 5
FREQUENCY=1000 MHZ
TEMPERATURE = 25.0 DEGREES CENTIGRADE

BIAS CONDITIONS ARE 12.5 VOLTS AND 100.0 MILLIAMPERES

HIGH FREQUENCY SCATTERING PARAMETERS FOR A 2N5913

S11= 0.785 AT 131.500 DEGREES
REAL PART= -0.520 IMAG PART= 0.588

S12= 0.422 AT 56.500 DEGREES
REAL PART= 0.233 IMAG PART= 0.352

S21= 0.822 AT 27.500 DEGREES
REAL PART= 0.729 IMAG PART= 0.380

S22= 0.462 AT -167.500 DEGREES
REAL PART= -0.451 IMAG PART= -0.100

HIGH FREQUENCY HYBRID PARAMETERS FOR A 2N5913

H1E= 17.906 OHMS AT -4.703 DEGREES
REAL(H1E)= 17.846 IMAG(H1E)= -1.468

HRE= 1.026 AT 65.601 DEGREES
REAL(HRE)= 0.424 IMAG(HRE)= 0.935

HFE= 2.001 AT 216.601 DEGREES
REAL(HFE)= -1.607 IMAG(HFE)= -1.193

H0E= 0.060 MH0S AT -16.042 DEGREES
REAL(H0E)= 0.058 IMAG(H0E)= -0.017

SERIAL# 6
FREQUENCY=1000 MHZ
TEMPERATURE = 25.0 DEGREES CENTIGRADE

BIAS CONDITIONS ARE 12.5 VOLTS AND 100.0 MILLIAMPERES

HIGH FREQUENCY SCATTERING PARAMETERS FOR A 2N5913

S11= 0.776 AT 131.000 DEGREES
REAL PART= -0.509 IMAG PART= 0.586

S12= 0.389 AT 54.000 DEGREES
REAL PART= 0.229 IMAG PART= 0.315

S21= 0.902 AT 25.000 DEGREES
REAL PART= 0.817 IMAG PART= 0.381

S22= 0.417 AT -171.500 DEGREES
REAL PART= -0.412 IMAG PART= -0.062

HIGH FREQUENCY HYBRID PARAMETERS FOR A 2N5913

H1E= 14.058 OHMS AT -0.907 DEGREES
REAL(H1E)= 14.056 IMAG(H1E)= -0.222

HRE= 0.843 AT 59.788 DEGREES
REAL(HRE)= 0.424 IMAG(HRE)= 0.729

HFE= 1.955 AT 210.788 DEGREES
REAL(HFE)= -1.679 IMAG(HFE)= -1.000

HØE= 0.051 MHØS AT -21.393 DEGREES
REAL(HØE)= 0.048 IMAG(HØE)= -0.019

Appendix D

HISTOGRAMS OF h_{fe} FOR 2N918 AND GRAPHS OF h-PARAMETER MEASUREMENTS FOR 2N5913

BENDIX HISTOGRAM IDENTIFICATION NUMBER 00918			DATE 11050				
PART NUMBER 000000005		LOWER SPEC.	6.00000	UPPER SPEC.	16.00000		
LOWER CELL BOUNDARY	UPPER CELL BOUNDARY	NUMBER IN CELL	HISTOGRAM PLOT WITH SCALING FACTOR OF 1				
-99999.00000	6.50049	0					
6.50050	7.00049	1	X				
7.00050	7.50049	0					
7.50050	8.00049	8	XXXXXXXXXX				
8.00050	8.50049	9	XXXXXXXXXX				
8.50050	9.00049	2	XX				
9.00050	9.50049	8	XXXXXXXXXX				
9.50050	10.00049	7	XXXXXXXXXX				
10.00050	10.50049	3	XXX				
10.50050	11.00049	2	XX				
11.00050	11.50049	5	XXXXX				
11.50050	12.00049	3	XXX				
12.00050	12.50049	0					
12.50050	13.00049	1	X				
13.00050	13.50049	1	X				
13.50050	14.00049	0					
14.00050	14.50049	1	X				
14.50050	15.00049	0					
15.00050	99999.00000	0					
N	MEAN	STD DEV	QU	QL	SKEWNESS	KURTOSIS	RANGE
51	9.60078	1.6093349	3.976	2.237	0.793	0.347	7.3499994

2N918

h_{fe} at 100 mHz

$V_{ce} = 5$ volts, $I_c = 10$ ma dc

BENDIX HISTOGRAM IDENTIFICATION NUMBER 00918 DATE 11050
 PART NUMBER 0000000006 LOWER SPEC. 250.00000 UPPER SPEC. 290.00000

LOWER CELL BOUNDARY	UPPER CELL BOUNDARY	NUMBER IN CELL	HISTOGRAM PLOT WITH SCALING FACTOR OF 1
-99999.00000	256.00487	0	
256.00488	258.00487	1	X
258.00488	260.00487	6	XXXXXX
260.00488	262.00487	19	XXXXXXXXXXXXXXXXXXXXX
262.00488	264.00487	10	XXXXXXXXXX
264.00488	266.00487	4	XXXX
266.00488	268.00487	3	XXX
268.00488	270.00487	4	XXXX
270.00488	272.00487	3	XXX
272.00488	274.00487	0	
274.00488	276.00487	0	
276.00488	278.00487	0	
278.00488	280.00487	1	X
280.00488	99999.00000	0	

N	MEAN	STD DEV	QU	QL	SKEWNESS	KURTOSIS	RANGE
51	263.35876	4.2518406	6.266	3.142	1.605	2.923	21.3999023

2N918

h_{ie} at 100 mHz in degrees

$V_{ce} = 5$ volts, $I_c = 10$ ma dc

DISTRIBUTION

	Copy
B. W. Colston, AEC-KCAO	1
V. C. Vespe, AEC-ALO	2
R. F. Pippert, D/100	3-4
J. V. Parks, D/231	5
H. T. Barnes, D/534	6
H. T. Johnston, D/534	7
L. Stratton, D/535	8-9
R. P. Frohmberg, D/800	10
E. R. Elmer, D/863	11-12
D. D. Peterson, D/863	13
J. H. Swafford, D/863	14