LARGE-SIGNAL S-PARAMETER CHARACTERIZATION OF UHF POWER TRANSISTORS*

R. J. Chaffin and W. H. Leighton

Sandia Laboratories

Albuquerque, N. M.

Abstract

The problems involved in the measurement and application of large-signal S-parameters for UHF power transistors are discussed. Experimental results obtained using a specially designed high-power S-parameter test set are reported.

The characterization of small-signal UHF transistors is usually accomplished by measuring their small-signal S-parameters.[1] These parameters provide a convenient representation for analytical design of small-signal amplifiers.[2,3] Unfortunately similar methods have not been available for characterization of large-signal UHF power transistors. Hence circuit designers have been forced to utilize cut-and-try methods in the design of large-signal UHF transistor amplifiers. The purposes of this paper are to describe an experimental method of measuring large-signal S-parameters and to present the results obtained on a typical UHF bipolar power transistor. The applicability of these large-signal S-parameters to analytic circuit design methods for high power amplifiers is demonstrated in a companion paper.[4]

The measurement of meaningful large-signal S-parameters requires adequate attention to several problem areas: (1) The nonlinearity of the device at high drive levels generates harmonics which must be properly accounted for; (2) Bias conditions must be similar to those of the intended circuit application; (3) High measurement accuracy is required (±1%) since the input and output impedance levels of the transistor are generally much different than the 50 Ω reference level of the measurement system resulting in near-unity reflection coefficients. In addition, the measurement system must be capable of generating very high input power levels. For example, in the case of class C bias most of the incident power from the 50 Ω system is reflected and a power level of 30-40 W may be required to turn a transistor on. To overcome these problems a special high power S-parameter test set was developed.

Figure 1 shows a simplified block diagram of the system. Extensive use of high wattage components and careful design allows input power levels of up to 50 W to be used with this system. Incident power and reflected or transmitted power are applied to the reference and test channels of the vector voltmeter through directional couplers and their ratio is calculated by the computer. The systematic measurement errors are eliminated through use of standard mathematical calibration procedures[5] using an on-line, time sharing computer terminal. Typical measurement repeatability for the system shown in Figure 1 is $\Delta S = \pm 0.005$ $\pm 0.5°$ at power levels up to 50 W. The usable frequency range of the system is from 25 MHz to 1 GHz. The low frequency limit occurs due to rolloff in the directional couplers while the high frequency limit is imposed by the vector voltmeter used to perform the measurements. The measurement frequency range could easily be extended upward by use of different directional couplers in the test set and a different sampling voltmeter (the HP-8410 for example).

To illustrate the parameters being discussed, measurements were made on a PHI-1003 UHF transistor (manufactured by Power Hybrids, Inc. of Torrance, CA). The PHI-1003 is a moderate power (3 W nominal output) silicon bipolar common base transistor. The S-parameters of this device were measured at 500 MHz under both class A and class C bias conditions at power levels ranging from -30 dBm to +35 dBm. The nonlinearity problem mentioned above is clearly illustrated by Figure 2. This figure shows the voltage waveform measured at the terminals of the transistor when operating at approximately the 1 W level class C in both the S-parameter test set (A) and in an actual matched amplifier circuit (B). Figure 2A shows that in the S-parameter test set the collector-base voltage waveform is nearly sinusoidal and the emitter-base voltage waveform is distorted showing clipping effects. On the other hand, Figure 2B shows that both the collector-base and the emitter-base waveforms are nearly sinusoidal in the matched amplifier case. The difference in the waveforms is due mainly to the different circuit bandwidths in the two cases. In the S-parameter test set the circuit is a flat 50 Ω system and hence all harmonics are permitted. In the case of the matched amplifier the narrow band matching networks do not permit energy to flow at the harmonic frequencies and the resulting waveforms are more nearly sinusoidal. The effects of the harmonics are accounted for by placing a filter (or several different filters in a sequence of measurements) in the test channel of the vector voltmeter.

Figures 3 and 4 show the results of the S-parameter measurements. Figure 3 shows that the class A and C measurements of S_{11} start out quite far apart at low power levels and approach each other as the power level is increased. This is attributed to an increase in class C self-bias that occurs with increased power levels. At some power level the average collector current for class C bias becomes equal to the class A value and it is significant to note that at this point the values of S_{11} are identical (the point where the curves cross). The values of S_{22} for class A and class C are seen to lie fairly close together and to be relatively independent of power level. This is not surprising since S_{22} is dominated primarily by the collector-base depletion capacitance in either bias case. Figure 4 shows that values of S_{21} for the class A and class C cases approach each other as the power level is increased. The reasons for this behavior are also related to bias level as discussed above. The magnitude of S_{12} was found to be quite small (about 0.03) and independent of power. The angles of S_{12} for the class C and class A cases remain quite different even at high power levels. This behavior is associated with the fact that for the measurement of S_{12} the power is incident from the collector side of the device and as a result the device never draws appreciable collector current regardless of the class C power level and hence only in the class A case is the emitter-base junction forward-biased.

In conclusion, this paper has discussed the problems involved in the measurement of large signal S-parameters of UHF transistors and presented methods for overcoming these problems. Experimental results have also been presented showing the dependence of S-parameters on power level and bias conditions.

References

* This work was supported by the US Atomic Energy Commission.

1. S-Parameters... Circuit Analysis and Design, Hewlett Packard Application Note 95, Sept. 1968.
2. W. H. Froehner, "Quick Amplifier Design with Scattering Parameters," Electronics, Oct. 1967.
3. G. E. Bodway, "Two Port Power Flow Analysis Using Generalized Scattering Parameters," Microwave J.,

May 1967.
4. J. G. Webb and R. J. Chaffin, "Power Transistor Amplifier Design Using Large-Signal S-Parameters," G-MTT International Symposium, June 1973.
5. R. A. Hackborn, "An Automatic Network Analyzer System," Microwave Journal, May 1968.

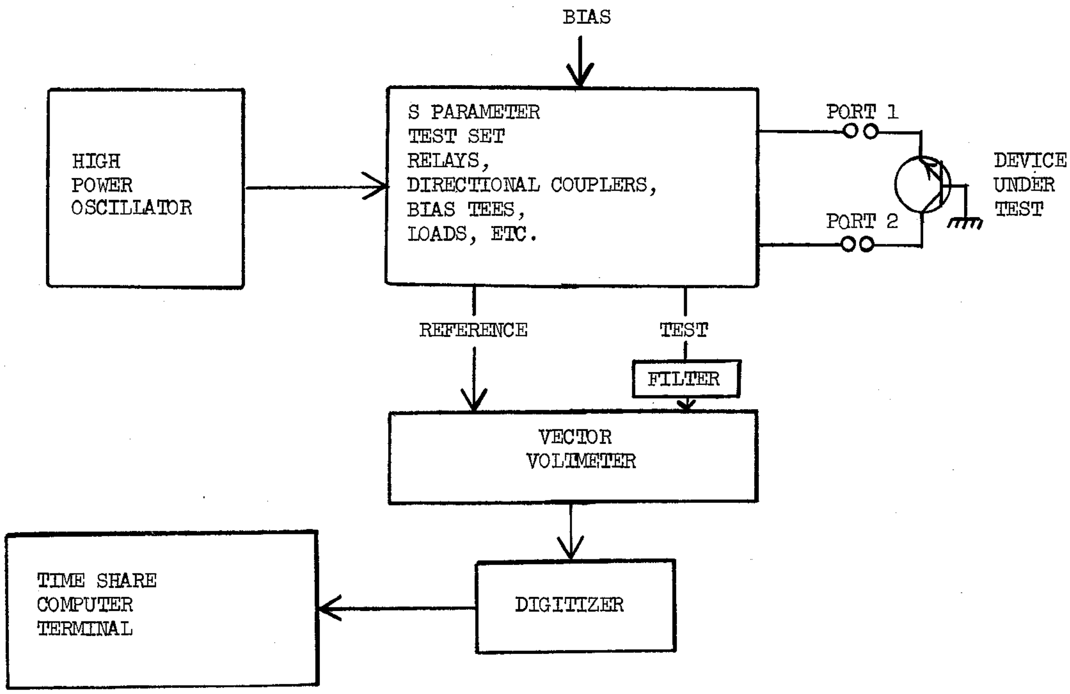

FIG. 1. HIGH POWER S-PARAMETER TEST SET

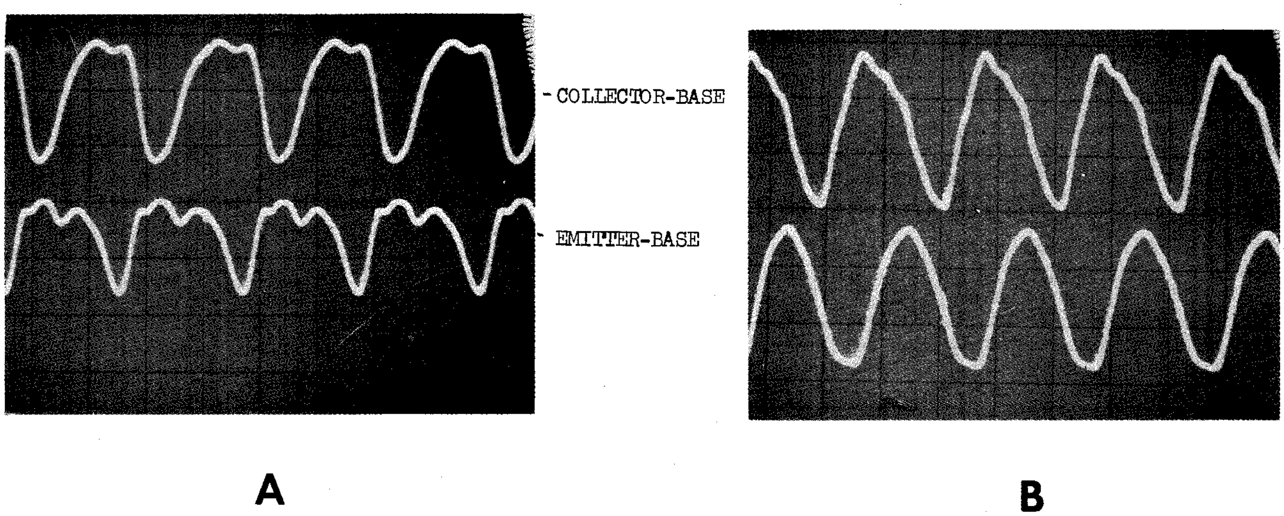

FIG. 2. WAVEFORMS OF PHI-1003 UHF POWER TRANSISTOR. (A) IN THE S-PARAMETER TEST SET: (B) IN THE MATCHED AMPLIFIER

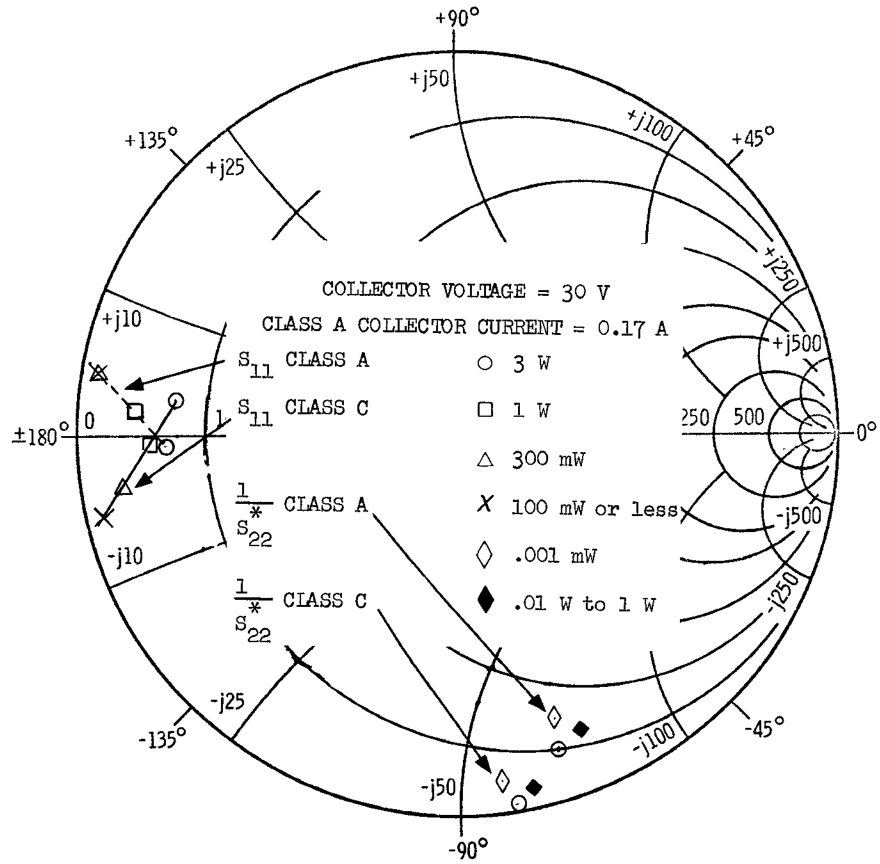

FIG. 3. S_{11} AND $1/S^*_{22}$ AT 500 MHz FOR THE PHI-1003 TRANSISTOR.

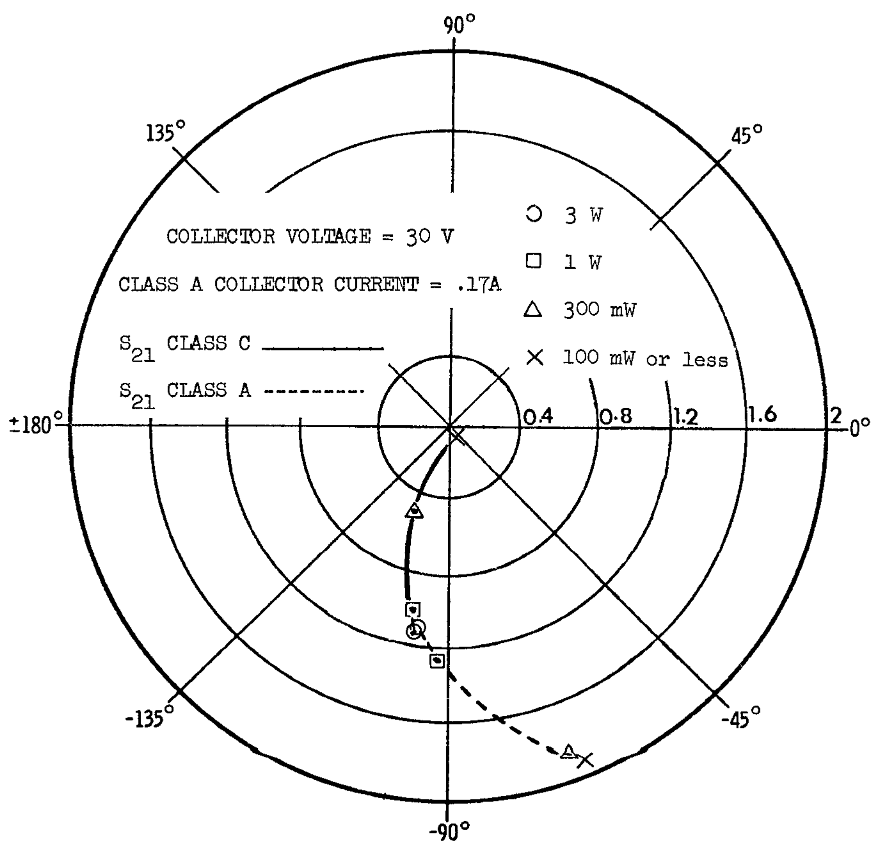

FIG. 4. S_{21} AT 500 MHz FOR THE PHI-1003 TRANSISTOR

NOTES