CHARACTERISATION OF LARGE-SIGNAL BIPOLAR TRANSISTORS IN L-BAND

John L Hutchings

Council for Scientific and Industrial Research
Pretoria, Republic of South Africa

ABSTRACT

Practical problems encountered in the characterisation of an L-band common base bipolar power transistor using three different characterisation techniques are discussed. One of the techniques, an improved "load-pull" measurement technique, is shown to be a superior characterisation method. Results obtained from this method can be used to design a collector matching network.

INTRODUCTION

The characterisation of high-power microwave transistors is considerably more complicated than their small-signal counterparts. While at least three different characterisation techniques for microwave power transistors have been proposed in the literature (1-3), the design engineer intending to perform such measurements is faced with the task of choosing the most reliable of these methods. Such a choice can be influenced by the practical problems encountered with these methods.

This paper discusses practical problems encountered in using the large-signal S-parameter characterisation method presented in (1) (referred to here as Method #1) and (2) (referred to here as Method #2) during the characterisation of a common base bipolar power transistor in L-band. To overcome these problems the application of an improved "load-pull" measurement set-up, described in (3) (and used to characterise power MESFETS), is demonstrated and shown to be an effective characterisation method for bipolar microwave power transistors.

Since the collector matching network of a power amplifier is primarily responsible for realising good collector efficiency and adequate output power, the design and realisation of such a network using the results obtained from the "load-pull" measurements is briefly discussed later in this paper.

PROBLEMS ENCOUNTERED WITH LARGE-SIGNAL S-PARAMETER CHARACTERISATION

Method #1

(a) Large-signal S-parameters should ideally be measured under conditions approximating those which will exist in the "intended amplifier". Method #1 fails to simulate practical amplifier conditions as no collector current (I_c) is observed to flow during the measurement of S_{22} and S_{12}.

(b) Measurements made of output power (P_o) versus collector supply voltage (V_{cc}) (see Fig. 1) did not display the distinct saturation "knee" reported in (4). It is uncertain how accurately one can pinpoint the correct saturation point on this "knee" should it indeed be obtained.

Method #2

(a) Method #2 does not lend itself easily to computer control and error correcting techniques due to the fact that generation of circular loci is done by means of a mechanical phase shifter.

(b) The centres of circular loci generated (see Fig. 2) must be visually estimated, thus introducing errors in determining the values of the S-parameters, especially with loci of large radii.

(c) While circular loci are being generated, the input power (P_i) has to be adjusted continually in order to maintain a constant I_c. When this is done the RF drive conditions change from those of the "intended amplifier".

(d) It is difficult to determine beforehand what I_c value can be expected for maximum P_o and good efficiency (for which S-parameters must be measured).

0149-645X/85/0000-0165 $01.00 © 1985 IEEE 1985 IEEE MTT-S Digest

"LOAD-PULL" CHARACTERISATION

In recent years a number of papers have been published on "load-pull" measurement techniques for the large-signal characterisation of microwave power transistors (5-7). One of the drawbacks of "load-pull" measurements has been the limited accuracy (due to unknown stub tuner losses) in determining P_o. Significant power measurement errors can result when a power meter is placed behind a stub tuner with undetermined losses. Losses of several dB's in a passive tuner have been reported in (8) and observed by the present author.

A "load-pull" characterisation method which overcomes this power measurement problem, using computer-aided vector error correction techniques, is described in (3). A simplified version of this measurement set-up, using only one network analyser, was implemented and is shown here in Fig. 3. The error-correction techniques used are based on a signal flow graph model obtained in (3) for the combined directional coupler, power splitter, power meter and network analyser system. The model includes all sources of error such as coupler directivity and transmission loss, connector mismatches, and cross-coupling between the reference and test channels. The measurement set-up was implemented to measure collector load reflection coefficient (Γ_L) as it was felt that determining the collector loads which satisfy output power and collector efficiency requirements makes up the major part of a power amplifier design.

"Load-pull" measurements were made at three frequencies on a common base bipolar power transistor (the MSC82003) for a constant P_o of 3,2 W. The MSC82003 transistor has a nominal output power of 3 W. A typical measurement sequence involves choosing a random setting for the output stub tuner. The input stub tuner is then adjusted to match the input of the device at the desired input drive level P_i. At the same time an X-Y plotter indicates the position of Γ_L (on a Smith Chart) for the initial output stub tuner setting. With these conditions the computer display of P_o (as shown in Table 1) is observed. The output stub tuner is then manually adjusted until a Γ_L is found which provides the desired P_o. Γ_L is then recorded on the Smith Chart using the X-Y plotter. This procedure is repeated for other Γ_L's which provide the same P_o until a closed contour is obtained on the Smith Chart, as shown in Fig. 4.

From the "load-pull" contours obtained specific Γ_L's can be selected to satisfy collector efficiency (η_c) requirements. The Γ_L's which, on each of the three contours shown, provided the best η_c (approximately 43%) are indicated in Table 1 with asterisks. A constant η_c curve can thus be drawn through these points. Larger I_c's were observed for other Γ_L's chosen along each of the P_o contours shown, resulting in poorer collector efficiences.

COLLECTOR MATCHING NETWORK

By using a judicious choice of Γ_L's from the "load-pull" contours of Fig.4, a model of the output equivalent circuit of the transistor can be found which satisfies the gain-bandwidth restrictions discussed in (9). By using this model and the lumped network synthesis techniques described in (9) and (10), a collector matching network can be synthesised in lumped form and realised in microstrip. The realisation of such a network providing a P_o of 3,2 W and minimum η_c of 34% will be discussed during the presentation.

CONCLUSION

The "load-pull" technique is shown to be a preferred and more reliable method of characterising high-power common base bipolar transistors. Results obtained can be used to design a collector matching network. The results and problems discussed should be of value to engineers intending to develop similar microwave power amplifiers.

REFERENCES

(1) R J Chaffin and W H Leighton, "Large-Signal S-Parameter Characterisation of UHF Power Transistors", 1973 IEEE G-MTT Int Microwave Symp, pp 155-157.

(2) S R Mazumder and P D van der Puije, "Two-Signal Method of Measuring the Large-Signal S-Parameters of Transistors", IEEE Trans Microwave Theory Tech, Vol MTT-26, No 6, pp 417-420, June 1978.

(3) P D Bradley and R S Tucker, "Computer-Corrected Load-Pull Characterisation of Power MESFET's", 1983 IEEE MTT-S Int Microwave Symp, pp 224-226.

(4) W H Leighton, R J Chaffin and J G Webb, "RF Amplifier Design with Large-Signal S-Parameters", IEEE Trans Microwave Theory Tech, Vol MTT-21, No 12, pp 809-814, Dec 1973.

(5) Y Takayama, "A New Load-Pull Characterisation Method for Microwave Power Transistors", 1976 IEEE MTT-S Int Microwave Symp, pp 218-220.

(6) S C Cripps, "A Theory for the Prediction of GaAs FET Load-Pull Power Contours", 1983 IEEE MTT-S Int Microwave Symp, pp 221-223.

(7) J M Cusack, S M Perlow and B S Perlman, "Automatic Load Contour Mapping for Microwave Power Transistors", IEEE Trans Microwave Theory Tech, Vol MTT-22, No 12, pp 1146-1152, Dec 1974.

(8) E W Strid, "Measurements of Losses in Noise-Matching Networks", IEEE Trans Microwave Theory Tech, Vol 29, pp 247-252, 1981.

(9) R M Cottee and W T Joines, "Synthesis of Lumped and Distributed Networks for Impedance Matching of Complex Loads", IEEE Trans Circuits and Systems, Vol CAS-26, No.5, pp 316-329, May 1979.

(10) G L Matthaei, "Tables of Chebyshev Impedance-Transforming Networks of Low-Pass Filter Form", Proc IEEE, Vol 52, pp 939-963, Aug 1964.

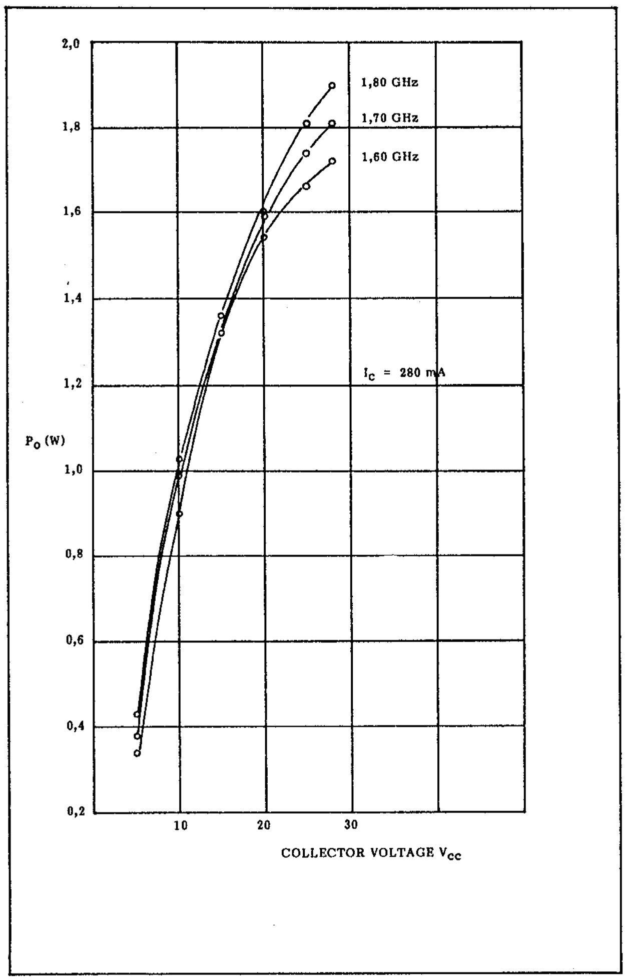

FIG.1 : Plot of output power P_o vs collector supply voltage V_{cc} for the MSC82003 transistor.

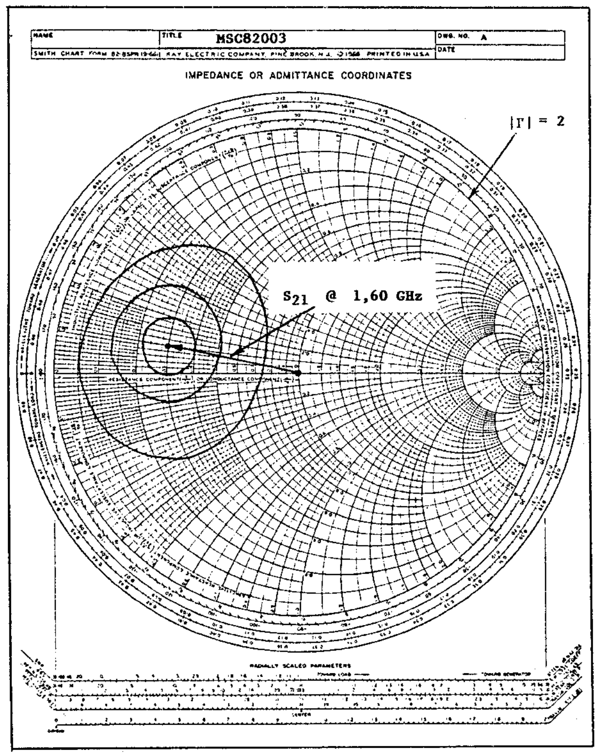

FIG.2 : Circular loci generated during the measurement of S_{21} for the MSC82003 transistor using Method #2. Smith Chart normalised to 10 ohms.

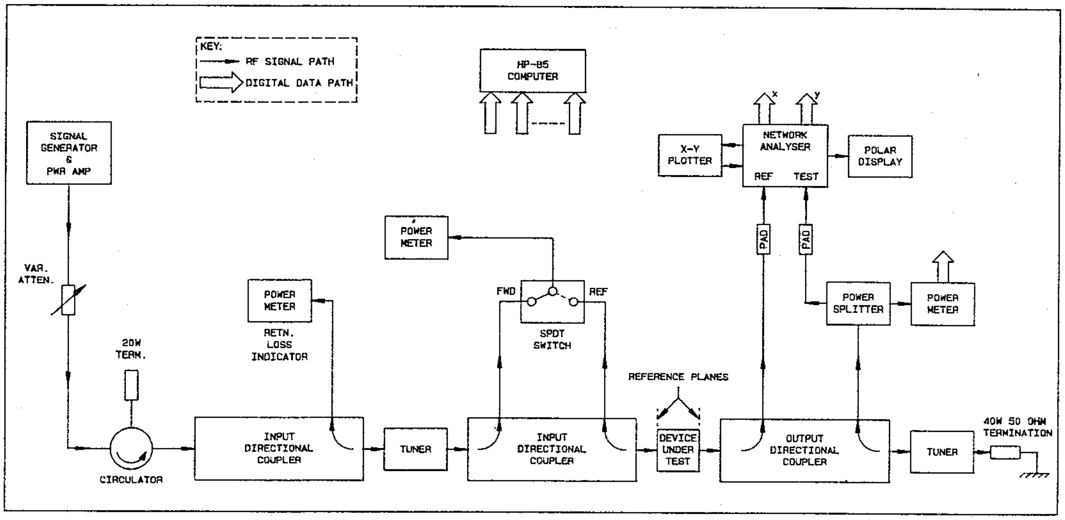

FIG.3 : Simplified "load-pull" measurement set-up used in generating the contours of Fig.4.

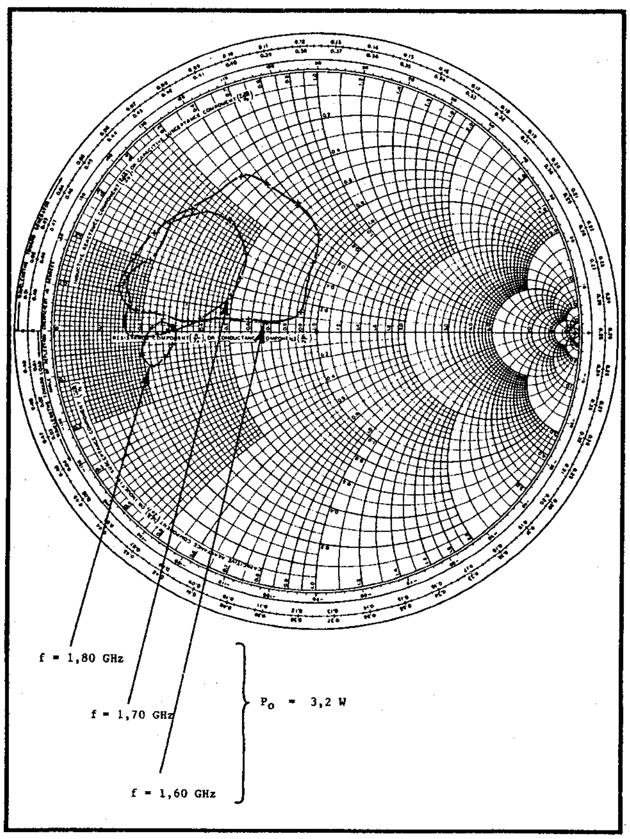

FIG.4 : Contours of constant-output-power P_o on the load reflection plane for the MSC82003 transistor with a P_i of 650 mW. The Smith Chart is normalised to 10 ohms.

TABLE 1 : Computer error-corrected values of Γ_L and P_o obtained for P_i = 650 mW. Asterisks show best efficiency points on each contour.

FREQ = 1.800 GHz

COLL LOAD |MAGN|	REFL COEFF |ANGLE|	OUTPUT PWR |WATTS|	
.595	176.9	3.25	
.549	178.4	3.23	* I_c = 273 mA
.630	178.9	3.23	
.556	- 174.3	3.20	
.646	- 167.6	3.26	
.676	- 172.0	3.28	
.662	- 176.1	3.26	
.589	- 170.0	3.21	

FREQ = 1.700 GHz

COLL LOAD |MAGN|	REFL COEFF |ANGLE|	OUTPUT PWR |WATTS|	
.719	173.4	3.23	
.690	157.1	3.26	
.564	- 179.8	3.22	
.446	174.2	3.26	
.353	157.9	3.28	
.396	132.8	3.26	
.538	128.3	3.26	* I_c = 265 mA
.629	134.2	3.29	
.691	144.2	3.26	
.757	166.2	3.24	
.352	146.1	3.24	
.706	- 178.3	3.28	
.608	- 178.5	3.21	

FREQ = 1.600 GHz

COLL LOAD |MAGN|	REFL COEFF |ANGLE|	OUTPUT PWR |WATTS|	
.257	93.2	3.26	
.494	98.5	3.27	
.656	116.3	3.26	
.665	136.0	3.25	
.749	157.5	3.20	
.775	167.5	3.24	
.265	170.6	3.30	
.493	175.8	3.26	
.590	174.3	3.22	
.693	173.8	3.26	
.093	130.4	3.41	
.724	149.3	3.23	
.366	88.7	3.24	
.587	108.6	3.29	* I_c = 250 mA