AUTOMATIC LOAD CONTOUR MAPPING FOR MICROWAVE POWER TRANSISTORS

J. Cusack, S. Perlow and B. Perlman
RCA Laboratories
Princeton, New Jersey 08540

Abstract

A technique for large signal characterization of microwave power transistors is described. A computer controlled apparatus is used to map contours of constant output power and efficiency, on a Smith Chart, for dynamic matching of both input and output circuits.

Introduction

Although extensive characterization procedures have been developed for linear transistors operating at small signal levels relatively little equivalent work has been done for power transistors. Since the operating characteristics of large signal devices are a function of both the signal level and the circuit impedance, most designs have been based on the use of empirical design techniques. However the latter approach becomes prohibitively difficult when it is necessary to design broadband circuits where considerations of constant power and efficiency become important.

Power Load Contours

At a single frequency the maximum output power from a power transistor can be determined by simply tuning both the input and output matching circuits for best performance. Over a broad bandwidth it is very unlikely that a circuit can be realized which will provide maximum output power or best efficiency at each frequency. Under these circumstances trade offs must be made to obtain the best compromise. The information for these trade offs can be obtained from a set of power-load contours.

The power load contours consist of a series of curves on a Smith Chart representing constant output power. When drawn at several frequencies over the band of interest, they represent loci of required output impedance for various output power levels. If constant efficiency contours are overlayed on the constant power contours, the efficiency is also known at each of the load impedances. With this information the circuit designer knows exactly what output power and efficiency can be obtained for various values. A realizable circuit can then be designed to best meet the required specifications.

Any one of these load contours consists of many measured points. If only three frequencies and three output power levels were used more than three hundred measurements would have to be made for every device. The measurement would have to be repeated for any change made on the device or its carrier. Since doing this manually is almost impossible, an automated servo-controlled tuning network has been developed.

Automated Servo-Controlled Matching Network

A special double-slug tuner was designed using two servo motors. The motors control the separation of a pair of teflon dielectric slugs and the position of the carriage to which they are attached, relative to the input end of a match-terminated precision slotted line. The tuner is adjusted in response to a pair of voltages derived from the computer. Positioning the carriage affects the phase angle of the tuner, while slug separation determines V.S.W.R. and alters phase as well. The net driving point impedance of this combination, ZDP, is a function of the two control voltages VA and VB and of the frequency of operation, F:

ZDP = f(VA, VB, F)

The function f can be determined quantitatively by precalibrating the slotted line as a function of each variable using an automated network analyzer. A block diagram of the overall test system is shown in Fig. 1. A photograph of the servo-controlled matching network is shown in Fig. 2.

Constant power contours are found experimentally to be closed curves, where the transistor load impedance ZDP can be represented as a contour on a Smith Chart. The object of the automation procedure is to find a set of voltage pairs (VA, VB) at a given frequency (F), for which output power is maintained constant. These points can be mapped onto a Smith Chart in terms of the impedance function f(VA, VB, F). From the mutually exclusive vectors VA and VB, we can construct a voltage plane V. It is in this plane that the computer search takes place. A graphical description of the search algorithm is given in Fig. 3.

The search is initiated by manually tuning the impedance ZDP to some point at which the desired power can be found. This point is characterized by a set of control voltages (VAO, VBO) in the voltage plane V (Fig. 3). The computer calculates the rectangular coordinates of the head of the search vector, and translates them to a set of voltages for controlling the impedance tuning apparatus. The motors respond to the pair of control voltages and are allowed to settle before the computer reads the power meter and determines whether the power is higher or lower than the desired value. The primary advantage of the vector search technique is that the curve which is being traced must intercept the arc of a circle, and hence, two search vectors will bound the direction of the curve. Once bounded, the exact direction can be determined by any conventional technique which finds a zero of a function in a bounded interval. In this case the zero occurs when the error function, ER = (PM-PO), changes sign. (i.e., PM is the power measured, and PO is the desired power.)

After a contour is found, (as shown by point 2 in Fig. 3), a new initial search vector is constructed at the new point, in line with the vector which connects the previous point to the new point. The angle of the search vector is incremented on alternate sides of the initial vector, until two adjacent vectors bound the direction of the point. This procedure is shown by the numerical sequence 1-4 in Fig. 3. The angle may be determined more precisely if desired. The tip of this search vector is a contour point, and it becomes the base point for iteration of the search. In this manner, the contour can be traced by mapping all base points onto the Smith Chart.

In practice, a fifteen degree search increment is sufficient to trace the contour acceptably. The vector search technique is self-correcting, since if one base point is slightly above or below the contour, the accuracy of subsequent points is unaffected.

Applications of Power-Load Contours

The most important use of power-load contours has been in the determination of output VSWR sensitivity of an amplifier. If the load changes from its optimum value, the loss in output power may cause increased power dissipation in the amplifying device with the possibility of burn-out. However, a fact that is often overlooked is that the power-load contours provide important information about the device itself.

A power transistor operated in the class C mode has an output equivalent circuit which may be represented by a non-linear current or voltage generator and a non-linear admittance or impedance. To obtain maximum output power, the load impedance must produce the maximum current and voltage swing. The relationship between the required load impedance and non-linear output impedance determines the shape of the power-load contour. It can be shown that the shape and size of the power-load contour vary with input drive level. For low drive levels, the contour is almost elliptical. As the drive level increases toward the point where the transistor current saturates, the power-load contour expands into a circle which approaches a true VSWR circle, i.e., a constant transmission loss circle. Figure 4 shows the power-load contours for an RCA TA 8407 as provided by the automated servo-controlled tuning network for several drive levels. The contours were taken for 1 dB transmission loss. Since the non-linear output impedance of the transistor depends upon the rf current saturation level and rf breakdown voltage, these contours also provide information about these parameters.

The contours clearly show that a wideband amplifier requires a high drive level so that the power-load contour encloses the maximum area possible on the Smith Chart. The same holds true if the amplifier is to operate in an environment in which high load VSWR's must be tolerated.

Conclusions

The automated servo-controlled tuning network represents a significant improvement in power transistor amplifier design procedure due to the large number of data points that can be taken in a short time interval. In addition to providing the circuit designer with much needed information on bandwidth, efficiency and VSWR sensitivity, the power-load contours also provide information about the device itself.

Since the automated servo-controlled tuning network is basically a matching network, it may be used for examining many other linear and non-linear devices by simply changing the associated software. Intended future applications include optimized noise figure matching, oscillator pulling, and linear power amplifier matching circuits.

Acknowledgement

The authors would like to acknowledge Messrs. H.C. Johnson and L.W.Mackey for their effort in the design and assembly of the servo-controlled matching network, and to thank Mr. G.E.Theriault and Dr.E.F.Belohoubek for many helpful technical discussions.

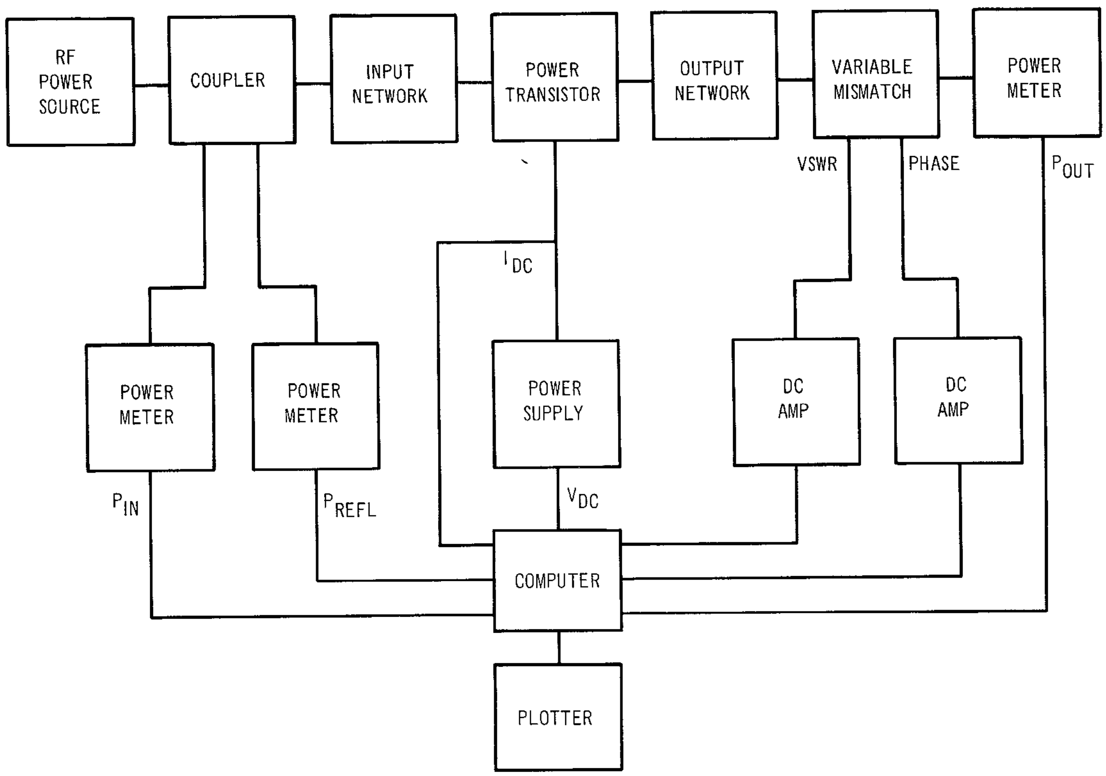

Figure 1 Diagram of computer-controlled impedance tuning system.

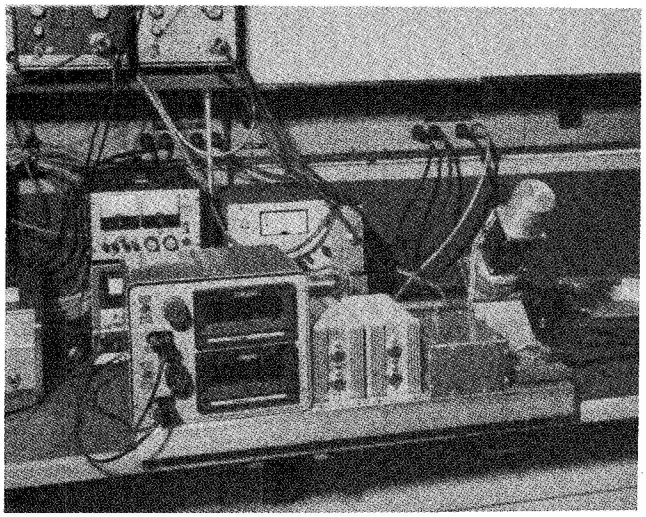

Fig. 2 Servo-controlled impedance tuner.

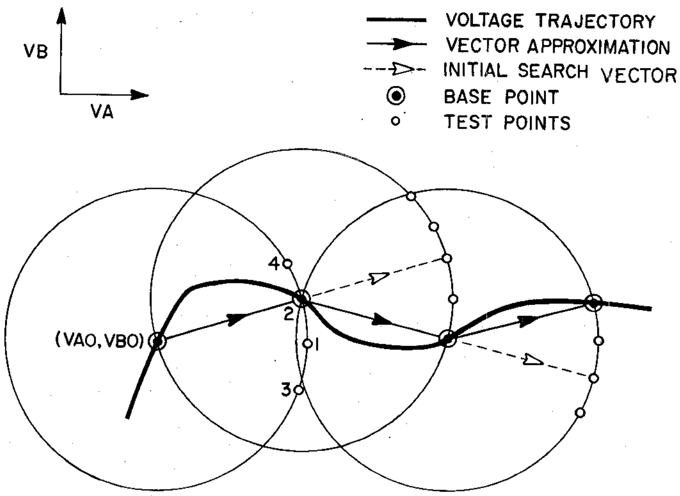

Fig. 3 Description of vector search algorithm.

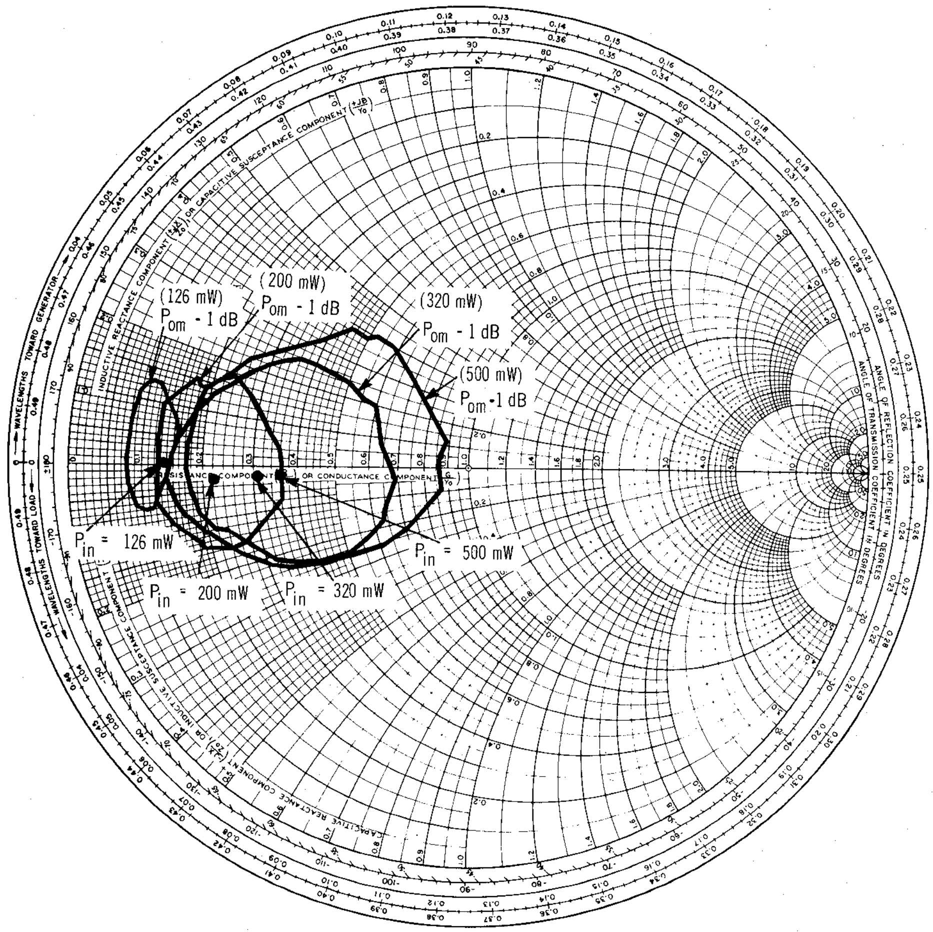

Fig. 4 Power-load contours for an RCA TA 8407 transistor.