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CONDUCTANCE CURVE DESIGN MANUAL

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INTRODUCTION

The *Conductance Curve Design Manual* has been prepared to make available to engineers, scientists, and technicians, a group of data organized to help the user design circuits which function in the manner desired, with a minimum of readjustment. It is divided into three principal sections:

(1) a brief explanation of the special curves and their application in typical R-C amplifier designs.

(2) a set of tables useful in making tube substitutions, and tables to simplify the selection of tubes for given applications.

(3) a special set of curves organized to facilitate tube circuit design.

Chapter 1 describes briefly the forms of curves, and gives examples of the use of the additional data. As the principal purpose of this *Manual* is to provide data on the tubes, organized in a form which simplifies design, a brief discussion of the different sets of curves is included here.

Chapter 2 of the *Manual* develops, from the general plate current equation for tubes, some of the more commonly used equations for both triode and pentode amplifiers. This discussion is intentionally limited to several typical R-C amplifier problems as most of the design principles are displayed in the examples. The use of the techniques on more complex circuits can be readily deduced, or obtained from the appropriate reference articles in the bibliography.

Chapter 3 provides some typical design examples for both triodes and pentodes, showing the calculation of amplification and distortion and the selection of bias. In addition, the problem of selecting both the screen and cathode bypass capacitors is solved.

The first of the two tables in the cross-reference data shows the *Manual* equivalents for several hundred common tubes, and includes structure and basing data. The second table lists tubes for which curves are included, and all their equivalents as provided in Table 1.

The two power-handling tables, one for triodes and one for pentodes, may be used to improve operational reliability. These tables list the tubes in ascending order of plate conductance or screen-to-plate transconductance.

Tube curves themselves represent the characteristics of 71 tubes. Lowpower and high-power tubes, triodes and pentodes, and several mixer tubes are included.

Because of the great familiarity of the term RETMA in the engineering field, we have retained this term rather than use the newer abbreviation resulting from the Association's recent name change: EIA ~ Electronic Industries Association.

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PREFACE

Electron tube information supplied by manufacturers generally consists of static characteristic curves, maximum ratings, and typical operating conditions. Although these data are useful, they are inadequate for design work, as component values that are selected based on them, usually have to be altered in the actual circuit to achieve the desired performance. Extensive use of cut-and-try methods by circuit designers clearly indicates the need for additional electrical information on these tubes, and for modification of the mathematical methods for handling this information. The triode curves given in this *Manual* consist of standard plate characteristic curves with contours of constant grid-to-plate transconductance (g_m), and contours of constant plate conductance (g_p), superimposed on them.

Curves provided here for tetrode and pentode tubes have been designed to present the rapidly varying relations in full, and reduce the more slowly varying relations to correction curves. For this reason, the contours of constant grid bias are plotted as a function of screen voltage and plate current, rather than as standard plate characteristics.

In addition, contours of constant grid-to-plate transconductance (G_{m1}) are superimposed on the static screen characteristics. The pentode curves also include correction curves for X_p and X_{c2} as a function of e_b/E_{c2} to allow adjustment of the design for any ratio of plate-to-screen voltage. This permits the determination of both plate and screen current at any value of plate and screen voltage. Tube data presented in these forms are called "G-Curves." G-Curves permit design over a wide range of operating conditions and help in the design of circuits which, when actually built, conform closely to the predictions of the calculated design.

G-Curves contain the dynamic as well as the static characteristics of a tube in a single convenient graph. One of the important advantages of the G-Curve technique is that the designer can meet specific requirements by making, on paper, point-by-point determinations of dynamic operating conditions anywhere within a tube's ratings. It is therefore possible to optimize a design so that a given performance can be obtained with minimum tube element dissipation. Tube life and circuit reliability are enhanced and the experimental readjustment often required in electronic circuit design is minimized.

In brief, the circuit design technique presented here is based on the fundamental equations of vacuum tube circuits. The small-signal parameters such as g_m and g_p, which appear in these equations are obtained directly from the G-Curves included in this *Manual*. Quantities of interest, such as output voltage, gain, distortion, etc., may be obtained explicitly for use with the fundamental equations because of the additional data available with the G-Curve technique. In most treatments of vacuum tube fundamentals, the circuit equations are developed and the concept of small-signal parameters, although well explained, are not used as a basis for circuit design.

The use of these curves and the equations listed in Chapter 2 enable the designer to understand more dearly in what manner circuit performance changes whenever any circuit parameters are varied. Also, it becomes evident that when a required performance cannot be obtained without operating the tube at or near its peak rating, another tube type with greater power-handling capability should be chosen.

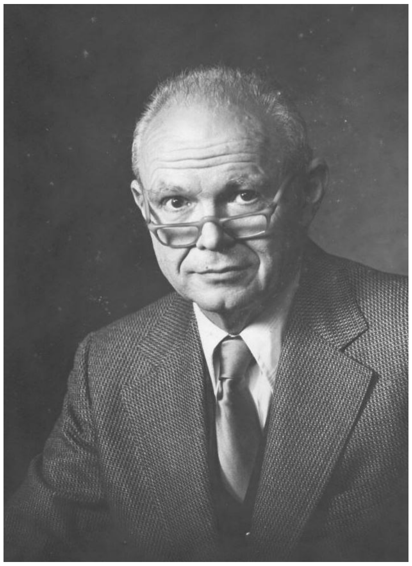
The selection of a different tube type is relatively simple in terms of the tables of power-handling ability included in this *Manual*. First, amplifier distortion and tube dissipation are calculated. If the distortion is larger than desired and/or the dissipation is high, a tube having a larger nominal value of g_p or G_{m2} should be selected. If on the other hand the distortion is lower and/or the dissipation is much less than permissible, then a tube having a lower g_p or G_{m2} may be selected.

Tube reliability is one of the major problems confronting designers of specialized equipment. It may be attained by the design of conservatively rated circuits where the selection of tubes and operating conditions is such that circuit performance is accomplished with the lowest possible element dissipation. The G-Curve technique is well suited to the design of conservatively rated circuits since it provides the design information required.

The author wishes to thank Mr. W. E. Babcock of RCA for his technical review and comments on this *Manual*. He wishes also to note the assistance of H. G. McGuire and T. Turner in the preparation of some of the material.

Kingsville, Md. Keats A. Pullen, Jr., Eng.D.
March 1958

About the author of *The Conductance Curve Design Manual* :



Keats A. Pullen, Jr. ED, PE

was born in Onawa, IA, in November 1916. He attended schools in Los Gatos, CA, then earned a B.S. in physics from the California Institute of Technology, Pasadena, CA, in 1939. He received his Doctorate in Engineering from Johns Hopkins University in 1946 and became a licensed professional engineer in Maryland in 1948.

In June 1946, Dr. Pullen started working at the Ballistics Research Laboratory (BRL), Aberdeen Proving Ground, MD, where he remained until 1978. He transferred from BRL to the U.S. Army Material Systems Analysis Activity (AMSAA) in 1978, where he remained until his retirement from the Army in 1990.

While working at BRL and AMSAA, Dr. Pullen designed and evaluated designs for a wide range of electronic systems for military use, such as DOVAP, DORAN, EMA, a drone program, satellite systems, Havename, and other systems. During his years working at Aberdeen Proving Grounds, he was also on the faculty of several universities where he taught college courses in engineering. These included the Pratt Institute of Technology in Brooklyn, New York, the University of Delaware, and Drexel University.

Dr. Pullen was a Life Fellow of the Institute of Electrical and Electronics Engineers, President of the Aberdeen Chapter of the Armed Forces Communications and Electronics Association, a member of ADPA, AUSA, the Association of Old Crows, and Sigma Xi. In 1982, he received the Marconi Memorial Medal from the Veteran Wireless Operators Association.

During his lifetime, Dr. Pullen published nine books, more than 25 reports, and many more papers and letters. He also was the holder of six patents. He was active in developing improved communication systems for the Special Operations Forces, Airland Battle 2000, and in developing grounding improvements for the Army, to protect the increasingly delicate systems that support the U.S. Military.

Dr. Pullen died in December 2000, at age 84, as the result of a fall. He was survived by his wife, Dr. Phyllis K. Pullen, four sons, Peter, Paul, Keats III, Andrew, his daughter Victoria Leonard, and seven grandchildren.