

A New Digital Beta Meter Device to Assess Teaching Basic Electronics*

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A novel digital beta meter device was designed as a project for a microprocessor course. Its prototype was constructed and evaluated in a student environment. The meter provides an easy and convenient way to measure β (large signal forward current ratio) at different quiescent points. This experience is presented in a very systematic approach to show the advantages of going through senior project stages. The β calculations [1,2,3] usually are done by mathematical/graphical modeling and the curve tracer method. This produces approximate and inefficient results and often causes confusion to students as well as engineers. This paper presents a complete digital β meter design.

INTRODUCTION

THE TRANSISTOR is the most important example of an 'active' component, a device that can amplify, producing an output signal with more power in it than the input signal. The additional power comes from an external source of power (the power supply). Note that voltage amplification is not sufficient. For example, a step-up transformer, a 'passive' component, has voltage gain but no power gain. Devices with power gain are also distinguishable by their ability to make oscillators when feeding an output signal back into the input. Thus, the transistor is the essential ingredient of every electronic circuit from the simplest amplifier or oscillator to the most elaborate personal computer.

A good understanding of transistors is very important, even though most of the circuits are made from integrated circuits (ICs). It is important to understand the input and output properties of the IC in order to connect it to the rest of the circuit and to the outside world. The transistor is the most powerful resource for this interfacing. The reader of this paper can be referred to any of the books listed in the reference section for a complete understanding of the design and analysis of transistor circuits.

In electronic courses and laboratories students and engineers go through a complete design of BJT amplifiers. An essential parameter of BJT is the large signal forward current ratio, beta (β). This parameter is found mathematically by working

through the specific transistor circuit and model or by using the characteristic curves of transistors as seen on a curve tracer. Once β has been determined, the student goes through the design of a sound biasing circuit to operate the BJT at a certain Q point. The main BJT amplifier configuration depends on β , its importance for some configurations is shown in [2] Table 4.2.

The senior design experience that satisfies ABET engineering design criteria requires such courses to include, but not be limited to, hands-on experience and the use of the computer, microprocessors and creative thinking. The β meter is considered to be one of the complete design processes of applying various techniques and scientific principles for the purpose of defining a device, a process, or a system in sufficient detail to permit its physical realization. The general flow of the design process of the beta project is outlined as follows: initiation, exploration, concept formulation, preliminary design and development, detailed design, modification and improvements, and documentation.

The teachers and students in a senior design project interaction start the experience early in the course. The initiation of the problem comes from either the teacher or the student. A pre-proposal is followed, accepted and/or modified. When students register for the senior design course, a proposal is submitted and by the end of the course a complete report and a workable prototype are presented. These include objectives, specifications, anticipated results, methods and ideas used in the construction of prototype, testing and evaluation, references, lists of components with cost, times spent in the project and conclusions.

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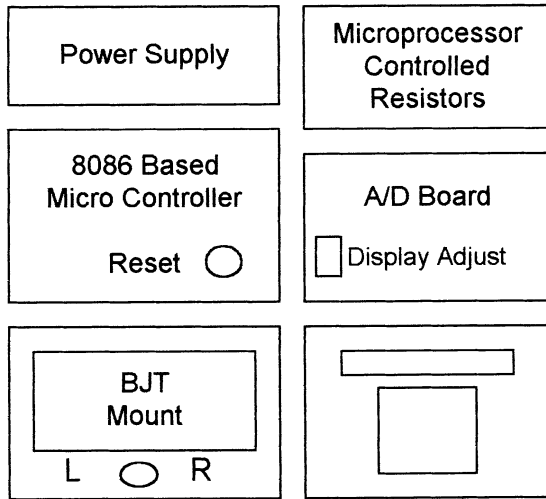


Fig. 1. Beta meter block diagram.

HARDWARE AND SYSTEM OVERVIEW

The main function of this device is to determine beta and polarity of BJT's at specified quiescent (Q) points. The overall operation of the Beta meter will be described, and Fig. 1 illustrates its block diagram. The meter consists of two main functional components; the 8086-based microcontroller and the black box. The 8086 microcontroller is a typical microprocessor-based system that consists of 8086 CPU, ROM, RAM, I/O devices and assorted support devices [4].

It is useful to think of the microcontroller as the 'brain' of the system. It simply controls the black box, keyboard and display. The black box is the heart of the β meter. Its operation is best understood when some facts about transistors are explained. In the transistor circuit shown in Fig. 2, β is the ratio of collector current to base current for a given V_{CEQ} and I_{CQ} . Simple circuit analysis shows that β can be calculated from the following equation:

$$\beta = [(V_{CC} - V_{CEQ})/R_C] / [(V_{CC} - V_{BEQ})/R_b] \quad (1)$$

The black box consists of digitally variable resistors R_b and R_C , and analog to digital converters to measure V_{CEQ} and V_{BEQ} . Additionally, the polarity of V_{CC} is controlled to fit PNP and NPN transistors.

The operation of the meter can now be

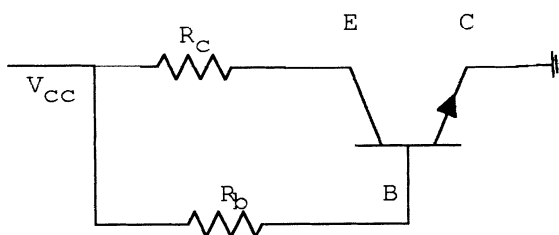


Fig. 2. Transistor circuit.

explained. Using the keyboard and display, a valid V_{CEQ} and I_{CQ} are entered. The microprocessor calculates and outputs the value for resistor R_C . The polarity of the transistor is found, and V_{CC} is adjusted. R_b is then adjusted by the microprocessor until V_{CE} matches V_{CEQ} . The values of V_{CE} and V_{BE} are read, R_b and R_C are known, and β is calculated. This value and the polarity of the transistor are then displayed on the LCD.

DETAILED DESIGN DESCRIPTION

The functional description of the main parts of the β meter and its operations have already been approved and are shown to be acceptable. The details of the operation of each of the components of the meter are described.

Digitally controlled resistors R_b and R_C

Recall that the collector and base currents of the transistor being tested are controlled by the collector and base resistors. Thus, to measure β , digitally controlled resistors are necessary. The design is simple. Relays simply switch resistors in or out of a parallel network. The relays are driven by two parallel output ports of the microcontroller. The most difficult part of the design is the selection of values for the individual resistors [2]. Insight into the design procedure can be gained by reexamining the equations governing the base and collector currents:

$$I_{CQ} = (V_{CC} - V_{CEQ})/R_C \quad (2)$$

$$I_{BQ} = (V_{CC} - V_{BEQ})/R_b \quad (3)$$

These equations are not linear with respect to R_C and R_b . For most engineers, this is bothersome. Nonlinearities can be dealt within software by using lookup tables and cumbersome conversion codes, but a happier solution exists. Thinking in terms of conductances, the above equations yield:

$$I_{CQ} = (V_{CC} - V_{CEQ})G_C \quad (4)$$

$$I_{BQ} = (V_{CC} - V_{BEQ})G_b \quad (5)$$

Thus, collector and base currents can be controlled linearly by varying the collector and base conductances linearly. Minimum and maximum values for G_C and G_b are found from the β meter specifications: $1 \text{ mA} < I_{CQ} < 10 \text{ mA}$; $3 \text{ V} < V_{CEQ} < 12 \text{ V}$; $50 < \beta < 300$. From equation (4):

$$G_C = I_{CQ}/(V_{CC} - V_{CEQ})$$

which implies:

$$G_{C \text{ MAX}} = I_{CQ \text{ MAX}}/(V_{CC} - V_{CEQ \text{ MAX}}) = 3.33 \text{ mS}$$

Similarly:

$$G_{C \text{ MIN}} = I_{CQ \text{ MIN}}/(V_{CC} - V_{CEQ \text{ MIN}}) = 83.33 \mu\text{S}$$

Following the same procedure for base conductances, we can find:

$$G_{b \text{ MAX}} = 13.61 \mu\text{S}$$

$$G_{b \text{ MIN}} = 226.8 \text{ nS}$$

Using these extreme values, the conductances in the parallel networks can be found. A typical conductance network is shown in Fig. 3. The switches are the normally open contacts of relays that are driven by the microcontroller. Note that the total conductance seen at points A and B are the value on the data lines (D_0 through D_n) multiplied by the conductance G_1 . For the base conductance network, seven lines are used with $G_1 = 125 \text{ nS}$. For the collector conductance network, six lines are used with $G_1 = 62.5 \mu\text{S}$.

Keyboard and display

The β meter uses a commercially available 16 character by one line LCD alphanumeric display. ASCII data is simply transferred to the display RAM via a microcontroller output port and it shows up on the screen. The keyboard is a 12-key 4 by 3 matrix connected to a split parallel port (8255-2 port C). This port has three input lines for the rows and four output lines for the columns. Software scans the keyboard, debounces the keypress, and converts the row and column position into the appropriate number.

Power supply

The power supply provides the following voltages and currents:

- +5 V, 1.5 A DC
- +15 V, 300 mA DC
- 15 V, 300 mA DC
- +6 V, 1.5 V DC

The 6-volt supply has its own ground and is isolated from the other supplies. It is used to power the relays that are optically coupled to the system. This design eliminated problems with noise

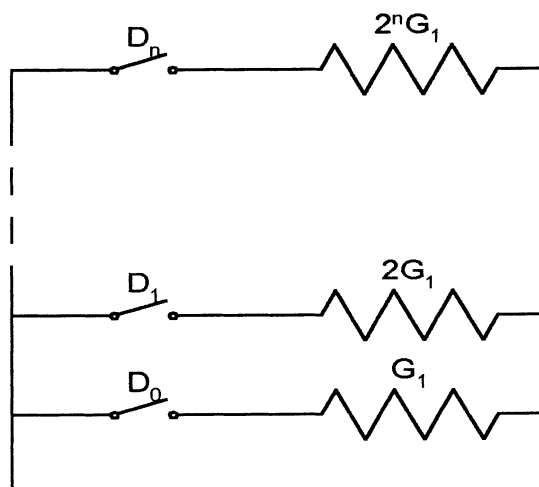


Fig. 3. Conductance network.

due to the relays, and demonstrated the use of transformers and other components.

Analog-to-Digital conversion and relay drivers

For the β meter to function, the microcontroller must have access to V_{CE} and V_{BE} in a binary format. This is the function of the analog-to-digital conversion board. The heart of this board is the ADC 8089, an eight-channel, eight-bit A/D converter. This chip linearly maps a voltage between 0 and 5 V to a binary number between 0 and 255. It is driven by a 100-kHz clock derived from a type 555 timer. Two input channels are used, I_{N0} for V_{CE} and I_{N1} for V_{BE} . Operational amplifiers and voltage dividers are used to guarantee that the +15 V to -15 V possible input voltages are converted into the 0 to 5 V ranges acceptable to the A/D chip. High impedance (10–12 M Ω) buffers are used to minimize loading on the actual transistor being tested.

Three relays are used to control the polarity of V_{CC} , V_{CE} , and V_{BE} . Relays were chosen over analog switches because of their low contact resistance, high current handling capability and wide voltage range. However, relays have some drawbacks. They are noisy and draw large currents (in our case 72 mA). Optical driving circuits eliminate the noise problem and are used for all relay drivers in the β meter. The designs in this portion integrated science courses, microelectronics, microprocessor, digital and analog conversion principles. It also integrated testing and troubleshooting of the designed circuits in some sections of the meter.

Software

Software for the β meter was developed using the SDK-86 development system. The program demonstrates the use of principles from the computer programming course.

PROJECT CONSTRUCTION AND SPECIFICATIONS

The black box was designed and tested, using breadboard techniques. After each section was approved, it was interconnected by wire wrapping. The entire black box is then connected to the SDK-86 development system where integration with software took place. Finally, after the system was completely debugged on the SDK-86, the microcontroller board was built and the software transferred to its EPROM. A power supply was built, and the β meter was complete.

Specification

Function: to determine β and the polarity of BJTs at a specified Q point.
 Ranges: $3 \text{ V} < V_{CEQ} < 12 \text{ V}$; $1 \text{ mA} < I_{CQ} < 10 \text{ mA}$;
 $50 < \beta < 300$.

Power: 25.5 W (max)

Accuracy: $\pm 1\%$ at $V_{CEQ} = 7.5\text{ V}$, $I_{CQ} = 5\text{ mA}$

Usage method

The β meter is used as a standalone unit that measures the DC forward current transfer ratio of a bipolar junction transistor for a given quiescent point. Its use is simple and straightforward.

GENERAL INFORMATION

- The student is expected to devote one half of the course to a project that encompasses the design and construction of an 8086 microprocessor-based application.
- The level of required staff assistance is minimal. Staff supplies the lab space, a development station for each registered student, and the instructor provides technical support for the students.
- The student work accomplished individually. However, about one half of the class participate in a design team to standardize the microprocessor portion of the project.
- The outcome is a project report written in a standard prescribed format.
- The project represents 25% of the grade for a 4-credit hour course.
- The project presentation to the class is expected to require 10–15 minutes.

CONCLUSIONS

A good learning experience from the initial project stages through the different design steps depends on the student/teacher interaction. It also depends on how well a senior design project can assimilate most of the undergraduate's educational experience with an ultimate goal of a packaged prototype. A microprocessor-based β meter prototype design can be constructed and evaluated in a student laboratory environment. The design and functional use of the different components is also shown. The β meter provides a quick and convenient way to measure the BJT β at various quiescent points. This is particularly useful when designing BJT amplifier biasing circuits. Also, it can provide an instant verification of the β found from a curve tracer. This can increase students' and engineer's confidence for an efficient transistor circuit when using this device. The microprocessor can be upgraded any time to include more features and more recent chips.

A senior design project presented here, is of a high technical level. The complete systematic learning process, the student preliminary design on paper, was implemented in the second to last semesters before graduation. A prototype was constructed, tested, debugged, and a well-documented report was submitted. An oral presentation with demonstration of the operation of the beta meter was performed. Such experience has rounded up, and equipped students to be original, creative and productive engineers.

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