

AC 1996-405: A Senior Design Project of a FI Meter Device to Assess Teaching Electronic Concept

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A Senior Design Project of a β Meter Device to Assess Teaching Electronic Concept

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ABSTRACT

A novel microprocessor-based large signal forward current ratio Beta (β) meter device was designed as a senior design project. Its prototype was constructed and evaluated in a student environment. The meter provides an easy and convenient way to measure β 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 and its importance, specifically at high frequencies and temperature^{1,2} in BJT's electronic circuit, usually are done by mathematical/graphical modeling and the curve tracer method. This results in approximate and inefficient results and often causes confusion to students and was also time consuming for engineers as well as students. This paper presents a complete β meter design which is aimed to:

- Demonstrate the interaction/integration between faculty/student and senior design/courses, and ideas learned in an accredited electrical and electronic engineering College/University program. Such integrations include electrical circuits, electronic circuits, programming, microprocessors and many other aspects of electrical engineering.
- Help students and engineers in design efficient electronic BJT's (bipolar junction transistors) or other transistor types amplifier circuits.
- Alleviate the confusion for students in the electronic design courses and laboratories.
- Replace the method for determination of β through curve tracer or other mathematical or graphical methods.

This paper illustrates the new meter design and its fictional use. It is not intended to give a good understanding of the transistor. It highlights the importance of the parameter β and its use in electronic biasing circuits and design. β is a constant for the particular transistor. For modern npn transistors, β is in the range 100 to 200, but it can be as high as 10003. The meter provides a quick and direct measure of values of β at different conditions. It helps in developing confidence when using a curve tracer and using the BJT's characteristics to find β .

Therefore, it maybe a very valuable device for basic electronic design laboratories and manufacturers. It is extendable, easy to use and may use other microprocessors with minor modifications of the circuitry. Experience using the device was appreciated by students and engineers. Comments were made about its range and improvement.

I. 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 what matter. For example, a step-up transformer, a “passive” component, has voltage gain but no power gain. Devices with power gain are distinguishable by their ability to make oscillators when feeding an output signal back into the input. 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. In addition, the transistor is the most powerful resource for interfacing, whether between ICs and other circuitry or between one subcircuit and another. 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 going through the specific transistor circuit and model or by using the characteristic curves of transistors as seen on a curve tracer. A student also goes through 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 reference 2 (table 4.2).

The senior design experience so obtained does satisfy “ABET” engineering design criteria which require such courses to include, but not limited to, hands on experience and the use of the computer, microprocessor and creative thinking. The β meter is considered to be one of the complete designs 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 duration of the course a complete report and a workable prototype are presented. These include objectives, specification, anticipated results, methods and ideas used in the construction of prototype, testing and evaluation, references, lists of components with cost, times spend in the project and conclusions.

H. HARDWARE AND SYSTEM OPERATION

The main function of this device is to determine beta and polarity of BJT's at a specified quiescent (Q) points. The overall operation of the Beta meter will be described, and Figure 1 illustrates its block diagram. The meter consists of two main fictional components; the 8086-based micro controller and the black box. The 8086 micro controller is a typical microprocessor-based system that consists of 8086 CPU, ROM, RAM, I/O devices and assorted support devices⁴.

For now, it is useful to think of the micro controller as the “brain” of the system. It simply controls the black box, keyboard and display. The black box is the nuts and bolts of the β meter. Its operation is best understood when some facts about transistors are explained, In the transistor circuit shown in Figure 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:

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

Thus the black box consists of digitally variable resistors' R_b and R_C , and analog to a digital converter 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 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,

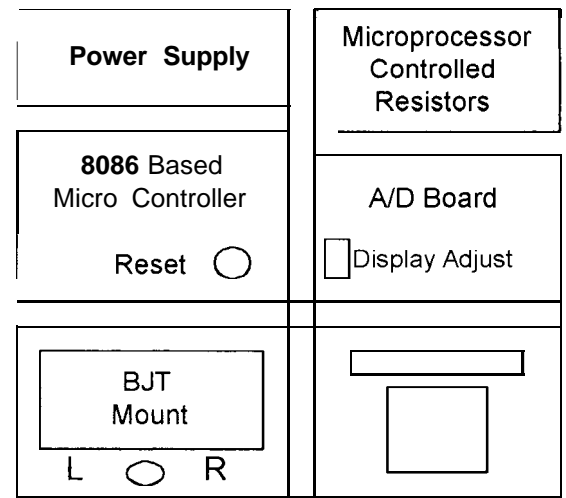


Fig. 1 Beta meter Block Diagram

III. DETAILED DESIGN DESCRIPTION AND BUGS FOR PRODUCTION

The fictional description of the main parts of the β meter and its operations have already been approved and shown to be acceptable and have performed what is needed to do this project, The details of the operation of each of the components of the meter are:

A. 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 micro controller, The most difficult part of the design is the selection of values for the individual resistors' 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 conductance, 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 conductance linearly.

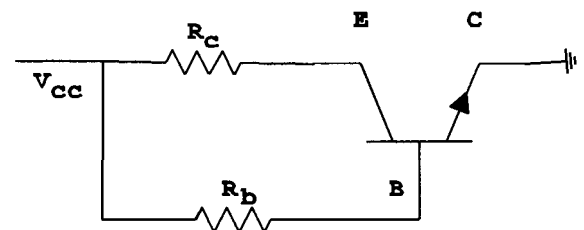


Fig.2 Transistor Circuit

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:

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

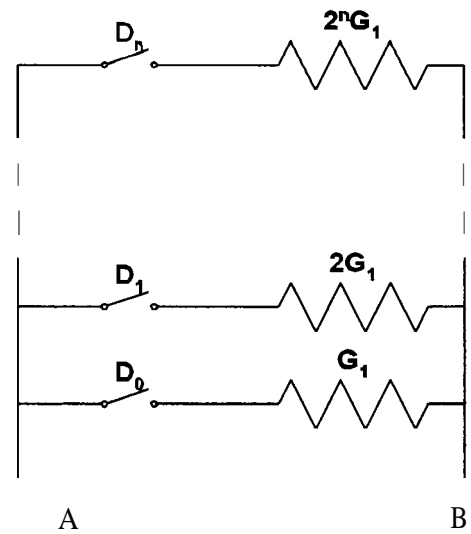


Fig. 3 Conductance Network

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

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

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

Using these extreme values, the conductance in the parallel networks can be found. A typical conductance network is shown in Figure 3. The switches are the normally open contacts of relays that are driven by the micro controller. 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 $G_1 = 62.5 \text{ } \mu\text{S}$.

B. Keyboard and Display

The β meter uses a commercially available 16 characters by one line LCD alphanumeric display. ASCII data is simply transferred to the display RAM via a micro controller output port and it shows up on the screen. The keyboard is a 12-key 4 x 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,

C. Power Supply

The power supply provides the following voltages and currents:

+5V 1.5A DC
 +15V 300mA DC
 -15V 300mA DC
 +6V 1.5V 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 due to the relays, and demonstrated the use of transformers and other components.

D. Analog to digital conversion and relay drivers

For the β meter to function, the micro controller 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 ADC8089, eight channels, eight bit A/D Converter. This chip linearly maps a voltage between 0 and 5 volts to a binary number between 0 and 255. It is driven by a 100-kHz clock derived from a 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 +15V to -15V possible input voltages are converted into the 0 to 5 volt ranges acceptable to the A/D chip. High impedance (10-12m 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 these problems and are used for all relay drivers in the Beta 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 and find solution and improvements of some sections of the meter.

F. 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.

IV. PROJECT CONSTRUCTION AND SPECIFICATIONS

The black box was designed and tested, using breadboard techniques. After each section was approved, it was wire wrapped. 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 micro controller board was built and the software transferred to EPROM. A power supply was built, and the β meter was complete.

A. SPECIFICATIONS

Function: determine β and the polarity of BJTs at a specified Q point

Ranges: $3V < V_{CEQ} < 12V$, $1 \text{ mA} < I_{CQ} < 10\text{mA}$,

$50 < \beta < 300$.

Power: 25.5W (max)

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

B. USAGE METHOD

The β meter is used as a stand alone 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.



V. CONCLUSIONS

A proper experience preparation from the initial project stages through the different design process depends on the student/teacher interaction, It also depends on how well a senior design project can assimilate most of the undergraduates educational experience with an ultimate goal of a packaged prototype. A microprocessor-based β meter prototype design is constructed and evaluated in a student laboratory environment, The design and fictional 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 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 last two semesters before graduation, A prototype was constructed, tested, troubleshooted, 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 the student to be an original, creative, productive engineer.

VI. REFERENCES

1. P. Horowitz and W. Hill, The Art of Electronics, Cambridge University Press, Cambridge (1989).
2. A. S. Sedra and K.C. Smith, Microelectronic Circuits, Saunders College Publishing, New York (1991).
3. D.F. Stout and M. Kaufman, Handbook of Operational Amplifier Circuits, McGraw Hill, New York (1976).
4. 8086 Intel manufacturer manual
5. SDK-86 Development system

VII. BIOGRAPHY

MOHAMED SHWEHDI was born in A1-Berkah, Benghazi on June 25, 1950. He received his B. S. in 1972 from the University of Tripoli, a MS from the University of Southern California in 1975 and the Ph.D. (E. E.) in 1985 from Mississippi State University. He is currently with King Fahad University. His research interests include Power System Transient Analysis, Lightning and Surges in Power Systems and Power Electronics.

AKRAM AL-RAWI was born in Rawah, in 1951, He received the M, S. degree in electrical engineering from the University of Manchester, and the Ph.D. degree from the University of Bath, U. K., in 1978 and 1981 respectively. From 1988-1990, he was with the college of Technology in Kuwait. Since January 1991, he is with Colombia College. His current teaching includes C++, Pascal, Visual Basic, COBOL, and Logic Design.

