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***Transaction Network, Telephones, and Terminals*:**

Transaction Printer

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An inexpensive, reliable, impact pin printer adjunct has been designed to increase the range of applications for the Transaction II telephone and Transaction III terminal. The printer will accommodate a wide variety of forms due to its slip printer format and its ribbon inking mechanism. The character set includes the upper and lower case alphabets, numerics, and 25 punctuation marks. These can be printed at densities of 30, 40, or 50 characters per four-inch line at a rate of approximately 1.0 line per second.

I. INTRODUCTION

User experience throughout the Transaction telephone program has indicated the versatile nature of the terminals. Units that were installed for field trials in late 1973 and 1974 were used for credit authorization from retail locations, as bank lobby terminals for account information inquiry, and for check validation in grocery stores. Transaction I telephones, first installed in April 1975, have been used for remote banking, for entry of orders into a computerized purchasing system, and as bank teller terminals. Prospective uses of Transaction terminals include inventory and payroll control, data entry for insurance claims, and the countless credit, debit, and transfer operations of an electronic funds transfer system.

Many of these applications would be enhanced by a hard-copy delivery mechanism at the terminal location. For this reason, it was decided, in the summer of 1975, to provide a printer adjunct for the then-to-be-released Transaction II telephone and Transaction III terminal.

II. DESIGN GOALS

The design goals for the Transaction printer were strongly influenced by the wide range of existing and projected applications for Transaction terminals. The requirements can be considered in three categories: those relating directly to the printing operation, those relating to the physical configuration of the printer, and those relating to the provision of printers by operating telephone companies.

2.1 Printing requirements

Virtually all projected printer applications required the printing of numerals; most also required the printing of alphabetic and punctuation data. A printer with full alphanumeric print capability was therefore required. A character set consisting of the upper and lower case alphabet, numerals, and 25 punctuation and symbol characters was chosen (Fig. 1). Capabilities of printing multiple lines and of accommodating at least 40 characters on a single print line were also felt necessary. To enhance the printer versatility, print densities of either 30, 40, or 50 characters per line were provided (Fig. 1). A requirement for optical character recognizable font (OCR) was considered but was not implemented for several reasons. Since only information transmitted to a Transaction

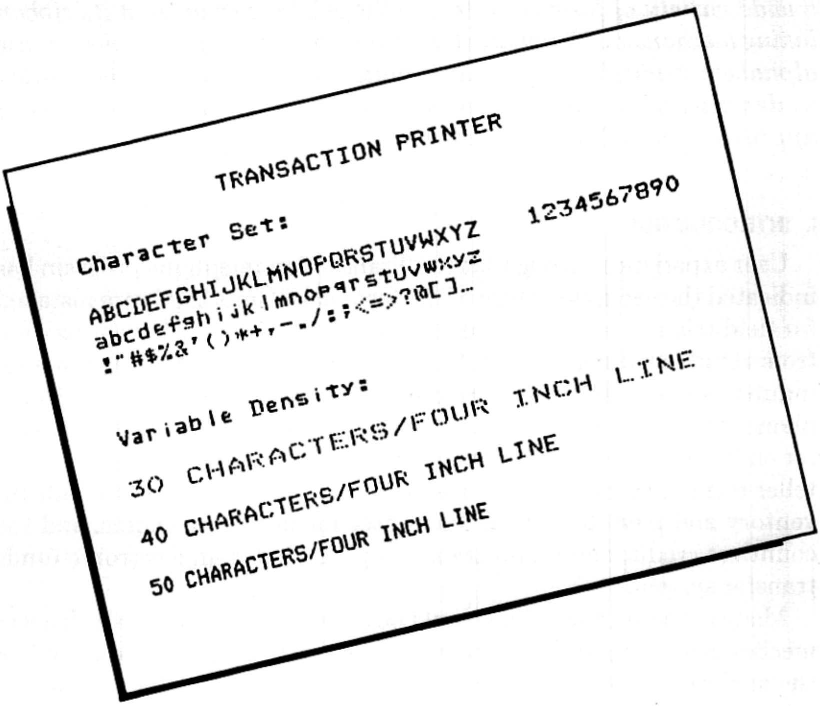

Fig. 1—Character set of printer.

terminal was to be printed, it was assumed that the data would already be stored in electronic form and that rereading the data from printed paper would be unnecessary.

Many printer applications would require printing on existing documents. In check authorization, for example, it would be desirable to print on the back of presently utilized bank checks. This required printing on plain paper. Impact printing using an inking medium, and not thermal printing or electric discharge printing, was thus mandated. Impact printing also satisfied another requirement, that of multiple copies. In credit validation, for example, multiple copies can be made by impact printing using conventional carbon or pressure-sensitive forms. Non-impact techniques require reprinting the message for multicopies, and this would have entailed new forms.

The need to accommodate a wide variety of special forms, many already in existence, required a printer which handled paper in a "slip" format; that is, a printer with physical access to the printing region from three sides in the plane of printing. Although paper handling is greatly simplified by roll printing (as in cash registers) or ticket printing configurations (as in credit slip imprinters), the slip printer allows printing anywhere within the rightmost X inches of an indefinitely long or wide piece of paper. The dimension X is determined by the physical configuration of the mechanism; four inches was considered an acceptable compromise between maximizing print area and tolerable mechanical constraints. The slip printer which resulted can accommodate paper ranging from check size up to ledgers or invoices. Fanfold bank deposit books have been proposed and could be accommodated by a slip printer.

The variety of forms and paper stock to be printed, and the need for multiple copies, suggested that a range of paper thicknesses (stack height) must be accommodated. The design specification ranged from 0.003 inch (a single check or bond paper) to 0.015 inch (an original and three copies with tissue carbons).

Print speed was not firmly specified, but it was felt that a 100-character message, including line feeds and carriage returns, should be printable in three seconds or less after receipt by the Transaction terminal.

2.2 Physical requirements

In addition to the normal environmental requirements for Bell System business terminals, e.g., temperature and humidity range, shock and vibration, etc., the Transaction printer was required to provide an appearance and configuration suitable to its range of applications. Small size was a fundamental requirement, yet the printer would always be offered in conjunction with a Transaction II telephone or Transaction

III terminal. The demands on space, both footprint and vertical space, of the terminal-printer combination had to be minimized and made as flexible as possible. A configuration had to be offered wherein the combination appeared to the customer as a single unit. One corollary requirement was thus that the printer must provide a concealed ac power outlet and concealed cord stowage for the Transaction terminal.

2.3 Service requirements

Two nontechnical requirements affected the design process as dramatically as any other requirements: price and availability date. The pricing target indicated that a completed printer would cost no more than the Transaction terminal to which it would be attached. Additionally, prototype models for field evaluation were to be available 12 months after inception of the project.

These requirements mandated the use of commercially available printing and paper-handling mechanisms. One advantage of using existing mechanisms was the availability of reliability data for proven print mechanisms. Reliability is often a parameter that can be readily traded for lower cost in an electromechanical design process. Yet product reliability and maintenance requirements were specified to avoid service impairment.

Marketing data suggested a typical location life of 2.5 years for a Transaction terminal. Ideally, the printer should not require maintenance or repair within this interval. The most critical element thus became the inking mechanism. Assuming 50 printed characters per transaction, 10 transactions per hour, for a 12-hour day, operating 360 days per year, the 2.5-year life translated into a requirement of 5.4 million characters before ribbon replacement. The printing mechanism life objective is 50 million characters and 5 million line feeds before failure.

III. PRINTER DESCRIPTION

The Transaction printer was designed to allow the Transaction terminal to be mounted on top of the printer so as to give the appearance of an integral printing terminal, as shown in Fig. 2. Alternatively, the units may be mounted separately, up to 10 feet apart for flexibility of installation or to allow several terminals to share one printer. The printer alone measures approximately 13 in. deep, 10 in. wide, and 7 in. high, and weighs approximately 15 pounds. Forms are inserted into the printer from the front or right side, aligned with registration marks on the print table and housing, and fed from right to left during printing. The open print table design with access from three sides allows easy removal of a wide variety of forms. To help ensure proper form insertion, feedback is given to the user via a rear paper stop and by a paper prompt display in the terminal, as discussed below.

Fig. 2—Transaction printer and telephone.

As can be seen in Fig. 3, the printer is made up of four parts—the housing, a power transformer mounted in the housing, a printed circuit board, and a printing mechanism.

3.1 Printing mechanism

This mechanism (Fig. 4) was developed to Bell System requirements by Practical Automation, Inc., of Shelton, Conn., working in conjunction with Bell Laboratories. It consists of a 7-pin impact printing head driven at a constant velocity on two guide rods by a reversible, synchronous ac motor and cable drive system. Head position detection is provided for the control circuitry by optical sensors located near the left- and right-hand extremes of head travel. A 25-yard long, ½-in. wide fabric inking ribbon is fed from open reels and between the printing pins and a hardened steel platen by an automatically reversing ribbon advance

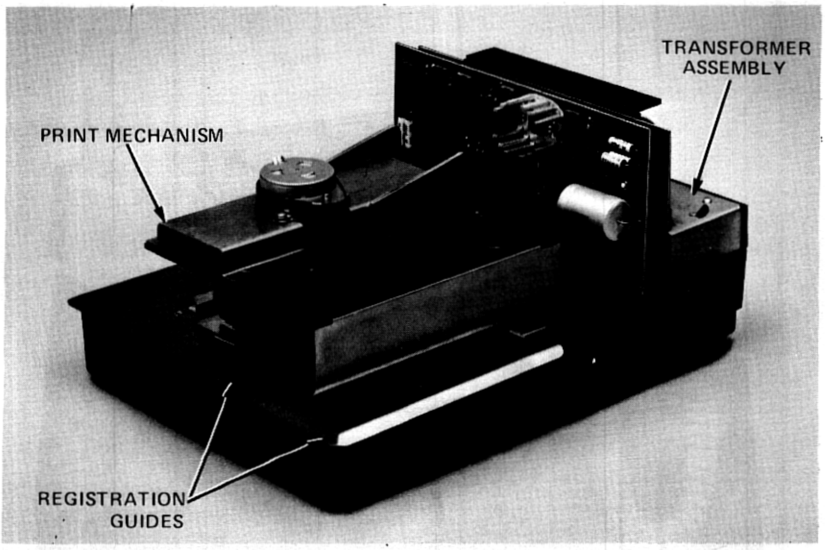

Fig. 3—Transaction printer, cover removed.

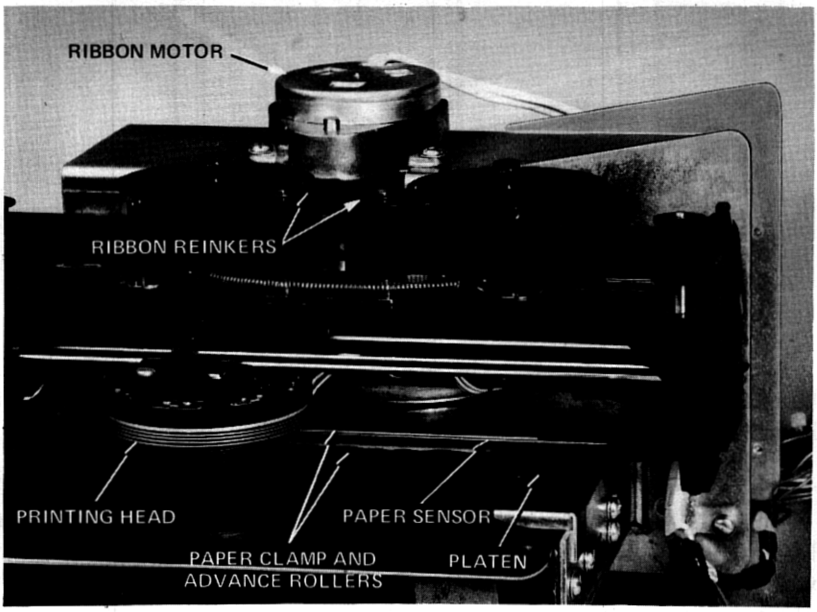

Fig. 4—Printing mechanism.

mechanism. This ratchet type mechanism is cam-operated from a unidirectional synchronous motor separate from the head drive motor. To improve ribbon life, the ribbon is fed in a skewed path across the print line and re-inked with a black oil-based ink by two porous inkers located on the ribbon feed mechanism. Ink selection is critical for impact pin printers. A conventional, pigment-based ink will cause premature head wear by abrasion of the pins. An oil-based ink must be used, which will lubricate the pins, provide adequate printing opacity, dry rapidly enough on glossy paper to prevent smearing, and yet not dry excessively on the ribbon or re-inking rollers. To ensure proper paper feed and minimize paper skewing, paper is inserted over a solid 4-in. wide paper advance roller. A solenoid-actuated top idler roller can clamp the paper on command by the Transaction terminal. Paper feed is accomplished with a solenoid-actuated ratchet drive mechanism. A mechanical paper-sensing switch protrudes through the print table to signal the control circuitry that paper is properly located between the rollers and against the rear paper stop.

The housing and print mechanism designs were configured to maximize the print area within the constraints of limited modifications to the commercially available mechanism. An unlimited number of 4-in. lines, starting 4.5 in. and ending 0.5 in. from the right-hand edge of the form may be printed subject only to the limitation of the 120-character buffer size when the printer is used with the Transaction terminals. Lines may start 7/8-in. from the top of the form and, on most forms, continue to the bottom of the form. Forms smaller than 4½ in. long by 6¾ in. wide can only be printed to within 1 11/16 in. of the bottom of the form; otherwise, these small forms disappear under the housing. This 1 11/16-in. restriction severely limits the useful printable area on petroleum industry and some credit-slip-sized forms, and studies are presently under way to consider adding a paper ejection means. With form ejection allowed, such forms could be printed to the bottom of the form, thus enhancing the versatility of the printer.

3.2 Circuit board

The printer circuitry, contained on the printed wiring board of Fig. 2, must interpret control and print character data from the Transaction terminal to properly operate the various paper sensing, clamp, feed, and printing functions provided by the print mechanism. An unregulated 50-V power source is generated on the circuit board to drive the paper clamp solenoid, paper feed solenoid, and the pins of the print head. Considerable savings in power supply cost and size are realized by using an unregulated 50-V supply. This is made possible by a novel head drive compensation circuit that will be discussed later. The remainder of the circuitry as well as the paper sense switch and head position sensors in the print mechanism are powered from a 5-V regulated supply. Twenty-seven volts ac is routed through the circuit board for control of the head and ribbon drive motors.

Care was taken in the power supply circuit design to protect the print head against overheating and subsequent failure in the event of circuit component failures. Both the circuit drive and voltage supply to the head solenoids are enabled only during the time the head is being activated to impact a print column. The low print-to-idle duty cycle ensures that the head does not have time to overheat to the point where it could sustain damage.

The majority of the hardwired control logic is implemented by CMOS gates because of the ease in providing the various time delays needed for proper printer operation. Control of the various print mechanism motors, solenoids, and print head solenoids are provided by triacs, discrete power transistors, and Darlington power drivers, respectively. A 1024 × 8-bit MOS ROM is used for character generation, control character decoding, and print density decoding (as discussed below). The eighth bit of each character word is coded to differentiate control characters and printable characters, thereby simplifying the logic design. To achieve circuit protection and proper printing operation in the presence of electrostatic discharges, the circuitry is packaged on a multilayer circuit board with a middle layer ground plane.

3.3 Printer-terminal interface

The printer connects to the Transaction terminal via a 10-lead interface containing 7 data leads, a data strobe (DS) lead, a data response (DR) lead, and a ground lead. The DS-DR protocol is designed to control the data transfer between the terminal and printer and to inform the terminal when a printer is attached, when paper is present, and when a printing error has occurred.

The printer-terminal interaction is best explained by proceeding through a typical printing sequence. Initially, the printer is in the idle mode, which corresponds to deactivation of all the printer motors, solenoids, and sensors. A high (logical 1) voltage is on the DR lead to indicate to the terminal that a printer is attached. Before printing a message, the terminal ensures that the printer is in its correct (idle) stage by setting up an ASCII-encoded ETX on the data leads and loading it into the printer data register during the positive transition of the DS lead. The terminal then interrogates the printer to determine if paper is present by loading a "∧" into the printer. If paper is present, DR momentarily drops in response to DS and the terminal proceeds to the printing sequence. If paper is not present, the word "PAPER" appears on the Transaction terminal display to prompt the user. When paper is inserted, the display prompts the user to push the END button on the keyboard by displaying "PUSH END." After the END button depression, the terminal transfers the data associated with a normal printing sequence.

A typical printing sequence starts with an STX loaded into the printer, which clamps paper, starts the ribbon moving, and turns on the optical head sensors. The first print character activates the printing cycle. DR is held low as the character is being printed and is raised after each character is printed to signal the terminal to load a new character. DR is also held low during line feeds (which cause a line feed, then carriage return) and carriage returns to inhibit further character loading until the head returns home and is ready to start a new line. Should the print message be improperly formatted or contain errors such that these control characters are not received, the optical sensor in the print mechanism senses the line overrun and maintains the DR lead low. When the terminal obtains no response on the DR lead in an appropriate time interval, it displays an error code indicating a printing error. Should paper be pulled out during printing or be misfed so as to deactivate the paper sensor, the DR lead is latched high and fails to respond to the next character. This produces the same error message in the terminal. Horizontal tabbing from any print location to the 11th, 21st, 31st, or 41st character is implemented in the terminal software and achieved by sending the printer an appropriate number of print spaces. The printing sequence is normally terminated by an ETX which returns the printer to the idle state.

3.4 Character printing

Before the first printable character is loaded into the printer, paper has been clamped and the ribbon set into motion by the STX character. The Transaction terminal then sets up the first print character on the 7 data leads and sends the printer a 400-μs DS pulse. After a 15-μs integration period to eliminate short duration noise transients, the terminal interface circuit generates a 385-μs strobe pulse. The leading edge of this pulse latches the data, and the trailing edge starts the head moving to the right and enables a voltage-controlled oscillator (VCO) and 4-bit counter. The VCO is nominally arranged to run at 1000 Hz to print a 40-character line in 400 ms. If a "BEL" or "/" is received prior to the first print character of the line, the oscillator frequency is scaled appropriately to achieve a 50- or 30-character line, respectively. The counter counts to eight and temporarily halts. After the head reaches a uniform velocity, it exits the start-of-line optical sensor and the count is reinstituted, continuing from 9 through 16. The 9th count corresponds to a one-column space on the left of the first character, and the 10th through 16th counts make up the seven vertical column strokes in the 7×7 character font. On subsequent characters, the counter is arranged to cycle from a 7th through 16th count. The 7th through 9th counts make up the three-column intercharacter space, and the 10th through 16th counts correspond again to the seven column strokes of the printed character. The three least significant counter bits control the ROM address for the proper character generation, and the most significant bit is used in the print head drive circuit to allow the ROM outputs to activate the print solenoids.

3.5 Printer circuitry

Three aspects of the printer circuitry may be considered as novel:

(*i*) The use of a single ROM for character generation and control functions.

(*ii*) The use of variable print density under remote software control.

(*iii*) The use of variable solenoid drive timing to compensate for power supply fluctuations.

These features are illustrated in the schematic drawing of Fig. 5.

The ROM has 10 input leads and 8 output leads. Seven of the input leads receive an address in the form of an ASCII code which may indicate a printing character or may indicate a control character. The other three ROM inputs come from the counter discussed above. Seven of the ROM output leads are connected, through gates, to high current drivers which control print head solenoids. The eighth ROM output indicates whether the ASCII address indicated a printable character. If it did indicate a printable character, output lead 8 will go high, enabling the data on output leads 1 through 7 to be fed through gates to the print head solenoids. If output lead 8 goes low, in response to an ASCII input for a non-printing character such as line feed, carriage return, etc., the signals from output leads 1 through 7 will not be communicated to the high current drivers and instead can be used for other control functions.

Let us consider Fig. 5 in the case of a printing character present on ROM input leads 1 through 7. Output lead 8 will be high, and the two AND gates on the left side will be disabled by the action of the inverter. The high on output 8 will enable timer A, and timer A will generate a series of pulses whose frequency will be determined by capacitor C_1, resistors R_1 and R_2, and any current fed from resistors R_3 and R_4. The duration of each pulse from timer A is determined by resistor R_2 and capacitor C_1, and is of no consequence in the operation of this circuit. The rising output to each pulse of timer A will trigger timer B to respond with a single pulse whose duration is determined by the value of capacitor C_2 and the current fed into C_2 through resistors R_5 and R_6. This output from timer B will act on the seven AND gates, allowing the high current drivers to respond to the signals on output leads 1 through 7 of the ROM.

The rate of pulses out of timer A determines the rate at which the character font is formed. Since the print head moves across the paper at a constant velocity, fixed by a constant speed motor and gears, the rate at which characters are formed can be adjusted by varying the rate at which the solenoids are activated. The Transaction printer can vary this rate so that 30, 40, or 50 characters may be spread evenly over a 4-in. printing line. It varies the rate in the following way. To print 30 char-

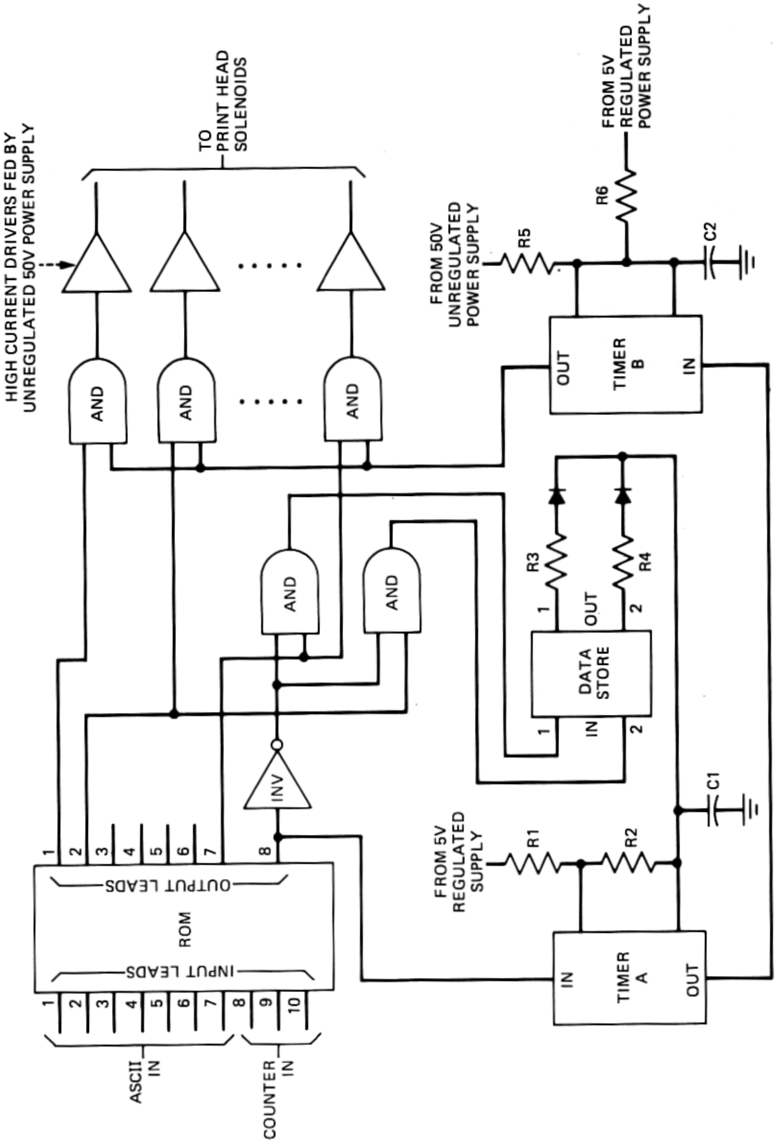

Fig. 5—Printer circuitry.

acters per line, the slowest rate out of timer A, current is fed into C_1 through resistor R_1 and R_2. To increase the rate of pulses out of timer A to the 40-character-per-line rate, current is also fed through R_3 by raising output 1 of the data store. To further increase the rate of pulses out of timer A, so as to obtain 50 characters per line, current is fed through both R_3 and R_4 by raising both data store outputs. The data store outputs are changed by the data store inputs which are sensitive to certain of the ROM output leads 1 through 7. This only occurs when ROM output lead 8 is low, indicating a nonprinting character. By this means, a special ASCII word can change the printing density.

Timer B controls the length of time when the high current driver feeds power from the unrelated 50-V power supply to the print head solenoids. Timer B produces a single output pulse in response to each input pulse from timer A. If the 50-V power supply were unvarying in its voltage, timer B could produce a pulse of uniform length and yield acceptable print. Unfortunately, the print head may draw currents as high as 10 A

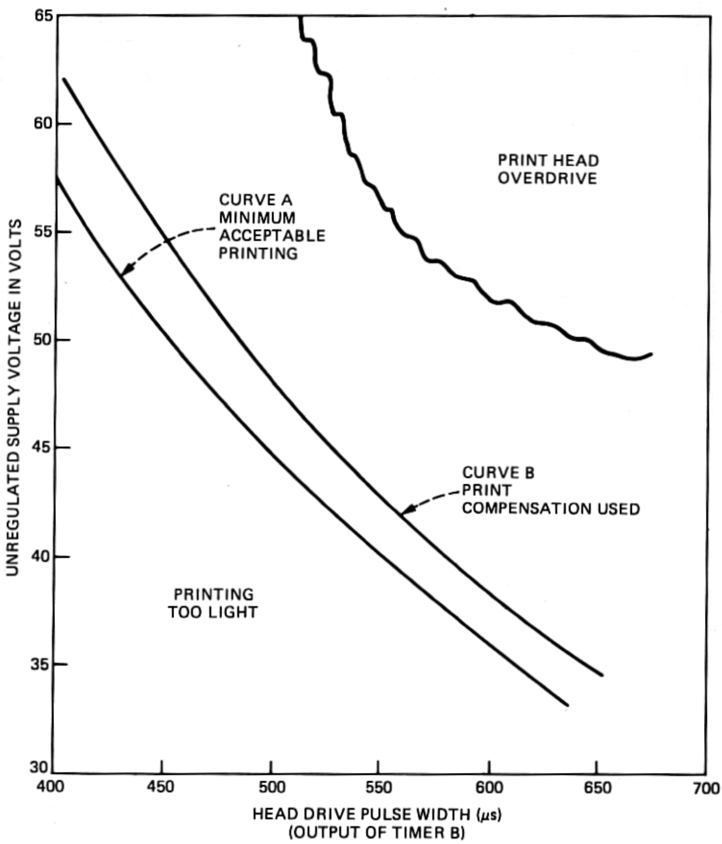

Fig. 6—Power supply voltage and pulse width for acceptable printing.

when printing a vertical column. It is economically unattractive to construct a power supply that can yield such high current pulses while not varying its voltage output more than a small amount. A more economical power supply design would vary its output voltage over a wide range, say, plus 10 percent, minus 50 percent, when large currents are drawn and/or the ac line voltage is varied. If timer B produced constant length pulses, this inexpensive power supply would yield unacceptable printing.

Curve A in Fig. 6 shows the range of power supply voltages and pulse widths which yield acceptable print quality. Too low a voltage and/or too short a pulse width will result in printing which is unacceptably light. Too high a voltage and/or too long a pulse width will waste power, will overheat the print head, and may cause blurred printing. The combination of resistor R_5, feeding from the unregulated 50 V supply, and R_6, feeding from a regulated 5 V power supply into capacitor C_2, causes timer B to exhibit the pulse width versus supply voltage variation shown by curve B in Fig. 6. This yields satisfactory print over the entire operating range of the low cost, unregulated 50-V power supply used in Transaction printer.

IV. CONCLUSION

First Bell Laboratories prototype models of the Transaction printer were available in the summer of 1976. Further prototypes were provided for a field trial starting in the fourth quarter of that year. After incorporation of certain design improvements, design information was released to Western Electric for the production of the 5000A Transaction printer in the second quarter of 1977.