To the Graduate Council:

I am submitting herewith a thesis written by Reza M. Habibi entitled "A Survey of Digital Displays." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Electrical Engineering.

Robert W. Rochelle

Robert W. Rochelle, Major Professor

We have read this thesis
and recommend its acceptance:

Robert E. Bechhoefer

Donald W. Bouldin

Accepted for the Council:

L. Evans Roth

Vice-Chancellor
Graduate Studies and Research

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A SURVEY OF DIGITAL DISPLAYS

A Thesis

Presented for the

Master of Science

Degree

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Reza M. Habibi

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ABSTRACT

The rapidly expanding demand for communications between machines and human beings has spurred intensive innovative efforts to achieve electronic-to-visual transducers which most closely fit the needs of the developing communications systems. This thesis serves the purpose of reporting the current state-of-the-art, as well as the trends, in the development of new display devices in the U.S.A. and abroad. In addition, for a dedicated real-time system requiring much man-machine interaction, this thesis provides a working description and review of the salient features of the most available electronic display device, namely the Cathode-Ray Tube (television screen display).

A model, which consists entirely of integrated circuits, was designed and developed for interfacing a digital alphanumeric keyboard to a home television screen in order to demonstrate the feasibility of a CRT display over the other display devices for a dedicated application.

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CHAPTER I

INTRODUCTION

During the last decade there has been a tremendous growth in the use of computers and in computer technology, because of this growth there is an ever increasing demand for communications between human beings and computers. As a result there are intensive innovative efforts to achieve electronic-to-visual transducers which most closely fit the needs of the developing communications system for human interaction.

In a very real sense, electronic display devices constitute an "optical transducer" between the human observer and an electronic system. Therefore, the only way to measure their efficiency is to examine the information flow through this interface. In the process one must recognize that any constriction at this interface can not be compensated elsewhere. The human eye-brain combination is capable of assimilating information in a remarkably wide latitude of formats, intensity, spectral and signature variations. Thus far, these parameters have challenged display designers' attempt to quantitatively define and, therefore, develop analytical criteria for display design.

Display design for applications such as for military use is further complicated by the variety of applications which must be supported. For example, some of the applications are:

- Large area display of strategic and tactical information for command and control applications.
- Ruggedized, compact multi-function, multi-format displays for the presentation of raw data from sensors used in such applications as fire control, mapping, weapons delivery, status monitoring, and surveillance.
- Large area display devices for simulation and training.
- Instrumentation and interactive displays which are usually single function.

In addition, to varying degrees, the situation may be even further complicated by the need for specialized features such as hard copy, short term memory, and designation of land marks or moving targets.

The diversity of these display areas and associated requirements and environments can not be satisfied by a single display device or technology, and this is the source of some problems associated with the manner in which display designers conduct themselves in this business.

There are a great variety of competing options in electronic display technology that perhaps warrant further investigation relative to the many applications. For example, display devices such as the Cathode-Ray Tube (CRT) are optimizable for analog displays with high data and update rates. On the other hand, matrix addressable displays may be better suited to alphanumeric and graphic applications where data and update rates are comparatively low.

On the basis of the number of characters per display, computer equipment has the largest segment of the display market. The remote-terminal growth rate of 50% per year creates a display demand that will exceed one hundred million characters by the year 1980. For this single application over 95% of those characters will appear on CRTs. By 1980, gas plasma and gas discharge panels will be price-competitive with Cathode-Ray-Tubes below three hundred characters, and will compete in applications placing a premium on packaging, form factor, and operating voltages. Designers will have to pay 1.8 times a CRT price for a plasma panel instead of a CRT in a one thousand characters application.

Below sixteen characters, light emitting diodes (LED) will dominate the market and gain a substantial popularity over the others. In 1971, 26,000 displays were full alphanumeric LED matrices. By 1975, computer equipment was using nearly 200,000 matrix LEDs, 70% of them in small terminals. Automobile instrumentation represents a major potential market. Electronic digital instrumentation was introduced to automotive industries in 1975 and volume was anticipated to double each year for four to five years. Automotive applications favor solid state displays for their integrated circuit compatibility, form factor, and cost. Liquid crystals will dominate digital electronic watches for their low power consumption.

At the present, most communication and navigation equipment use electromechanical numeric displays in radio and aircraft equipment. The largest increase for use of digital displays will be in the tele-

communications area, particularly push-button telephones to help eliminate miss-dialed numbers. Industrial equipment used in dispensing and measuring, such as gasoline pumps and weighting stations, count for over two million characters per year by 1980. Newer designs in communication use electronic displays because of the trend toward computer control.

The major equipment trends that will effect electronic displays' acceptance are portability and integrated circuit compatibility. For instance, electronic calculators and test equipment are being designed to fit smaller housing and operate from batteries. Compatability with integrated circuit (IC) voltage supplies is growing more important in both industrial and consumer markets. Design trends require low voltage and power, compact packaging, and high reliability under varying environmental conditions. Solid state displays will meet all of the requirements, and will become dominant technology by 1980. While LED's and liquid crystals will compete for many applications, the unique characteristics of each insures usage of both. The LED is compatible with the bipolar integrated circuits in both processing and operating speed. Also LEDs emit a bright, monochromatic light unequaled in any other technology and can be made in a size range that qualifies them for most applications requiring less than sixteen characters. Since they emit light, they consume a significant amount of power in a steady state condition. As a result, portable equipment using LEDs will require rechargable batteries.

Unlike other displays, liquid crystals do not emit light, but rather reflect it or scatter light transmitted from behind. Only microwatts of power are needed to change characters. This creates a substantial advantage for battery-operated portable equipment. Since reflective mode is similar to viewing a printed word, the contrast ration increases in proportion to ambient light. This ensures the use of liquid crystal where readability must be maintained in bright or changing ambient light environment.

Vaccum fluorescent and incandescent displays will not be significant technologies by the late seventies despite their IC-compatibility. The tube-package form factor detracts from otherwise desirable characteristics. Gas discharge technology will find its way into multiple-character panel displays and gas plasma panels by 1980. Emerging from classic gas discharge technology, the gas discharge panels hold some promise of competing against cathode-ray tubes.

With a growth rate that could be termed explosive, distributed processing applications, in turn, stimulate the proliferation of offerings in the CRT terminals. At the present, for application which require man-machine interaction, CRT provides adequate performance and versatility at the lowest possible price (1).

The purpose of this thesis, in addition to survey of electronic displays, is to design a system which will be used to interface a keyboard to a home television receiver. In the following chapters, the system design is described in detail including a description of the operation of the TV display system relevant to the above.

CHAPTER II

SELECTION CRITERIA FOR DISPLAYS

Displays are physical entities that require human interpretation. No single type of digital display has all of the advantages of low cost, suitability for all environments, best appearance, highest reliability, and fully compatible supplies. Today's highly competitive and stringent market requirements have encouraged the development of many different display types. Each display type has its own special capabilities and disadvantages. The result is a wide variety of products from which a designer may make a choice to best suit his application. However, selecting a process must meet certain criteria required for a specific system design.

Manufacturers' literature naturally tends to emphasize the strongest features, and photos of the readout display are frequently retouched. Therefore, actual demonstrations are essential in making intelligent comparisons for a given set of parameters. The value of any given parameter depends heavily on the particular application. For instance, telephones, avionics, laboratories, and computer equipment, which function in different environments, have highly diverse users with varying goals. Good design must take these uses and users with their criteria into account.

The trade offs are varied. For example, readouts using directly viewed hot filaments are brighter, but the line widths are narrow; sometimes uncomfortably so. Fluorescent displays claim lower brightness, but the broader line widths make easily readable and particularly

attractive displays. The assortment of the familiar Nixie* type is very pleasing in comparison, for instance, with the more stylized seven segment readout, displays, but the Latter's coplanar display makes it easier to read over a wide viewing angle. On the other hand, a defective segment can give inaccurate readings.

Price Consideration

Understandably for most applications, price is the ultimate consideration, and the designer looks for a display device that will provide adequate performance at the lowest possible price. However, even identically described displays may differ substantially in reliability.

Some displays, such as light-emitting diodes (LED), have better relative pricing in larger quantities than they do in single quantity. Although the pricing of light-emitting diode devices has dropped substantially since emerging commercially in 1968, it is by no means certain that they will match prices of alternate displays in the near future.

The most important single development in displays has been the LED, which provides the reliability, ruggedness, and compatibility of semiconductor devices. Some designers prefer the 5 x 7 dot matrix to the multisegment display, but the price is higher. Also, the cost of driver circuitry and power supplies must be considered in comparing

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*Burroughs Trademark

the display types and making a choice. Other types of displays, however, may be better suited for particular applications. Incandescent types, for example, are generally cheaper and brighter, have multicolor outputs where required, and have a lift expectancy of 50,000 to 100,000 hours and up. Liquid crystal displays may radially alter the price picture in the next year or two.

Life Expectancy Consideration

It is particularly important to evaluate the manufacturer's data (and field experience) on life expectancy. Are these devices made reliable enough for military application? Are life expectancy predictions based upon accelerated tests in a benign laboratory experiment? Since predictions are frequently overly optimistic, the designer should determine the basis and reliability of the data provided.

Designing displays for military use is a difficult task, combining highly theoretical with empirical factors. However, for most commercial applications, the key is to focus on the intended use. Also, the designer must consider how the display will harmonize with the panel design and how the user will review the display.

Power Consumption

Power consumption consideration is an important criterion of any instrument. When it is high, it increases the cost of heat sinking and power supply and transient problem. Quite often it places an additional restriction on the permissible maximum operating (ambient) of an instrument.

For battery operated, portable instruments, the implications of higher power consumption are even more direct. Assuming an eight-hour battery criterion, one 2.3 ounce, "C" cell, NiCd battery is required for every additional 250-300 mW of power. The cost in 10,000 quantity is about $1.50. One watt of additional power increases battery cost by five dollars to six dollars, and weight by seven ounces to nine ounces. The effect on size and weight reduces the degree of portability.

Since instrument power, not display power, is the concern, specification must be evaluated in light of the application of the display to a given instrument. In an ac line-operated application, gas discharge tubes normally operate from an unregulated full or half-wave rectified voltage of approximately 200 Volts. A Nixie tube consumes 200 Volts at 3 mA average, or 600 mW per tube. Losses in the power transformers typically run another 100 mW per digit, for a total of 700 mW per digit.

A typical gas discharge display with all segments lit, consumes 370 mW per digit. This saves 30-40%, compared to a Nixie readout. Considering light-emitting diodes, power consumption directly depends on the character size, light intensity, and mode of operation (dc or strobe). As one example, the MAN-1* typically operates from a five Volts supply, uses a current limiting resistor, and requires 105 mA, or 525 mW per digit. In normal ac line operation, the display operates from a regulated five Volts having a typical voltage drop of four Volts,

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*Monsanto Trademark

across the regulator. The total power includes that dissipated in the regulator and the transformer, and is approximately 1040 mW per digit (2).

Viewing Angle Considerations

Most applications will necessitate particular viewing angles. Although viewing angle is usually greatest when the display surface is brought as close as possible to the plane of the front panel, some displays have highly directional light intensity patterns. Consequently, the designer must be certain there will be ample light output at the extreme viewing angles. The required viewing distance is one of the major factors in selecting character size.

Power Supply Considerations

Most, but not all, display devices of interest operate at something under five Volt supply. For the ones with higher power supply requirement, the cost of non-standard power supply is an important selection factor. Note that light-emitting diodes operate on a given current rather than a voltage basis, and require resistors to drop from five to one or two Volts. On the other hand, light-emitting diodes, being diodes, do not require isolation diodes in strobed applications. Sometimes it is possible to use the raw six or seven Volts dc from which the regulated five Volt is derived, thus conserving regulated power. However, in fluorescent and incandescent displays, filament voltage drastically reduces the life expectancy.

In battery-operated environment where power drain is a critical element in the performance, the designer is advised to consider the relatively new liquid crystal displays, which operate on micro-Watts.

Multiplexing Considerations (Support Circuitry)

Strobing or multiplexing is a way of cutting costs through the use of common electronics. It is the key to per-digit cost minimization in large panel displays. The cost of electronic circuitry dedicated to the strobing function determines the minimum number of display characters for which strobing is feasible; display response time, the response to high amplitude, short duty cycle pulses, and driver circuitry determine the practical maximum number of characters that can be strobed. As mentioned above, LEDs, in particular, lend themselves to strobing; they are diodes and are inherently isolated, respond fast, and can be effectively overdriven by short-life pulses.

Gallium Arsenic Phosphide, the active material of most LEDs, though less efficient than GaP, delivers more peak light without saturating. Both types, however, are successfully used in strobed displays.

As a practical matter, approximately sixteen digits of gas discharge or fluorescent display devices, and perhaps half this number of incandescent displays may be strobed. For light-emitting diodes, 15 to 20 GaAsP types or half of that number for GaP type can be multiplexed.

Optical Factor

In measuring the brightness or luminance, the concern is with the portion of the electromagnetic spectrum in which the wave length of radiation lies between 4×10^{-7} and 7×10^{-7} meter, or 400 to 700 nanometers. Photometers which measure foot-lamberts include a color filter which shapes the response to approximately that of the human eye. Eye response is the greatest at 555 nm, corresponding to a green in wave length. The curve falls to nearly zero at the extreme wavelength; for example, the relative response to red (650 nm) is down by a factor of ten.

Manufacturers normally specify luminance in foot-lamberts as a function of current input. An efficiency factor can be defined in terms of radiated energy at a given wavelength and input electrical energy. However, a more convenient factor for comparison is foot-lambert per watt, or foot-lambert per milliampere.

Since each manufacturer specifies light output so that his own display device appears in the best light, it is very difficult to compare luminances. For example, some light-emitting diode displays exhibit a brightness which vary markedly from point to point. The average luminance would obviously give a fairer description than would the commonly specified peak luminance. Similarly, if extremely high luminance occurs over a very narrow line-width, the foot lamberts reading may not provide a fair comparison. One proposal is that candelas per unit character area be used as a fairer basis for comparison, where unit character area defined as the product of character height and character width.

Brightness is best controlled by varying input voltage with a simple series resistor control, brightness decreases with increasing load current. Pulse-width modulation of dc supply avoids this problem and provides an efficient method of voltage control.

Along with brightness, contrast is another important parameter affecting readability. It relates to difference in luminances between the displayed character and its background. Contrast diminishes with increased ambient light levels; it is increased by surface treatment to reduce reflection, and by use of filters. Circularly polarized filters are often used for this purpose (3).

CHAPTER III

DISPLAY DEVICES

Introduction

A device known officially as the Numerical Indicator Experimental Tube number one was dubbed NIXI (Pronounced Nixie) during its development at the Buroughs Corporation. The name has continued as a synonym for digital display for many years. Like teletypes, core memories, and IBM cards, the Nixie has been made obsolete due to the advances in readout technology, yet more are sold today than ever before.

Though Nixie shows no signs of expiring, there are a lot of contenders for the market. In the past, displays were extensions of vacuum-tube technology, and manufacturers used already existing equipment, while the newer types of display designs are planar, many are still technically vacuum tubes. The widening acceptance of digital displays has led the designers and manufacturers directly into the use of multi-digit arrays.

When deciding on a display to incorporate into your design, you should first look at three important selection factors: (1) power requirement, (2) ambient lighting condition and (3) application format. When one of these factors form a paramount constraint in your design, the choice becomes easy. For example, when only micro-Watts are available to power the display, liquid crystal technology becomes the choice, or if the display must operate in intense sunlight, high brightness, and high power consuming incandescent technology takes

precedence. When application requires long messages to be displayed, high-Voltage gas discharge panels become the technology of choice, and when interactive systems are desired, cathode-ray tubes prevail.

Rarely, however, are design choices so apparent. In most cases, you must trade off power, brightness, size, packaging, and display application flexibility. For these situations, light emitting diode displays appear to offer the most versatility. This chapter briefly treats and sorts out different displays technologies, based on information from the leading manufactureres. Each section attempts to describe the salient features of each technology and its limitations.

Light Emitting Diodes

Light emitting diodes (LED) displays are fabricated from discrete diodes arranged in bar segment arrays or dot matrices. The forward biasing of selected groups of diodes light up the desired character. Though small monolithic displays do exist, material cost prohibits this approach much above 0.5 inch character height.

LEDs first became commercially practical in 1968 and now being utilized in an increasing number of applications. LEDs are electrically very similar to ordinary semiconductor diodes, except that they emit light. Since efficiency is directly related to current density, LEDs generally have small junction areas to maximize brightness. They can also be used as indicator lamps, and in conjunction with photosensitive detectors, as isolators in switching applications.

The most efficient LEDs generate red light (650 nm). Although red units have been commercially available for several years, Monsanto Company recently announced the commercial availability for the first green and yellow displays - important new developments for the equipment designers. The eye's increased sensitivity to green and yellow makes up for the reduced efficiency of the new LEDs in relation to red.

Being ICs themselves, LEDs are obviously IC compatible and therefore easily drivable. Several displays offer LEDs and support decode-drive circuitry in the same package. Voltage and current levels are low and size can be very small when needed; although flat packages are mostly popular, LEDs come in DIPs. Brightness is current variable permitting use of LEDs in a wide range of ambient lighting. Since the emission spectrum is very narrow, external optical filters can provide character enhancement and allow use in very high illumination environments.

Semiconductor compounds are preferred for LEDs over the more familiar elemental germanium or silicon materials because their p-n junctions form much better light emitters. A semiconductor-theory explanation for this significant difference can be made in terms of energy-band properties (4).

Consider large current (electron) flows in forward-biased p-n diode junctions. In germanium and silicon (called "indirect gap" materials) electrons travelling from the n-side conduction band to the p-side valence band can not maintain their momentum, and they give up most of their energy in the form of lattice-vibration heating.

In GaAs (called a "direct gap" material) electrons can make the transition directly without changing momentum, so they can give up most of their energy in the form of quantum of light. Ternary compounds of GaAsP with less than 45% phosphorous are also direct-gap materials; with more than 45%, they are less efficient emitters and special processing such as nitrogen doping is used to improve emission characteristics.

LED light output is monochromatic covering a very narrow wavelength band. Wavelength, or color, depends upon the material's band-gap energy value.

Noticeable light output also accompanies the high reverse-current flow induced by a reverse polarity breakdown voltage. However, the light emitting mechanism is quite different, and operating a LED this way can damage the device.

Turn-on and turn-off speeds of much less than one microsecond are inherent because of the spontaneous nature of the light-emitting mechanism. Light output increases with drive current which depends directly upon active emitting area. Since a small emitting area reduces the drive current needed, it is possible to achieve a larger character size by optical means without needing a significantly increased current.

Direct operation of LED readouts is practical in some simple applications. In most cases, however, considerable circuit economy is achieved through use of multiplexing techniques and pulsed rather than steady-state operations.

The two major commerical LED materials are gallium arsenide phosphide (GaAsP) on a host material of gallium arsendie (GaAs), and gallium phosphide (GaP). Both types are good red emitters while green emitting products are attainable from GaP.

In the visible spectrum GaAs and GaAsP are opaque. From green through red, GaP is transparent. This feature allows the light to reflect many times inside the crystal without appreciable absorption and finally to escape. This transparency contributes to the material's efficiency.

Doping GaP with zinc oxide forms red light-emitting isoelectronic traps. The quantum efficiency, for example, of photons out to electrons in, is about 1% compared to 15% for GaAsP. Because the response of the eye differs with wavelengths, the ten to one power efficiency advantage of GaP over GaAsP is reduced to three to one over four to one in luminous efficiency. For a typical small pellet, GaP emits about five millilumens versus about one and one half millilumens for GaAsP, both at a drive current of 20 mA (5).

Because GaAsP is opaque, the p-n junction must be close to the top surface making the device a surface emitter. Most segments (bar) displays use diffused junctions in the form of square or dots on the bar of GaAsP. In the case of GaP, which is transparent, the junction does not have to be close to the surface. A small 0.015-inch chip can be used in a rectangular reflector to obtain a bar of light 0.15 x 0.025 inch by making use of light emitted from the sides of the

pellet as well as the top. Because of the fact that only one small LED pellet is used in each segment, this method promises to be a low cost display.

Gas Discharge Displays

After twenty years, the Nixie tube remains the standard against which new displays are invariably compared. The Nixie, a gas filled, cold-cathode display, has a common anode and several individual metallic cathodes. Numeric tubes contain ten cathodes which are formed into the shapes of numerals zero to nine. Alphanumeric tubes have thirteen to fifteen in-plane cathode-segments, combinations of which form the ten numerals, the letters A through Z and many special symbols.

Multiplexing causes several tubes to appear continuously energized and reduces overall circuit cost. Generally, a refresh rate of 50 Hz or higher gives flicker-free performance although lower rates are acceptable if the viewer remains stationary.

When displays are multiplexed, the maximum duty cycle for each of the N indicators is 1/N. Without brightness compensation, the apparent brightness decreases and N increases. Since the light output of the Nixie is proportional to cathode current, you can maintain the brightness level when the duty cycle decreases by increasing the cathode current. At a duty factor of 20% and an anode current of fifteen milliAmperes, a typical Nixie series indicator appears as bright as it would under normal three milliAmpere dc operation and also saves total power in the overall system.

The potential economics of multiplexing or time sharing can only be achieved if a recirculating or sequential memory is already part of the digital system, such as in a calculator. Then the only additional readout components are driver cathode circuits. The saving in cost and power per digit increases substantially as the number of tubes approaches the upper limit of about twenty. The memory also serves the secondary purpose of display refreshing.

In non-multiplexed or dc displays the entire memory contents must be available simultaneously in the form of dc levels such as the outputs of flip-flop registers. In many situations, a dynamic register would still be required to perform serial arithmetic. Over four to five digits, this dual storage requirements, in addition to separate decode-drivers for each tube's cathode, makes dc Nixie operation uneconomical.

For multi-digit display application Panaplex* is a low cost display used in applications such as calculator and instruments. The different models range from eight to eighteen characters. Panaplex has nine wire cathodes for displaying seven or nine segment characters.

The most significant aspect for these planar multi-digit displays is that they can be driven directly from MOS circuits. Although each panel operates from +170 Volt dc, the turn-on voltage swing is as low as twenty-five Volts at peak current of only a few microAmperes (6). This is about a third of the usual voltage swing needed in previous gas discharge displays and about one-tenth of the other current displays. Power consumption averages less than 5 mW per segment.

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*Burroughs Corporation

There is a delay between voltage application and conduction (ionization), which is a function of the availability of charged particles and the applied voltage. The time required to ionize a digit in a multi-digit display is considerably less than for a single digit, since ions are available from adjacent digits. However, the first digit scanned does not receive the supply of charged particles, particularly with leading zero blanking or at low scan rates. This is a result of the last digit scanned being farthest away, while ions from nearby digits have already delayed. To provide a uniformly bright display, the ionization delay time should be a relatively small part of a digit's duty cycle.

A twelve-digit seven-segment display with decimal and comma, has 108 active conduction paths, each with its own ionizing and sustaining voltage. In properly fabricated displays the 108 characteristics are extremely uniform, so only a small potential difference need exist between on an off segments. Usually a 25-Volt swing provides a sufficient margin at useful scan rates.

The minimum cathode voltage swing required to drive the panel increases with supply voltage, cathode current, and scan rate. Since reionization time determines the minimum panel voltage, cathode swing must be balanced against scan rate and power supply regulation. Although relatively small voltage swings are required, anodes and cathodes in a gas discharge devices are separated by the tube voltage drop of approximately 150 Volts. This necessitates a panel supply voltage and level shifting of cathode or anode drive signals.

Another form of gas discharge display is planar cold cathode, neon gas discharging which is manufactured by Sperry Rand Corporation. In these displays characters are formed by sinking current through appropriate segment combinations. They can be operated in either dc or time multiplexed modes. The wide line characteristic of the glow discharge display eliminates the usual gaps between segments, improving readibility. Characters are neon orange with black background for a high contrast ratio. Life expectancy is between 20,000 to 100,000 hours. These devices are currently used in instrumentation of aircrafts where reliability and ruggedness are most needed. Electrical requirements, in terms of current, is very little usually in hundreds of microAmperes but requires 170 Volts dc (7).

Incandescent Filament Displays

Incandescent filament displays are generally available in the seven segment design. In some, the filaments are themselves arranged as segments, to be viewed directly. Other types use an array of lamps, with light channeled by a variety of means from the individual lamps to the corresponding segments. Each kind has special virtues.

Some direct viewing types, such as the RCA's Numitron*, operate in ac, dc, or multiplex modes and are manufactured in miniature vacuum-tube configuration. These designs take advantage of the immense vacuum-tube production capability developed in the past years to provide a low cost of known reliability. Other types bypass the vacuum type configuration, packaging the filament array in a specially

*RCA Trademark

designed and tooled vacuum chamber which is part of the whole readout assembly. The specially designed units offer the advantage of bringing the filaments very close to the front surface, rather than having them recessed as in a vacuum tube package. This obviously permits a wider viewing angle, and may be attractive in some applications.

In those units where the lamps are located separately from the display surface, a variety of means have been devised for bringing light to the viewing point. Frequently, a transparent plastic wedge is brought from the vicinity of the lamp to the viewing surface where its cross section takes the shape of one of the seven segments. In a typical design, the wedges are cast in black epoxy for high contrast ratio, and for an output flush with the viewing surface. Other variations include the use of fiber optics as light conductors, where the individual segments consist of lines or dots. When carefully designed, the efficiency of light conduction approaches 100%, although there are units available where lower cost is achieved at the price of reduced efficiency. In all cases, the separate light channels must be shielded from one another to avoid "optical crosstalk." Suitably coating the light conductors helps to achieve the required isolation while increasing the efficiency of light transmission. As in directly-viewed filament designs, lamps should be substantially derated for long life (8).

Since directly viewed incandescents operate at lower temperatures than incandescent lamps, they are far more reliable. Their ruggedness and proven reliability has served well in avionics, panel

meter scale, cash registers, clocks, and in industrial controls. Reinforcing the ruggedness is the structure with pins protruding through a high-contrast black substrate to rigidly support the low mass, single-helical coil segments. Since segment mass is extremely small, shock rating of 200 grams and vibration of 20 grams in the 60 to 500 Hz region is obtainable.

Since the coil segments are essentially wire-wound resistors, changing the voltage varies the brightness. Filament wire diameter and coil size are so small that the temperature rise time is eight to fifteen milliseconds and the fall time is ten to twenty milliseconds. In-rush current does not degrade life, for while it may exceed rated current by a factor of five to eight, its duration is short (being approximately ten milliseconds) and it declines to steady-state value as the filament warms up. Temperature never exceeds the steady state value. Pulsing the segments during strobing also does not degrade life. The long thermal time constant helps to smooth out flicker. To avoid flicker, it should operate at 40 Hz or above.

Cost effective multiplexing is possible at pulse voltages significantly higher than maximum recommended dc values. However, exceeding the breakdown voltage rating and the maximum output current rating of the decoder driver must be avoided. Since the incandescent segments are resistors, isolation diodes are needed in series with each one to prevent simultaneous lighting of coil segments in adjacent devices.

Incandescent displays offer the advantage of high contrast and clutter-free display when viewed against a dark background. They have

a wide viewing angle and use standard low-cost sockets or could be directly applied on pc boards. They are compatible with IC decoder drivers with two and one-half to five Volt supplies. Low power consumption is another added feature for incandescent displays, typically 500 mW (9).

Vacuum Fluorescent Display

The vacuum fluorescent display is the simplest form of electronic display next to the light bulb. With the requirements of low voltage and current, it is adaptable to portable battery-powered equipment. It meets the requirements to be used with IC's since it has MOS compatibility, full color versatility, and can be multiplexed. This display is a vacuum diode with a common cathode consisting of two very fine parallel wire filaments. Typically seven phosphor-coated anodes form a familiar format of seven segments placed at a predetermined distance behind the filaments; a single digit or multidigit array structures are sealed into glass envelopes.

When any of the anodes is connected to a positive potential, typically 25 Volts, filaments electrons are attracted which strike the phosphor and cause it to glow. Since all the characters are formed in one plane near the tube wall, the parallax free viewing angle exceeds 150^{o}, while distance can exceed forty feet.

Though the filaments are between the viewer and the anodes, they are very small (about 0.4 mil) and operate from 600^{o} to 700^{o} C just at the threshold of incandescence. They disappear completely

when the background segment is illuminated. Since they are spring loaded, they maintain their geometry when they elongate from thermal expansion.

The use of different phosphors for different colors is impractical because very few phosphors operate efficiently at the low accelerating voltages required. Using filters makes all readouts interchangable in any display and keeps manufacturing costs to a minimum.

Brightness in fluorescence is proportional to anode voltage. The ability of MOS to handle thirty Volts at currents up to a few milliamperes, and the ability of the fluorescent display to respond, result in an ideal compatibility between fluorescent display and MOS circuits.

Thermal inertia of the filament prevents instantaneous turn off by opening the cathode circuit. Therefore, strobing must work on switching the potential differences between anode and cathode from zero volts to the operating voltage. By taking advantage of the thermal inertia concept, one can bias a common filament supply for several tubes to anode potential, and as the logic information is fed into each readout, reverse the bias (10).

Liquid Crystals

The liquid crystal display differs from other types of semiconductor displays in that it does not emit light but produces visual images by modulating or scattering the ambient illumination. Consequently, a liquid crystal display can not be seen in complete

darkness; unlike any light-emitting diode display, the brighter the ambient light, the brighter the liquid crystal display. Displays based on liquid crystal are temperature sensitive and are slow to respond to changing inputs. On the other hand, they consume very little input power and offer the long term potential of becoming the least expensive of all display types.

Liquid crystals are organic materials which maintain an ordered structure even after melting from the solid. This molecular arrangement persists over a range of temperature until the thermal energy of the liquid is sufficient to produce complete isotropy. There are hundreds of liquid crystal compounds, divided into three major groups: nematic, smetic and cholesteric, and differing mainly in their molecular grouping. At present mainly nematic liquid crystals are used for display purposes, even a number of optical properties of cholesterics have been recorded (11).

In a practical configuration a display element consists of a layer of liquid crystal material, about ten micromil thick, sandwiched between two electroded glass plates carrying electrodes. A dc voltage applied to the electrodes changes the liquid crystals optical characteristics.

The liquid crystal material now in use is a nematic liquid, which is a transparent organic compound having certain crystalline properties. The key feature is that applying an electric field across the crystal causes it to scatter light and become opaque; contrast ratio of twenty are observed and are entirely suitable for most applications.

Because bulk behavior rather than junction characteristics apply, the active material is inexpensive and noncritical to prepare. The low current drain makes it suitable for interfacing with MOS circuits, again reducing costs. Battery operation is particularly practical. Liquid crystals displays inherently have flat-panel construction and can accommodate a variety of colors and symbols. Tooling up of specials is easy.

A typical liquid crystal is p-methoxy benzylidene-p-n butyl aniline, which solidifies at about 21^{o}C, becomes isotropic at about 45^{o}C, and is normally transparent as a thin film over this temperature range. Then nematic molecules can be thought of as cigar shaped and in the liquid crystal temperature range they are aligned by their electrical molecular coupling. If an electric field of about 10 kV/cm is applied (20 Volts across a film 20 μm thick) molecular reorientation and turbulence occur, and strongly optical scattering is exhibited because the liquid crystal is optically anisotropic.

As voltage is applied and removed, response is relatively slow. Ion flow commences several milliseconds after the voltage is applied. Although ion generation ceases when the field is removed, a significant time is required before the molecules are restored to their relaxed positions. The delay time depends on temperature and the crystal material.

However, delay time is several hundred milliseconds. It is long enough to be annoying to the viewer. Several fast turn off techniques

have been devised, based upon applying brief bursts of voltage, to reduce delay times to the order of five milliseconds.

The power required for liquid crystal displays is very small, and very good contrast can be obtained using thirty Volts at about five microAmperes per cm^2 area. Liquid crystal may be operated from dc or low-frequency supplies although an ac supply is preferred to give maximum life. There is a tendency for electrolytic disassociation of the liquid crystal to occur under continuing dc operations, and some electrode materials accelerate this process. Liquid crystals rarely fail catastrophically, but gradual discoloration and non-scattering area may develop usually after several hundred hours of dc operations (12).

Electroluminescent Displays

Electroluminescence is a phenomenon whereby light is emitted from a semiconductor material when subjected to an applied electric field. Light is generated by the recombination of free charge carriers produced in the material by the electric field. A typical electroluminescence cell consists of a transparent conductive glass substrate to which a phosphor dielectric layer is applied, with a second electrode applied to the opposite surface of the substrate. Light emitting films of such polycrystaline phosphors are relatively insensitive to temperature, variations, shock, and vibration. The electrodes may be segmented to form a desired pattern of light-emitting area. Displays made from these films have virtually no limit as to size or form. For instance, displays made, using ZnS:Mn powder, with digits from 0.03 to 10 inches and in arrays containing up to eighty digits (13).

Operating temperatures are specified from -70°C to +70°C, and operating units have been cycled from LN_2 to boiling H_2O with no detrimental effects. Displays of electroluminescent are legible in direct sunlight.

The light output of an electroluminescent display that peaks in about twenty to thirty microseconds stabilizes until electrical excitation is removed. The persistance period is a hundred times longer than the initial excitation period. This is very important because it means that the light emitting film has an integral memory of two to three milliseconds and is ideal for multiplexing with a one percent duty cycle.

Cells are designed to operate on ac at a few hundred Volts RMS. Brightness increases sharply with frequency, duty cycle, and amplitude of excitation pulses. Although continuous-duty-cycle operation is possible, the electroluminescent display is mostly suitable for low intensity applications. In normal and high brightness cases, pulse drive is recommended since continuous excitation decreases life sharply.

CHAPTER IV

DESCRIPTION OF A TELEVISION DISPLAY SYSTEM

The picture tube used for television (TV) reception is a cathode-ray tube (CRT). A television picture or illumination is formed on the screen of the picture tube by the systematic movement of a focused electron beam capable of being deflected either up or down or horizontally across the screen. Illumination of the screen by lines of light in this manner produces the raster. Therefore, a TV line is one sweep of the electron beam from the left of the picture tube to the right (as viewed from the front of the set) and is initiated by the horizontal sync. The amount of the illumination formed at any point on the scanned screen is proportional to the intensity of the electron beam at the time it strikes that point. If the beam is of high intensity, it produces white on the screen, and if cut off entirely in some parts of the screen, these parts will be black. Between these two levels are various shades of gray.

Interlaced Scanning

The scanning system standard in the United States for monochrome video makes use of interlaced scanning. In interlaced scanning the electron beam first scans the entire screen of the CRT. It then returns to the top of the screen to rescan the same area as before. However, during the second scanning, the lines formed by the scanning beam do not fall in the same position as before, but in between the lines of the first scan. Each scanning of the TV screen is called a

field. A set of two interlaced fields, forming a complete scanning cycle, is called a frame. After completion of each frame the scanning cycle starts repeating itself.

Interlaced scanning is illustrated in Figure 1. The first fields starts at Point A in the upper left hand corner of the screen. The electron beam is pulled from Point A to Point B by the horizontal deflection system of the CRT. The line is shown slanting because while the horizontal deflection system pulls the beam across the screen at a rate of 63.5 μsec per line, the vertical deflection system is pulling it down the screen at the much slower rate of 16.67 ms. (60 Hz) per field. At Point B a blanking pulse eliminates retrace while the beam is returned to Point C. This scanning action continues until the electron beam reaches Point D at the bottom of the picture. All of field one has been formed as represented by solid lines of Figure 1. A vertical blanking pulse eliminates retrace while the electron beam is returned to the top of the picture, to Point E. There are 262½ scanning lines in the first field (14).

The first line of the second field starts at Point E, and half line EF is scanned first. The scanning process continues as before until the second field has been scanned as indicated by the dotted lines in Figure 1. There are also 262½ lines in the second field, thus constituting 525 lines per frame. After a frame is completed the electron beam returns to Point A where a new frame is started.

The scanning rate is thirty frames or sixty fields per second. This frequency is used because of its relationship to the standard power line frequency of the United States (60 Hz). With this field

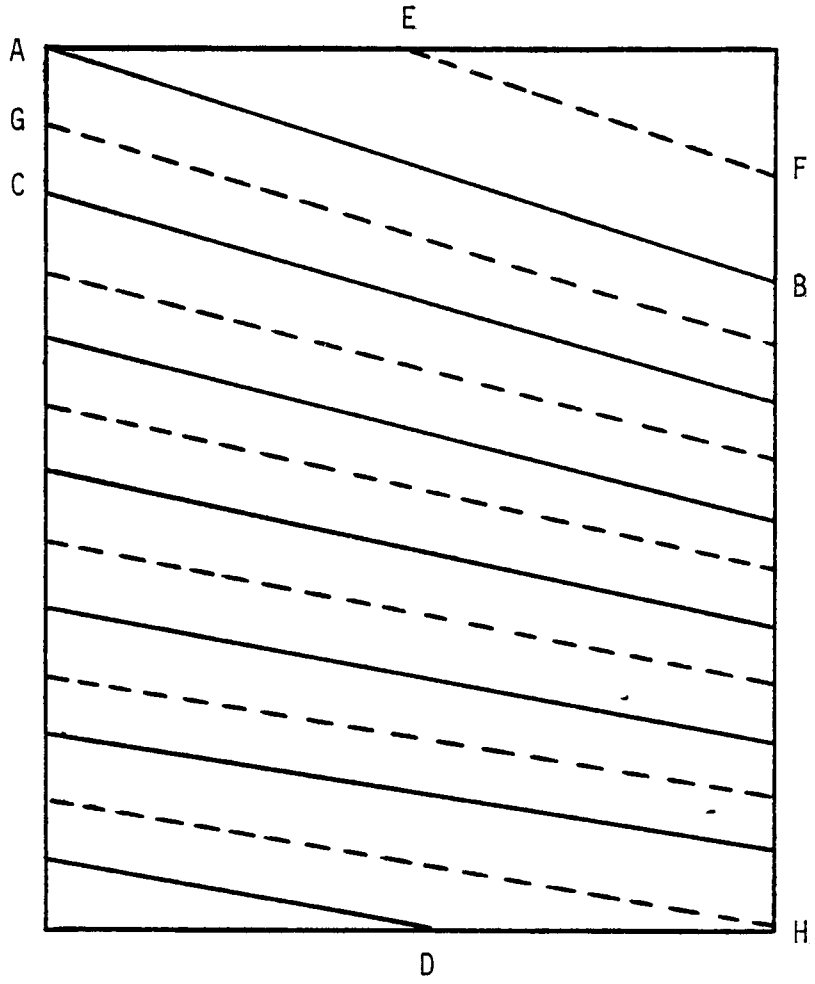


Figure 1. Interlaced Scanning.

frequency any ripple due to imperfect filtering of the power supply remains stationary on the screen and is not noticed.

The use of interlace scanning eliminate flicker in the picture. If the picture is scanned at the rate of thirty times per second, a noticeable flicker appears. However, this flicker is eliminated by scanning the picture area sixty times per second. Furthermore, the use of interlace scanning reduces the bandwidth required to transmit the video signal.

A complete picture is formed by two consecutive frames that are interlaced with one another. Interlacing means that the horizontal lines of one frame fit between the horizontal lines of the other frame. The result is thirty complete pictures every second of about 484 usable lines each. Because of the interlacing, however, the screen is illuminated at a 60 Hz rate. This eliminates an objectionable "flicker" that would be seen if the screen were only scanned at a 30 Hz rate (15).

Television Interface

The TV signal received at the antenna terminals contain the information needed to generate the vertical and horizontal sync, blanking, and video. The interface system simulates a TV signal by supplying a composite signal form containing the same information normally present except sound.

Figure 2 shows a set of standards. The signal is DC coupled and always positive going. Syncs are grounded. The normal open

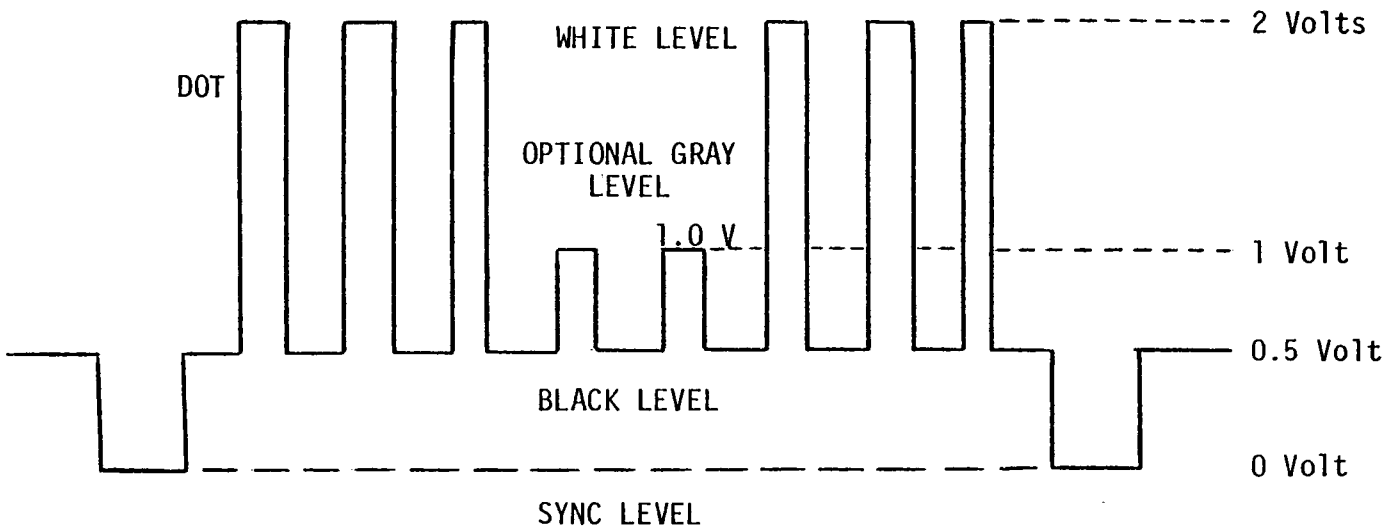


Figure 2. Standard Video Interface Levels (Source Impedance = 72 or 100 Ohms).

circuit black level is positive by one-half a Volt, and the white level is two Volts positive with respect to sync. Between one-half Volt (black) and two Volts (white), intermediate levels exist and there will be some shade of gray, proportionately brighter with increasing positive voltage. With this system, only the three states of zero Volt (sync), one-half Volt (black), and two Volts (white) would be used.

Synchronizing pulses are generated within the system sync generator. The signal with a frequency of 15,750 Hz which produces the horizontal sync pulses and is obtained by a series of chain division from a clock source in the system. The 60-Hz vertical sync pulses are also obtained from chain division of frequency dividers.

System Description and Theory of Operation

The scanning nature of television raster requires that the video signal (or brightness on the screen) be sent in serial form to control the electron beam as it sweeps lines across the screen. Suppose, for example, that the proper ASCII code for the letter T were applied to the ACSII inputs to be displayed. The first line of the character can be represented as 11111, ones signifying light spots (dots) and zeros signifying dark spots (space). The remaining six lines of the character can similarly be represented as a series of dots and dark spaces; 00100 00100 00100 00100 00100 00100. When the seven lines are displayed one above the other, the character "T" is seen. A sample of the five by seven matrix is seen in Figure 3.

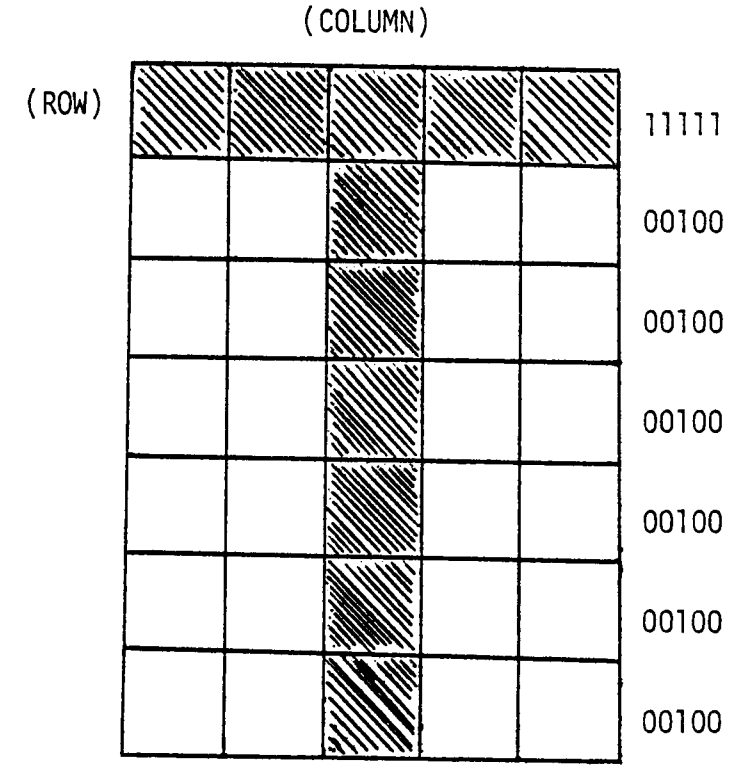


Figure 3. An Example Of A Dot Matrix Pattern Displaying Letter "T".

Character Generation

The heart of the converter is a Signetics 2513 read-only-memory character generator. This unit is already programmed by the manufacturer. It is often used to generate what is known as a five by seven matrix display. A five by seven matrix is a rectangular area in which 35 dots (usually LEDs) are arranged in a grid of five columns by seven rows. By selectively lighting the proper dots (or LEDs), any of the 64 ASCII characters can be displayed.

The purpose of the row output character generator (ROM) is to provide the different configurations of dots to form a character to be displayed on the television screen. The row output character generator has five output lines corresponding to a horizontal row of dots. It has six input lines which accepts the ASCII (six bits) code for a character, and three timing input lines to address the appropriate row of a five times seven matrix. Thus, at any instant, there are five bits at the output lines of character generator corresponding to a horizontal row of a character.

Since only one row of the output is available at a time, the entire character is displayed by scanning the row-select inputs of the ROM while simultaneously energizing the corresponding row on the display. By scanning at a sufficient rate, the eye integrates the light output and no flicker is apparent, just as is done with the scan lines in a television screen (CRT).

Timing and Control

In this system a standard television receiver is used as the display device instead of the five by seven matrix of LEDs. Characters

are, however, displayed in the five by seven format. This is accomplished by assigning each of the television horizontal scan lines to one of the seven rows and then subdividing each scan line into a finite number of points. Five of these points are assigned to the five character columns.

The television horizontal scan frequency is normally 15,750 kHz (16). This, along with the vertical frequency of 60 Hz results in

$$15750/60 = 262\frac{1}{2}$$

$262\frac{1}{2}$ is the number of horizontal scan lines per vertical scan (or field). In normal broadcasting each field constitutes half of the entire transmitted picture. The scan lines of alternate fields are interlaced, producing thirty complete pictures per second. The number of lines needed for a complete picture is

$$262\frac{1}{2} \times 2 = 525.$$

Interlacing is employed to reduce the flicker for nonstationary pictures. Since in this system the display of characters will be essentially stationary, interlacing is not used.

All the various frequencies required for the system are derived from a single oscillator and a frequency divider chain. Since the frequencies in a divider chain are harmonically related, it will be difficult to provide the normal horizontal easily to vertical frequency ratio of $262\frac{1}{2}$. Instead, 264 is chosen and implemented by

$$8 \times 3 \times 11 = 264.$$

In the block diagram for the system, Figure 4, the crystal oscillator is first divided by six in order to obtain six possible columns per character. Five of which form the five columns of the character and the remaining one is blanked to provide a space between characters. The next stage provides sixty possible character positions across the entire horizontal scan. Since portions of the horizontal sweep are not visible due to overscan, only forty of the sixty possible character positions are used. The output of the divide by sixty stage is used to generate the horizontal sync pulses.

The next divide by eight section provides eight rows per character. Only seven are used and the eighth one is blanked. The final stage in the divider chain provides thirty-three possible rows of characters across the entire vertical scan. Only one of the thirty-three rows of characters is enabled, resulting in a single row of forty characters in the middle of the screen.

The output of divide-by-thirty-three section generates the vertical sync pulses which must be exactly 60 Hz to avoid hum bars. The clock frequency of 5,702,400 Hz is selected to meet the 60 Hz vertical sync pulses requirement.

$$F_{clock} = 60 \text{ Hz } (8 \times 3 \times 11 \times 60 \times 6) = 5{,}702{,}400 \text{ Hz.}$$

In addition, note that the horizontal frequency is

$$60 \times 8 \times 33 = 60 \times 264 = 15{,}840 \text{ Hz.}$$

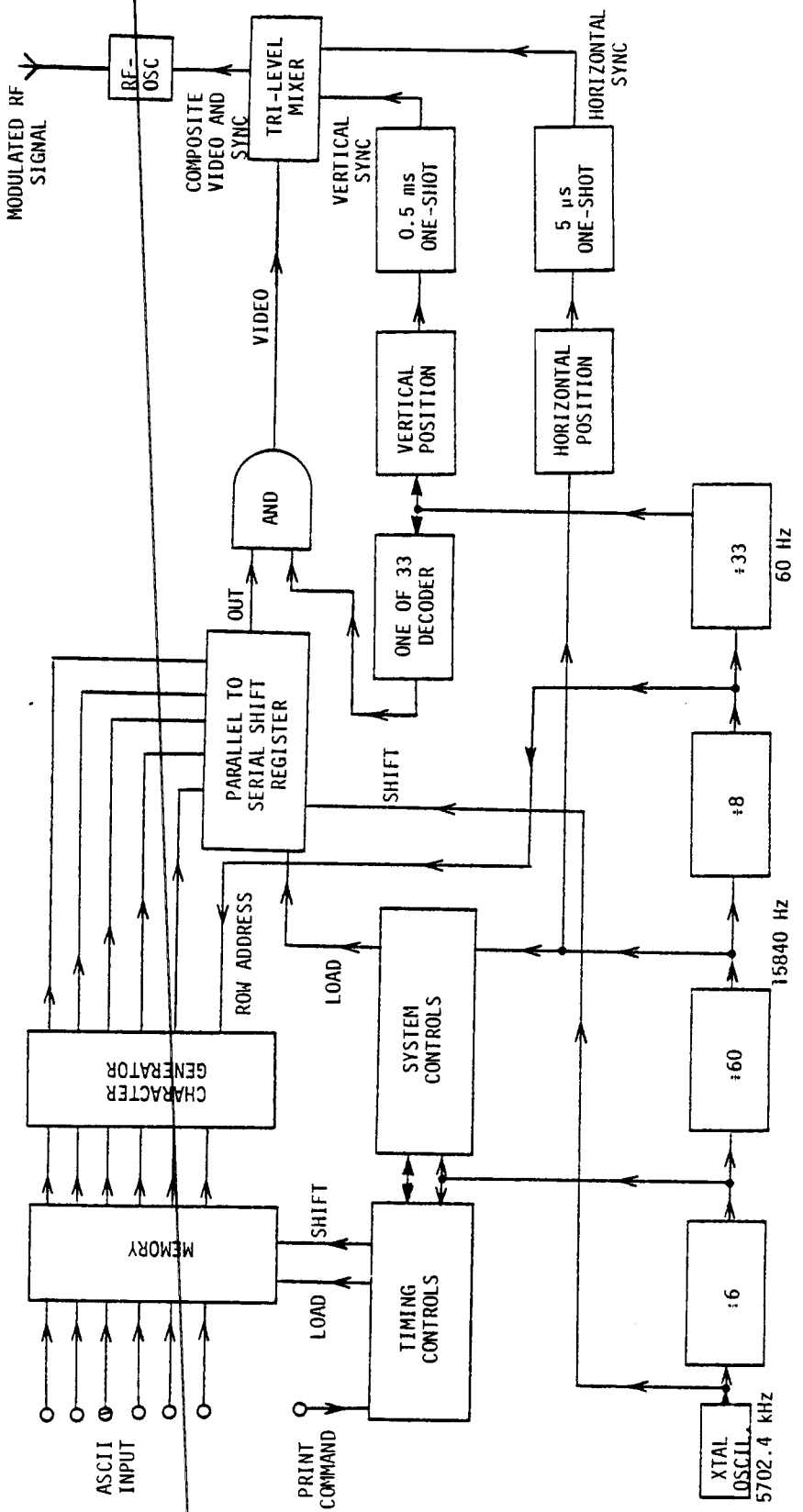


Figure 4. Block Diagram Of The System.

This is very close to the normal horizontal frequency of 15,750 Hz that most television sets will not even require adjustment of the horizontal hold control in order to obtain sync.

Memory

The ASCII code for all forty of the displayed characters must be made available to the character generator ROM once during each horizontal sweep. Therefore, each character must be stored in a memory device once it is entered. This function is peformed by 2519 (17), shift register which contains six identical forty-bit shift registers. All the registers have a common shift and load control. When no load signal is present, the registers recirculate in this mode, the output of the fortieth stage is internally connected to the input of the first state. Thus, the registers never empty, but continue to circulate the same data. When a load signal is applied, the internal connection from output to input is broken and inputs to the registers are now connected to the device input pins. When a shift pulse is applied, the ASCII code present on the input is loaded into the first stage and the code contained in the fortieth stage is shifted out and lost.

Forty shift pulses are applied to the registers during each horizontal sweep, thereby, cycling through each of the ASCII characters. A print command in the system sets a flip-flop which stores the fact that a new character is to be entered. It remains set until the visible portion of the horizontal sweep is complete. Then during retrace, the flip-flop causes a load command and forty first shift pulse to be generated which enters the new character.

The ROM character generator has all five column outputs available at one time (in parallel). However, TV systems requires that the bits should be presented serially for (one at a time) each horizontal sweep line. For this purpose, a five-bit parallel-to-serial shift register is used. The output signal of the parallel-to-serial shift register is enabled by the signal from timing part of the system (one of thirty-three-decoder), thus disabling the video output for all but one of the thirty-three available rows of character.

Horizontal and vertical sync pulses are implemented by two dual one-shots, 74123. In both cases the first one shot is variable, and the second is fixed at approximately standard broadcast sync pulse widths. The adjustable delay provides control of where the sync pulses are entered during the scanning and are used to center the row of characters on the screen.

In Figure 4, the diagram of the system, the three-level mixer is used to combine the video signal with both horizontal sync and vertical sync into a composite signal having three finite voltage levels corresponding to white, black and sync. This signal in turn amplitude modulates a radio frequency (RF) oscillator producing a final output which closely resembles that of a commercial broadcast station.

Circuit Description

The circuit which was designed to interface the digital keyboard to a television consists of the following which are explained in con-

junction with appropriate schematic. In Figure 5, the print command is capacitively coupled to a flip-flop made up of IC12 (SH7402 quad two-input NOR gate). Capacitive coupling causes the flip-flop to be set by, and only responsive to the leading edge (for example, the zero-to-one transition) of the print command signal. This, in turn, enables one of the inputs of IC11 (SN7430 eight-input NAND gate). When the other inputs of the NAND gate are also high (which occurs once during each horizontal retrace), an output pulse is generated which is used as the load pulse for the hex 40-bit shift registers. The trailing edge of this load pulse also resets the flip-flop IC12. Whenever a load pulse occurs IC13 (SN7400 quad two-input NAND gate) generates a single shift pulse while NAND gate in Figure 6 generates forty shift pulses during each horizontal scan. Both sources of shift pulses are summed in the remaining NAND gates, resulting in a single output having either forty or forty-one shift pulses, depending on whether a new character has or has not been entered.

In Figure 7 the SN7420 (dual four-input NAND gate) provides the gating necessary to inhibit all but one of the thirty-three available rows of characters. In Figure 8, the clock for the system is implemented using IC1 (SN7404 hex inverter). Because oscillator stability is extremely important in this particular application a crystal-controlled clock is used. A divider chain consisting of ICs (SN7492, SN7490, SN7492, SN7492, SN7492) in Figure 9 is used to get different frequencies for the system. This chain starts out by dividing the frequency by six to give six possible columns per character. Five

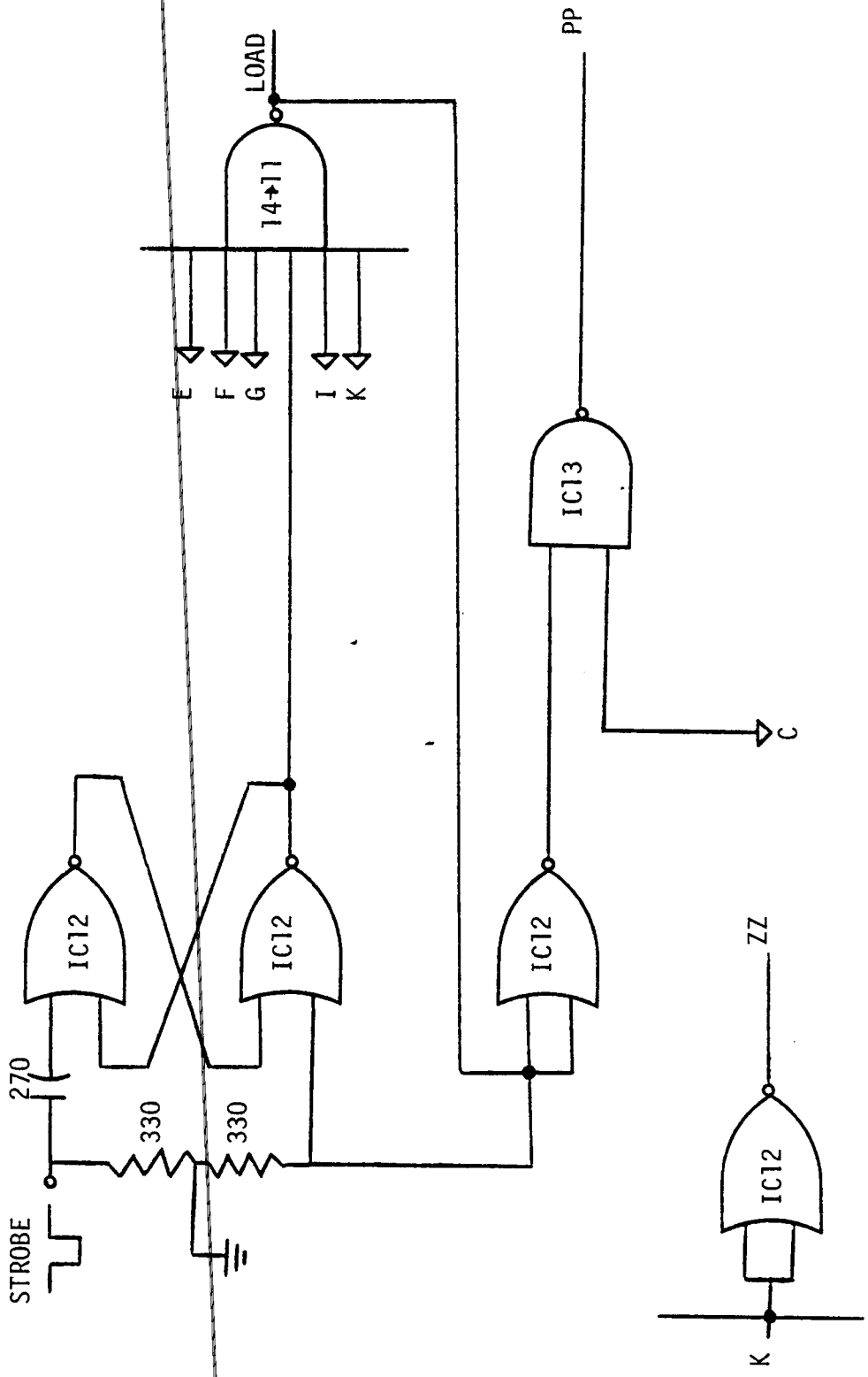


Figure 5. Logic Circuit To Acknowledge Strobe.

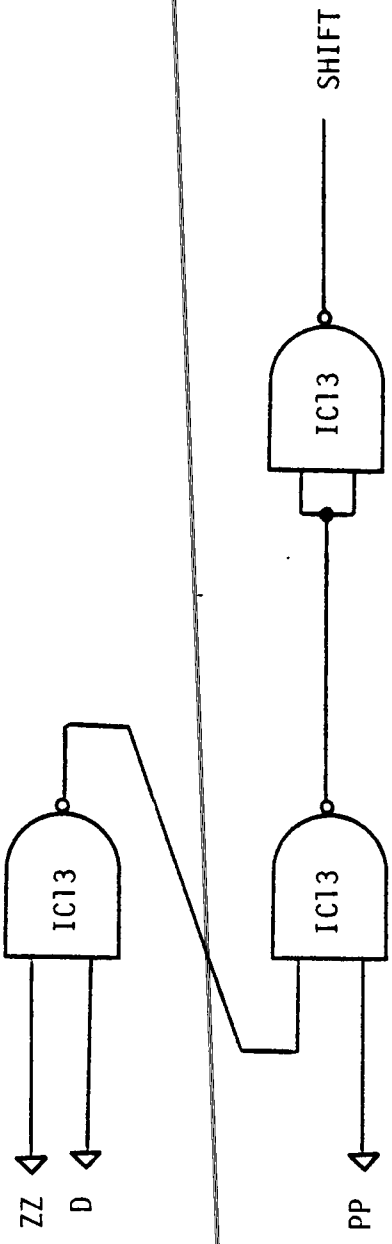


Figure 6. Logic Circuit For Shift Command.

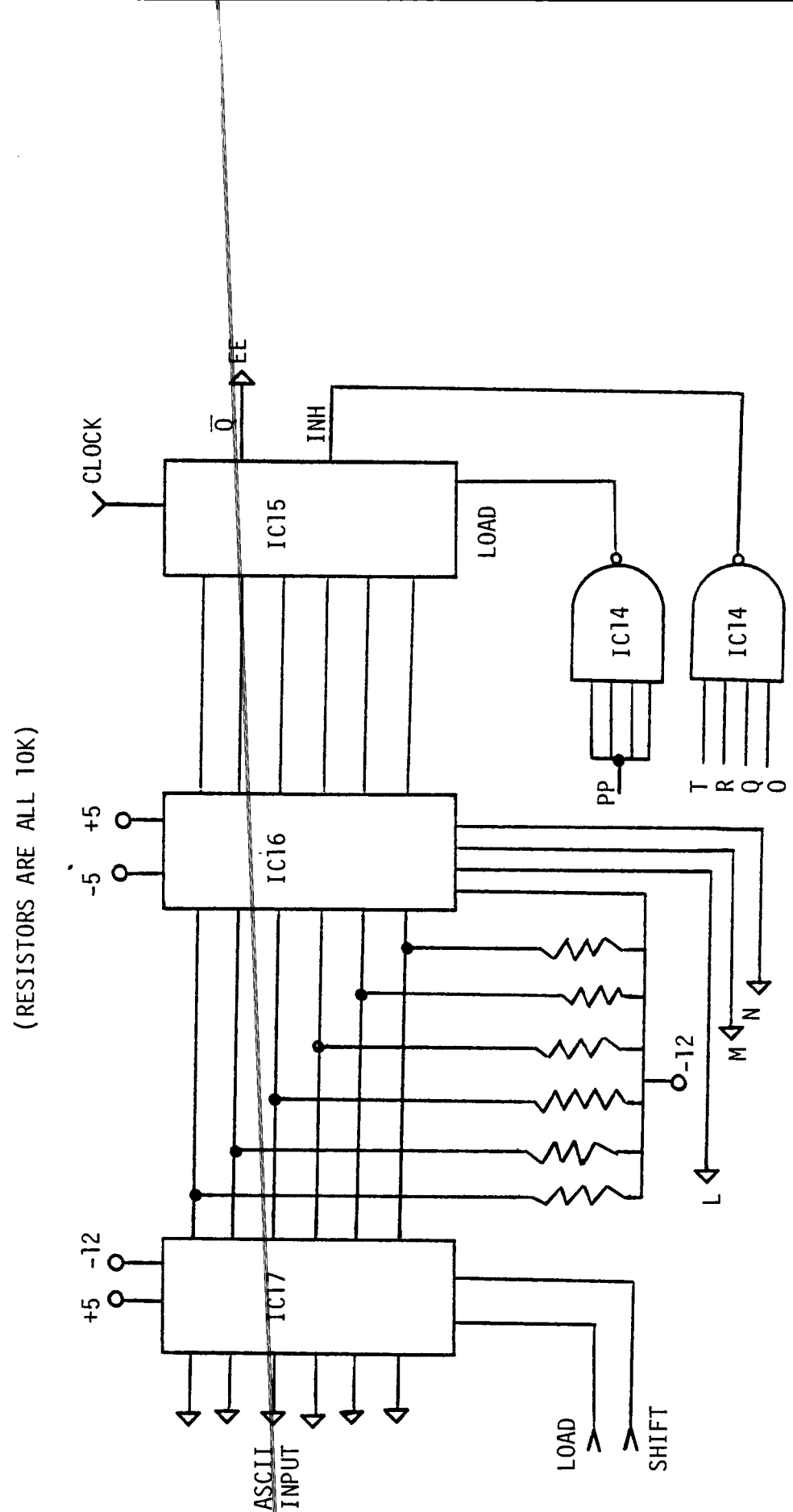


Figure 7. ASCII Character Generation And Parallel To Serial Converter.

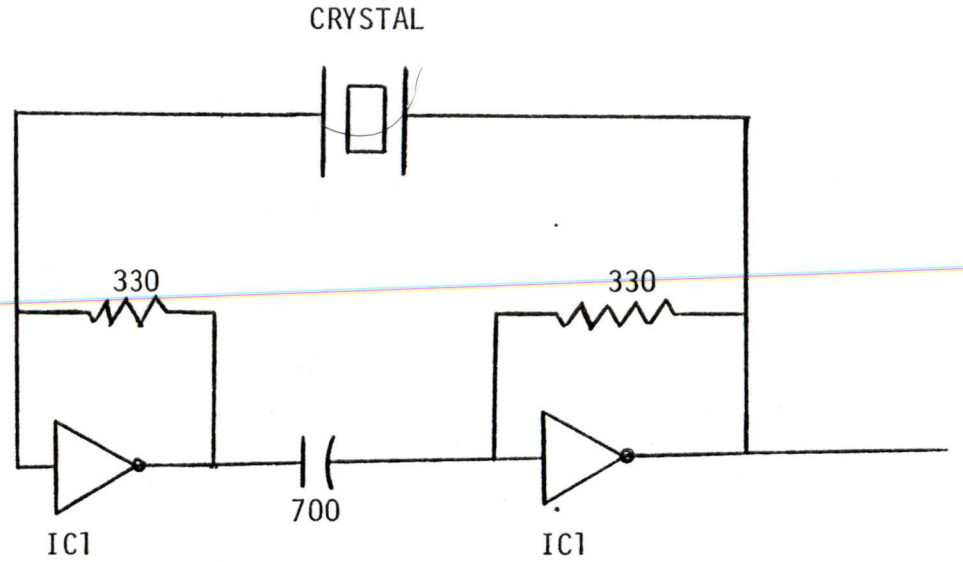


Figure 8. Crystal Controlled System Clock.

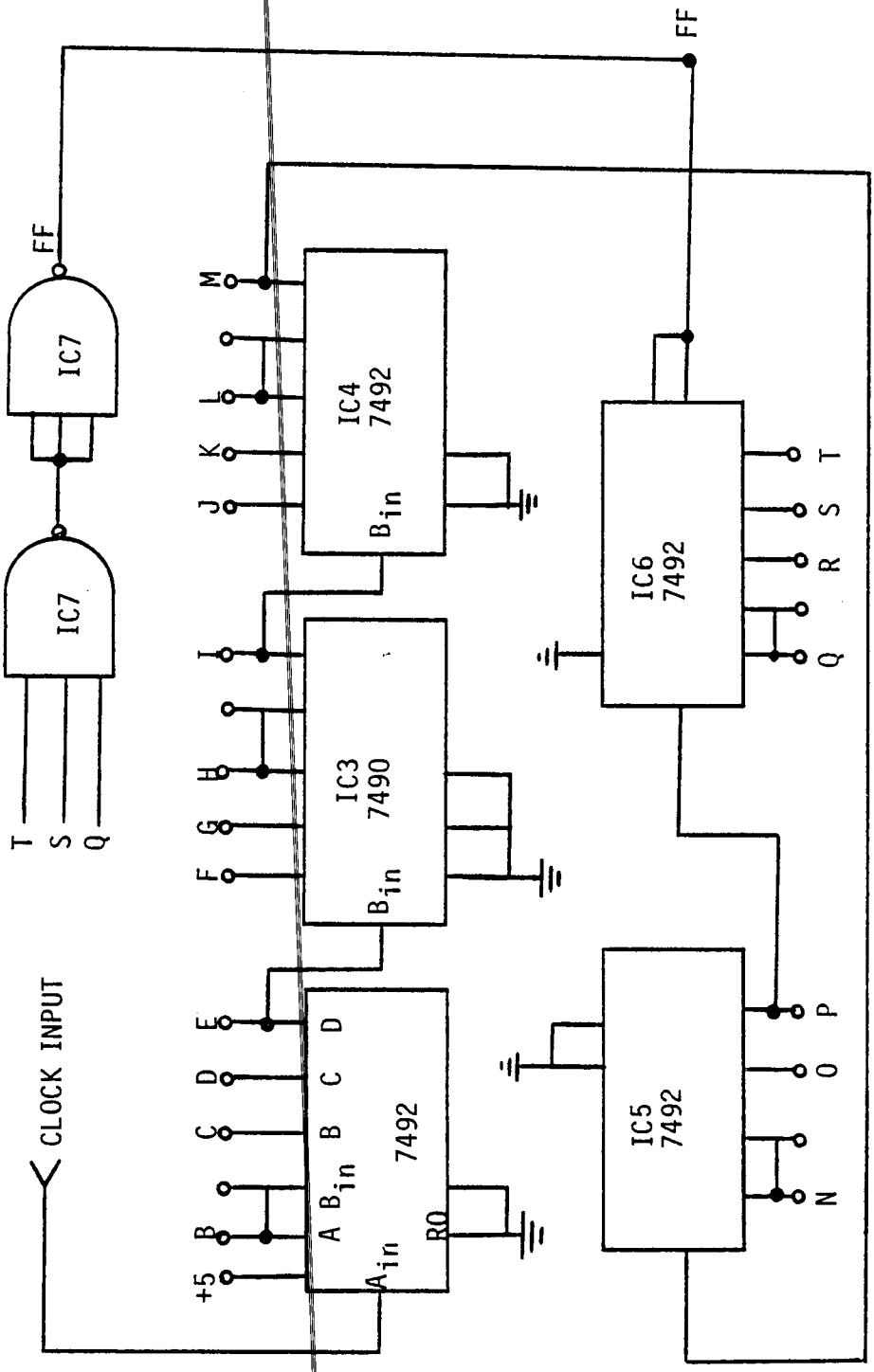


Figure 9. Logic Circuit To Obtain Horizontal And Vertical Frequencies.

forms the character and one is blanked to provide a space between characters. The remaining of this frequency chain division was discussed in the previous pages under Timing and Control of this chapter. Note that IC6 normally divides by twelve but the gating produced by IC7 (SN7410 triple three-input NAND gate) terminates the count prematurely, resulting in the desired divide-by-eleven function. In Figure 7 IC14 (SN7420 dual four-input NAND gate) operates as an inverter and provides forty load pulses to the parallel-to-serial shift register (SN74165 eight-bit parallel-to-serial shift register).

In the tri-level mixer function, Figure 10, is provided by IC10 (SN7401 quad two-input NAND gate) which is an open collector device. Open collector devices produce no output voltage but rather behave as either open circuit or short circuit to ground, depending on their state. If the upper right hand gate is conducting, the output would be at zero potential (sync level). If the upper right hand is not conducting but the lower gate is, then the two registors form a voltage divider and the output is about two Volts (black level). When neither the upper or the lower gates are conducting, the resulting output is plus five Volts (white level). In Figure 11, ICs eight, nine (SN74123, dual one-shot) are used to obtain the horizontal and vertical sync pulses respectively. In both ICs, the first one-shot is variable, and the second one-shot is fixed at approximately standard broadcast sync-pulse width. The adjustable one-shots are to provide delay control of where the sync pulses are

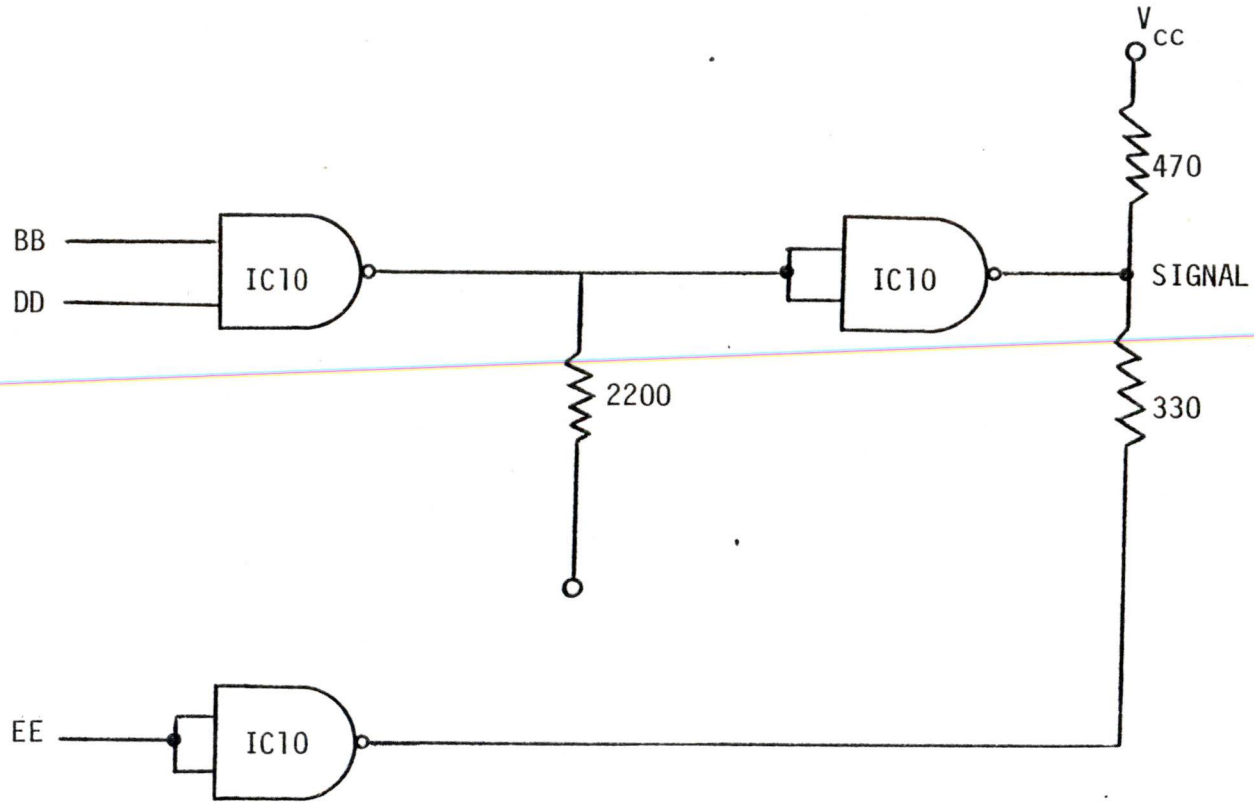


Figure 10. Tri-Level Mixer (Using Open Collector Gates) To Obtain Video Signal.

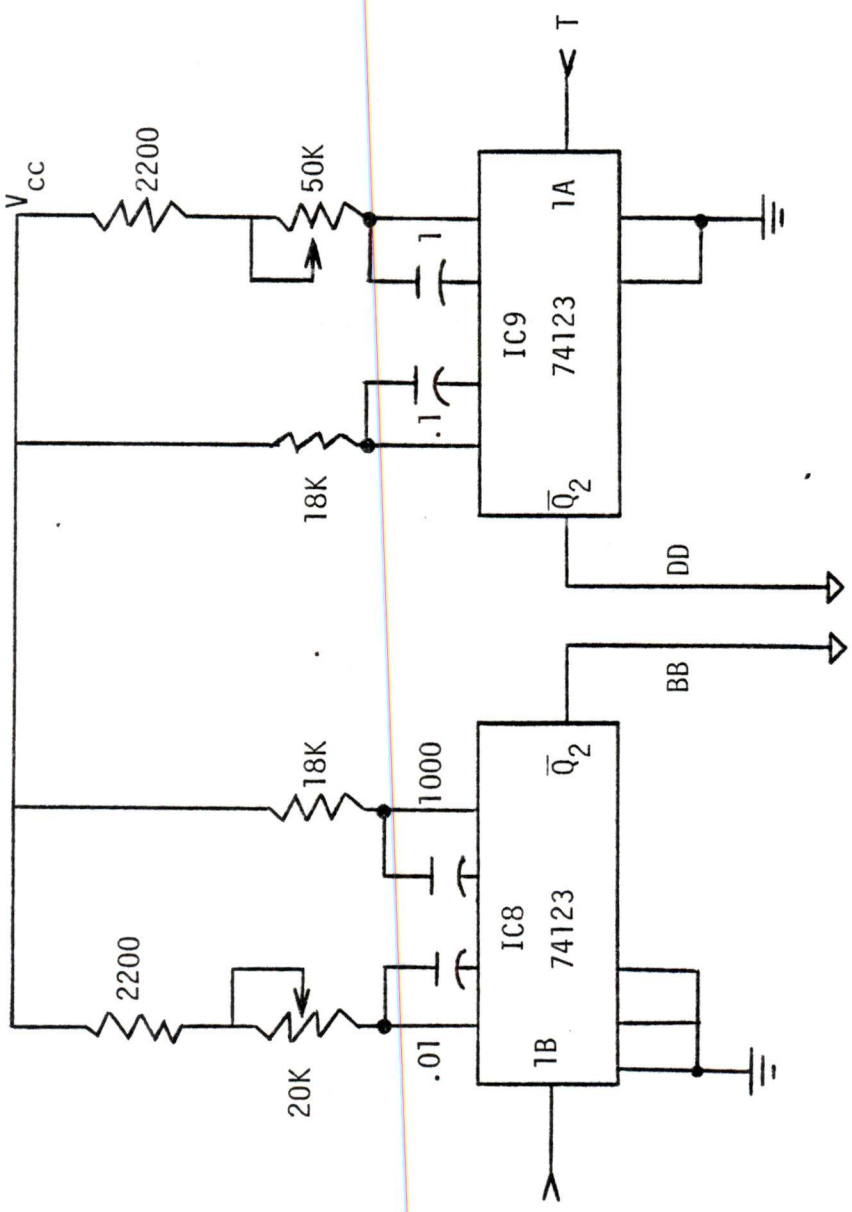


Figure 11. Horizontal And Vertical Sync Pulse Generator.

entered during the scan and thus, are used to center the row of characters on the TV screen.

The RF oscillator is a Hartly type in the common base configuration manufactured by International Crystal Company, Incorporated of Oklahoma City, Oklahoma. The catalog number for RF oscillator is 035101.

CHAPTER V

CONCLUSIONS

As stated previously, the purpose of this thesis is to examine the variety of digital display devices available for communication between human beings and machines. This examination has shown that there are many display devices available for almost any application.

Gas discharge displays which are evolved from vacuum tube technology have enjoyed wide usage for years, and are evident in a wide variety of equipment. The most severe complaints result from the individual digits being recessed at different depth within the tube, restricting viewing angle and visibility. They have very low current requirements. The reliability of these displays is excellent. The continuity of segments result in a pleasant overall aesthetic appearance, and these displays have found wide applications in consummer products such as digital clocks and electronic scales.

Incandescent filament displays offer the advantages of high-contrast, clutter free displays viewed against a dark background. They have a wide viewing angle (120^{o}). They are compatible with IC decoder/driver and free from induced or radiated interference. Since these displays operate at lower temperatures than incandescent lamps, they are far more reliable. They have moderate to low power consumption (500 mW - 175 mW). Their low power consumption and ruggedness has served well in avionics, panel meters, cash registers and industrial controls.

Vacuum fluorescent is the simplest form of displays next to the light bulb. With low voltage and current requirements, it is adaptable to portable, battery-powered equipment. It has MOS compatibility, full color versatility and can be multiplexed. It has the capability of full alphanumeric with fourteen to sixteen segments and variety in font and style.

The liquid crystal display differs from other types discussed here in that it does not emit light; rather, it provides a surface of controllable reflection which needs external illumination. A strong advantage is that it is easily visible in direct sunlight. Liquid crystal displays are slow to respond to changing input. They offer excellent advantage of low power requirements over the other types of display devices. Because of the flexibility of size and shape, advertising displays, scoreboards and annunciator panels can be made with liquid crystals. All indications are that liquid crystals could be the lowest cost displays in a few years.

Electroluminescent displays are relatively insensitive to temperature variations, shock and vibrating environment. They are rugged and this makes them suitable for spacecraft and avionics application. They have moderate life and low light output.

LEDs offer the proven advantage of solid state devices. Being ICs themselves, they are IC compatible and therefore easy to drive. Several displays offer LEDs and decode/drive electronics in the same package. Turn on and turn off speeds of much less than 1μsec are inherent because of the spontaneous nature of the light emitting mechanism.

Although, choosing the best display device for an application involves many factors, the field of choice is quickly narrowed by viewing working samples of the likely display devices. Available supply voltages and pricing also helps in making this preliminary comparison. In the interactive type of applications between humans and machines, LEDs among the other types of displays will be the most suitable display because of IC compatibility and their inherent fast response and low power requirements. Where the requirements for display exceeds a certain number of characters, for example; sixteen, the multiplexing scheme becomes complicated and costly.

By virtue of the fact that TV screens provides essentially a free display, the field of choice is narrowed for a dedicated interactive type of display. In order to demonstrate the feasibility of a TV screen for display over the other types of display devices for a dedicated application, a circuit was designed and a model was constructed on a Protoboard to interface an alphanumeric keyboard to a CRT employing a home television screen. In developing the circuit, the hardware cost was kept to a minimum. At current prices, the cost of the interface is approximately thirty dollars excluding power supply and an ASCII keyboard.

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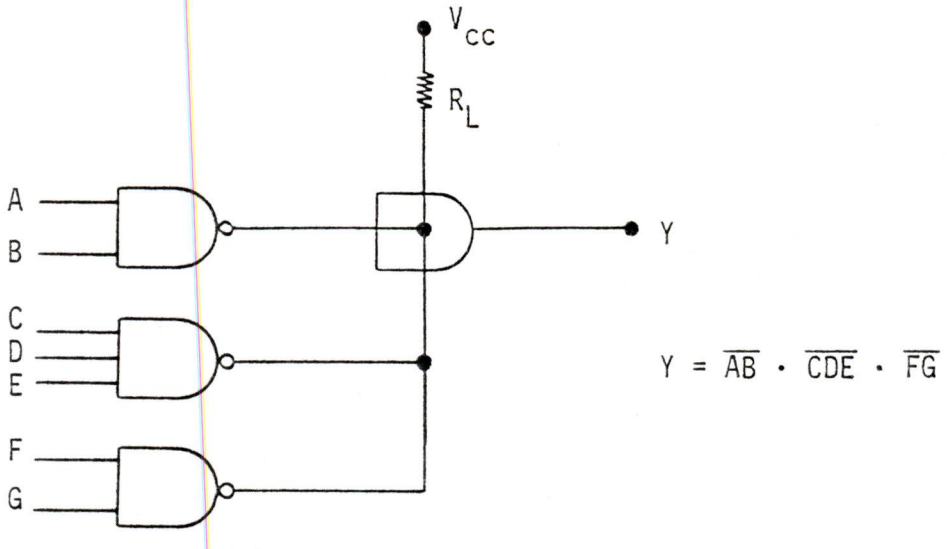
APPENDIXES

APPENDIX I

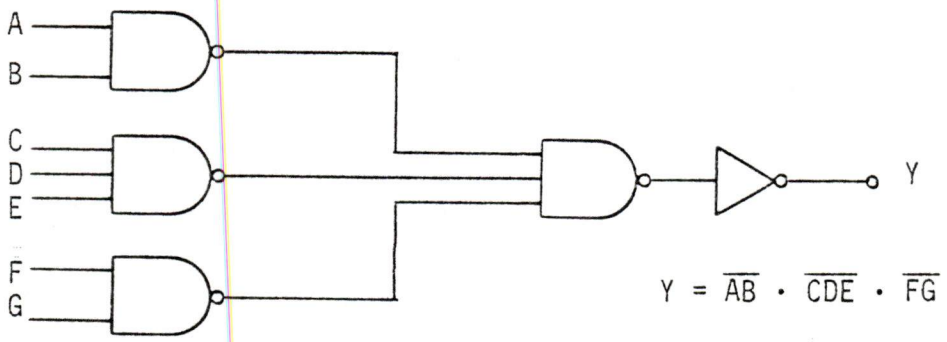
OPEN-COLLECTOR GATES

The regular TTL gates (totem pole output configuration) has the advantage of low output impedance in both logical states and is largely responsible for the capability to drive highly capacitive loads, the low noise susceptibility and the high speed performance characteristics of series 57/74. This output circuit configuration, however, is not well suited to the wire-AND logic connection.

Wire-AND-ing means simply tying gate outputs together (Figure 12a) to obtain the AND function. In comparison with the method of using three NAND gate levels (Figure 12b) to obtain the NAND-AND function, this saves two levels of logic and their associated delays. In the wire-AND configuration, there is a very good possibility that a single gate will have a logical zero output, and all others will be at a logical one. If the wire-AND connection were implemented using gates with totem pole output stage, this single output stage in the zero state would be required to sink current from the active pull-up transistors of all the other gates. Apart from degradation of the logical zero voltage level, there exists the possibility of high current damage to the output stage transistors. A totem pole output can source as much as 55 mA, and a gate output is guaranteed to sink only 16 mA. It is for these reasons that the open collector versions exist and that gates with totem pole outputs are not generally recommended for use in the wire-AND configuration.



(a) Wire-AND Connection.



(b) Connection Using Gates With Totem Pole Outputs.

Figure 12. Comparison Of Open-Collector Gates In Wire-AND Configuration with Totem Pole Output Gates.

APPENDIX II

Input Bits						Output Characters
A_6	A_5	A_4	A_3	A_2	A_1	
0	0	0	0	0	0	@
0	0	0	0	0	1	A
0	0	0	0	1	0	B
0	0	0	0	1	1	C
0	0	0	1	0	0	D
0	0	0	1	0	1	E
0	0	0	1	1	0	F
0	0	0	1	1	1	G
0	0	1	0	0	0	H
0	0	1	0	0	1	I
0	0	1	0	1	0	J
0	0	1	0	1	1	K
0	0	1	1	0	0	L
0	0	1	1	0	1	M
0	0	1	1	1	0	N

Figure 13. ASCII (American Standard For Computer Information Interchange) Code Upper Case Alphabets And Numbers.

Input Bits						Output Characters
A_6	A_5	A_4	A_3	A_2	A_1	
0	0	1	1	1	1	0
0	1	0	0	0	0	P
0	1	0	0	0	1	Q
0	1	0	0	1	0	R
0	1	0	0	1	1	S
0	1	0	1	0	0	T
0	1	0	1	0	1	U
0	1	0	1	1	0	V
0	1	0	1	1	1	W
0	1	1	0	0	0	X
0	1	1	0	0	1	Y
0	1	1	0	1	0	Z
0	1	1	0	1	1	[
0	1	1	1	0	0	\
0	1	1	1	0	1	]

Figure 13 (continued)

Input Bits						Output Characters
A_6	A_5	A_4	A_3	A_2	A_1	
0	1	1	1	1	0	^
0	1	1	1	1	1	_
1	0	0	0	0	0	SPACE
1	0	0	0	0	1	!
1	0	0	0	1	0	"
1	0	0	0	1	1	#
1	0	0	1	0	0	$
1	0	0	1	0	1	%
1	0	0	1	1	0	&
1	0	0	1	1	1	'
1	0	1	0	0	0	(
1	0	1	0	0	1	)
1	0	1	0	1	0	*
1	0	1	0	1	1	+
1	0	1	1	0	0	,

Figure 13 (continued)

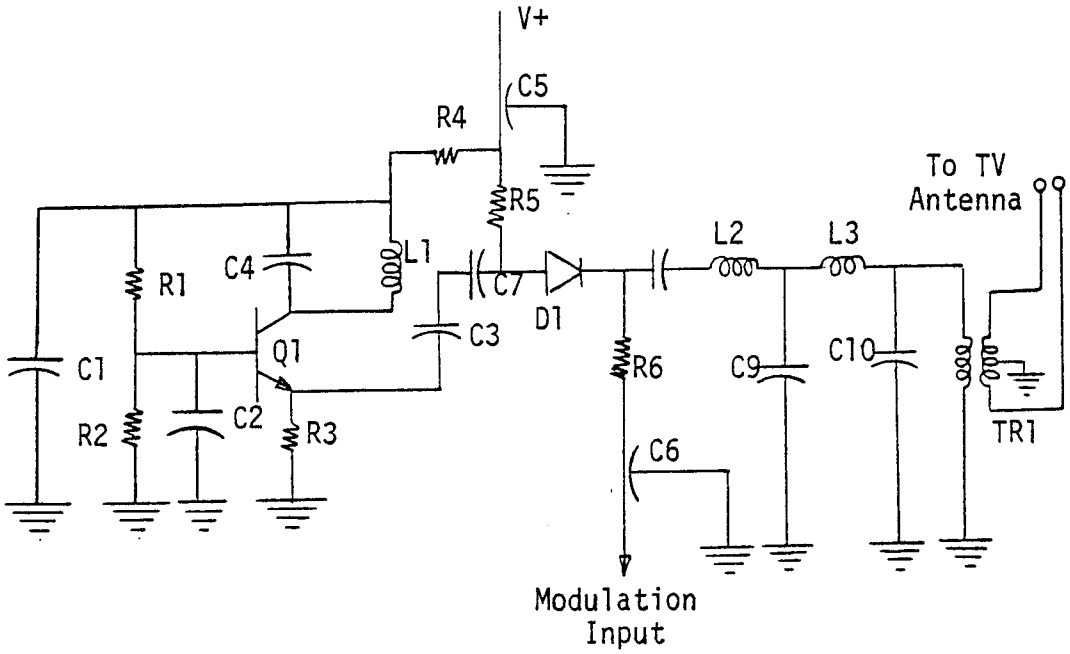
Input Bits						Output Characters
A_6	A_5	A_4	A_3	A_2	A_1	
1	0	1	1	0	1	-
1	0	1	1	1	0	.
1	0	1	1	1	1	/
1	1	0	0	0	0	ZERO
1	1	0	0	0	1	1
1	1	0	0	1	0	2
1	1	0	0	1	1	3
1	1	0	1	0	0	4
1	1	0	1	0	1	5
1	1	0	1	1	0	6
1	1	0	1	1	1	7
1	1	1	0	0	0	8
1	1	1	0	0	1	9
1	1	1	0	1	0	:
1	1	1	0	1	1	;

Figure 13 (continued)

Input Bits						Output Characters
A_6	A_5	A_4	A_3	A_2	A_1	
1	1	1	1	0	0	<
1	1	1	1	0	1	=
1	1	1	1	1	0	>
1	1	1	1	1	1	?

Figure 13 (continued)

APPENDIX III



R1, R2	2.2 KΩ	C1	.01 μF
R3	18 to 24 KΩ	C2	470 PF
R4	10 Ω	C3	27 PF
R5	22 Ω	C4	10 PF
Q1	2N708	C5	1000 PF (Feed Thru)
D1	1N4148	C6	1000 PF (Feed Thru)
L1	Condat Type L1	C7	10 PF
L2, L3	1 μH	C8, C9	10 PF
TR1	75:300 Ω Balun	C10	10 PF

Figure 14. RF Oscillator.

VITA

Mohammad Reza Habibi was born on December 27, 1949 in Khomain, Iran. He attended elementary school and junior high in Tehran, Iran. For further education, he came to the United States of America. Upon graduation from Spring Brook High School in Silver Spring, Maryland, he entered the University of Tennessee. He received a Bachelor of Science Degree in Electrical Engineering in March 1974. He accepted a Teaching Assistantship in the Electrical Engineering Department while working for a Master of Science Degree. He was also a consultant and part-time instructor in the Computer Science Department during his graduate work at the University of Tennessee.

He is a member of the Institute of Electrical and Electronics Engineering and Delta Upsilon Fraternity.

He is married to the former Shirin Sirang of Tehran, Iran.