MINIATURIZATION OF ELECTRONIC EQUIPMENT

BY

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1951

Submitted to the faculty of the Graduate
School of the Oklahoma State University
in partial fulfillment of the requirements
for the degree of
MASTER OF SCIENCE
May 29, 1960

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PREFACE

This paper is intended to serve as a guide for engineers new in the field of packaging electronic equipment. The author has tried to assemble under one cover enough material for the new engineer to get a start in the involved job of designing and packaging new compact electronic equipment.

Several acknowledgments are certainly in order. I would like to acknowledge the assistance given by Norman Hug, Dave Coryell, Gordon O'Riley and J. Whitney of Douglas Aircraft Co., Tulsa Division. These men helped in locating the latest information describing the problems involved and the methods of solving these problems of new and more reliable packaging.

In preparing this paper the acknowledgment of Dr. H. Jones, Oklahoma State University, Electrical Engineering Department, is certainly necessary. Dr. Jones has been my adviser through out the preparation of this manuscript and has given numerous helpful suggestions.

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CHAPTER I

INTRODUCTION

The development of the transistor by the Bell Telephone Laboratories in the 1940's help to understand the physical working of the semiconductor material. This paved the way for possibility of miniturizing electronic equipment.

Discussion of some of the problems and methods of reducing the size and weight of electronic components and circuits, that have been developed by industry will be the major task of the later chapters. There will also be an attempt to look at the possibility of subminiaturized systems, using methods being worked out by several top research companies of the United States.

Miniaturizing electronic equipment is not just a matter of making system smaller. As a device is made smaller, accessibility goes down and rejection rate, operating temperature and cost generally go up. With signal circuits miniaturized, there still remains a problem of power handling equipment.

Definition

Any discussion of the techniques known as "printed circuits" or "printed wiring" begins with a definition of these terms. "Printed wiring" refers to the use of solid metallic conductors bonded to an insulating base material. "Printed circuits" use printed wiring plus components such as inductors, capacitors or resistors made by similar techniques.

The two terms "printed circuits" and "printed wiring" are used interchangeably and not always in their true sense.

History

Printed wiring makers still debate about the date of the first printed wiring. Many ideas similar to present-day printed wiring are found in early U. S. patents. Some dating back to the latter part of the 19th century.

The first may however, be a British patent grated April 28, 1927 to a Frenchman named Cesar Parolini. This patent specifically spells out the printing and electroplating process. The method consists "of an ebonite plate for radio outfits having an electrolytically deposited system of connections."

Between this beginning and the limited use during World War II, the art of printed wiring remained relatively unexplored. It was not until about 1952 that printed circuits makes its greatest entry into the electronics field.

Industry's acceptance to the printed circuit idea was done without thought as to the difficulties that would be encountered. Therefore, the cost and size savings that was anticipated often did not materialize. Standards needed to be set up to help achieve the desired production technique.

Credit for much of this early development in the United States belongs to the National Bureau of Standards.

CHAPTER II

PRINTED WIRING BOARDS

Much of the electronic equipment has been reduced in size and weight by the use of the printed wiring circuit board. Because printed wiring is so well adapted to mechanization it has a very important place in the future of miniaturization in the electronic industry, for this reason this chapter will try and explain some of the design philosophy of making printed wiring boards.

Consideration of many factors such as (1) required current, (2) number and types of required components, (3) temperature of operation, (4) use of the circuit, and (5) quantity of units needed, are studied and evaluated as they affect (1) conductor width, thickness and spacing, (2) hole size, shape and spacing, (3) component placement and lead dress, (4) circuit teminations and (5) materials and production means.

Standardization

To insure reliability and uniformity of product at the lowest possible cost, Arma Division of American Bosch Arma Corp., Garden City, N. Y., established a project to set up design procurement and processing standards for printed wiring.

Basic printed circuit design standards as established by this study are shown in Table I. The established width of the conductors was based primarily on: fabricators tolerances; pin holes in the copper foil; bond strength and current carrying capacity.

TABLE I

BASIC DESIGN STANDARDS
USING EPOXY GLASS LAMINATE,
BOTH SIDES 2-OZ COPPER

	NOMINAL	MINIMUM
Conductor Width-Inches	1/16	3/64
Conductor Spacing-Inches	1/16	3/64
Pad Diameter-Inches	1/8	0.100
Hole Diameter-Inches	0.063±0.007	0.038±0.007

A fabricator's tolerances could reduce a given 0.032 inch conductor width, thus affecting reliability.
For example:

0.004 inch tolerance when 4 times artwork is reduced,

0.005 inch tolerance from screening process,

0.010 inch undercutting from etching.

0.019 inch total tolerance

0.032 inch desired conductor width

Thus, this gives a possible conductor width of 0.013 inches after fabrications.

Conductor spacing is dependent upon voltage differences. Table II is the guide used at Arma, nominal conductor spacing is 1/16 inches. Where space is at a premium, a minimum of 3/64 of an inch can be used. Table III shows the hole diameter as a function of the board thickness and wire size. Pigtail type components are mounted on the printed circuit board. To hold the components in place, the leads are clinched on the solder side of the board.

TABLE II

MINIMUM SPACING OF ADJACENT CONDUCTORS

POTENTIAL DIFFERENCE PEAK VOLTS	MINIMUM SPACING-INCHES
0 to 300	3/64
301 to 500	1/8
Greater Than 500	0.0003-Inches Per Volts

TABLE III

PLATED THRU HOLE DIAMETER
VS BOARD THICKNESS

WIRE SIZE-INCHES	PLATED THRU HOLE DIAMETER-INCHES	MAXIMUM BASE MATERIAL THICKNESS-INCHES
Up to 0.022 Diam	0.038 to 0.007	1/32
0.023 to 0.045 Diam	0.063 to 0.007	1/16
Over 0.045 Diam	Wire Size Plus 0.015	Equal to Hole Diameter

All the component leads should be straight for a minimum of 3/32 of an inch from the component body to the point of bend. Bend radii for the various lead diameters are shown in Table IV.

Components are mounted to 0.100 inch grid intersection. These standards assure uniform design, and greater reliability at a lower tooling cost.

TABLE IV

BEND RADIUS VS LEAD DIAMETER

LEAD DIAMETER-INCHES	LEAD WIRE BEND RADIUS-INCHES
Up to 0.028	0.032 Min.
0.029 to 0.045	0.062 Min.
0.046 and Greater	Twice Lead Wire Diameter Min.

Components should be mounted separately. Where components are tied into a common lead, separate mounting holes should be used. If a component has to be replaced it will therefore not be necessary to unsolder the other components.

Components have been developed to fit the dip-solder techniques used by many of the manufacturers in making printed wiring boards. For example, tube socket have terminals that snap into holes in the board. Other new miniature components that have been designed to meet printed wiring requirements, include; relays, potentiometers, and variable capacitors. These new components improve reliability and even helps to reduce the size and weight of the newest circuits.

Table V shows some suggested design techniques to improve reliability.

Design Methods

After the circuit design has been completed, it is inked on a good stable white stock with a flat black ink. It is necessary that all lines be sharp and clean for best

TABLE V

SUGGESTED DESIGN TECHNIQUES TO IMPROVE RELIABILITY

1. Use single-sided printed wiring boards instead of double sided.
2. Use smallest possible board (6 inches square).
3. Use 0.1 inch grid layout as standard.
4. Use "free flowing" lines, rounded corners.
5. Make conductors as short as possible.
6. Deep DC near edges.
7. Holes for component leads should be spaced at least 1½ times the thickness of stock apart and from outside edges.
8. Smallest hole no smaller than 2/3 stock thickness.
9. The minimum spacing between conductor lines, copper pads be no closer together than 0.032 inches.
10. Boards 1/16 to 3/32 inches thick should be supported at intervals no greater than 4 inches. Boards thicker than 3/32 shall be supported at intervals of not more than 5 inches.

results. Drawings are made 2 or 3 times size to permit closer tolerances in the final product; for an example, an error of 0.048 inches in a large drawing will be 0.016 inches after a three-to-one reduction. In laying out the printed wiring boards, the designer is faced with the decision of whether to use a single-sided or double-sided circuit board. The double-sided circuit board has the advantage over the single-sided board in size and weight reduction and it tends to decrease the warpage of the circuit board during fabrication. It has a disadvantage however, of adding complexity which can be a source of unrealiability. Therefore, the single-sided printed circuit board is usually chosen over the double-sided board.

Board size must be determined. For optimum ease of handling in production, and to facilitate mounting problems, it has been suggested a size of 6x6 inches as maximum. Overall width and length of the board should coincide with the lines of the 0.1 inch grid pattern.

Component should be oriented in both the horizontal and vertical planes. Where crossovers are necessary to achieve a certain component layout, wires may be used. These wires should be treated as components.

The printed wiring board consist of a metal conductor pattern formed on a base of insulating material in a specific circuit configuration. In the most acceptable method of producing such a board (the substractive process), the circuit is printed on a electrical grade of plastic laminate to which has been bonded a thin layer of copper foil. After the replica of the circuit is printed on the copper foil, the unwanted metal is removed by a controlled etching process, thus leaving the desired conductor pattern.

Proper Care and Handling

To insure proper reliability of printed wiring, proper handling care of the board from the time it is prepared until the final assembly of the circuit is very important. Manufactureres of laminates constantly check each step in the production process. This insures the fabricator a good quality uniform product.

After incoming inspection by the printed wiring fabricator, the copper-clad sheets are often put in stock. In exposed storage, the copper or solder plated copper will oxidize. Oily or acid atmosphere will contribute to difficulty in getting good solder joints. Therefore, the incoming stock should be cleaned and then placed in sealed plastic bags for storage. Once the board is removed from the bag it should go into production immediately. One of the methods of cleaning the board is to scrub with pumice cleaner and a scrub brush.

After etching, the acid coating must be completely removed. Alcohol, acetane or other commerical cleaners may be used to remove the acid coating. About 90% of the printed wiring problems can be blamed on poor cleaning. Production contamination results from the etching bath and solder fluxes. Handling contamination is the result of fingerprints and dust.

A board that has been stored in open air or has been handled, should have the areas that are to be soldered burnished. A suitable material for burnishing the board is a "typewiter" eraser of the pencil type. In very bad cases 4/0 steel wool can be used. Care must be used to insure that steel whiskers are not trapped under eyelets, or fastenings on the boards.

The following formula is suggested by Cleveland Metal Specialties Co., for use in cleaning of the circuit board.

8 oz Ammonia

8 oz Murphy's Oil Soap

1 oz Swift & Co. No. 900 Solar Detergent

1 gallon water

Heat water 140°F to 160°F, dissolve soap (stir slowly for minimum studs). Add ammonia; solar detergent.

Use stock solution at above temperatures in cleaning printed wiring. One gallon will treat approximately 15 square feet of two sided printed wiring material.

After the circuit has been washed it should be allowed to stand in the heated solution for at least 20 seconds. A stiff brush should be used to scrub both sides of the printed wiring board, rinsed in filtered tap water, and forced dry by air blast.

The board should be handled by the edges at all times during the rinsing and drying of the board. They must then be dried on lint free blotters.

After soldering the circuit, the flux and other residue should be removed. To remove this residue the entire assembly is placed in a shallow pan of suitable flux removers such as toluol, or liquid trichloroethylene and allowed to soak. About 20 to 30 seconds should be allowed for softening and loosening the residues. The assembly then should be dried by a blast of clean compressed air.

After this cleaning of the finished assembly, the assembly then can be protected by a coat of varnish or plastic spray to prevent leakage and to render the areas humidity proof.

All etched circuits should have a protective coating. Some of the other coatings that have been suggested by Methods Manufacturing Corp., is as follows;

(a) Protective laquers, wax, or varnish compounds to prevent oxidation.

(b) Flux coating. This coating is a soldering aid.

(c) Solder resist mask, this keeps solder off the parts of the circuit that are not to be soldered.

(d) Silver Flash is useful where excellent appearance at low cost is desired.

(e) Electrosilver plate used for switching and applications where good conductivity is important.

These suggested finishes are a few of the many special finishes that are being developed by printed wiring manufacturers.

CHAPTER III

MINIATURE COMPONENTS

Miniaturization would be impossible without the reduction in the size of the circuit components themselves. This includes the reduction in size of capacitors, potentiometers, fixed resistors, inductors, switches and the like.

Capacitors

Capacitors have been reduced in size considerably by the use of new materials and configurations. Materials that are being used include cermics, teflon, tantalum, glass and mylar.

In the vitramon capacitors a porcelain or vitreous enamel dielectric is used with silver electrodes and leads. The dielectric and vitrious material are fused into a monolithic block. A process of appling the enamel leaves a dielectric only a few mils thick.

Mylar has been used in capacitors as a dielectric and as an encasing material. Mylar dielectric capacitors encapsulated in epoxy are supplied by the Texas Capacitor Co. in values up to 0.025 μfd with a ¼ inch diameter and 9/16 inch length at 400 volts. Diameters very with capacitors and voltage ratings range from 1/8 to 1 inch.

The tantalum capacitors have made possible a great reduction in size at low voltage. These capacitors are ideal for transistor circuits. Mallory TAP capacitors that can operate in a temperature range from -55 to +85 degrees centigrade use a sintered pellet anode. Dimensions of these units are ½ inch in length by 0.225 inches in diameter.

Fixed Resistors

A resistor that is in use by many manufacturers is the "Little Devils" made by Ohmite. These resistors are ¼ watt rating and are available in values from 47 Ohm thru 22 Megohm. They are 0.09 inches in diameter by ¼ inch long. Ohmite also manufacture a miniature resistor with a power rating of 1/10 of a watt and are available in values from 10 ohm to 1 megohm. These resistors are only .062 inches in diameter by .12 inches long. These little resistors are ideal for transistor or other low voltage, small current applications.

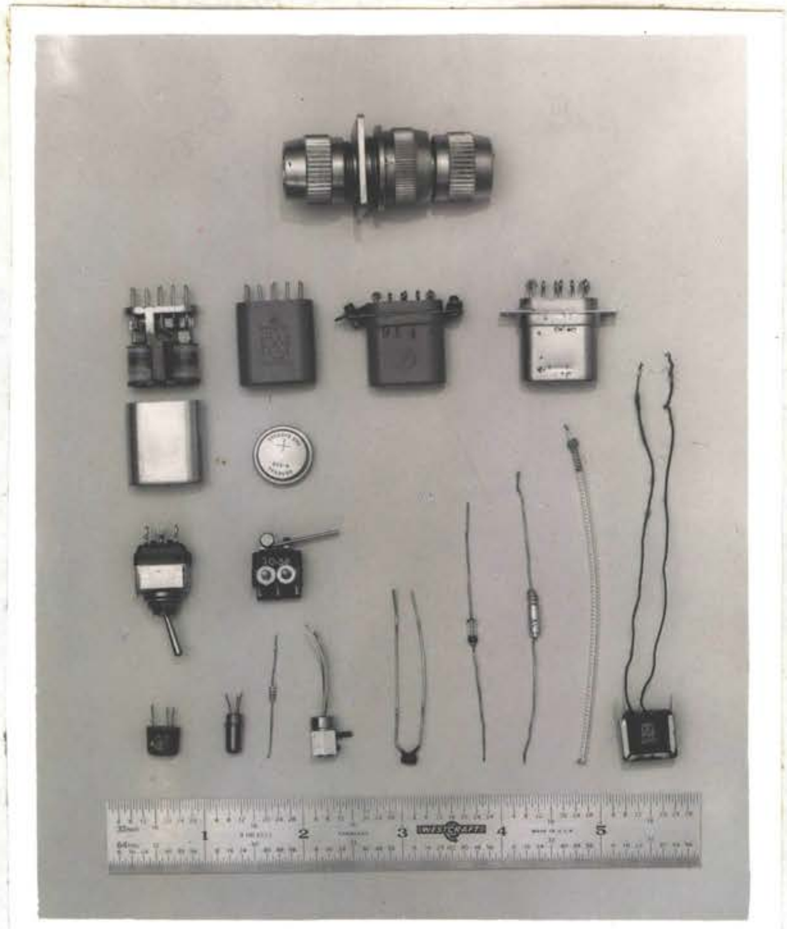
Diodes

In crystal diodes, size has been reduced to a little more than the thickness of the connection leads. Typical dimensions are 1/10 inches in diameter by about ¼ of an inch long.

Photographs of some of these miniaturized components are shown in Fig. 1.

FIGURE 1

MINIATURIZED COMPONENTS



Top Row: Electrical Connector

Second Row: Miniature Relays

Third Row: Miniature Battery

Fourth Row: Toggle Switch, Micro Switch

Bottom Row: Transistors, Resistor, Potentiometer, Capacitor, Diode, Tubular Capacitor, Coaxial Cable, Choke Coil

Transformers

Much has been done to help reduce the size and weight of the very heavy and bulky transformers. New insulating materials, finer drawn wires and more efficient steels for cores have helped to make this reduction possible.

Teflon tape has been used by Goslin Corp. in reducing a 42,000 volt transformer from 20 lbs. to 14 lbs. A smaller transformer made by this company was reduced from 11 to 2 lbs. This Teflon tape has a dielectric strength of 400 to 500 volts per mil and a dielectric constant of 2. Dissipation factor is 0.0002. This tape is used for interlayer insulation, wrapping of the coils and lead wires and as a case lining to house the transformer.

In transistor circuits the low current, voltage and impedance has made possible this design of extremely small transformers. Laminated cores for these transformers can be obtained in core size of ½x7/16 of an inch.

Panel Components

In miniaturized equipment, panel space for mounting switches, indicators, jacks, potentiometers and controls is limited. Space behind the panels is also limited. Controls must be selected to permit mounting in close proximity to one another, without the danger of mechanical or electrical interaction.

A 12-position rotary switch is manufactured by R. F.

Electronics that requires only a space of 3/4 of an inch square behind the panel. Up to six decks can be combined for a single-knob operation.

A subminiature pushbutton switch manufactured by Micro Switch Company. This switch, ISXI-T, has dimension of .500 inches long by .350 inches height by a thickness of .200 inches. It electrical rating is 7 amps at 28 vdc or 115/230 vac 60 cycles 5 amps resistive and inductive.

A subminiature jack and plug combination made by Telex is about 1/3 of the size of previous units. The miniature plug is ¼ inch in diameter at its widest point, length is 1 3/16 inch including tip.

Panel meters designed for use in miniaturized equipment by Marion Electrical Instruments Company provide a scale arc of more than 1½ inches in a panel hole of 1 35/64 inches in diameter. The mechanism is self-shielding and can be mounted on either magnetic or non-magnetic panels without affecting calibration.

Tunnel Diodes

One of the newest component to be developed is the tunnel diode. The development of this diode was made possible through the work of Leo Esaki in 1958. The first tunnel diode was manufactured by General Electric Co.

The tunnel diode should move a lot of enticing products out of the Labs and into the assembly lines. It will make possible the "Dick Tracy" two way wrist-watch radio.

The tunnel diode takes its name from the physical phenomenon that makes its operation possible; "quantum-mechancial tunneling" which describes the manner in which the electrical charge moves through the device. This motion takes place at the speed of light compared to the relatively slow motion of the electrical charge carriers in a transistor.

This high speed makes it possible for the tunnel diode to operate at extremely high frequency. Oscillation frequencies higher than 200 mc. have already been obtained.

The tunnel diode is more than a thousand times as resistant to nuclear radiation as the transistor. It is smaller than the transistor and will operate at temperatures from liquid helium up to 650° F. Conventional silicon transistor will not operate above 400° F. It requires only one thousandth the power required by a transistor.

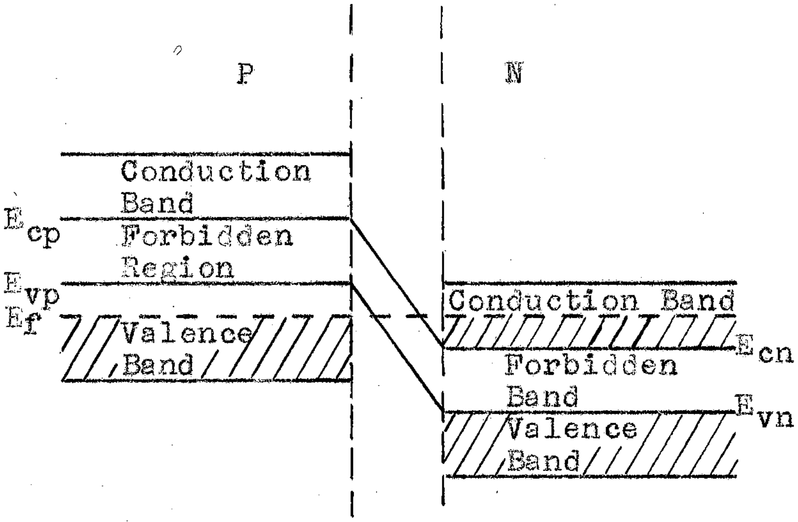
The tunnel diode differs from a transistor in that it has only one junction region. The junction of a tunnel diode must be very thin, on the order of 150 Angstrom units. The Fermi level must be within the conduction band on the n-type side and within the valence band on the p-type side. Highly impurity concentrations is very important to achieve the necessary tunnel effect. This concentration should be greater than $5x10^{19}$ per cubic centimeter for silicon and greater than $2x10^{19}$ per cubic centimeter for germanium. In the tunnel diode this region is very much thinner than in transistors. This therefore, enables the electrons, instead of slowly drifting across the base region, to apparently "tunnel" the barrier if a slight bias potential is applied.

Figure 2 (A) shows the energy level of a highly doped p-n junction at zero bias voltage. Notice there are some electrons in the n-material conduction band that have the same amount of energy as some electrons in the p-material valence band thus, a net current of zero. Figure 2 (B) shows the same p-n junction with a small positive bias applied. The junction barrier is decreased and n-material conduction electrons are situated opposite the p-material available states at the same energy level. There is a net current flow from n to p material. In Figure 2 (C) the bias is increased thus the junction barrier is further decreased and the n-material conduction electrons are opposite the forbidden region of the p-material. Since electrons can not move into this forbidden region the current will be decreased.

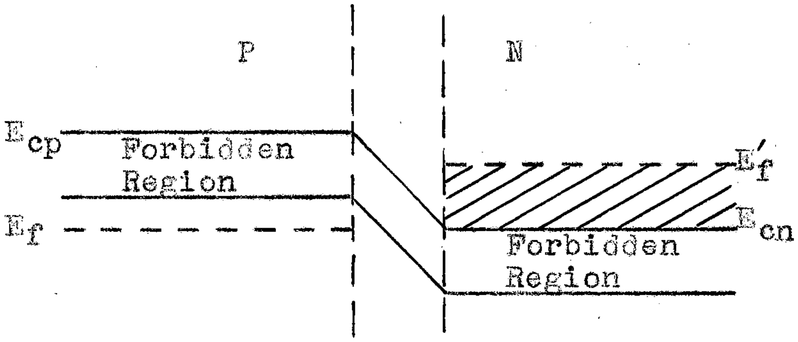
The tunnel diode has the disadvantage of isolating the input circuit from the output circuit. This is true of all two terminal devices. But with research in circuit design, this disadvantage will certainly be overcome in a very short time.

FIGURE 2

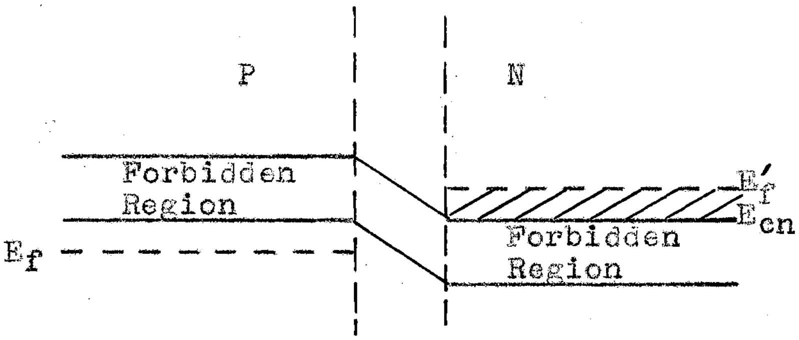
ENERGY LEVEL IN A TUNNEL DIODE



(A) ENERGY LEVEL OF A HIGHLY DOPED P-N JUNCTION WITH ZERO BIAS APPLIED



(B) ENERGY LEVEL WITH A SMALL POSITIVE BIAS



(C) ENERGY LEVEL WITH AN INCREASED POSITIVE BIAS

CHAPTER IV

UHF APPLICATIONS

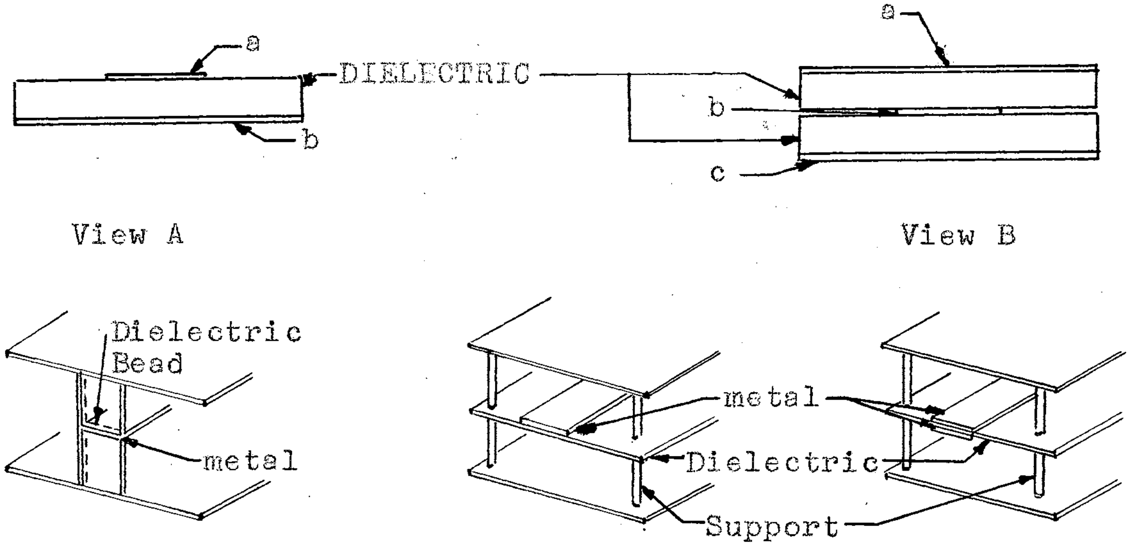
One of the important tends in the miniaturization of microwave equipment has been the development of "flatstrip" components fabricated with printed circuit techniques.

Special design considerations such as impedance matching and power limitation must be studied in order that the miniaturizing of microwave equipment may be fully realized.

Three types of printed circuit transmission lines are shown in Fig. 3. The Microstrip, View A, is a printed-wire

FIGURE 3

PRINTED CIRCUIT TRANSMISSION LINES



View A

View B

View C

View D

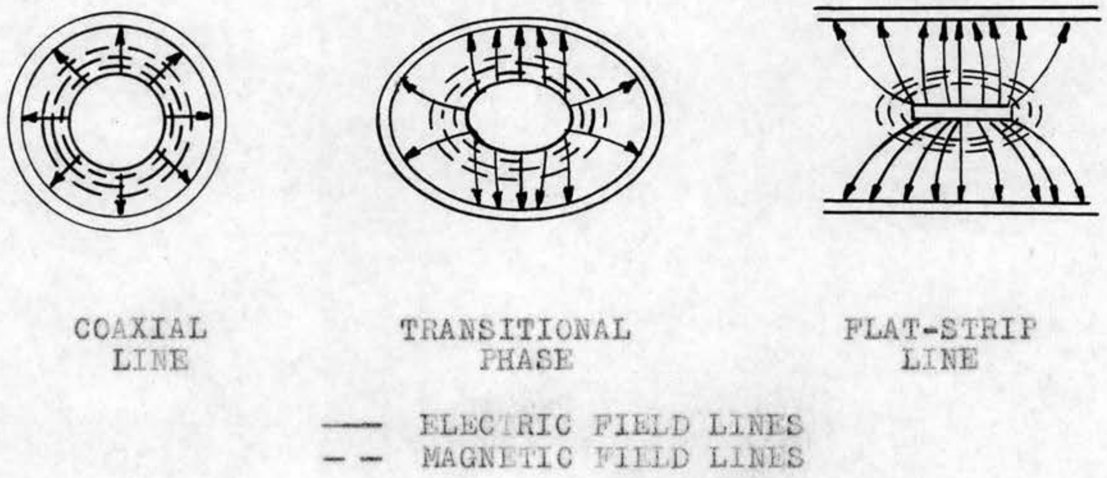
View E

two wire transmission line. Conductor "a" is printed on one side of a Teflon-fiberglass base. The other side of the dielectric board also has a printed wire which acts as a conducting plane. The Microstrip has a rather high dielectric loss and requires shielding to prevent radiation loss. It is very usefull where a high Q is not required or where a short run of transmission line is needed. The tri-plate, View B, which was developed by the Sanders Associates Co., can be considered the printed equivalent to a coaxial transmission line. A single conductor positioned between two ground planes produces a Tri-Plate transmission line. It eliminates the radiation leakage of micro-strip and is more rigid. Its dielectric loss is however, higher than the Micro-strip. The third line is the Stripline. This line development of the Airborne Instruments Laboratory, is formed so that a flat conductor is centrally placed between two ground planes. The flat conductor can be either a solid copper strip or a dielectric sheet with a printed conductor. View C shows the ground plane to be bounded to a dielectric sheet, and the flat center conductor is supported by dielectric beads. This structure can be compared to equivalent-size coaxial line. The center conductor strip can be undercut at the bead supports to provide a constant characteristic impedance. In part D a dielectric sheet between the two ground planes carries a single copper conductor and the dielectric sheet is supported by either metal or dielectric posts. The double clad line, part E, has even lower losses because the electric field exist from each strip conductor to its corresponding ground plane and only fringing fields exist in the dielectric sheet.

Energy is carried in the TEM mode of operation by all of these flat strip transmission lines. Fig. 4 shows the evolution of the flat strip transmission line. This is

FIGURE 4

EVOLUTION OF FLAT-STRIP TRANSMISSION LINE



COAXIAL LINE

TRANSITIONAL PHASE

FLAT-STRIP LINE

—— ELECTRIC FIELD LINES
– – MAGNETIC FIELD LINES

shown by taking a regular coaxial line and flattening it into the flat-strip line. The inner conductor of the coaxial line becomes a flat strip of finite thickness, while the outer conductor is broken into two semi-infinite groundplanes.

The electric field is entirely bounded by the flat outer conductors in the region of the centerstrip and is relatively uniform within the region directly between center strip and outer ground plates. The field external to this space decays very rapidly. Therefore, no electrical field component exists lateral to the center conductor. Thus, sidewalls are unnecessary.

Many r-f systems use both printed and other types of transmission lines, requiring transitions between the different types of lines. Fig. 5 shows two methods of transition. A parallel-plate line into a wave guide. The sandwich of metal and dielectric is made wider as it extends into the waveguide until it fills the guide. A wedge shaped section of polystyrene allows gradual transfer of energy from the printed line to the guide so that reflection and attenuation of the energy is minimized. The transition between the strip and the coaxial cable is also shown. Dimensions are shown in terms of the width of the strip. The triangular end of the strip connects directly to the center conductor of the coaxial cable.

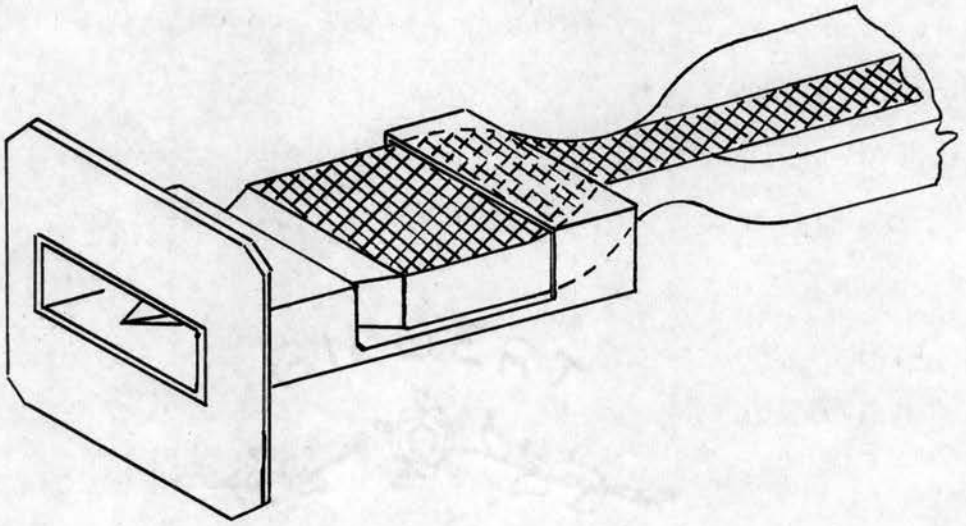
Antenna Miniaturization

Because of the rapid growth in electronic equipment placed aboard our missiles and aircraft, the antenna designer is becoming more and more confronted with designing antenna to fit in smaller and smaller spaces.

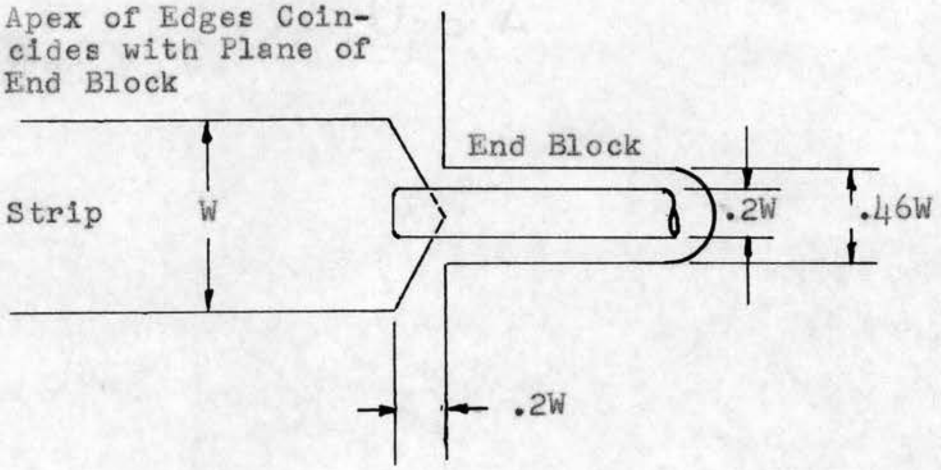
The slot antenna has application in flush mounted systems of missiles and aircraft. Here reduction in size is very important. The reduction in size of the slot antenna system can be approached in two ways. First shortening the slot length by loading and secondly reduction of the cross section or volume of the transmission line or cavity associated with the slot.

FIGURE 5

TRANSITION FROM PRINTED LINES
TO CONVENTIONAL LINES



(A) Polystrene Transition from Waveguide to Parallel Plate Line

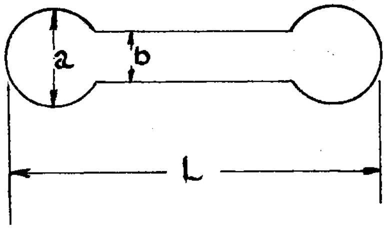


(B) Fifty-ohm Coaxial-to-Strip Transition

First consider the reduction in slot length. The simple slot is at resonance when it is physically one half wave length long. A method which has been used to load the slot is to deform the slot to a dumbbell shape. This is shown in Fig. 6. The length "L" for a particular frequency is shortened as "a" the diameter of the end circles is shortened as "b" the gap distance is decreased. Folding may be accomplished by cutting a slot parallel to the driven slot and connecting them at the ends. Folding will normally decrease the radiation resistance and can be used for matching purposes.

FIGURE 6

DUMBBELL SHAPED SLOT



A slot antenna system may be reduced in size by decreasing the volume or cross section of the cavity associated with this system. The cavity does not need to be resonant at the same frequency as the slot, this does not therefore restrict the size of the cavity. The cavity does present a parallel reactance to that of the slot, the value of this reactance depends on the cavity dimensions. The reduction in the size of the cavity therefore, affects the resonant length of the slot. It has been found that this effect is negligible if the cavity is about $\frac{1}{4}$ wave length deep. If the cavity depth is reduced to less than this the slot will be loaded so as to increase its resonant length.

One new type of printed circuit radiator that has been developed recently, is the "sandwich wire" antenna. This antenna is adaptable to printed circuit techniques and can be constructed as a flat or curved plate structure with linear polarization for either pencil beam or shaped radiation pattern.

The structure of the sandwich-wire antenna is basically the same as the strip line transmission line. Strip lines are normally nonradiating but can be made to radiate by simple changes. If the center conductor is inclined so that it is no longer parallel to the outer plates, an unbalanced condition results. Since its excitation is progressively phased, the TEM mode is not constrained but propagates in the general direction of the length of the strip line.

For the TEM wave to propagate broadside to the center conductor of the strip line, the phase must be periodically reversed between radiating points on the strip.

To obtain this periodic reversal the center conductor is bent so that the direction of its slop is regularly reversed.

If the center strip and outer plates are compressed to one-dimensional conductor the antenna can be made by use of printed wiring techniques. The two outer conductors are parallel to each and are at ground potential, while the center conductor is bent into a sinusoidal form with a period equal to the wave length. This type of antenna may prove to be extremely valuable in high speed aircraft and missiles because of its weight and size.

CHAPTER V

PACKAGING OF MINIATURIZED EQUIPMENT

Packaging is one of the important requirements of the completed miniature circuit. All of the engineering put into the laying out of the circuit board and choosing the right components can go for nothing, if the engineer does not think about the packaging of the equipment. The engineer must know if the circuit is to be of the throw away type or one that can be repaired. If the first type is used it can be potted or encapsulated, while the second one must be packaged so that it can be taken apart to allow the components to be replaced without destroying the circuit wiring and other components.

Encapsulation

Small compact packaging may also be done starting with a printed wiring board with components stacked on the board one above the other to form a three dimensional unit thus, reducing the size and weight. After the circuit is complete the unit is often encapulated or potted. This method is very effective to protect the electronic circuits from the effects of vibration, humidity, and acceleration. Fig. 7 shows a keying circuit that was designed and packaged by a

FIGURE 7

MINIATURIZED PACKAGING KEYING CIRCUIT

leading aircraft company. The completed package measures 1⅛x1 5/32x2¼ and weighs about 0.463 pounds. Since this package is a throw away unit, it was found that encapsulating in an epoxy resin was an ideal package.

Potting Material

Materials are available to encapsulate anything and they will operate in ambient temperatures from -60 degrees centrigrade to as high as 316 degrees centrigrade.

Epoxies resins can be used very sucessfully for potting of the circuit. They can be obtained clear, excellent idea for first prototype. Epoxies can also be produced in any color that is desired. Epoxy resin weighs about 13 pounds per cubic foot.

A new foam plastic is often used where weight is very important. This foam weighs about .06 pounds per cubic foot. The foam plastic should have a protective cover of fiber glass or plastic resin.

Repairable Packaging

Commerical items such as computers often have printed wiring boards which plug into a main chassic so that the units can be made more flexible. These units are often packaged on slide out racks that plug into the completed assemble. One very important design problem, especially in circuits that have a great deal of power dissipation involved, is how to dissipate the heat. One very much used method is by the use of heat sinks.

The power dissipating components should be mounted directly on a piece of metal or on the metal chassic itself thus the heat can be carried from the component more easily.

3-D Packaging

A new technique that will give high density electronic packaging is often referred to as 3-D packaging. This technique involves mounting minature components side by side and forming the electrical connections on a three-dimensional basis. The wires are joined by electrical resistance spot welding. After the unit is assembly and electrically checked, the unit is encapsulated in epoxy potting compounds to form a module.

CHAPTER VI

SOLID STATE CIRCUITS

The component engineer dreams of the day when all components will give continuous top performance and be completely reliable. The system engineer dreams of the day when there will be no components.

While performance and reliability requirements for future electronic systems are mounting their weight and size allowables are shrinking. To meet such conflicting specs., radically new design approaches are needed.

There has been strong efforts in research today to get rid of not only the components but also the circuit. These will be replaced, researchers hope, by the use of monolithic blocks of materials each of which performs a complete electronic function.

This new science within a science is called Molecular Electronics, or "Moletronics". It is concerned with the arrangement of the molecular structure of matter so as to give it the properties needed to control the flow of charged carriers and thus accomplish a desired result.

Moletronics is based on a new state of matter uncovered by semiconductor research. Nearly all conductors and semiconductors of interest have crystal-line structure.

Solid-state physicists have found that by purposely introducing chemical impurities and structural imperfection into the lattice, they can create materials with certain electrical properties. Most present research and development efforts aim at developing a set of rules by which the electric properties of a material can be correlated with certain lattice structures. Once a firm scientific framework is laid down, the physicists can proceed with little resort to empiricism.

The system engineer of the future will start at a new level of synthesis, specifying his needs only in terms of basic system functions and properly weighed objectives. The moletronics design group select the basic material and rearrange its crystal lattices to bring about the desire oscillation, amplication, storage, delay, etc.

Just to understand the workings of moletronics, the engineer will have to forget the R, L, and C concepts and substitute the theory of electron spin, fields, and energy exchange.

Westinghouse under a $2 million Wright Air Development Center grant, has been able to grow thin, uniform ribbon of germanium instead of the round ingots. Westinghouse has already produced two circuits made of this monolithic germanium blocks: First a light telemetry amplifier that has a volume of .001 cu. inches and uses one part in place of 14 parts in the transistorized unit. The second circuit is a slightly larger pulse generator with a 10-100 kc pulse rate frequency and a pulse width of approximate one microsecond.

Texas Instruments has developed similar circuits using such processes as controlled masking, etching, and diffusion. T. I. has already built a multivibrator and a phase shift oscillator using solid-state circuit no bigger than a match head.

CHAPTER VII

SUMMARY AND CONCLUSIONS

The art of miniturization of electronic equipment started in the United States in the late 1940's. The early work was mostly done by the National Bureau of Standards. In the 1950's Bell Telephone Laboratories advanced the art with the development of the transistor. Because of the transistor, the power dissipation and operating voltage could be reduced in value, thus making it possible to develope smaller circuit components.

The development of printed circuit and printed wiring technique not only reduced the size and weight of the unit but made it possible for the manufacturer to highly mechanize the manufacturing of their units.

There is a form of printed circuit techniques used in almost all of the present, or near future, methods of compact packaging. For this reason this technique is the main discussion of this paper, as it applies to the engineering and development of new and lighter electronic equipment.

The engineer, as he is confronted with the job of reducing the size and weight of a certain piece of equipment, must consider the problems involved not only in the circuit design itself but also the difficulties that may be faced in the manufacturing of said equipment.

It is therefore, the hope of this author that this paper may help the engineer by pointing out certain standards to keep in mind while designing the miniature equipment necessary in todays and tomorrows field of electronics.

Increase demand by the missile and aircraft industry for smaller and lighter units with greater reliability, started the study of making a complete unit from a piece of semi-conductor material, "moletronics". This is thought by many of the scientists and engineers to be the answer for the altimiate in size and weight of the equipment that is asked for by the industry.

It is the opinion of this author that although a great deal of study and development has been done in miniaturizing electronic equipment, more work needs to be done. This is especially true in the area of electrical connectors. It is possible with the ever increasing use of miniature equipment, the use of smaller connecting wire will be possible. Therefore, it will be possible to make design changes that will make the connector the desirable size.

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