# Design of Thin Film Resistor and Capacitor Circuits

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**Design procedures provide a tool for making an initial evaluation of new applications for thin film resistors and capacitors.**

MINIATURIZATION, STABILITY AND RELIABILITY are the advantages that thin film technology has to offer to both apparatus and equipment designers. With recent improvements in the thin film manufacturing process, thin film circuits are also becoming more cost competitive with discrete-component circuit designs. As a result, there are many applications in which thin film circuits can be applied with a savings in both cost and space. In many instances new applications of thin film circuits can best be determined by those most familiar with the product design. Consequently, the parameters, techniques and procedures of thin film resistive and capacitive circuit design are presented here as a guide to product, design and development engineers in making an initial evaluation as to the potential value of thin films in their areas.

## Parameters

Ohms per square (symbolically $\Omega/\square$) is a term commonly used when discussing and designing thin film resistors. Ohms per square is the dimension of sheet resistance and is derived from the basic formula for resistance based on uniform current flow. (See Fig. 1.)

$$R = \frac{\rho l}{A} = \frac{\rho l}{tw} \tag{1}$$

where $R$ = resistance, in ohms
$\rho$ = specific resistivity, in ohm-inches
$l$ = length of resistive path, in inches
$A$ = cross sectional area of resistive path, in square inches
$w$ = width of resistive path, in inches
$t$ = thickness of resistive path, in inches

When the length of the resistive path equals the width of the path the top area is a square and the resistance of the square becomes

$$R = \frac{\rho}{t} \text{ (in ohms per square)}$$

or

$$\Omega/\square = \frac{\rho}{t} \tag{2}$$

Thus the resistance value can be calculated by multiplying the sheet resistance by the number of squares.

$$R = (\Omega/\square)\,\frac{l}{w} \tag{3}$$

The design value of the ohms per square for a particular resistor design is dependent upon the power

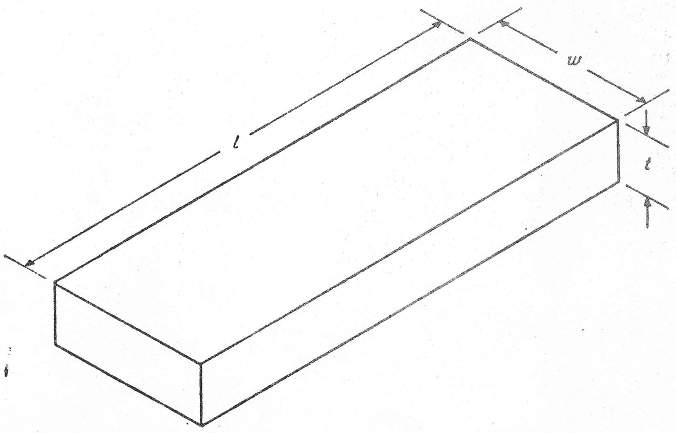


Fig. 1—Bar resistor of uniform cross section.

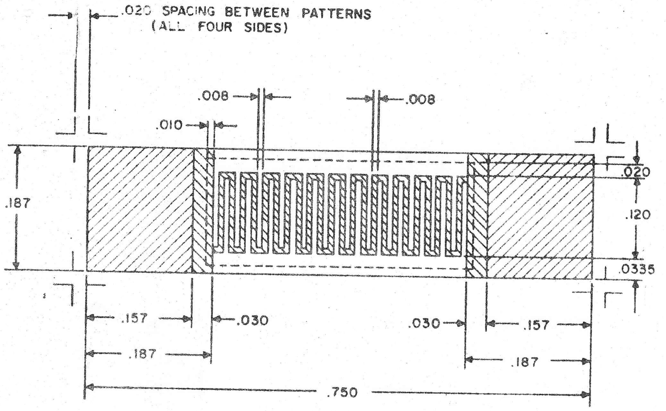


**Fig. 2**—Standard resistor pattern which may be used to evaluate different film depositions.

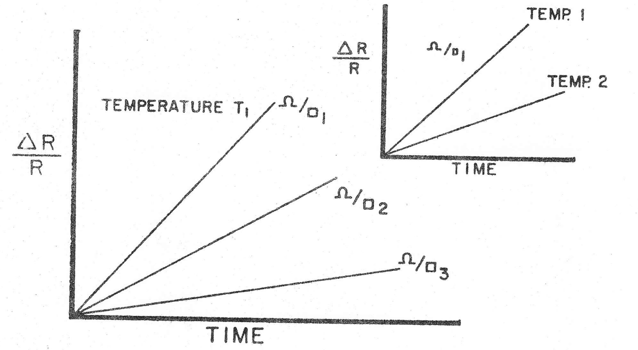


**Fig. 3**—Stability vs. Time for different sheet resistivities and temperatures.

dissipation, stability performance and resistance value.

### Bar Type Resistors

There are two basic requirements to meet in designing thin film resistors. First, the length and width must be in correct relationship for a particular sheet resistance to yield the desired resistance value. Second, the surface area of the resistor must be sufficient to dissipate the heat generated in circuit operation at a temperature which will insure resistance stability.

As an example of the first requirement, assume $R = 500$ ohms and $\Omega/\square = 50$. From Eq. (3):

$$l = 10\,w$$

As long as the length to width relationship remains 10:1 the resistance will be 500 ohms.

In determining the area of the resistor required for power dissipation consider the relationship:

$$\phi = \frac{P}{A} = \frac{E^2/R}{l\,w} \tag{4}$$

where $\phi$ = power rating, in watts per square inch
$P$ = dissipated power, in watts
$A$ = area of the resistor, in square inches
$E$ = voltage drop across the resistor, in volts

In relating Eq. (3) and (4) one finds:

$$w = \frac{E}{R}\sqrt{\frac{\Omega/\square}{\phi}} \tag{5}$$

$$l = E\,\frac{1}{\sqrt{\phi\,(\Omega/\square)}} \tag{6}$$

or the minimum width and length required to meet the design value of resistance. The $E$ and $R$ terms of equations (5) and (6) are established by the circuit requirements. The values to use for $\Omega/\square$ and $\phi$, however, can be many and the choice of the correct ones can sometimes be difficult. The ideal thin film circuit is one where the resistor area is as small as possible while still keeping the film temperature at a value which will meet the stability requirements. Any resistor which is not operating at this maximum allowable temperature could be reduced in size and along with it the overall circuit area as well. The temperature of the film is the important factor of the film resistor as it is directly related to the stability or $\Delta R/R$ relationship of the material.

The first step in choosing the correct $\Omega/\square$ and $\phi$ is to establish the relationship between them and temperature and stability. This will then allow the thin film circuit designer to choose the values of $\Omega/\square$ and $\phi$ which will result in the most practical and economical thin film package.

The ohms per square is determined by both the specific resistivity and the thickness of the film as shown in Eq. (2). If the value of $\rho$ is held constant for a particular film material, different ohms per square can be achieved by simply varying the thickness of the deposition. Generally, a standard resistor pattern, such as the one shown in Fig. 2, is used to evaluate the different film depositions.

The $\Delta R/R$ and temperature relationships with $\Omega/\square$ can easily be determined either by placing the thin film resistor samples under accelerated life conditions and measuring $\Delta R/R$ and the hot spot temperatures or by placing the thin film samples in a temperature controlled atmosphere, such as an oven, and performing the same measurements. In either case, a relationship is established between $\Delta R/R$, temperature and $\Omega/\square$ as shown in Fig. 3. Once these relationships are established, if a particular $\Delta R/R$ is desired the circuit designer can simply choose the value of $\Omega/\square$ which will meet the stability requirements and also produce the smallest area component. High values of ohms per square are preferred for high value resistors, and low value resistors are more economically manufactured if the $\Omega/\square$ is low. One thing to note is that generally the thicker the film, the more stable it will be. This is quite convenient since low ohms per square resistors (i.e., large thicknesses) generally have high power requirements while the high value resistors, where high values of ohms per square are preferred, usually have low power requirements.

If the specific resistivity of the film can be varied, as is done with tantalum film when different amounts of nitrogen are used during the sputtering operation, the relationship of $\triangle R/R$ to temperature can be extended to various ohms per square as the specific resistivity, $\rho$, is varied, as well as thickness, $t$. Although this evaluation can become quite involved, it is necessary if the best design criteria are to be established. Usually after all the data is collected only a few values of ohms per square are chosen as the design value for all circuits. Those chosen usually meet the large majority of circuit requirements. In the Bell System an ohms per square value of 50 is the most popular choice. Other values however, are used when the situation demands it.

The value of $\phi$ to be used can readily be calculated for the standard resistor pattern by using the data gathered to establish the ohms per square relationships. By calculating the power applied to the resistors in the accelerated aging investigations and measuring the surface area of the films, the watts per square inch can be calculated and related to $\triangle R/R$ and temperature and the film deposition. This is shown in Fig. 4. Thus when the thin film resistor designer is given the resistance value $R$, the potential across the component and the required $\triangle R/R$, he can choose the appropriate $\Omega/\square$ and $\phi$ and calculate the minimum width, $w$, and length, $l$, by using Eqs. (5) and (6).

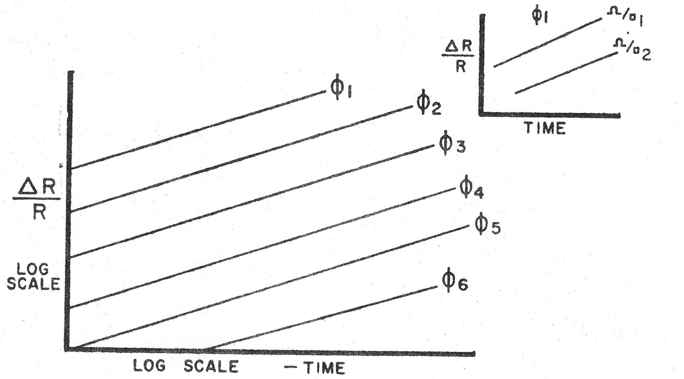


**Fig. 4—Stability vs. Time for different power ratings.**

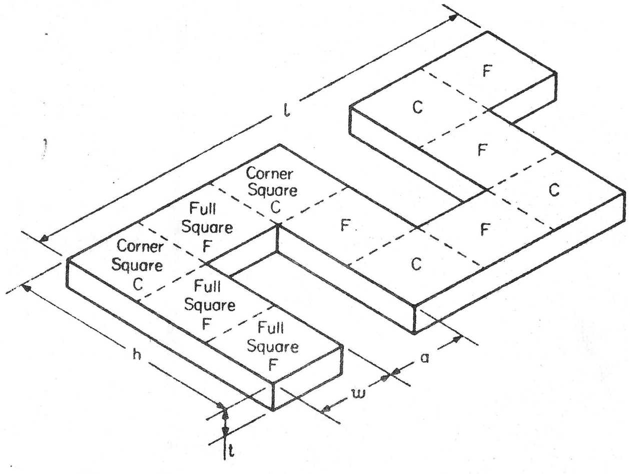


**Fig. 5—Zig-zag or meandering resistor.**

The power ratings, $\phi$, which are established by using the standard resistor pattern are generally used for all resistor patterns of the same deposition characteristics. Studies[1] show that these values are not constant but vary with many parameters such as resistor area, substrate area, the ratio of these areas, substrate thickness, resistor location and other factors. The manipulation required to account for these factors can become quite tedious and involved. Generally, they are not considered unless the design resulting from using the $\phi$ determined by the standard resistor pattern is not adequate for the application. In fact, most thin film designers assume $\phi$ to be constant for all film depositions unless the resultant design demands a closer scrutiny. The $\phi$ for tantalum deposited upon glass is 10 watts/in$^2$ while its value is 20 watts/in$^2$ when the film is on a ceramic substrate. These assumed constant values usually prove quite adequate for the designer and allow the fastest design in the minimum time.

Assuming a $\phi = 10$ watts/in$^2$ for glass and 20 watts/in$^2$ for ceramic and $\Omega/\square = 50$, Eqs. (5) and (6) become (expressed in mils):

$$\text{for glass:}\quad w = 2{,}240\,\frac{E}{R} \qquad (7)$$

$$l = 44.8\ E \qquad (8)$$

$$\text{for ceramic:}\quad w = 1{,}580\,\frac{E}{R} \qquad (9)$$

$$l = 31.6\ E \qquad (10)$$

From Eqs. (5) and (6) it is seen that the minimum width of the resistive path is dependent on the current $(E/R)$ through the resistor, while the length is dependent on the voltage drop across the resistor.

Of special significance is the fact that each resistor is designed for the particular application, or power *customized*. Customizing each resistor minimizes the surface area of each component and collectively, the size of the circuit.

### Zig-Zag Resistors

There is a practical limit to the straight bar-type resistor, a length which would no longer be considered miniaturization. For instance, with the design parameters previously discussed, a 10,000 ohm resistor could be as long as two inches; however, by folding the length back and forth, a more compact shape results. This folded shape, known as the zig-zag or meandering pattern, is shown in Fig. 5. As the resistance increases the number of folds increase.

Since in the initial investigation it would be very time consuming to draw in detail the exact resistor pattern, only the block area of the resistor is considered for preliminary designs. In Fig. 5, the block area

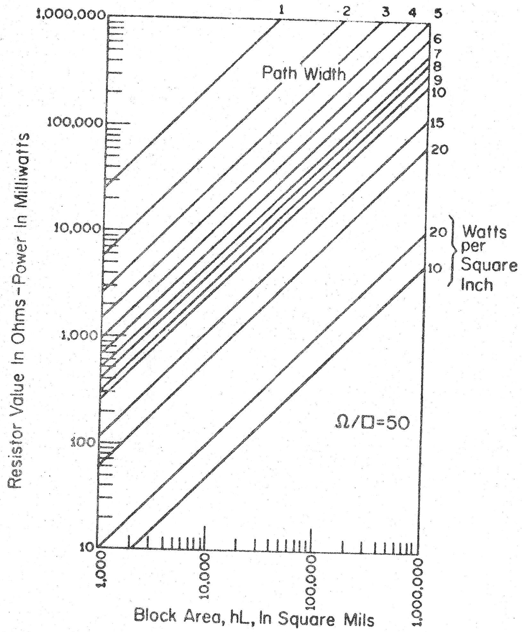


**Fig. 6—Nomograph for determining the block area and path width of a resistor when the resistance, power, and substrate power dissipation capacity are known.**

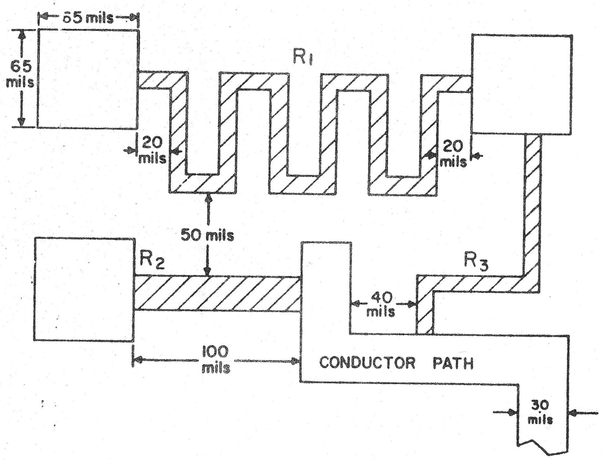


**Fig. 7—Minimum dimensional requirements for resistors.**

is defined by $h$ and $L$. The $w$ still references the width of the resistive path and $a$, the dimension between the zig-zags. The approximation describing the block area relationship is:

$$hL \cong (a + w)\ l \tag{11}$$

The values of $l$ and $w$ are determined from Eqs. (5) through (8) which define the length and width of an equivalent bar resistor. In most applications the spacing, $a$, is equal to the path width, $w$, and therefore the approximation (11) becomes:

$$hL \cong 2lw \tag{12}$$

In analyzing the equations (7) through (10) and (12) one finds that the area of the resistance path described in the zig-zag design is actually larger than the area of a bar resistor of width, $w$, and length, $l$. The degree of inaccuracy is dependent upon the $L$ to $h$ relationship of the block, and the spacing, $a$. This inaccuracy is counteracted by the fact that the ohms per square of a corner square (see Figure 5) is only 0.55 that of a square in a straight run$^2$. When a conductor path makes an abrupt change in direction, current and voltage distributions in the area of the change are non-uniform. Current flow, like low-velocity water flow, follows a partially streamlined path which may not conform to the apparent conductor path. As a result, a corner square of a conductor path has less resistance than an identical square in a straight run. Additional length of path is therefore required to achieve the design value of resistance.

A typical design problem requires a resistor of 15,000 ohms on a ceramic substrate. The voltage drop across the resistor is forty volts and the sheet resistance is fifty ohms per square.

From Eq. (9), $w = 4.2$ mils
From Eq. (10), $l = 1{,}264$ mils
From Eq. (12), $hl = 10{,}618$ square mils

From the area requirements, a combination of $h$ and $L$ (in mils) is selected to produce the shape best suited for the particular application, *e.g.*,

$h = 25$; $L = 424$
$h = 50$; $L = 212$
$h = 100$; $L = 106$, etc.

Equations (6) through (12) have been combined into a nomograph (see Fig. 6) for a sheet resistance of fifty ohms per square and $a$ equal to $w$. The nomograph is read in the following manner:

1. Calculate the power (in milliwatts) that the resistor must dissipate.
2. From that value of power on the ordinate of the nomograph go parallel to the abscissa to the correct watts per square inch line (ten for glass substrate; twenty for ceramic) and then perpendicular to the abscissa. The value at the intersection with the abscissa is the minimum substrate area which will dissipate the rated power.
3. The coordinate point of resistance value and minimum area establishes the width of the film path in accordance with the path width curves.

## Grouping of Resistors and Circuits on Substrate

Once all of the resistor block areas have been determined, the circuit can be laid out on the substrate. In making the layout there are two limitations to be considered in addition to the constraints imposed by the available product space: the thin film manufacturing process and the standard substrate size.

Operations in the manufacture of thin film circuits require that particular design dimensions be employed to ensure good process yield and high process rate of operation. The thin film circuit designer must keep in mind that circuits initially produced by the engineer under development conditions must eventually be made by factory workers at much higher rates and yields if the circuit is to be manufactured economically. Thus in the initial design, concern should be shown towards mass production techniques.

The dimensional requirements will vary depending upon the types of material used and the techniques employed to manufacture the circuit. While the dimensions presented in Fig. 7 are for tantalum film components, they do not in any way imply that these are the minimum ones for economic circuits. These minimum dimensions change as manufacturing technology improves and hence it is difficult to give values which won't become obsolete at the time of publication. In addition, other factors may determine the minimal dimensions to use. For example, if miniaturization is the prime goal, the dimensions may be tightened up even though the resulting circuit may be a bit more expensive to produce. Each manufacturer of thin film circuits should establish his own minimum dimensions depending upon his own needs and the needs of the particular circuit.

If the resistors are to be adjusted to value anodically (as are tantalum resistors), the 50 mil dimensions shown in the figure allows both to be anodized at the same time but with individual control and with no interaction. If, however, the two resistors are not interconnected in any way, they may be anodically adjusted together in the same anodization solution without interference. Thus the 50 mil dimensions can be reduced and in fact the resistors can even be interwoven as shown in Fig. 8 without any ill effects at anodization.

The 100 mil dimension for the minimum length of resistor, while aiding in mass anodization, can be a hindrance for low value resistors. Consider, for example, a 10 ohm resistor with an ohms per square value of 50. Using Eq. (1) where $l$ is 100 mils, $w$ would be 500 mils. This is rather wide and consumes valuable area. A way to avoid this and still allow the 100 mil length is to deposit a material with high conductivity over the resistor area but one which will not hinder the anodization process. Such a material is aluminum. The net effect is shown in Fig. 9. Here the length of the resistor is still 100 mils but the effective length only 10. Thus the resulting width needed is only 50 mils and the overall area of the resistor is reduced.

### Circuit Dimensions

In order to reduce handling costs during manufacture, the small thin film circuits are frequently processed on substrates which contain more than one circuit. For example, the picking up of a substrate, whether it is 2 inches by 3 inches or 500 mils by 300 mils, costs basically the same. Thus, if the larger substrate contains 40 small circuits, the cost of handling for the operation per circuit is 1/40 of the cost for an individual small circuit substrate. A more detailed explanation of economy versus circuit size is contained in a paper by other Western Electric personnel.[3]

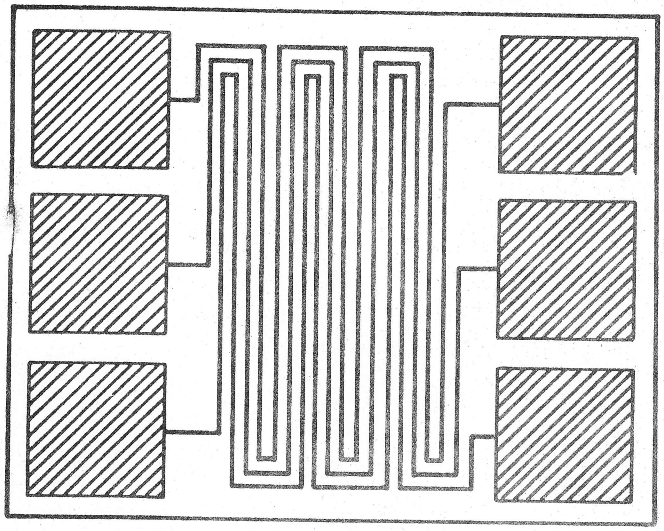


Fig. 8—Interwoven resistors.

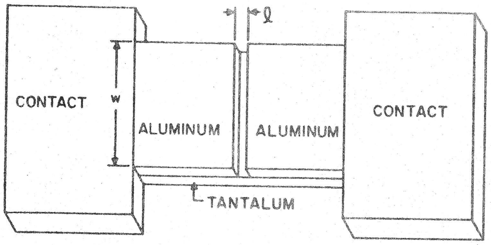


Fig. 9—Aluminum overlay.

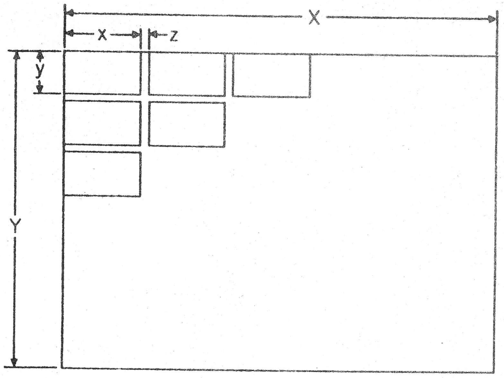


Fig. 10—Multiple circuits on large substrate.

Once the large substrate size is chosen, it is advantageous to know the allowable dimensions of circuits when different numbers of them are placed on the substrate. Figure 10 shows a large substrate where

$X$ = length of substrate in horizontal direction
$Y$ = length of substrate in vertical direction
$x$ = length of circuit in horizontal direction
$y$ = length of circuit in vertical direction
$z$ = spacing between circuits

| Number of Circuits for Dimension | Circuit Dimension In X Direction X (Mils) | Circuit Dimension In Y Direction Y (Mils) |
|---|---|---|
| 2 | 1990 | 1615 |
| 3 | 1320 | 1070 |
| 4 | 985 | 798 |
| 5 | 784 | 634 |
| 6 | 650 | 525 |
| 7 | 554 | 447 |
| 8 | 483 | 389 |
| 9 | 427 | 343 |
| 10 | 382 | 307 |
| 11 | 344 | 277 |
| 12 | 315 | 254 |
| 13 | 289 | 232 |

**Fig. 11—Chart for determining number of circuits which may be placed on a 3½" x 4" substrate when the circuit dimensions are known.**

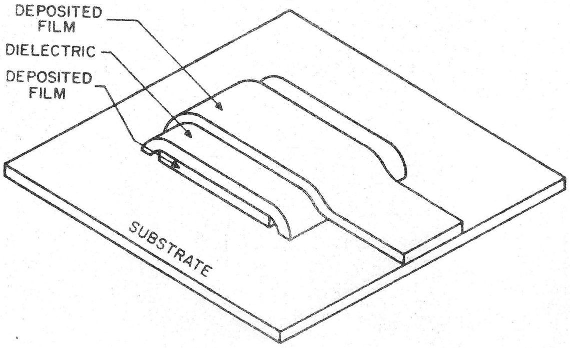


**Fig. 12—Capacitor structure.**

Equations are available which give the allowable dimensions.

$$N\,(x) + (N\text{-}1)\,z = X \tag{13}$$

$$N\,(y) + (N\text{-}1)\,z = Y \tag{14}$$

where $N$ = number of circuits in the direction.

For convenience of reference, the dimensions of circuits can be calculated for different numbers and grouped together on a chart.

**Example**

Assume

$$X = 4000 \text{ mils}$$
$$Y = 3250 \text{ mils}$$
$$z = 20 \text{ mils}$$

For six circuits in the $X$ direction, the $x$ dimension is:

$$6\,(x) + 5\,(20) = 4000$$
$$6\,x = 3900$$
$$x = 650 \text{ mils}$$

The chart in Fig. 11 is based on a substrate 4 inches by 3¼ inches. If the circuit designed has dimensions of 580 mils by 820 mils, the number of circuits possible is $6 \times 3 = 18$ or $5 \times 4 = 20$, depending on which way the small circuit is oriented on the large substrate. If the $5 \times 4$ orientation is chosen, the circuit dimensions could be increased to 634 mils by 985 mils with no decrease in the number of circuits per large processing substrate.

This chart can be used as a guide to produce the most economical circuit size.

### Thin Film Capacitor Design

The type of material of which the thin film capacitor is composed and the way in which it is formed will establish manufacturing procedures. Once these are chosen, the guide lines presented here, which are not for any particular film material, should aid the thin film circuit designer in including the thin film capacitor element in his circuits.

Figure 12 shows the basic structure of a thin film capacitor element. The thin film technology lends itself well to the parallel plated capacitor shown. The dielectric of the capacitor may be deposited or anodically formed (as is done in the tantalum material element). Regardless of how it is formed, the important items to the circuit designer are to establish the relationship expressed in the following equation:

$$C = \frac{KA}{t} \tag{15}$$

(where t = thickness of dielectric and A = area of the capacitor) and to consider breakdown voltage, working voltage, leakage currents, and other important capacitor parameters.

The procedure generally followed is to keep the $K$ constant, (*i.e.*, do not change the material which makes up the dielectric), keep the area $A$ constant, and vary the thickness $t$ of the dielectric material. The capacitor quality characteristics should be established for each thickness.

For each particular thickness, the area is held constant and a number of capacitors made until the capacitance value is determined. Once this is established, the value of $K$ can be calculated.

$$K = \frac{Ct}{A}$$

rial is of the same composition. In many cases, it is difficult to determine the value of $t$ accurately. Sometimes this value of $t$ is related to voltage, if the dielectric is anodically formed, or to the deposition rate, if formed in that manner. Even if the exact thickness is unknown a capacitor design procedure can be established. Consider for example a capacitor whose dielectric is formed anodically. If this is true, then:

$$t = K_1 V \tag{16}$$

Substituting this value of $t$ into Eq. (15), we obtain

$$C = \frac{KA}{K_1 V} = \frac{K'A}{V} \tag{17}$$

Now the $C$, $A$ and $V$ can be easily determined and the $K'$ thus established. As long as the same anodizing voltage is used this value of $K'$ should remain fairly constant. The parameters such as working voltage, leakage currents, etc. should also remain fairly constant for the single value of voltage, $V$. If another value of capacitor is desired other than the one used to establish $K'$, it can easily be obtained by using the simple relationship:

$$K' = \frac{CV}{A} = \frac{C_1 V}{A_1} \tag{18}$$

Since the voltage $V$ is the same,

$$\frac{C}{A} = \frac{C_1}{A_1}$$

or

$$A_1 = \frac{C_1 A}{C} \tag{19}$$

Knowing $A$ and $C$ from the sample component and knowing the value of capacitance $C_1$ required, the new value of area $A_1$ can easily be determined. This relationship can be predetermined and the design curves of Fig. 13 used. In the figure, the design lines are shown for various thicknesses or voltages. The circuit designer should first determine the requirements of his capacitor, such as working voltage, and then pick out the dielectric thickness which will give him the smallest capacitor and still meet these requirements.

The tolerances of thin film capacitors are usually established by the variances produced by etching or forming the capacitor area, the thickness of the dielectric, the placing of the counterelectrode on top of the dielectric material and the dielectric constant. Studies must be made to establish these variances so that the thin film circuit designer is aware of the limitations.

Minimum dimensional requirements are also necessary for economical manufacture of thin film capacitors. Just as it is difficult to establish dimensions which do not become obsolete for resistor designs, the same is true for capacitors. Figure 14 shows the dimensions for one capacitor process but again it must be remembered that these vary with the type of capacitor produced. It is important, however, that the limitations are established so that the designer can fit the capacitor element into the circuit design most economically.

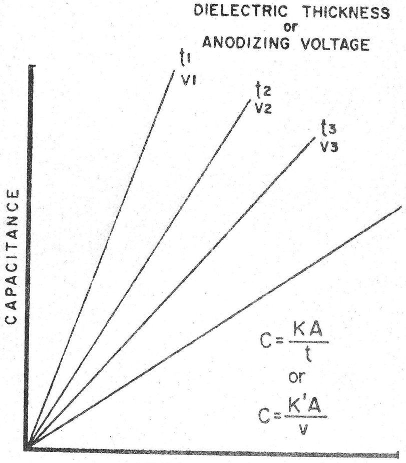


Fig. 13—Capacitor design curves.

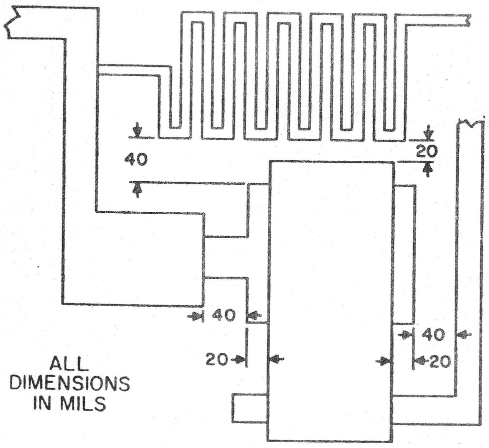


Fig. 14—Minimum dimensional requirements for capacitors.

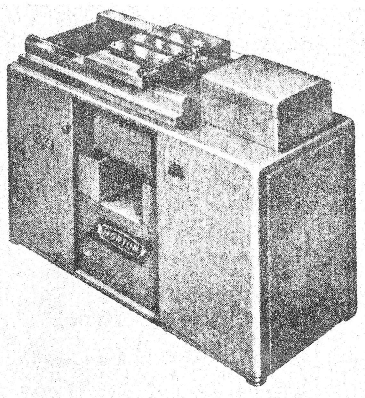
## Conductors

The conductors which are used to interconnect the thin film elements and provide termination bonds for external leads or non-thin-film components are generally deposited by the evaporation technique. The materials used may vary as long as they meet the requirements of adherence, high conductivity and high resistance to oxidation and can be bonded or soldered to easily. The width of the conductor paths should be kept as small as possible so that valuable area is not taken up by them. Of course, capacitance effects of the conductors must be considered for particular applications.

## Conclusion

The restrictions and guidelines presented in this article should not be construed as the final measure of feasibility of any particular circuit design on thin film. Rather, they are given as a starting point to cover the general application of nitrided-tantalum thin film to components and circuits. Certainly advances in thin film technology will change much of

*(continued on page 64)*



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the design data. In addition, other values of sheet resistance or substrate materials may better fit particular design requirements. Because of the possible advances in the state of the art or production alternatives, further investigation is necessary before a final "yes-no" decision should be made for any particular application.

### REFERENCES

1. John R. Peek, "Reduce Thin Film Circuit Size," *Electronic Design,* Vol. 14, No. 24, October 25, 1966.
2. R. J. Dow, "The Conjugate Function Approach for Describing Current Density and Resistance in Odd Shape Conductors," *Proceedings of the 1962 Electronic Components Conference,* May 1962, pp. 47-52.
3. E. F. Steiner and J. F. Paulsen, "Economic Substrate Size for Ceramic Thin Film Circuits," American Ceramic Society Conference—Electronics Division, Los Angeles, California, October 28, 1965.

### Marketing/Distribution

Lindberg Hevi-Duty Division, Sola Basic Industries, Chicago, will market a line of laminar air flow booths specifically designed and built for the Division by Dexon, Inc., Minneapolis. The recently-reached sales agreement is the latest step in a program designed to broaden Sola Basic's services to the growing semiconductor industry. Dexon-built booths accommodate tube-weight center lines of Lindberg Hevi-Duty's new Diffusitron Mark IV series of diffusion furnaces and those of earlier Mark II and Mark III models. Laminar air-flow stations provide a controlled atmosphere for handling diffused devices.

Amperex Electronic Corp., Hicksville, N.Y., has developed a Franchised Distributor Program for the sale of Printed Circuit Assemblies to OEM accounts. A recommended inventory, based upon the needs of individual trading areas, has been drawn up for participating distributors. The introduction of the line has already resulted in the appointment of 5 franchised distributors. Continuing response to the program indicates widespread approval and it is expected that at least 25 distributors will be franchised within the next few months.

### Acquisitions

HITCO, Gardena, Cal., has acquired, for an undisclosed sum of cash, InterKem Systems Corp., Costa Mesa, Cal., developers of Tubelets, a new electroformed feed-thru tubular type connection device for electronic circuitry.

The Thomas & Betts Co., Elizabeth, N.J. has recently acquired the Flexible Circuitry Division of Garlock Inc., Cherry Hill, N.J. This facility has been added to the Arthur Ansley Mfg. Co., New Hope, Pa., a wholly owned subsidiary of Thomas & Betts Co. Ansley is now able to produce printed flexible circuitry which employs unique developments to utilize Teflon, Kapton, Mylar and Epoxy film as substrate material.

Taylor Corporation, Valley Forge, Pa., and Small Fibre Stampings, Ltd., Scarborough, Ontario, have signed an agreement for Taylor to acquire 50% of the stock of Small Fibre Stampings for an undisclosed amount. Taylor manufactures laminated plastics and vulcanized fibre and fabricates parts from these materials. Small Fibre Stampings manufactures stamped, sheared and formed parts from a wide variety of electrical insulating materials.

Aerovox Corporation has acquired Microcircuits Inc., Canoga Park, Cal., manufacturers of thick film hybrid integrated circuits. The facility will be operated as a wholly-owned subsidiary.

Silicon Transistor Corp., Garden City, N.Y., has completed the acquisition of KSC Semiconductor Corp., West Newton, Mass. The acquisition of KSC, and that of M.S. Transistor Corporation, Elmhurst, L.I., several months ago, gives the company a broad line of special purpose high performance semiconductor devices.

Amperex Electronic Corporation, Hicksville, L.I., N.Y., has acquired a majority interest in Science Accessories Corp., Southport, Conn. The stock acquisition included the minority interest previously held by Ortec. Initiated as a specialized scientific activity in the area of high energy physics, Science Accessories Corp. is presently marketing spark chamber systems and sophisticated components and assemblies for high energy physics applications.

### Financial

Sales of Mallinckrodt Chemical Works for 1966 were $58,964,000, an increase of 20% over last year's $49,191,000. Net income climbed to $3,161,000, or a 39% gain from $2,268,000 for 1965.

Sola Basic Industries reported earnings up 45% on 35% higher sales for the 2nd quarter of the current fiscal year. For the first 6 months, net income was up 58% to $1,728,856, or $1.17 per share, compared with net income in the 1st half of the prior fiscal year of $1,096,441, or 74¢ per share. Sales for the current first half were $40,299,399, a 36% increase over sales of $29,626,250 in the first 6 months of the prior year.

BTU Engineering Corporation announces the increase of its quarterly dividend payment from 6 to 7¢ per share on the outstanding Common Stock of the Corporation in view of rising sales and profits. Sales and earnings for the 9 months ended February 28, 1967 were $2,297,300 and $283,600 respectively compared with sales of $2,150,000 and earnings of $257,300 for the same period of the previous year.

On many occasions, the power requirements, of large values of resistance, are small. The value of w calculated by equation (5) may be much smaller than is possible to economically produce. When this occurs, the minimum practical value of w is then chosen. The area hL can easily be calculated by referring to equation (3) which states:

$$R = (\text{ohms per square}) \times (\text{number of squares}) \qquad (3)$$

The number of squares of a zig-zag resistor can roughly be calculated by referring to Figure (5) and using the relationship:

$$\text{number of squares} = \frac{\text{area of film}}{\text{area of square}} = \frac{1/2\ hL}{w^2}$$

Therefore (3) becomes:

$$R = \frac{\Omega/\square \quad hL}{2w^2}$$

or

$$hL = \frac{2w^2R}{\Omega/\square}$$

This equation proves quite adequate for predicting the necessary area required for the zig-zag or meandering resistor. It does assume $w = a$.