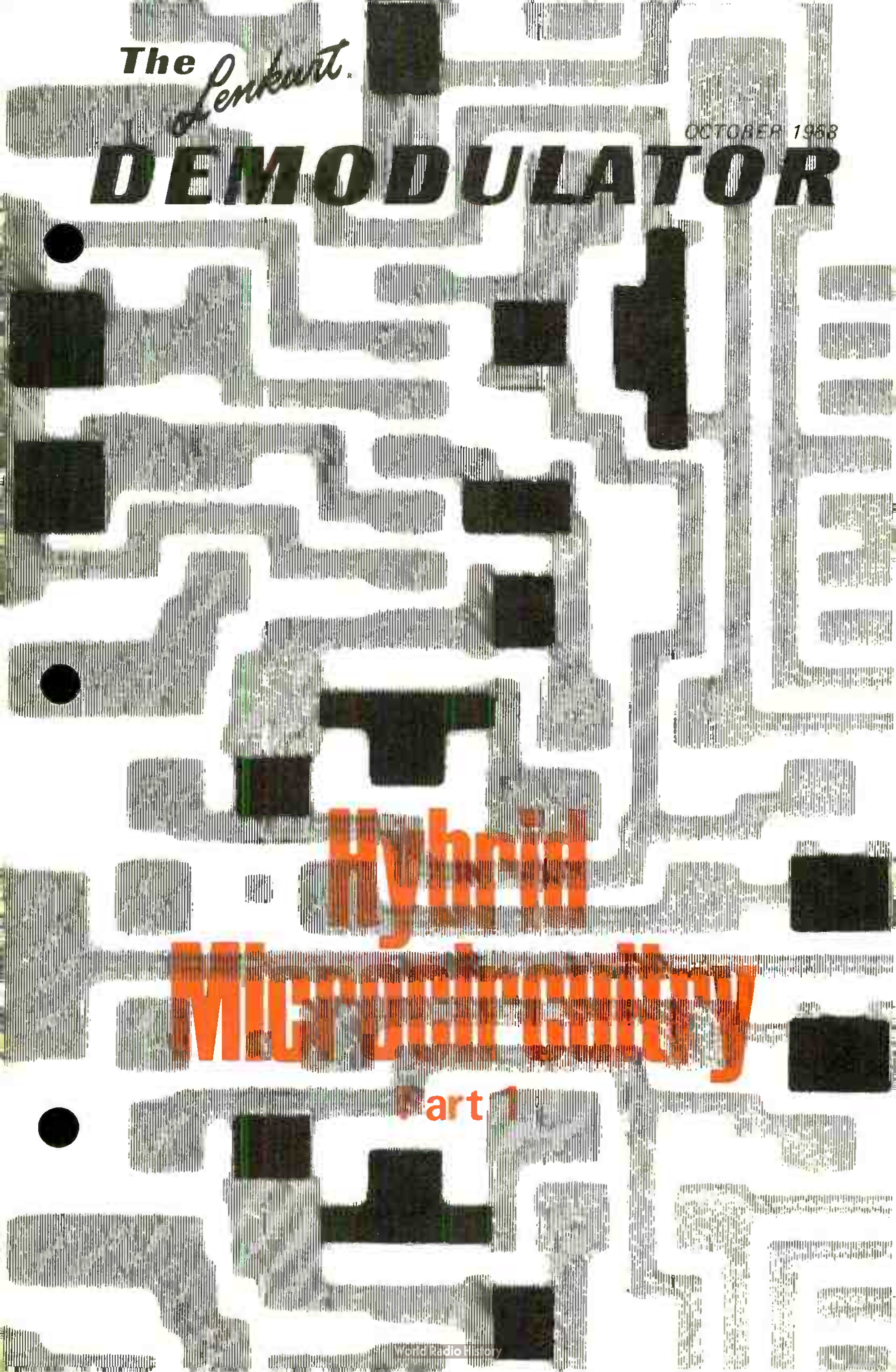
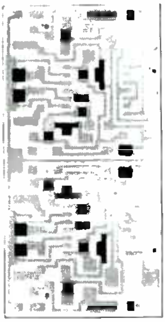


The Lenkurt DEMODULATOR

OCTOBER 1968

Hybrid Microcircuitry

Part 1



Thick film, a modern application of an ancient art form

Since the advent of the transistor, the dominant trend in electronics has been toward more and more miniaturization. The advantages of microelectronics go beyond simple space saving, although size itself is certainly a considerable factor. Experience has shown that solid-state microcircuitry provides higher reliability, reduces problems of heat dissipation and readily lends itself to mass production. Thin and thick films, multi-layer printed circuits, integrated circuits – monolithic, medium, and large scale – are some examples of the relatively new technology of microelectronics.

In keeping with this trend, Lenkurt has been involved for some time with thick film process development as part of a general microelectronics program. Thick films were chosen for their wide range adaptability and relatively low initial expense. Also, thick film technology provides a springboard for ventures into other areas of microelectronics.

Thick -vs- Thin

Thick film is a microelectronic technique where the passive components of an electrical circuit such as conductors, resistors and capacitors are miniaturized by deposition onto a small piece of ceramic material. For general purposes, these circuits may be defined as passive thick film integrated circuits. They differ from thin films both in the thickness of the films themselves and in the method of deposition. Where deposition of thin films is done by sputtering or chemical evaporation in a vacuum chamber, thick films are deposited on ceramic substrates by a screening process using special resistive and conductive inks.

The actual process is simply a modification of the ancient methods used by potters and ceramists to decorate porcelain and clay. Using these methods, all of a circuit's passive components can be miniaturized to fit a small substrate. A substrate, in this case, is the small piece of white "china" on which a thick film circuit is deposited.

Ceramic substrates for the thick film process are typically 96% alumina and 4% glass; their dimensions range from less than one to several inches square and average about 0.025 inches in thickness, depending upon the circuit design. Recently, a beryllia substrate has also been used with considerable success.

Process flow in thick film fabrication is actually a series of interdependent – yet different – processes. First, the design of the circuit is laid out as original artwork on a precision drafting machine. The artwork is then reduced photographically and a silk screen replica of the circuit is made. Passive components such as conductors, resistors and capacitors are applied to a substrate which is then fired in a furnace. After the firing cycle, the resistive and conductive values are tested and adjusted. Finally, compatible discrete active components – transistors, diodes, IC's, – can be

Figure 1. A precision drafting machine such as a coordinatograph is a "must" for development of microcircuitry. Note the digital light display in the background.

attached, transforming the passive circuit into a hybrid thick film circuit. The entire circuit is then packaged for use in a system.

Original Artwork

When a design request is received, the first requirement is to lay out a large working model of the circuit. Design requests normally contain all the necessary engineering data. The artwork is done on acetate or other translucent, stable drafting film using an electronic precision drafting machine called a coordinatograph (Fig. 1). The coordinatograph is accurate to 0.001 inch; movement in the x and y axes is registered electronically with coordinates appearing on a digital light display.

After the original artwork is completed, the acetate masters go to the photo lab for photographic reduction. Using a specially built camera with height adjustable over six feet, the circuit layout is reduced in size by a factor of up to ten. One effect of reduction is to increase accuracy of the design by the same factor – hence, tolerances of 0.0001 inch.

Once the film is developed, the resultant negative (or a positive) is used to make a silk screen stencil of the circuit. The stencil film itself is a photosensitive gelatin composition backed with a very thin sheet of polyester.

After applying the negative to the gelatin film, they are put in the plate making machine and exposed over a mercury vapor lamp. Due to the comparatively slow warm-up time of the lamp, exposure is measured in light units (lumens) rather than in time.

Exposure hardens that portion of the gelatin not protected by the circuit pattern on the negative. The negative and stencil film are separated and the unexposed gelatin is rinsed away. Having been hardened by exposure, the circuit pattern resists removal by 110° water used for rinsing (Fig. 2).

After rinsing, the remaining pattern is further hardened under cold water, and the stencil is ready for mounting on a screen. The screens used in the thick film process are not actually silk screens but are made from fine stainless steel wires. The mesh, or wires per inch of screen area, range from 105 to 325 depending on film thickness and pattern accuracy requirements.

Using a transparent alignment mask to aid in centering, the stencil film is mounted wet on the screen. Extreme care must be taken at this stage to avoid accidents which later might ruin the registration of the pattern on the substrate. Since the pattern is so small, it is conceivable that some of its elements might not adhere properly and turn or even fall partly through the mesh of the screen.

When the stencil film has been fixed to the screen, excess water is blotted off – but some is left so as to allow capillary action to draw the film even more firmly onto the screen.

Final drying of the screen is best done naturally at room temperature. Since this normally takes several hours, attempts have been made to speed up the process with forced warm air. But this often results in a too brittle film and increases the danger of losing some of the finer parts of the circuit pattern.

A different screen must be made for each different pattern – conductive, resistor or final glaze – which is to be applied to a substrate.

How Clean is Clean?

From drafting room to final packaging, all of the work involved in the thick film process must be done in a strictly controlled environment. Since any of the processes involved can be adversely affected by dust, pollen, fibers or even fingerprints, extensive efforts are made to maintain a clean atmosphere. All rooms are air-conditioned. Dust and other foreign matter are filtered from the air, smoking is not allowed and technicians wear lab smocks and silk gloves while working. In this respect a thick film lab resembles a hospital operating room.

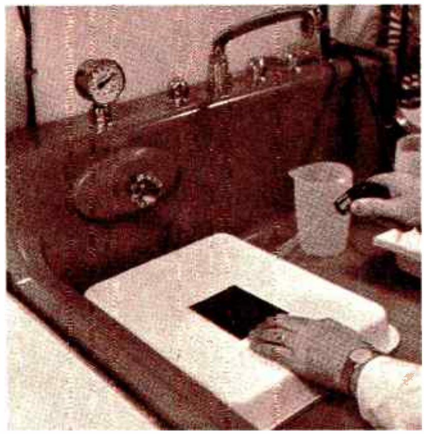


Figure 2. The resistor pattern can be seen emerging from the stencil film as the unexposed area is rinsed away. Using the temperature blender in the background, a steady water temperature of 110° is maintained.

The finished product begins to take shape when the conductor, resistor and glaze patterns are screened onto the substrates and the elements are fired in a conveyor furnace. Circuit patterns are applied to the substrate by a silk screen process using precious inks. The inks are actually slurries of noble metals suspended in a highly viscous paste. The metals may be gold, platinum, palladium, silver, or an alloy of any of these. The paste is mostly an organic compound with an evaporative binder or catalyst added.

Because of their nature and expense ($1.29 to $6.40 per *gram*), the slurries – or inks – require special handling. Their containers are stored on a rack of slowly rotating rollers. The continual rolling action keeps the inks ready for use. Constant agitation keeps the metal particles in suspension rather than collecting in the bottom of the jar.

Deposition

Called simply a screener, the apparatus for applying the circuit patterns to substrates consists of a vacuum chuck for holding the substrate securely, a micrometer-adjustable mount for the screen itself, and an adjustable squeegee which pushes ink through the pattern of the screen. The squeegee blade is usually polyurethane of a specific hardness. Adjustments are in all three directions to ensure perfect interaction between squeegee, screen, and substrate. The distance between screen and substrate is called the "snap-off".

Substrate, screen, and squeegee must be perfectly parallel and the squeegee's motion steady and horizontal or the thickness of the deposited ink will vary. Since the electrical values are a function of the ink's volume, varying thickness will cause inconsistencies in resistance and conductance.

Ink is spread onto the screen around the circuit pattern with a small spatula, and the squeegee is moved across the screen. This action forces the ink through the screen onto the substrate and prints the desired pattern.

Normally, several test runs are required before alignment of all the various parts is perfect. All of the ink used for testing and alignment is kept and returned to the supplier for reclamation. Used screens and substrates used in test screenings are washed in acetone, or thinner. This rinse along with other used ink, is returned to the ink manufacturer for credit.

After testing and final adjustments, any number of substrates may be screened as long as the screen itself holds up and is not "coined" or otherwise damaged. "Coining" results when screen and substrate are too close and the screen's wires are bent leaving an impression of the substrate.

Alignment of screen and substrates for subsequent screenings is done by using small registration marks on the screen. They line up precisely with other similar points left on the substrate by previous screens.

Drying and Firing

Firing is done in a cycle. The sequence is tied directly to the temper-

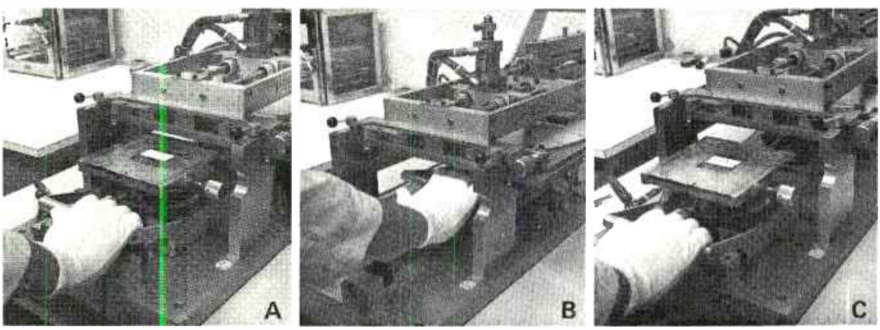


Figure 3. There are three steps in depositing the resistor pattern: (A) substrate is fitted to the vacuum check, (B) the substrate passes under the screen and the squeegee forces the ink through the screen and onto the substrate, and (C) the chuck is withdrawn with the pattern deposited on the substrate.

Figure 4. Using airbrasive powder for trimming resistors, the trimmer works in conjunction with an electrical bridge. The bridge measures resistance and enables the technician to trim resistors to within 0.1% of desired value.

ature profiles of the various component values of the circuit. Since resistance is inversely proportional to firing temperatures, components requiring higher firing temperatures are deposited and fired first. These will often be the conductor patterns. However, one or two resistor screenings are sometimes made before the conductor screening. This is done in special cases where resistor inks of very precious metals are used and higher firing temperatures are required.

The normal deposition sequence is; screening, settling, drying and firing. Immediately after screening, the substrates are set aside so that the ink can settle. Settling fills the voids and impressions left in the ink by the screen.

Drying is accomplished by leaving the freshly screened substrates in a temperature-controlled oven at 125° for about 15 minutes. The primary purpose of drying is to drive out the binder from the ink.

Firing temperature profiles vary (from 500° to 1050°C) according to desired electrical values. These values in thick films are a function of two factors, the volume of ink and the temperature at which they are fired. Since the resistance is inversely proportional to the ink's volume it can be increased by airbrasive trimming but never decreased. Consequently, resistor ink is likely to be applied some-

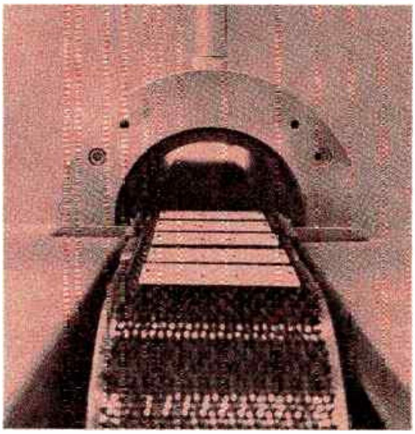


Figure 5. The conveyor type furnace can produce firing temperatures up to 1500°C.

what thickly. The term, airbrasive, derives from air-driven abrasive powder.

In some cases where more than one of a circuit's elements require the same firing temperature, resistor and conductor patterns will be screened and dried without individual firing. Then, after all the elements are deposited, the entire circuit can be fired.

Resistors and Capacitors

Typical sheet resistivities in thick film resistors range from 1 ohm/sq. to 1 megohm/sq. with thickness normally set a 1 mil. The formula for sheet resistivity is:

$$R = kt\frac{l}{w}$$

Where:

- *R equals sheet resistivity.*
- *k equals the resistivity constant of the ink.*
- *l equals length of the resistor pattern.*
- *w equals width of the resistor pattern.*
- *t equals thickness (assumed to be constant).*

From this formula, it can be seen that resistance in thick films is a function of the shape of a resistor. When length is increased in relation to width, resistance value is proportionately increased.

After firing, the distribution of values for any particular resistor pattern is normally ±10%. By firing resistors to only about 90% of the desired value, careful trimming can then increase accuracy to ±1%. Lenkurt engineers consistently produce thick film resistors with such value tolerances.

Though done somewhat less often, capacitors may also be fired into a thick film circuit. Capacitor inks are usually composed of oxides such as titania or barium titanate and multicomponent glasses. Inherent limitations of the inks used for capacitors make high capacitance values extremely difficult to achieve. Capacitances up to 100,000 picofarads per square inch can be achieved, but in the lower ranges – 10,000 $pF/in.^2$ – capacitors are more stable and can successfully pass breakdown tests up to 500 volts. For values beyond these limits, or for special tolerance and stability requirements, it is necessary to attach discrete components or chips after the thick film process is completed.

Once all the passive components – conductors, resistors, and capacitors – are fired, the substrate is coated with a glaze and refired. If the device has been designed merely as a passive circuit, it is now ready for packaging. Final packaging is a simple process of dipping the substrate into some kind of epoxy-based plastic after the leads have been attached.

If it is an active circuit, the glazed substrate must be presoldered before active components can be attached. Presoldering leaves bumps of solder at the points where active component leads will be attached. Typical active components are transistors, diodes and IC's. After the active components have been attached and final tests made, the entire circuit is encapsulated and ready for use.

Editor's Note – The November Demodulator will discuss some of the applications and extensions of thick film technology, as well as some limitations.

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