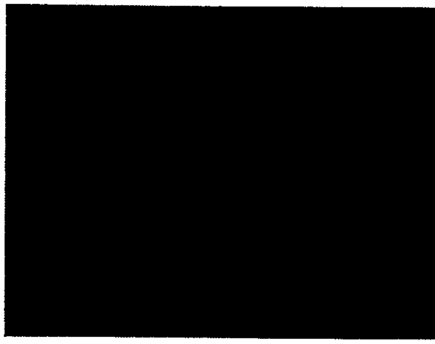
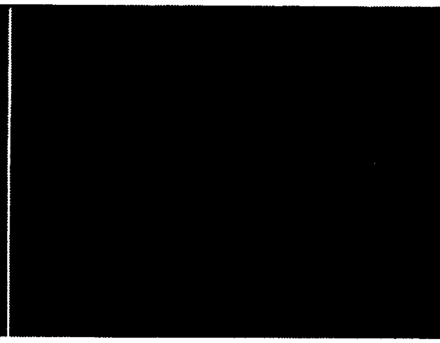
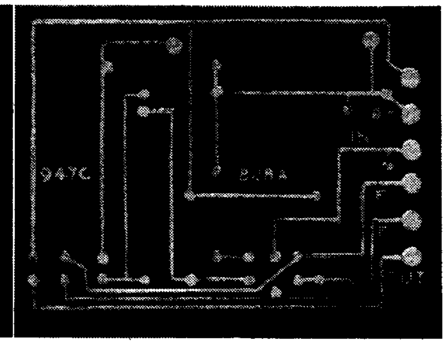


1 Copper-foil-coated phenolic chassis is starting point for auto-sembly of battery-powered audio amplifier



2 Conductor pattern is applied in acid-resistant ink by silk-screening or offset printing



3 Chassis after etching away unwanted metal in ferric chloride solution and removing resist

Auto-Sembly of Miniature

By S. F. DANKO and S. J. LANZALOTTI

Signal Corps Engineering Laboratories, Fort Monmouth, New Jersey

THE SYSTEM of miniature circuit assembly to be described was evolved as a result of several Signal Corps study programs, aimed at providing relief from the production, performance and maintenance problems attendant on highly compact sub-miniature equipment designs. The system designated as auto-sembly borrows the very convenient prefabricated conductor pattern of printed circuits, and permits rapid and effective electrical combination of this pattern with conventional quality components by a one-shot solder dip process. The elements of auto-sembly are: (1) Formation of the conductor pattern; (2) selection of components; (3) rapid assembly; (4) packaging.

Of the many techniques of metallization extant today, the etching of copper-faced laminates (electrolytic copper foil bonded to an insulating base) provides one of the most convenient means of pattern fabrication. In this subtractive process, a resist image of the desired conductor pattern is printed or otherwise delineated on the copper foil surface and the laminate then exposed to an etchant. The resist material protects the metal against the action of the etchant during the short etching period. The Signal Corps Laboratories demonstrated early in 1949, in collaboration with the Etched Products Corp. of Long Island, that the commercial offset presses of the etched nameplate industry could be readily adapted to the deposition of such resists on commercially available foil laminates for subsequent etching.

The photo-etch technique of the graphic arts industry was equally well adapted to such resist fabrications, particularly where higher orders of definitions or reproducibility were desired. Several other metallizing techniques, including the Mallory pressed powder technique and the Franklin Air-Loop stamping process, are also compat-

Mobilization Advantages

SAVES LABOR by eliminating manual wiring, which ordinarily requires more man-hours than any other step in electronic equipment manufacture

MINIMIZES REJECTS because etched wiring is absolutely uniform from chassis to chassis

ELIMINATES UNSOLDERED JOINTS because all joints are made simultaneously in one solder-dip operation

REDUCES INSPECTION TIME because mechanization reduces probability of errors practically to zero

SPEEDS ASSEMBLY TIME because leads of components are simply pushed into holes, with no hook or wrap-around joints

PERMITS GREATER MINIATURIZATION, because etched wiring takes practically no space and lends itself to stacking of chassis layers

IMPROVES RELIABILITY, because auto-sembly practically eliminates short-circuits between connections and leads

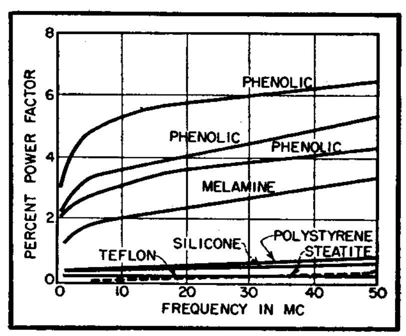
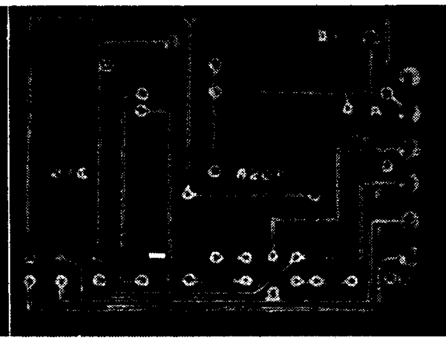
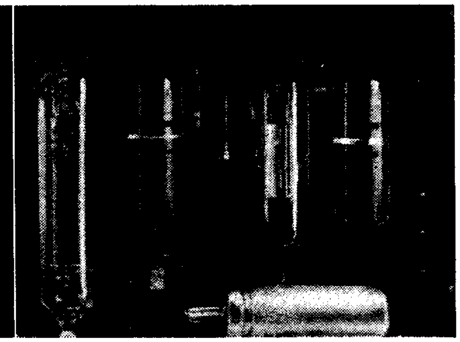


FIG. 1—Variation of power factor with frequency for some of the double-faced laminates used in auto-sembly. Note variations in phenolics from three different suppliers. Melamine, polystyrene, silicone and Teflon materials are glass-fabric or glass-mat loaded

4 Next step is punching or drilling of holes through which leads of components are inserted from rear



5 Underside of chassis after components are mounted and assembled by one-shot solder dip



6 Top of completed chassis, showing layout of tubes and components, with plug-in terminals at right

Military Equipment

Production of wiring by acid etching of copper-faced insulating laminates permits rapid assembly of high-quality conventional JAN components by inserting leads in punched holes, then immersing chassis surface in molten solder to make all joints simultaneously

ible with the auto-sembly system since they yield high-conductivity patterns which are amenable to component assembly by solder dipping.

It is the intention of this presentation to emphasize the etched-foil technique of preparing a conductor pattern, inasmuch as this process lends itself excellently to pattern fabrication by the laboratory designer for prototype model constructions. The choice of a process for forming the pattern for production depends on such factors as the detail required in the pattern, quantities involved, tooling costs, production rate and delivery time.

Laminates

The physical characteristics of the commercially available copper-faced laminates which are of prime interest for auto-sembly include bond strength of the foil to the laminate, compatibility of this bond with the temperature shock conditions which it will experience during solder dipping, dielectric constant, power factor, arc resistance and moisture absorption. Table I lists in a general way some of this physical data for comparison purposes, and Fig. 1 shows the relation of losses to frequency for several of these laminates. It should be noted that these loss curves apply where the base material is used as the total dielectric, between metallized faces on opposite sides of the material. In the usual application, where capacitances between adjacent lines are of concern, the losses are substantially lower than indicated since the dielectric is part air.

The laminates are also available with copper on both sides to permit fabrication of aligned patterns on both faces. Most common thicknesses of copper are 0.00135″, 0.003″ and 0.005″.

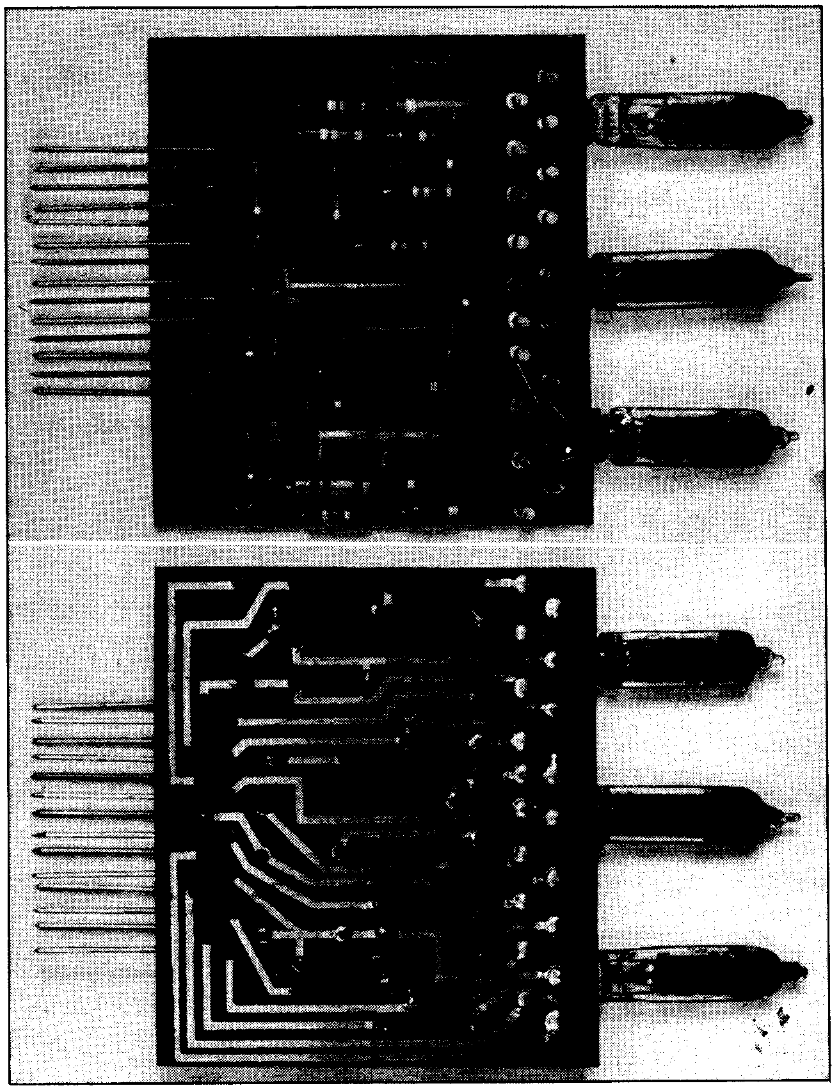
Resists

Within the design laboratory, screening of the resist is perhaps the simplest and most convenient method of printing the pattern prior to etching. The screens themselves may be prepared by any of

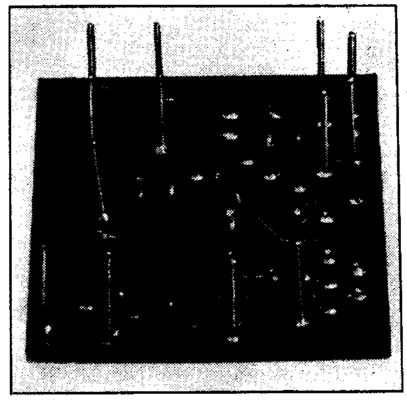
Table I—Characteristics of Copper-Faced Laminates

Laminate Chassis	Reported Bond Strengths* (lb)	App. Dielectric Constant	Power Factor at 1 mc	Moisture Absorption (24 hr)	Arc Resistance	Max. Operating Temp.
XXXP Phenolic	6–8	3.5–5.5	2.8 %	1.3 %	Poor	125°C
Melamine—Glass Fabric	7–9	6.8	1.3 %	2.0 %	V G	135°C
Silicone—Glass Fabric	2–8	—	0.35%	0.3 %	V G	200°C
Teflon—Glass Fabric	3–7	3.3	0.10%	0.3 %	V G	200°C
Polystyrene—Glass Mat	2–3	—	0.38%	0.55%	—	85°C
Polyester—Glass Fabric	(Under Development)				Fair	135°C

*Bond strengths are measured by pulling a scored one-inch copper strip vertically away from the laminate surface. The bond strengths vary among manufacturers but the values shown indicate the general range of values measured. (The bond strength of copper-phenolic is an exception, being representative of one manufacturer's item.)



Top and bottom views of auto-sembled chassis containing phase-shift oscillator, avc, and clipper-limiter circuits that serve as a unitized packaged plug-in assembly for a complex electronic fault locator. Embedment of chassis in casting resin will provide protection against moisture and give rigidity to plug-in terminals at left



Detailed view of solder-dipped pattern. Fillets at termination points are obtained by using a waxy flux. Long protruding leads go between components and into holes in next layer

the many commercial screening organizations or may be prepared within the laboratory without too much art or effort. For most general line work for conductors, a screen mesh of about 150 per inch is adequate.

Satisfactory resists for screening are many, but synthetic screening enamels available from the art supply houses have been particularly useful in this application. An example is the Synthetic Screen Enamel, series 1500, any color, obtainable from the Colonial Process Supply Co., New York City. Resists made by dissolving asphaltum in an appropriate vehicle are also convenient, but care must be taken to get the proper screening consistency. The synthetic enamel resists require approximately 8 hours to dry (overnight, or may be oven dried in a few hours).

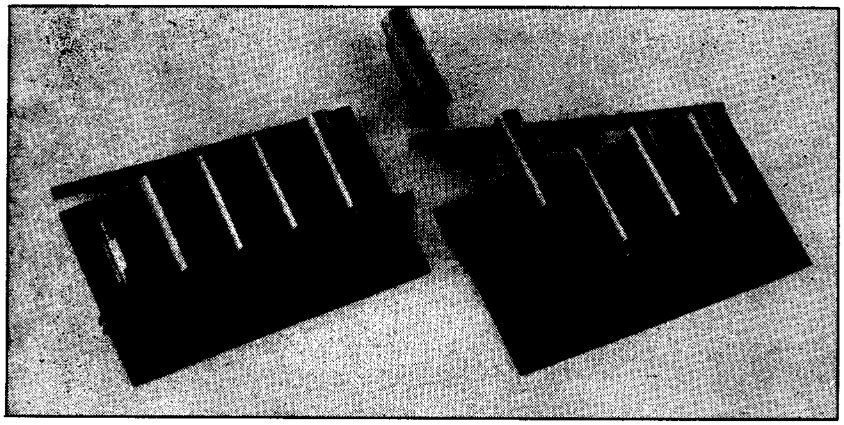
The foil laminates with the resist patterns may be etched in a rocking tray or may be mounted copper face down about one-half inch over the surface of the etchant, which can then be agitated by bubbling air violently through the solution. The recommended etchant for copper is a 50-percent solution of ferric chloride. This will etch through a 1.35-mil foil in about 5 to 7 minutes depending on the freshness and temperature of the bath. The patterns are then washed in running water, following which the enamel resist can be removed by use of a thinner or by light abrasion. Commercially these patterns would then be processed through a die stamping operation to provide the necessary holes through the pattern at each termination point. In the laboratory, of course, these perforations would be drilled or punched.

Conductor Characteristics

The thinner copper foils have more than adequate conductivity for general miniature circuit applications, as indicated in Table II. A 1.35-mil-thick conductor 1/32-inch wide on a representative 3 x 2-inch phenolic plate will carry over 3.5 amperes continuously with a 40-degree C maximum temperature rise of the conductor. A similar 3-mil-thick conductor under the same conditions will carry over 5 amperes. A studied effort has been made to discourage use of such ratings as fusing currents, peak current capacity and similar short-time ratings which do not provide useful information for a designer's guidance.

For general conductor applications a line width of about 1/32-inch is recommended, although widths down to 1/64-inch are dipped consistently. Experience to date indicates that an area of metal equivalent to about a 1/16-inch-diameter circle at each junction point is desirable since a well-formed and substantial fillet of solder will then be built up. Spacing of lines, in general, should be kept at least at 1/32-inch unless otherwise demanded by pattern layout.

On phenolic surfaces, the peak flash-over voltages at room ambient conditions with no coating protection over the 1/32-inch pattern spacings were about 1,800 v. This



Experimental five-stage impedance-coupled i-f amplifier having heat-dissipating metal back plate and individual metal tube envelopes for conducting tube heat to the plate

1/32-inch spacing has been used consistently on 300-v d-c circuits, with no failures recorded. In this respect, the desirable arc resistance features of some of the laminates are strong points in their favor. With this spacing, insulation resistances well over 100,000 megohms under ambient room conditions are measured between 3-inch-long copper lines on phenolic with no protective finishes applied.

The distributed capacitance between lines is significant and cannot be ignored at the higher frequencies. On XXXP phenolic, this capacitance is of the order of 1 $\mu\mu$f per inch for 1/32-inch spacing and 0.7 $\mu\mu$f per inch for 1/8-inch spacing. These values will be lower for the lower dielectric constant materials. Proper pattern layout will allow use of very short sections of r-f conductors, and it has been convenient at times to run short ground lines between two critical conductors to reduce this electrostatic coupling to a still lower figure.

Although the inherent power factor of such materials as phenolic is fairly high, the effective power factor is considerably better inasmuch as the dielectric of the distributed capacitance is part air and part insulating material. As a generality, this pattern capacitance can be said to be comparable in magnitude to that which may be encountered in conventionally wired compact assemblies, but with the advantageous feature of being identical from pattern to pattern.

The commercial offset press process can yield line work of the order of 8 to 10 mils in width as a matter of routine production. The photo-etch technique yields conductor widths down to about 4 mils without premium charges. These higher definitions are useful in delineating the precise geometry required of spiral-formed coils such as have been used in television tuners and high-frequency i-f coil patterns.

It is recommended that the finished copper patterns be silver-surfaced by dip plating (which yields a satisfactory flash coat) or by direct plating to eliminate oxidization of the metal on long storage with the subsequently increased difficulties of cleaning. The commercial etching houses will supply such surfacing as a matter of normal production processing.

Table II — Resistances of Etched Copper-Foil Conductors

Line Width (inches)	Ohms per Inch at 20°C for 100% Conductivity Copper		
	0.00135″ Thick	0.003″ Thick	0.005″ Thick
1/100	0.050	0.023	0.014
1/64	0.032	0.015	0.0087
1/32	0.016	0.007	0.0043
3/64	0.011	0.005	0.0029
1/16	0.008	0.0035	0.0022
3/32	0.0054	0.0024	0.0015
1/10	0.0050	0.0022	0.0014
1/8	0.0040	0.0018	0.0011
5/32	0.0032	0.0015	0.0009
3/16	0.0027	0.0012	0.0007
1/4	0.0020	0.0009	0.00055
3/8	0.0013	0.0006	0.00037

Copper has been mentioned exclusively as the conductor material because of commercial availability of the copper-surfaced laminate. However, some of the etching sources which do their own laminating have prepared patterns of brass, silver, iron, aluminum, bronze and even spring-tempered steel for special purposes. Some of these metals have proven particularly useful in delineating patterns for switches. It should be mentioned, too, that these laminators-etchers can supply embossed, flush or subsurfaced patterns for special purposes or provide upset metal nodules on the patterns where required for switch contact points.

Components

Auto-sembly requires that the components have stiff protruding terminations, preferably of a radial type, such that the component can be conveniently inserted into its designated place on the insulated side of the chassis. Resistors, capacitors or other components having axial leads can have these leads cut and shaped by jigging machines built for this purpose. The production arrangement can be such as to have the operator hold the conventional component momentarily in the jig for shaping and then in the next motion insert it into place on the pattern. The alternate proposition would be to supply the operator with pre-jigged components. Components where stiff protruding terminations are desired include termination devices such as sockets, connectors and receptacles. Current Signal Corps developments aim to provide such electro-mechanical devices that are particularly adapted to auto-sembly or other card-type systems.

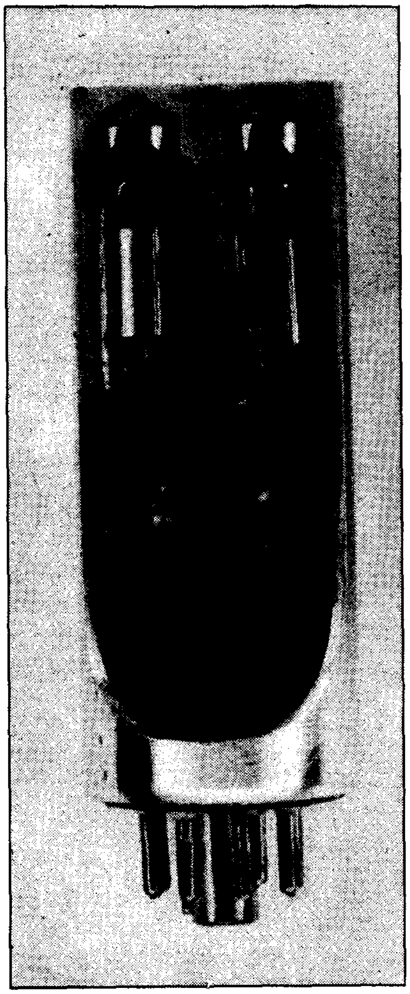
Most conventional components can be readily adapted to auto-sembly mountings. The use of conventional components is considered a desirable and realistic approach in this miniaturization technique. The designer has available for his choice not only the variety of components but also the full range of tolerances, electrical characteristics and physical sizes in the established quality lines of JAN or commercial components. There are no special skills imposed on the assembler of the equipment such as would be required if he were to deposit or print his own resistors or capacitors. The fabrication of such deposited components is still a highly specialized art. Where economic or performance advantages can be realized in any fabrication through the use of these printed circuit aggregates, then such groupings of deposited components (such as Couplates, Bulplates and multivalue capacitors) can be treated like any other component for autosembly.

Assembly

The use of the one-shot solder-dip technique has been particularly convenient in the fabrication of highly miniaturized assemblies. In this operation the insulating base, with the fluxed pattern on the underside and the components mounted on the topside, is momentarily dipped in a eutectic solder bath (63 percent tin, 37 percent lead) maintained at about 450 F. The period of dip recommended is of the order of two or three seconds, but this time may be increased if large areas of copper are left on the pattern for shield purposes or as heat radiation surfaces. Periods of dip as high as ten seconds have been made without delamination or deleterious effects on such base materials as phenolic, Teflon or silicone.

The success of the solder dip procedure is particularly dependent on the flux used just prior to solder dipping. The following formulation has been found successful: 1 part Glyco Wax No. S932 made by the Glyco Corp., Brooklyn, N. Y.; 1 part Kester No. 1015 (activated rosin in alcohol flux) made by the Kester Solder Co., Newark, N. J.; 1 part toluene (more toluene may be added if a thinner consistency is desired). The bath should be kept warm during use (about 110 F). The flux itself may be applied by dipping the pattern side momentarily in the flux or by brushing the flux over the pattern.

It is important that the pattern be removed from the surface of the solder bath with a sidewise lifting motion. This technique yields a soldered pattern with well-formed fillets at each termination point and a more or less hemispherical cross-section of solder on the conductor lines. The pick-up of solder on the conductor lines is extraneous and incidental to the process but it does add to the total conductivity of the conductors. One manufacturer on a production line basis has evolved a variation of this technique wherein his solder dip procedure deposits mechanized solder only at the termination points, a desirable process from the point of view of solder economy.



One-watt audio amplifier with portion of metal heat-dissipating container cut away to show use of folded circuit. Components are auto-sembled on flexible Teflon chassis that is rolled up and inserted in container, then cast in resin. Subminiature tubes fit into machined holes in solid metal end of container

Packaging

Packaging includes ruggedization, moisture protection, adequate heat transfer and provision of connective components such as may be required for plug-in use. Use of right-angled connectors provides a convenient means of integrating a connector quickly to the pattern since such a connector is treated as any other component in the course of the assembly operation.

Although stiff laminates have been discussed up to now, flexible laminates have been used as the chassis for the pattern in making folding circuits. Assemblies on thin sheet Teflon glass laminates and on silicone rubber (thicknesses of 3 to 10 mils) have been autosembled and then folded and inserted into capsules.

Conclusions

The complete and detailed coverage of all aspects of the autosembly system have not been presented here because of the voluminous nature of an exhaustive treatment of the subject. It can be shown, for example, that sections of auto-sembly circuitry can be decked by providing completed solder-dipped auto-sembled sections with stiff swaged-on protruding connectors which can be inserted into place on another deck and then solder-dipped into place. Cross-overs can be made by eyeletting and subsequent spot-soldering on double-faced laminates, or by use of staple-shaped wires as components.

The information as presented has been intended to show some of the more basic concepts and techniques of auto-sembly and the major considerations which govern its current applications in service and commercial equipment application. The use of the etched pattern and the auto-sembly system of integration both provide effective tools which are not necessarily limited to electronic circuit fabrication. These patterns, for example, are used in the preparation of heaters, Faraday shields, switching devices, and in one instance even for forming low value bypass capacitors. Autosembly is being used in new military equipment designs and is currently applied commercially to repetitive types of circuits such as are used in counters. The extrapolation of auto-sembly to other applications is dependent almost entirely on the imagination of designers familiar with the capabilities of these tools.