Automatic Mass Soldering of Wire Wrap Terminal/Multilayer Boards

Use of a closed loop thermal control with simplified shielding provides a unique radiant energy system for mass soldering

BY A. T. FARO

ABSTRACT. Wire wrap terminal-multilayer board configurations are reflow soldered by diffuse radiant heating modules. Initial facilities developments included diffuse and line focus radiant heating systems and precision conveyorized speed controls for the solder assembly of the multilayer board (MLB) units.

The present facility used in prototype production incorporates a static solder assembly technique without the need for precision conveyor speed controls. The MLB unit is shielded to minimize thermal gradients during the soldering cycle. A thermocouple probe is attached at or near the surface of the MLB unit. The millivolt signal of the thermocouple is the key to a closed loop control system that incorporates a solid-state programmer/controller station. Heating rates, preheat (if desired) and reflow soldering temperature and time are specified on the programmer card and maintained by the thermal controller. The thermal controller effectively modulates the silicon control rectified (SCR) power controllers of the tungsten filament quartz lamps.

Reflow soldering occurs when 60Sn-40Pb punched rings are melted and wet (bond) to the wire wrap terminals and plated through holes of the MLB. Units containing up to 21,000 solder joints are now being mass soldered by this technique.

Introduction

Multilayer printed wiring boards if used in conjunction with wire wrap terminals and connectors best satisfy the power and ground distributions needed in new electronic switching systems. The mixture of the two wiring systems (printed wiring and machine wiring) into a compatible assembly is accomplished by mass soldering wire wrap terminals to the plated through holes (PTHs) of MLBs.

Many soldering techniques were investigated initally and ruled out because of special Bell System requirements. The purpose of this report is to show how the development of a precision soldering process was accomplished in lieu of certain design and soldering restrictions intrinsic with prototype terminal/MLB configurations.

Process Development

The backplane assembly is composed of MLBs into which terminals and/or connectors are inserted. Solder preforms are assembled (one to each terminal) for the entire unit. Soldering flux is applied to the unit to facilitate the interconnection of the solder preforms to terminals and PTHs of the MLBs. The parameters of soldering must be precisely controlled because of thermal sensitivity of the epoxy glass MLB. The integrity of the wire wrap property of the terminals must be maintained via Bell System specifications, so wave soldering was not considered. Hot air soldering was eliminated because of the massive heat capacity of large MLB units, which would lead to very long soldering cycles.

Considerations of Radiant Energy

Radiant or infrared (IR) heating of the assemblies was investigated because of the high efficiency of radiant energy heat transfer and because of the fast, responsive nature of the tungsten filament quartz lamps when energized by silicon controlled rectifier (SCR) power controllers. The transfer of radiant energy from the lamps to the workpiece also offered a narrow spectrum of radiant energy with wavelengths less than four microns, and peak spectral wavelengh of about 1.3 microns. This characteristic of emitted energy is extremely important for the absorption and heating of the surface of the epoxy glass MLB which is composed of laminated epoxy glass copper circuitry interconnected to solder plated through holes.

The visible spectrum of electromagnetic energy is defined to be between 0.380 to 0.760 microns. From (Refs. 1, 2, 5) for opaque bodies having zero

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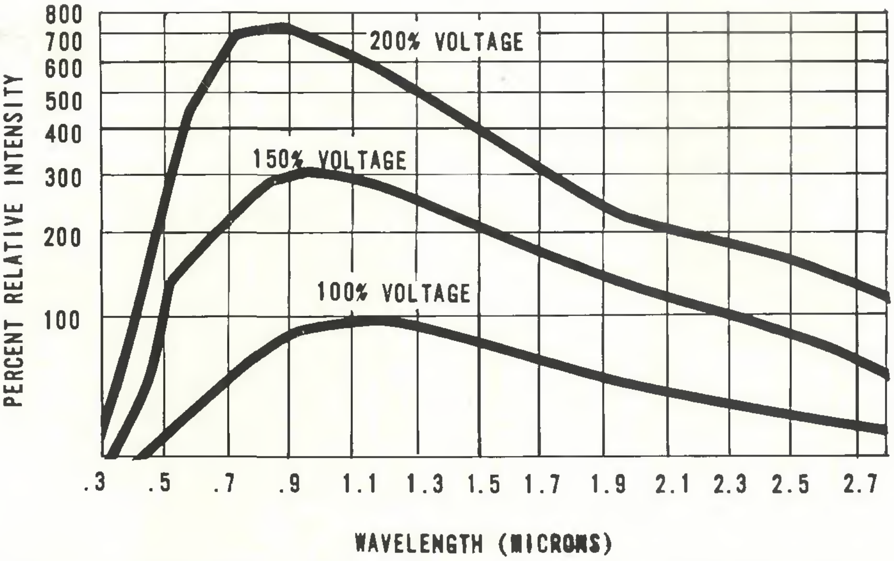

Fig. 1 — Spectral energy distributions vs. percent applied voltage for tungsten filament clear quartz lamp

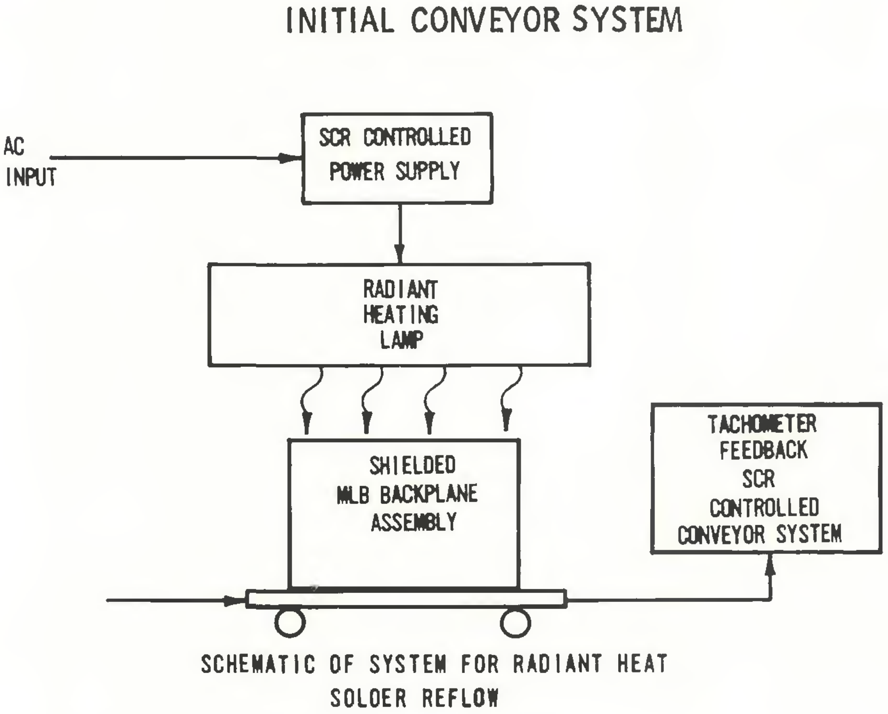

Fig. 2 — Schematic of an early model radiant-heat reflow solder facility

transmittance of energy, the monochromatic absorption $\alpha_\lambda(T)$ is defined by: $\alpha_\lambda(T) = 1 - \rho_\lambda(T)$, and α_λ and ρ_λ are dependent on the surface temperature. Thus, for efficient radiant transfer, the incident flux should be mainly short wavelength energy with α_λ high. Heating of metallic surfaces is higher with wavelengths of two microns or less. This is approximately the case as noted in Fig. 1, (showing spectral energy versus applied voltage for tungsten filament quartz lamps).

The energy emitted by an incandescent perfect emitter (black body) is not monochromatic but is a spectrum of electromagnetic energy in which the monochromatic emissive power ($e_{b\lambda}(T)$) is described by Planck's distribution. For an analytical radiant energy discussion, the reader is urged to review such heat transfer texts as Sparrow et al (Ref. 1) and Love (Ref. 2) from which the development of the following equations explain why the emissivity of surfaces is salient to the thermal distribution on the surface of terminal-MLB backplanes.

The monochromatic emittance of the surface,

$$e_\lambda(T) = \frac{e_\lambda(T)}{e_{b\lambda}(T)} \qquad (1)$$

is the ratio of the monochromatic emissive power e_λ of a real surface to that of a perfect emitter $e_{b\lambda}$. The total emissive power, e, of the tungsten filament is a function of the wavelength, λ, monochromatic emittance, e_λ, and the operating temperature, T_f, and is described by

$$e(T_f) = \int_0^\infty e_\lambda(T_f) e_{b\lambda}(T_f)\,d\lambda \qquad (2)$$

Total absorption of a real surface is the ratio of the absorbed radiant power to the incident power. The total absorption for a metallic surface at temperature, T_F, and a filament temperature, is given by

$$\alpha = \frac{\int_0^\infty \alpha_\lambda(T_m) e_\lambda(T_f) e_{b\lambda}(T_f)\,d\lambda}{\int_0^\infty e_\lambda(T_f) e_{b\lambda}(T_f)\,d\lambda} \quad ,(3)$$

Equation (2) can be reduced to the Stefan-Boltzmann law for the total hemispherical emissive power per unit area of the incandescent tungsten surface providing the spectral distribution of emittance is known.

The law is as follows:
$e = e_f \sigma T_f^4$,
where $\sigma = 5.6686 \times 10^{-12}$ watts/cm² deg^{-4}, the Stefan-Boltzmann constant, and e_f = total emittance of tungsten at temperature, T_f.

Thus, for the most effective heating of polished metallic surfaces, a higher tungsten filament temperature lamp will emit more energy at wavelengths less than one micron. For our application where the copper laminate has been etched and solder plated for use at the pad layer, the land areas do not represent a significant surface for absorbing energy. At lower rated power levels for the lamps, a slightly longer wavelength spectrum can be tolerated with effective heating of surface of the epoxy glass MLB. Later experimental tests (Ref. 4) on various MLBs also have shown that the emissivity of the epoxy glass board surface approaches a black body (totally absorbent).

The reflective nature of the copper alloy terminals above the surface of board attenuate appreciably the amount of incident energy impinging on the board. The copper innerlayers of the MLB are the subsurface heat conduction sources for bringing the terminal and plated through holes to a temperature range for solder reflow. The effect of variable terminal density throughout the MLB greatly affects the absorption of the radiant energy on the surface MLB and the internal copper circuitry in turn affects the rate of conduction of heat to the solder joint(s).

Aluminum shields have proved useful to balance the variability of reflective surfaces on the thermal/MLB backplane so that a uniform heating cycle can be attained for the entire unit. The selection of diffuse radiant heating modules made possible the use of non-critical heat shields as well as to minimize any hotspots on the assembly due to slightly warped mounting plates that hold the MLBs, since focal distance from the lamps is non-critical.

By bringing the entire assembly up to temperature, i.e., the terminals, epoxy glass and copper innerlayers for solder reflow, the consideration is that minimum thermal shock to the MLB and simultaneous reflow occurs over the unit without excessive times at reflow temperatures. However, knowing what was needed and doing it proved difficult.

Earlier efforts to shield the unit assembly and closely control the conveyor speed did not prove to be optimum. Differences in the heating and cooling of the assembly from front-to-back on the assembly were difficult to categorize as was the speed of the conveyor. This led to the investigation of radiometric devices to sense the surface temperature of the MLB assembly during heating. This effort proved frustrating because of the variation in terminal density, plating differences and aluminum shield surfaces interfering with the readings from the surface of the MLB. We attempted to calibrate the devices from thermocouples and found that the only consistent readings throughout were from the thermocouples, not the overly sensitive radiometers. The use of thermocouples to characterize the thermal characteristics of MLB assemblies during the reflow soldering cycle also lead to the decision to control the soldering operation based on thermocouple data as it was being generated.

Many types of contact-type thermocouple devices have been and are still being investigated and as such a detailed discussion on the optimum selection of the thermocouple probe cannot be made. From the practical viewpoint, as small a gauge thermocouple wire as possible was selected (we presently use 28 AWG, Type K thermocouple wire). The probe leads are highly insulated to minimize heat losses, but some are inevitable such that only relatively accurate, yet repeatable thermal data (±10 F) can be expected.

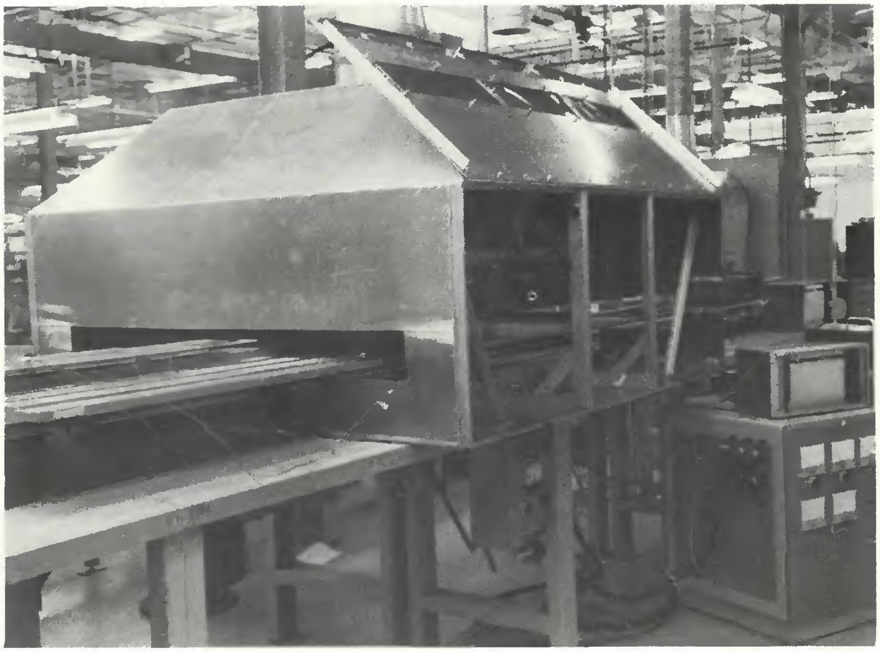

Fig. 3 — Radiant-heat reflow solder facility, present model

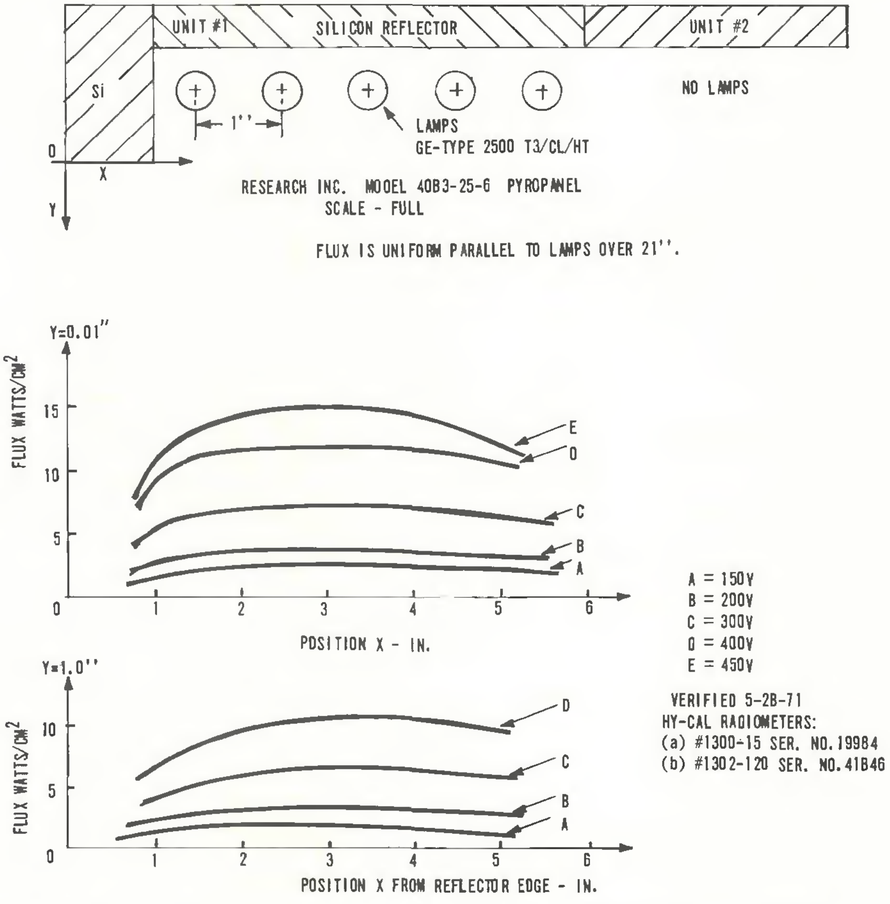

Fig. 4 — Reflector/lamp heating module — radiant energy distribution characteristic

The influence of operator control of the radiant heating lamps and conveyor speed was next eliminated. A solid-state thermal controller and programmer unit was installed with proportional gain, rate, and reset controls which could be operated in the program (fully automatic mode), set point, or manual modes. The controller/programmer unit is used with the surface thermocouple probe as the closed loop control system for the SCR power controllers and radiant heating modules.

Present Facility Configuration

Figure 2 depicts schematically our earlier operator controlled efforts,

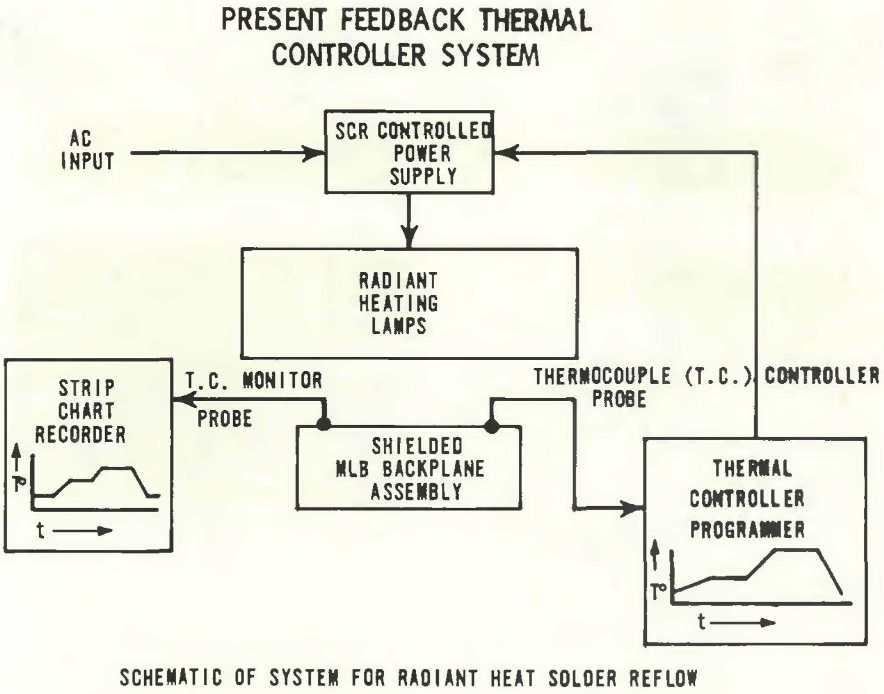

Fig. 5 — Schematic of the present model radiant-heat reflow solder machine

Fig. 6 — Typical terminal/multilayer board assembly

while Fig. 3 depicts schematically the approach to fully automatic control of the soldering cycle. The solid-state SCR power controllers drive incandescent tungsten filament quartz glass lamps. The lamp size is 41 13/16 in. overall length with a filament length of 38 in. and a design voltage of 570 V. The power controllers — each in series, have kVA ratings of 33.6 kW from a line voltage of 480 V and a maximum current rating of 70 A. The power controllers incorporate a lamp mode response time of four (4) seconds for full scale voltage use, reducing start-up surge when turning on cold incandescent lamps. Once the lamps reach temperature, a memory circuit reduces response time. Additionally, the power controllers have an automatic voltage regulation that incorporates high-gain integrated circuitry to provide ±1% of rated voltage stability over the adjusted setpoint operating range of 5-100% of rated output. This stability will be maintained within line voltage fluctuations of ±10%.

The heating unit modules that hold the lamps are by far the next most important part of the soldering facility in that the reflective surfaces distribute the radiant energy emitted by the lamps uniformly over our largest backplane assemblies. The ceramic reflector is composed of high temperature (silica) material with unlimited life and has proven to be essentially self cleaning. The ceramic reflector also eliminates the need for water cooling, and air cooling has proved adequate. The present facility incorporates four heating modules which include six lamps each except for two edge reflectors on the outer reflectors for a total of 22 lamps. Maximum effective (uniform) radiant energy distribution is about 30 in. wide by 38 in. long. Radiant energy emitted by the lamps at various voltage setpoints is measured by a calormetric device in BTU/ft^2-sec (watts/cm^2).

The backplane assembly is located approximately 2 in. from the surface of the infrared lamps. The distance between the workpiece and the lamps is not critical, but from a practical production standpoint, flux fumes are most easily removed by the natural draft exhaust without any appreciable cooling by the convective air currents at the two inch setting. Figure 4 depicts the heat flux distribution for various distances between 25 in. lamps and the calorimeter measuring device which has a high emissivity (0.89) graphite coating on the active sensor face covering a broad spectral range from 0.2 microns flat to 10 microns. Reproducible calibration curves on the instrument are supplied on a notarized certificate of calibration.

Results

The component schematic and the present facility are shown in Figures 5 and 3, respectively. With the successful operation of the prototype facility, however, has come the need for further characterization of the various backplane assemblies.

Present soldering cycles incorporate about a three minute interval. The unit assembly is generally preheated to about 250 F (just above the glass transition temperature of the epoxy glass resin system of our MLBs), then heated to about 430 F for 40 sec, and ambient air cooled.

Thermocouple data and heat transfer reports (Ref. 3) compiled to date have helped to characterize in part the behavior of the various MLBs during soldering and has been the source of data to develop the best soldering cycle. Functional lands, i.e., PTHs without interconnects heat up to reflow temperatures approximately five seconds before reflow temperatures are reached on ground, power, or signal PTHs. Consideration is being given to future design improvements in the design of the PTH printed wiring interconnection method. Larger land or pad sizes have been designed into new codes of MLBs so that the shielding design of open areas on an MLB assembly need not be critically addressed for fear of overheating. Early shielding design has been by trial and error but has been proved adequate and inexpensive. Figures 6 and 7 demonstrate the approach to shielding at present for terminal/MLB configurations.

Conclusions

New design changes in MLB and terminal arrays to meet electronic switching requirements reflect the need for multi-channel thermocouple monitoring of MLB assembly characteristics and computer analysis for optimum automatic reflow soldering of new MLB assemblies. However, having a useful probe and shield design still means little if the MLB assembly cannot be efficiently handled before and after the soldering process. Quick connect-disconnect shielding and probes have afforded our prototype production shop the capability to load and position the unit precisely, to actuate the power supplies and automatic program buttons, and (after about three minutes) to remove the MLB assembly for post cleaning.

Future facility considerations will incorporate a continuous conveyor system upon which the fluxed and shielded MLB assembly will be loaded with the thermocouple probe(s) in place. The operator need only attach the probe to the controller/programmer station and actuate the start cycle button. After solder reflow the thermocouple will be removed and the MLB assembly automatically defluxed by an in-line cleaning facility.

(Other considerations such as component solderability and design requirements in the assembly hardware have not been discussed here although the facility development was accomplished with an acute awareness of these parameters.)

To summarize, a temperature sensitive, rather than an emissivity sensitive probe to repeatedly and precisely measure the relative temperature of a given terminal/multilayer board assembly during the soldering cycle has evolved and is being successfully utilized.

Heat shielding of critical areas on terminal/multilayer configurations is accomplished through the use of a one-piece aluminum shield accurately attached to the assembly.

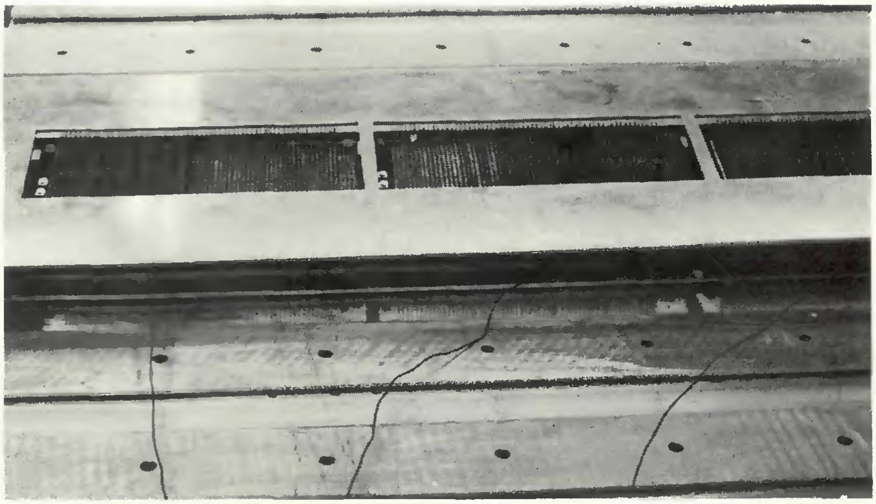

Fig. 7 — Typical terminal/multilayer board assembly with aluminum shield and thermocouple probes

A thermal monitoring probe measures the relative surface temperature of the MLB which feeds a closed loop control system that modulates the radiant energy of the lamps for a selected soldering cycle.

Any type of soldering cycle can be programmed into the control system to maintain given heating rates, time and temperature.

The combination of a closed loop control system utilizing a thermal monitoring probe with simplified shielding design is unique. The soldering technique offers a realistic approach to highly repeatable, automatic, production mass reflow soldering of a variety of terminal/multilayer configurations with zero process contamination of the parts.

Acknowledgements

The author wishes to gratefully acknowledge the critical evaluation of this process development effort by Mr. P. Haldopoulos, Supervisor, the much needed assistance given by Mr. J. L. Coffey, both of Northern Illinois Works, Western Electric Company, and the initial prototype facility assembled for us and the technical support given us by Messrs. R. Pfahl and D. Schoenthaler of Western Electric's Engineering Research Center in Princeton, New Jersey.

Special thanks also to Mr. R. G. Riley, Western Electric Company, Northern Illinois Works, for his photographic support and to the Art Department of Western Electric, Northern Illinois Works, for their support during this effort.

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