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AUTOMATIC ASSEMBLY OF HYBRID CIRCUITS ON A CERAMIC SUBSTRATE.(U)
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A system was developed to mass produce thick-film hybrid integrated circuits on ceramic substrate. This technology was tested successfully with the production of 3000 XM734 multi-option fuze amplifier assemblies. The high-volume, continuous production applies to military environments and incorporates high component density. Nonrecurring costs in capital equipment and minimal labor are among the major economic advantages. END

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FIGURES

1. INTRODUCTION

The U.S. Army Electronics Command awarded a contract to develop a system to automatically mass produce hybrid circuits on ceramic substrates in early 1973. The contractor was the Automated Systems Division of RCA, and the contract was technically managed by the Harry Diamond Laboratories. The method described here offers much in high-volume, low-cost production of any hybrid circuit, even one that must meet military reliability requirements.

The XM734 multioption fuze amplifier assembly was chosen as a test vehicle, since it represents a circuit in a viable product. Under this contract, the amplifier assembly was produced at a rate of 150 units/hr with 3000 deliverables (fig. 1).

The final RCA report on this contract describes an integrated automated manufacturing approach that will be available to provide

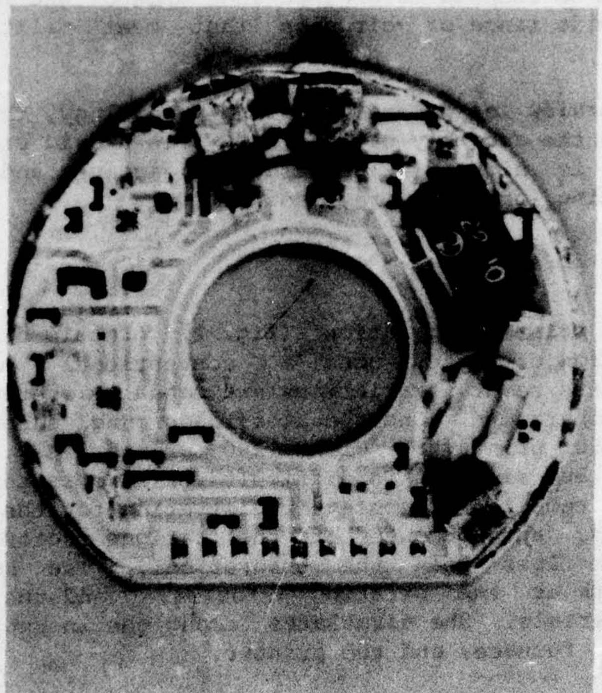

Figure 1. XM734 multioption fuze amplifier assembly.

greater use of resources in a mobilization emergency. Specifically, the development and subsequent series of circuit assembly demonstrations at RCA prove that it can do the following:

a. Effectively increase production rates with a lower manpower base

b. Through better reproducibility, increase yield and thereby significantly reduce cost and rework

c. Provide 100-percent automatic testing to contract specifications

d. Increase greatly the reliability factor and reduce the need for manual inspection

Hybrid microelectronics is the most significantly changing and expanding technology application. As such, manufacturing operations for automatic assembly of thick-film ceramic microcircuits must be flexible enough to respond to engineering demands and requirements and to adapt to a wide range of circuits that meet military reliability requirements.

As an overview of general existing technology, three major areas are involved in the assembly of the thick-film hybrid circuits in which labor content is high: (1) printing, (2) active and passive chip component handling, and (3) wire bonding.

2. OPERATION

The typical printing operation (fig. 2) practiced in the majority of microelectronic houses uses a conventional model printer. Unfortunately, its several variations are manually operated and require at least three operators. One operator loads and unloads the printer at 120 to 150 prints/hr, with 1200 prints/8-hr day possible theoretically. But since it is difficult for an operator to maintain the vigilance required to achieve registration for the manufacture of military hybrids, and because of the fatigue factor, the realistic output would be less than the theoretical. The second operator inspects the work at the printing station, and the third operator handles the materials. She circulates among the inspector, the drying oven, the firing furnace, and the printer.

This substrate fabrication operation leads into the manufacture of a hybrid substrate. At this point, the substrates are ready for the attachment of discrete active and passive components such as chip capacitors and chip semiconductors.

Figure 2. Typical manual printing operation.

The manual chip component placement requires several operations: (1) solder paste deposition, (2) passive or active chip attachment or both, (3) solder reflow, and (4) flux removal.

Chip attachment is accomplished with the use of a binocular microscope, a wall chart of the circuit, and a pair of tweezers. The operator refers to the microscope and places the component correctly on the substrate while it is on the microscope stage. She repeats this sequence at ~150 components/hr on many substrates per day (fig. 3).

Microelectronic connections achieved by using conventional wire bonding always impede mass production. Several other approaches have been conceived to eliminate this costly bottleneck, but they have presented other problems; because of these difficulties, they have yet to be used extensively.

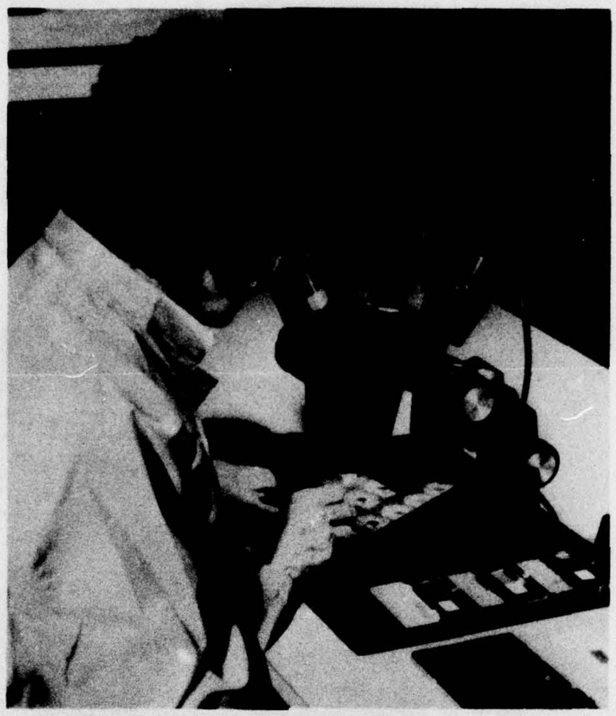

Figure 3. Typical manual chip component placement operation.

One typical wire-bonding operation is an ultrasonic heated substrate bonder (fig. 4). It is most commonly used in the manufacture of hybrid microelectronic circuits. Operators' varying moods are reflected in the quality and quantity of the products produced. In this segment of the production cycle, the operator picks up the substrate and places it on the heated work column. Then using the micromanipulator control, the operator, with the aid of the binocular microscope, locates the pad of the first chip accurately. She constantly refers to the wall chart ("assembly aid") until assured that she will perform the proper interelectrode connections. Then she connects them using the manually operated wire bonder. This sequence is repeated for every chip in the circuit. The average simple hybrid circuit has about six active chips and 15 wires. The XM734 fuze amplifier hybrid substrate has nine active chips and 42 wires.

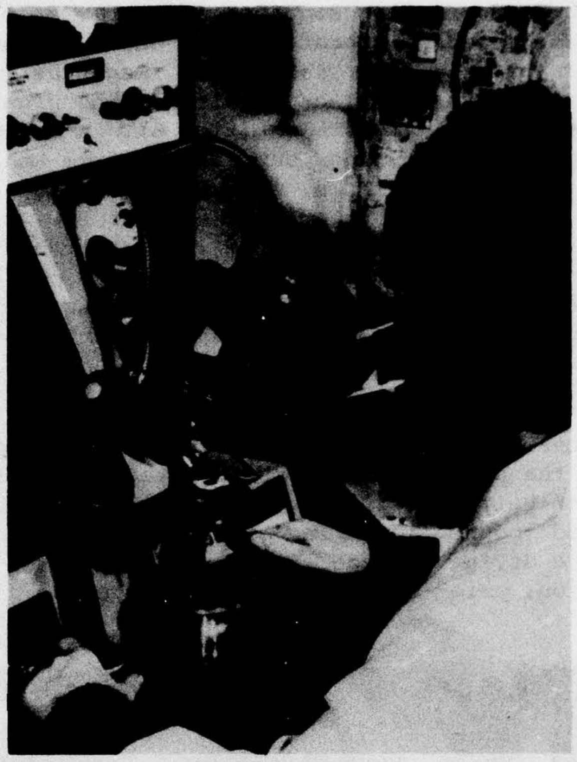

Figure 4. Typical wire-bonding operation.

One can hope to fulfill production rates required for a mobilization base with conventional wire-bonding equipment. But the manpower requirement would be staggering, quality would be highly inconsistent, and production rates would be more difficult to guarantee because of human factors. These factors rise with the number of operators.

The less significant suboperations vary from manufacturer to manufacturer and circuit to circuit.

For automated techniques demonstrated under the RCA contract, only the three major operations in the production of hybrid microelectronic circuits are described here.

In the automated printing sequence (fig. 5), substrate handling is reduced to magazine loading operations and one operator, whose various duties keep her alert. She loads the magazine in the autoloader, inspects, and does other tasks as required. The magazine can hold 400 to 450 substrates for 45 min of work (fig. 6). A logic system controls the loading and transfer of the substrates from the loader to the printer platen (fig. 7). This fluidic-pneumatic logic system is compatible with the control system of the printer. A vacuum pickup arm reaches down through the base of the printer table to engage the uppermost substrate. The arm lifts the substrate out of the magazine while the platen is in the printing position. As the platen returns from the printing to the loading position, the substrate is transferred by the printer ejector to an intermediate position and then to the collocator belt.

This belt moves in synchronous increments as dictated by the production rate of the printer. When the printed substrates reach the end of the collocator-belt tunnel, they are transferred to the dryer belt in a preselected count (such as four abreast) to use the full capability of the drying furnace. Then the substrates move through the inspection station, prior to the drying-oven cycle.

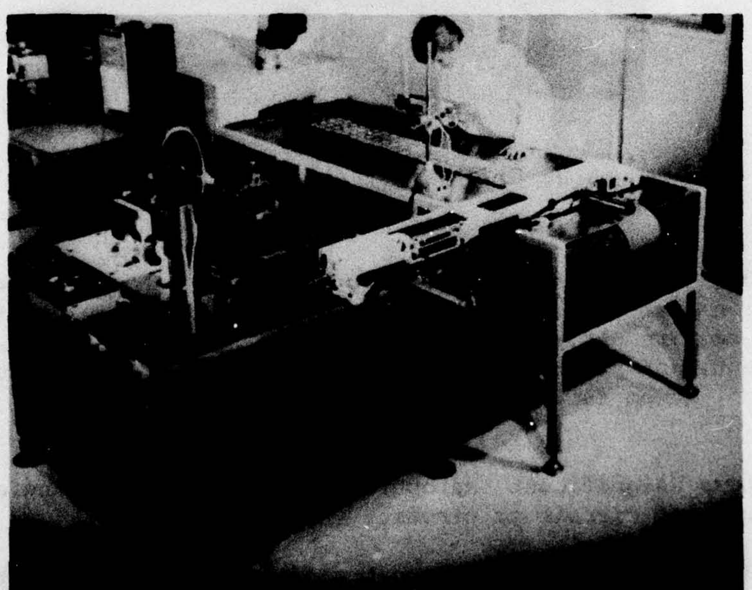

Figure 5. Automatic printer-oven complex.

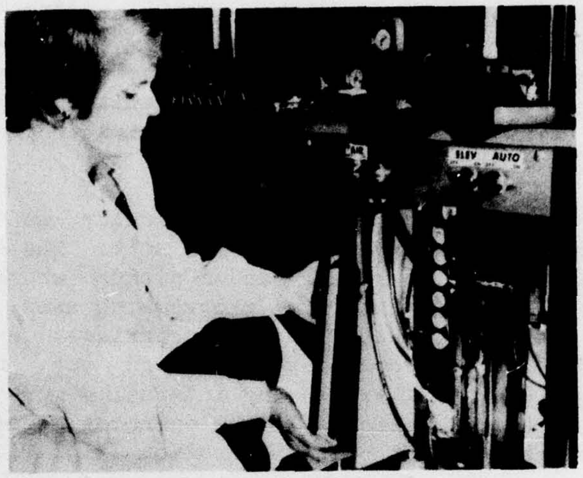

Figure 6. Magazine containing ceramic substrates.

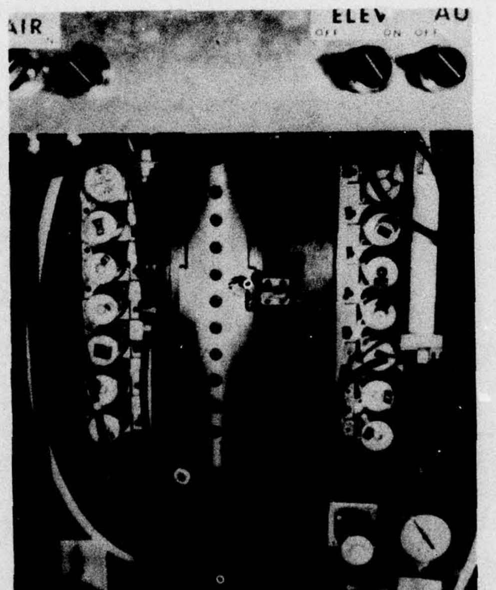

Figure 7. Fluid/pneumatic logic system.

This complex with one operator can print 750 substrates/hr. One important feature of this equipment is the camber sensor, which inhibits the printing of substrates whose topology limits good line definition. This inhibition allows faulty substrates to be removed after the first pass and so eliminates unproductive subsequent processing (fig. 5).

The chip assembly robot can automatically assemble 1400 chips/hr with an electronic memory and control unit. The chips are active and passive components. The small vacuum pickup chuck poises over the vibratory table. Of the five programming axes, four control the position of the vacuum chuck and its carriage, and one axis controls how the assembly platform moves in and out. The precise movement instructions are stored within the internal memory and may be unloaded on magnetic tape for future use. The operator merely presses the start button to initiate the automatic operation (fig. 8).

A linear vibratory feeder (fig. 9) moves the parallel rows of chips to a reference position for pickup with the vacuum chuck. After a chip is picked up, the other chips in its row move forward so that another chip is restored to the reference position. Held in an easily removable slotted tray, the chips may be loaded manually, or they may

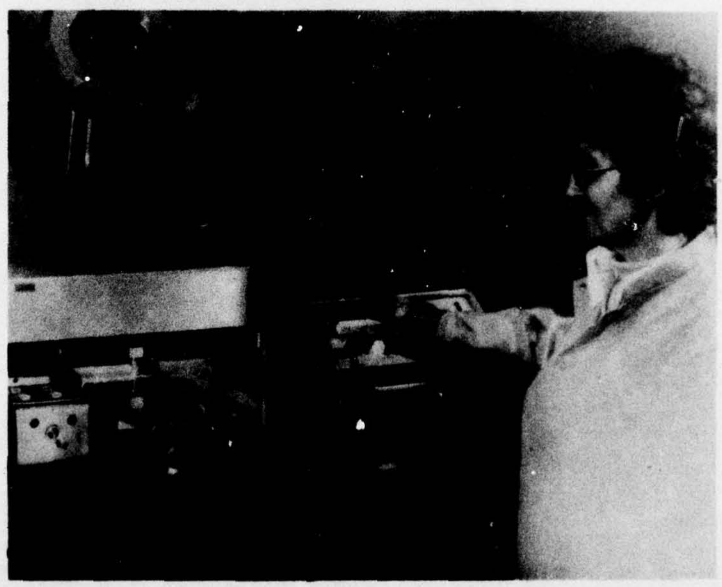

Figure 8. Chip assembly robot.

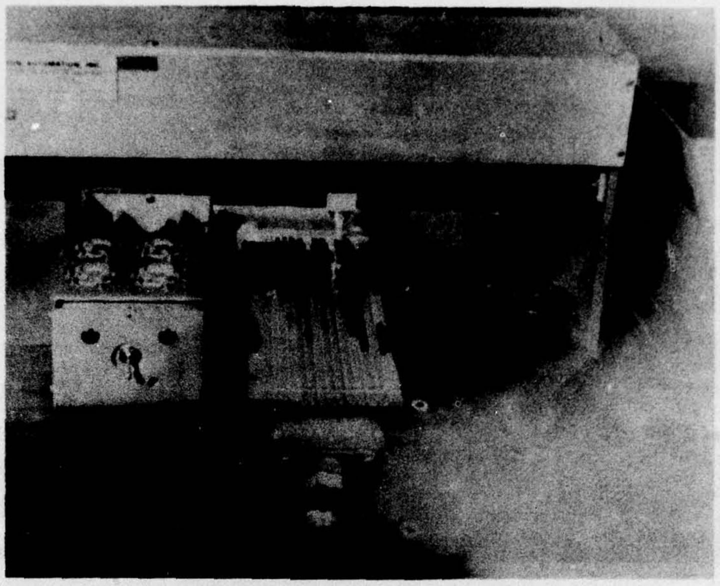

Figure 9. Close-up of robot: left, work table; center, vibratory feeder.

be loaded automatically from a separate vibratory bowl feeder. Generally, chips in a given row are picked up sequentially four times for placement at the programmed positions on the respective four substrates on the work table. This operation is repeated for each successive row of active or passive chips until all chips in the four substrates are emplaced. On a demonstration run with this unit, 180 capacitor sets/hr were emplaced on ceramic substrates for the XM734 fuze.

Finally, the automatic wire bonder (fig. 10) dissolves the major production bottleneck. It is essential to the development of low-cost, microelectronic interconnections. The only critical operator function is the chip alignment--the machine bonding rate exceeds 3000 wires/hr. Ultrasonic bonding is used, since thermal compression bonding would impose serious limitations in microelectronic hybrid assembly.

To program the pad locations, the digitized information is converted by the use of a "canned program," from a standard Telex computer terminal to a CPU source tape. As the finalized program, this punched paper tape can be stored for future use.

Figure 10. Automatic wire bonder.

The tape reader can read 300 characters/s. The format is a 32-bit word with 64 chip locations. The reader can go 1999 steps in the X direction and 999 steps in the Y direction with a movement resolution of 1 mil (0.254 cm)/step. A paper tape programs the memory (fig. 11).

Once the automated wire bonder is set up and programmed, the operator picks up the substrate and places it on the station. Automatically, the equipment snugger accurately registers the substrate by securely fastening it against a set of stops. Then the first chip is displayed on the video monitor. The operator aligns the lower left pad on this chip to a set of alignment lines on the video screen and depresses a button. All microelectronic connections from the pads to the lands are automatically wire bonded. Then the X-Y table brings the next chip into view on the monitor screen and at the work station. The sequences are repeated for all chips on the substrate. The operator then removes the wire-bonded substrate and replaces it with an unbonded substrate.

The speed of the system depends on (1) the bond dwell time, (2) the length of the wire and chip location runs, (3) the alignment time, (4) the accuracy of the die location, and (5) the arrangement of the pad geometry.

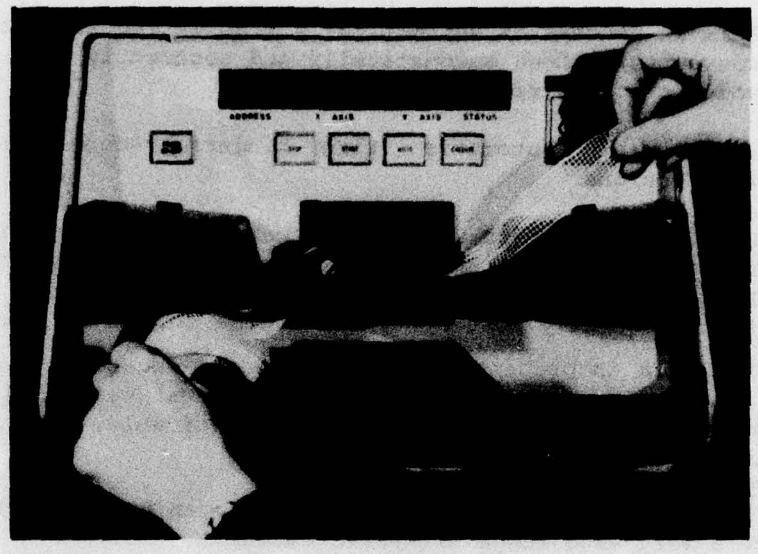

Figure 11. Paper tape program in the memory.

3. HIGH-VOLUME PRODUCTION LINE

The techniques demonstrated in the RCA contract could lead to the establishment of a fully automated production line for the manufacture of hybrid circuits with the following main features:

a. The substrate size would be standard; the same automated handling equipment could be used for any circuit.

b. The size, configuration, or both for a circuit are made unique through laser scoring. If the size of the circuit permits multiple image printing, the circuit printing rate substantially increases.

c. The magazine would handle all work in process. The operator would never directly handle any work in process. The operator would move only the magazines loaded with batches of work.

d. For such a production line, laser trimming is 10 times faster than its abrasive counterpart.

e. Work in process is automatically transferred from magazines to indexing conveyors. These automatically and accurately move the work to and through the required operations.

f. Programmable automatic wire bonders reduce the time of microinterconnections.

g. Semiconductor chips would be prepared for automatic assembly by probing the wafers. Chips are transferred by category on an adhesive-backed plastic strip similar to 8-mm movie film. The data required to subsequently sort by type would be stored on magnetic tape.

h. The work in process is to be stored in magazines for effective lot and inventory control. This storage allows easy correction of work-flow imbalance caused by occasional, unavoidable, random equipment downtime.

i. Due to its modular nature, the line can be readjusted readily to produce a very wide range of hybrid circuits.

A multiple image ceramic plate would be used for production of the XM734 fuze amplifier (fig. 12). The present configuration would be converted to an octagon to maximize the benefit of multiple-image printing. An area 4 × 4 in. (10.16 × 10.16 cm) contains nine images, a nine-to-one advantage against single-image printing. The holes would be punched out in the "green state," but the laser-scored lines between circuits should be generated just before the circuits are separated. This configuration would be used in all further processing.

A circuit of any size or configuration could be manufactured on this line, provided that its length and width were 4 in. (10.16 cm) or less. The only difference would be the number of images per plate: smaller circuits would have more images, and larger circuits, fewer images.

The following details of this automated hybrid assembly concept describe the operations having the major labor content--(1) passive and active, (2) component attachment, and (3) wire bonding.

In the first operation of the passive component attachment module (PCAM), a solder paste is screened by a magazine-loaded printer, just as was demonstrated on the RCA contract. The substrates are then ejected from the printer onto an indexing conveyor and moved to the first work station. The conveyor accurately locates the capacitors to the appropriate "wetted" position on the substrates. Each passive component on the hybrid microcircuit has a station. After the last

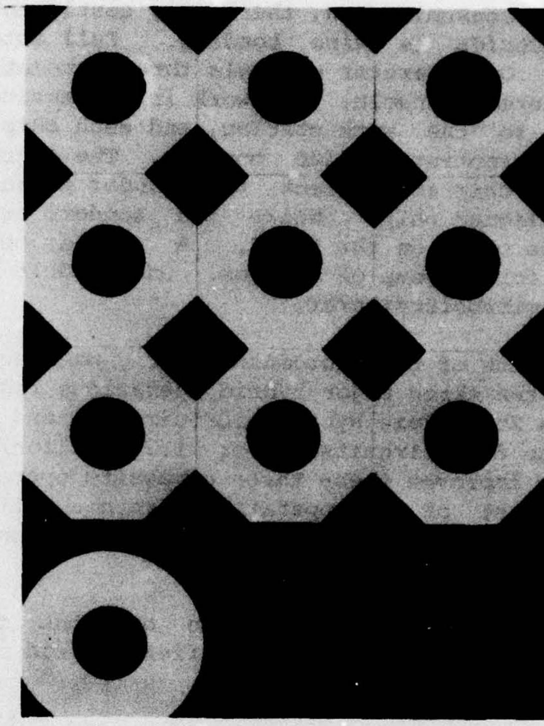

Figure 12. Multiple image ceramic plate.

component "attach" station, the work proceeds through a conveyor reflow and cleaning station and then is automatically reloaded to magazines. This PCAM could produce about 1200 XM734 fuze hybrid microcircuits/hr.

With the active component attachment module, the work would similarly be transferred from the magazine to the indexing conveyor, from station to station, and back into the magazine by the same equipment as for the PCAM. But the epoxy to attach the active chips to the substrate cannot be screened on, because relatively massive components are already attached to the substrates. Instead, a multinozzle dispenser would deposit the epoxy.

Tested, good active components then would be transferred from the adhesive-backed plastic film strips on reels to the appropriate epoxied locations on the substrates by pick-and-place equipment identical to that used on the PCAM. The epoxy is batch cured while the substrates are in magazines. As in the PCAM, this module could produce 1200 XM734 fuze hybrid microcircuits/hr.

The most time-consuming and, therefore, costly operation in the manufacture of hybrids is wire bonding. Full automation greatly reduces this cost. One operator controls three automated wire bonders through a multiplexed console. The work is automatically transferred from the magazine to the work station, and each chip is sequentially displayed on the appropriate video monitor. The operator only has to align the displayed chip and direct the bonder to automatically make all bonds on the aligned chip. While two bonders are operating, the operator aligns the chips on the third. A second operator loads and unloads magazines for a group of modules. One module can produce 150 XM734 fuze hybrid microcircuits/hr.

For the economics of this automated hybrid manufacturing, one must compare costs for the three major hybrid operations regarding (1) their ability to produce XM734 fuze hybrid microcircuits and (2) the staffing required to produce 600 circuits/hr or 1.2 million/yr on an 8-5-1 basis. Automation improves these three composite operations nearly 20 to 1. Since the rest of the operations are not fully automated, the differences in cost for automatic and manual operation for the entire line are less.

Automation reduces by nearly nine to one the total manpower to produce the XM734 multioption fuze amplifier hybrid at a rate of 600 units/hr (fig. 13).

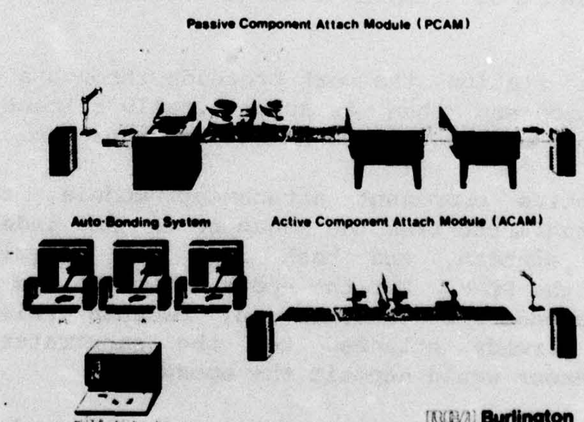

Figure 13. Automated hybrid assembly.

4. SUMMARY

The effort under this RCA contract has shown that automated techniques can replace human-dependent operations by predictable, automated repeatable processes. Thus, automation significantly lowers ceramic hybrid microcircuit costs, through the lower labor costs resulting from automation and high yields made possible by machine reproducible processing.

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