KULICKE and SOFFA
INDUSTRIES, INC.

DOE/JPL - 955287 - 79/1
Distribution Category UC-63

AUTOMATED SOLAR MODULE ASSEMBLY LINE

QUARTERLY TECHNICAL REPORT NO. 1

MARCH, 1979

MAX BYCER

JPL CONTRACT NO. 955287

KULICKE & SOFFA INDUSTRIES, INC.
507 Prudential Road
Horsham, PA 19044

"The JPL Low-Cost Silicon Solar Array Project is sponsored by the U.S.Department of Energy and forms part of the Solar Photovoltaic Conversion Program to initiate a major effort toward the development of low-cost solar arrays. This work was performed for the Jet Propulsion Laboratory, California Institute of Technology by agreement between NASA and DOE".

ABSTRACT

This quarterly report covers the period from December 13, 1978, to March 18, 1979. Progress during this period discussed in this report include: the gathering of information that led to the design approach of the machine, and a summary of the findings in the areas of study along with a description of each station of the machine.

The machine which Kulicke and Soffa will build is a cell stringing and string applique machine which will be flexible in design, capable of handling a variety of cells and assembling strings of cells which can then be placed in a matrix up to 4' x 2' in series or parallel arrangement. The target machine cycle is to be 5 seconds per cell.

This machine will be primarily adapted to 100 MM round cells with one or two tabs between cells. It will place finished strings of up to twelve cells in a matrix of up to six such strings arranged in series or in parallel. The design of the machine will be flexible so that it can be modified to handle other cell sizes, string lengths and module arrangements.

PREFACE

This is the first quarterly technical report on Contract No. 955287 between the Jet Propulsion Laboratory, California Institute of Technology (JPL) and Kulicke and Soffa Industries, Inc. (K&S). The JPL Technical Program Manager for the contract is Lloyd Sanchez.

This report covers the activity and work performed under this contract for the period of December 13, 1978 to March 18, 1979 under the supervision of Albert Soffa as Program Director, with Max Bycer as Program Manager, and Walter Vogelsberg as Technical Manager.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES

SECTION I

1. INTRODUCTION

This contract is part of the Near Term Implementation of Flat Plate Photovoltaic Cost Reduction under the Low-Cost Solar Array Project. It is directed toward accelerating the reduction in cost of any activity related to the production of flat plate photovoltaic modules during the period 1979 to 1981.

In this contract, Kulicke and Soffa Industries, Inc. (K&S) shall design, build, and deliver to the Jet Propulsion Laboratory, California Institute of Technology (JPL) an automated assembly line for a typical solar module and solar cell to be approved by JPL in accordance with the following goals:

(a) Flexible automated solar module assembly line which shall be adaptable to as many manufacturers' processes as possible.

(b) The equipment shall permit the assembly of up to a six-string module.

(c) Adaptable to permit strings to be assembled in series or series parallel relationship.

(d) Machine cycle of 5 seconds per cell.

(e) An automated solar module assembly line yield of 95% or better.

SECTION 2

2. TECHNICAL DISCUSSION

2.1 Information Gathering. In order to gather information as to the current state-of-the-art of the solar module manufacturing industry so as to be in position to meet the near term requirements of this project, K&S used the following methods:

(a) Literature Review
(b) Field trips to solar module manufacturers
(c) Consultations

2.1.1 Literature Review. In order to get an effective bibliography as quickly and efficiently as possible, K&S utilized the computer assisted information retrieval service, DIALOG, of the University of Pennsylvania. This search yielded articles from the following sources:

(a) National Technical Information Service (NTIS)
(b) COMPENDEX
(c) INSPEC

In addition, JPL forwarded pertinent technical reports from LSSA program as requested by K&S. Together, the above material formed an effective starting bibliography of reference material for the project.

2.1.2 Field Trips to Solar Module Manufacturers. Several field trips were made during the second and third month to solar module manufacturers to get their comments as to what an automated solar module assembly should consist of. The companies visited on these field trips are:

(a) Sensor Technology
(b) Spectrolab
(c) OCLI
(d) Arco Solar
(e) Solarex
(f) Solar Power
(g) Mobil Tyco

The salient points affecting machine design that were brought out on these visits are discussed in Section 2.2.

2.1.3 Consultations. K&S has retained Professor Martin Wolf, University of Pennsylvania, and Dr. Thomas Matcovich, Drexel University for this project for consultations with them in the areas of photovoltaic and micro-electronic technologies, since they both are recognized experts in these fields. There have been frequent consultations with them in these areas.

When it became apparent that the interconnect technique for near term implementation would be soldering (see Section 2.2.6), a consultation was arranged with Howard Manko, an acknowledged expert in this field. The use of solder and solder techniques in the manufacture of solar modules, and applying the best technology available that would be compatible to an automated assembly line of equipment, were discussed at great length. Mr. Manko had reservations about the reliability of a no-flux system, and strongly recommended a solder system with flux for our applications.

Further investigations into soldering techniques led to consultations with Argus, Inc. on infrared heating and Lepel, Inc. on induction heating since these two techniques lend themselves to simultaneous soldering of multiple leads (or ribbons) onto multiple pads.

2.2 Areas of Study That Affect Machine Design. The areas of study in the information gathering stage are discussed in the following paragraphs. In each paragraph are summarized the findings for the given topic as it affected machine considerations and design approach for the module assembly line to be designed and built under this contract.

2.2.1 Cell Sizes and Shapes. Most common cell sizes to be utilized for the near term are circular cells of 3 inches and 100 mm diameter and 0.010 to 0.015 inches thick. Other modules had square, hexagonal, semi-circular cells or quarter circular cells.

2.2.2 Module Sizes. The modules that were discussed had various outside dimensions with widths up to 18 inches, and lengths up to 48 inches. The number of strings varied up to five. This seems to confirm space requirements alloted for module matrix handling of 2 feet by 4 feet modules, with up to 6 strings/module.

2.2.3 Top Surface Treatment. Top surfaces were treated to maximize collector efficiency either by a texturize etch and/or a spray-on anti-reflective coating. Because of the ease in which microscopic pinnacles are fractured from the texturized surface, it was suggested that the equipment be designed to minimize any cell handling requirements touching the top surface of the cell.

2.2.4 String Configurations. Some modules had their cells interconnected in a continuous series of strings while others had several series of strings joined in parallel via the interconnect on the back plane or bus bar of the module. In some of the observed strings the end cells were oriented differently than the other cells in the string in order to be in position to make a series interconnect to a cell in the next string. Some modules were arranged so that all the cells in a given row of the module were not part of the same string.

The machine to be built will be designed to handle modules with all the cells in a given row as part of the same string with the cells in each string oriented the same way so as to be more compatible with an automated assembly line.

2.2.5 Interconnect Configurations. The cells observed had various interconnect configurations. The ribbons observed were both solid material and mesh ribbons. The cells had various number and length of interconnects from one short tab (ribbon interconnect) to two interconnect ribbons running the full length across a 100 mm cell. These interconnects had various bond patterns from a single bond to a series of up to 25 bond pads per ribbon on each of two ribbons (for a total of 50 bonds on a side). The cantilever overhang of the ribbons ran from a short distance (approximately 1/4 inch) to over 3 inches long.

Optimum interconnect configuration for machine considerations would be to have a minimum cantilever length beyond the cell and be of sufficient stiffness and cross-section to facilitate handling in assembly equipment.

2.2.6 Soldering as Interconnect Technique. The solar module manufacturers who were visited presently are using some kind of solder technique for making their interconnects on both top and bottom surfaces as well as making the interconnects of the cell string to the back plane or bus bar of the module assembly. These manufacturers indicated that it would be desirable for the equipment to incorporate a soldering technique that would meet their requirements.

Some of the soldering techniques utilized are:

(a) Pulse/Parallel Gap
(b) Steady State/Soldering Iron
(c) Infrared Heating
(d) Induction Heating
(e) Laser
(f) Vapor Phase Reflow

Induction heating will be utilized as the soldering technique because it lends itself well to diversity of interconnect configurations to be handled by the machine, the ability to bond multiple pads simultaneously, and the cleanliness of tooling and speed of soldering.

2.2.7 Testing of Tabbed Cells and Strings. A requirement for the machine is to deliver tested cells and strings to the module matrix. The solar module manufacturers incorporated a testing of strings as part of their manufacturing operation. The design approach in the machine to be built is to test each string interconnect after it has been made. Through microprocessor control any rejected cells and strings will be placed in a reject station.

2.2.8 Fluxing Operation. Each of the solar module manufacturers included a fluxing operation as part of the soldering technique in making the interconnects. They indicated that they would prefer to maintain this step as part of the process. This operation has been incorporated in the machine design for attaching both the 1st and 2nd (string) interconnects.

2.2.9 Cleaning Operation. Each of the solar module manufacturers incorporated a cleaning or defluxing operation after the tab interconnects were made. While a cleaning station is not part of the machine to be built, the design approach for the machine is to accomplish this function after the module matrix interconnects have been made and clean the entire matrix at one time.

2.3 Design Review. A preliminary design review took place at the K&S plant in Horsham, Pa. on March 14, 1979 by Lloyd Sanchez,JPL Technical Managerfor the contract. The background leading up to the machine considerations and design approach of the machine was discussed at this meeting. A formal design review is to take place at a presentation at JPL on March 21, 1979.

2.4 Proposed Machine System. The machine which Kulicke and Soffa will build is a cell stringing and string applique machine which will be flexible in design, capable of handling a variety of cells and assembling strings of cells which can then be placed in a matrix up to 4' x 2' in series or parallel arrangement. The target machine cycle is to be 5 seconds per cell.

This machine will be primarily adapted to 100 MM round cells with one or two tabs between cells (see Figure 1). It will place finished strings of up to twelve cells in a matrix of up to six such strings arranged in series or in parallel. A typical module to be processed in the machine is shown in Figure 2. The design of the machine will be flexible so that it can be modified to handle other cell sizes, string lengths and module arrangements.

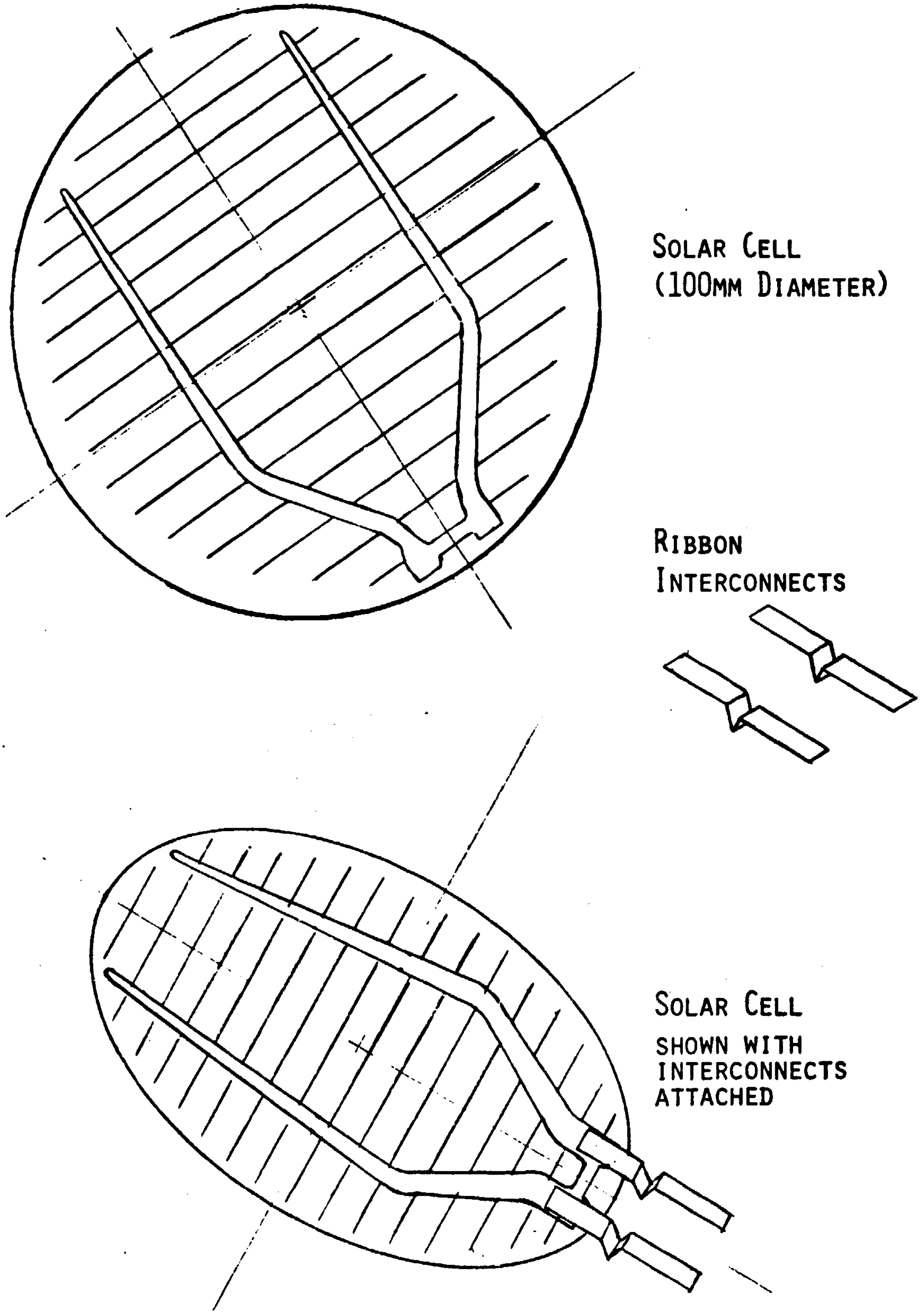


FIGURE 1 - TYPICAL SOLAR CELL AND INTERCONNECTS

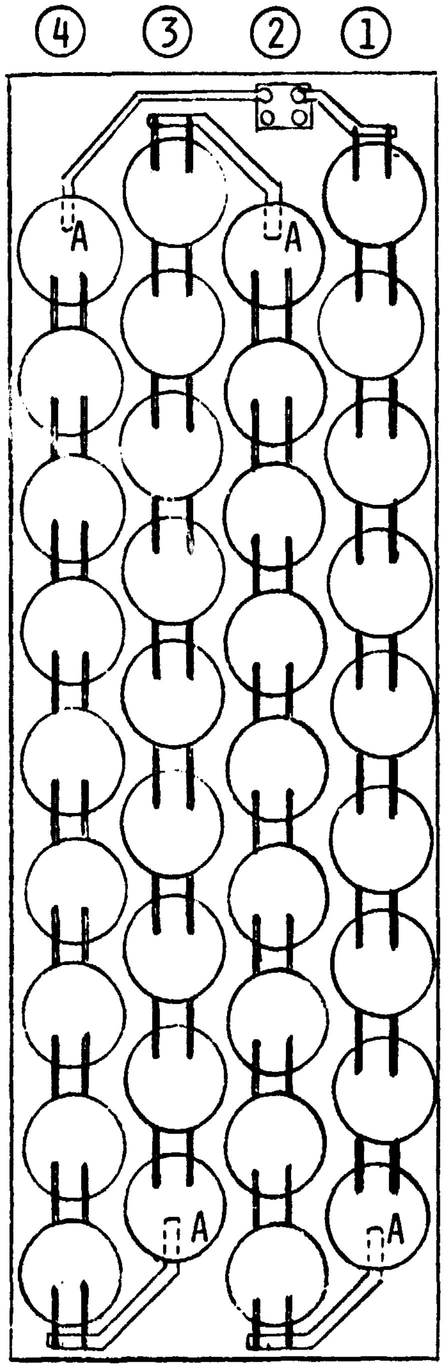


FIGURE 2 - TYPICAL MODULE

THIS MODULE HAS 4 IDENTICAL STRINGS IN SERIES AND REQUIRES MANUAL INTERCONNECTION OF THESE STRINGS AT 'A' (4 PLACES) AFTER THEY HAVE BEEN PLACED IN THE MATRIX.

The machine to be built (see Figure 3) will have a station where cells are automatically dispensed from a 25 cell cassette and are conveyed by belts to a receiving station. From this point, each cell is to be picked up by a walking beam conveyor and placed in an orientation station. In this station the cell is to be rotated and automatically positioned optically so that the pattern is in position for tabbing. Flux is then to be applied to the tab assembly areas. This orientation is to be maintained in the subsequent stations until the cell has been assembled in the string. In the next station the tabs are to be formed from continuous reels of ribbon, transferred into position above the cells, solder bonded by induction heating and cut off. In the next station flux is applied on the tab extensions.

A transverse walking beam then transfers the tabbed cell to the string conveyor without loss of orientation. On this conveyor the cells are held in registration to each other. The string interconnection is made in the first station and is tested in a subsequent station. When the string is completed, it is to be picked up manually using a track-mounted vacuum lance and then appliqued into a fixture or a matrix. The vacuum lance is to maintain the intercell mechanical spacing and the track will be provided with detents to locate the strings for correct interstring spacing or placement in a reject station for those strings that did not pass the electrical test. The fixture can then be used for subsequent operations such as interstringing, external lead connections, cleaning, etc.

A more detailed discussion of each station follows.

2.4.1 Station One - Cassette Unload. This station shall contain a Siltec Model 2601A cassette load/unload module. The 2601A module is designed to unload, without adjustment, cells

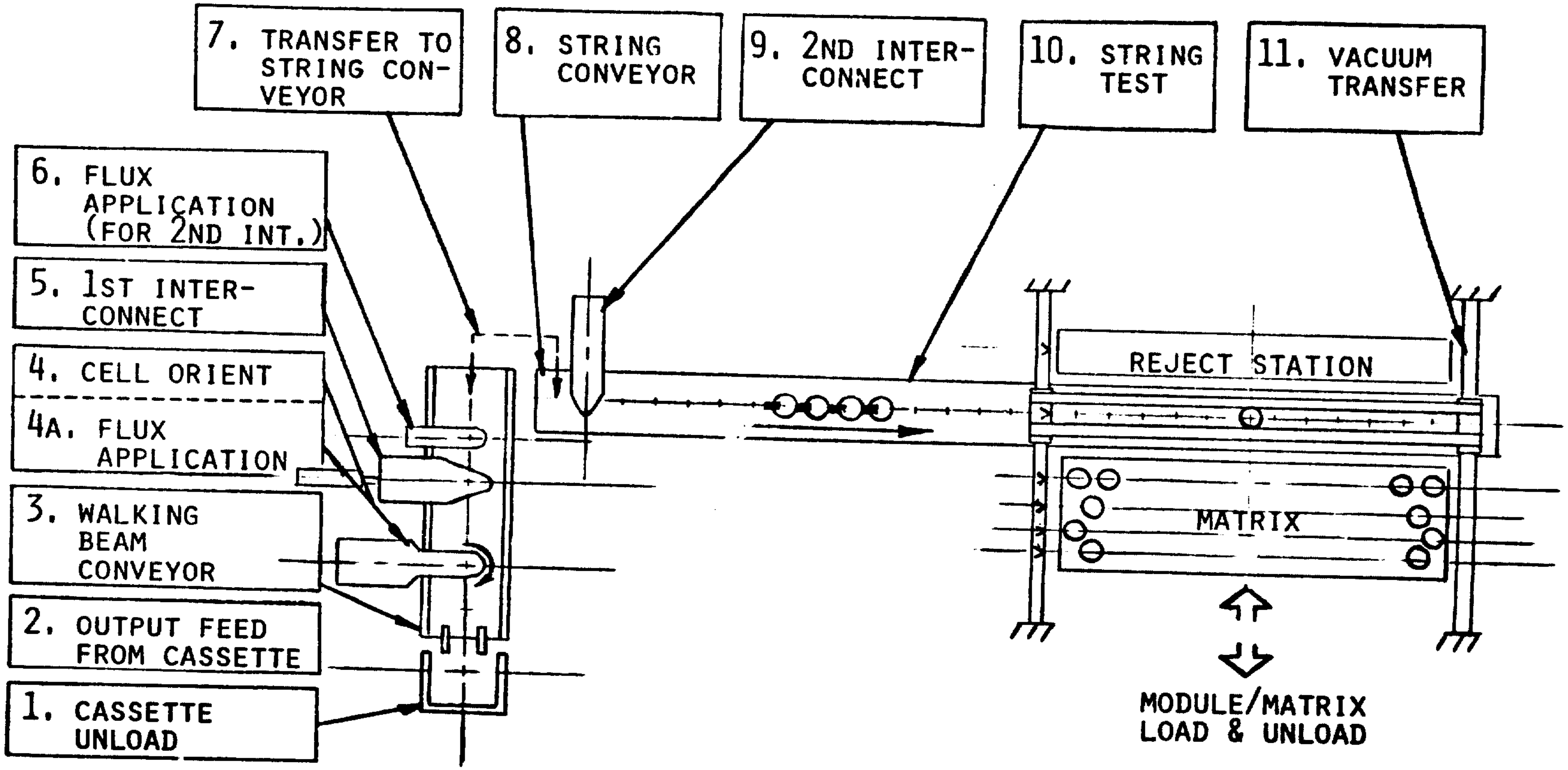


FIGURE 3 - PROPOSED MACHINE SYSTEM

from 2.0 to 5.0 inches in diameter from any standard 25-level "H"-bar bottom cassette with 3/16th inch pitch (Fluoroware PA-72 series for example). The 2601A module comes equipped with its own power supply control panel and load/unload platform providing a complete stand-alone unit. The machine will come equipped with two Fluoroware 100 mm cassettes. Both the Siltec load/unload module and the Fluoroware cassettes are widely used in the semiconductor and solar cell industry for wafer and cell handling operations. The use of these standard items will make them compatible to other equipment for this program. It should be noted at this point that while the overall machine frame can accept a wide range of sizes, the machine will be designed for 100 mm cells.

2.4.2 Station Two - Output Feed From Cassette. In this station the solar cells, which are automatically dispensed from the unload module in Station One, will be conveyed by belts to a receiving station from which they will be indexed through the machine.

2.4.3 Station Three - Walking Beam Conveyor. Walking beam conveyor refers to the indexing system that moves the cells through the various stations until it is transferred onto the string conveyor. Essentially the walking conveyor is a mechanism which picks up each cell individually, advances it to the next station where the cell is deposited for the function of that station after which the mechanism retracts back to be in position for the next index. This indexing system will contain a drive system which is controlled by the microprocessor for the machine and a common shaft which will house all of the indexing arms for the system.

2.4.4 Station Four - Cell Orient and Flux Application. The solar cell is placed into a platform in the station where it is rotated and automatically positioned optically so that the pattern is in position for tabbing. Flux is then applied to the tab assembly areas (see Figure 4). Once the correct orientation is achieved for the cell for subsequent operations this orientation is maintained in the subsequent stations until the cell has been assembled into a string on the string conveyor.

2.4.5 Station Five - First Interconnect. In this station the interconnect tabs are formed from continuous reels of ribbon, transferred into positon above the cells, soldered bonded by induction heating and cut off (see Figure 5). Figure 6 shows a schematic of the induction heating tooling at the point of bonding. The cell with its solder on its top surface had flux applied in Station No. Four (see Section 2.4.4). The ribbon interconnect is fed from reels until it is in position, at which time the resilient pressure pad of the tooling descends vertically to maintain contact between the ribbon and the fluxed solder pad. The induction coils are then fired to accomplish the soldering action.

There will be a back-up support block at this point of force application to protect the cell. The pressure pad will hold the ribbon in contact with the fluxed solder pad of the solar cell during the bond and cool-down cycle while the soldering operation is performed. The design of the induction coil with its concentrator will be optimized for the sample cells to be run through the machine for testing purposes.

The ribbon feed system at this station will utilize large reels of ribbon so as to minimize the necessity of frequent changes. This feed system will be designed to accommodate a variety of widths and lengths of ribbon. The mechanism

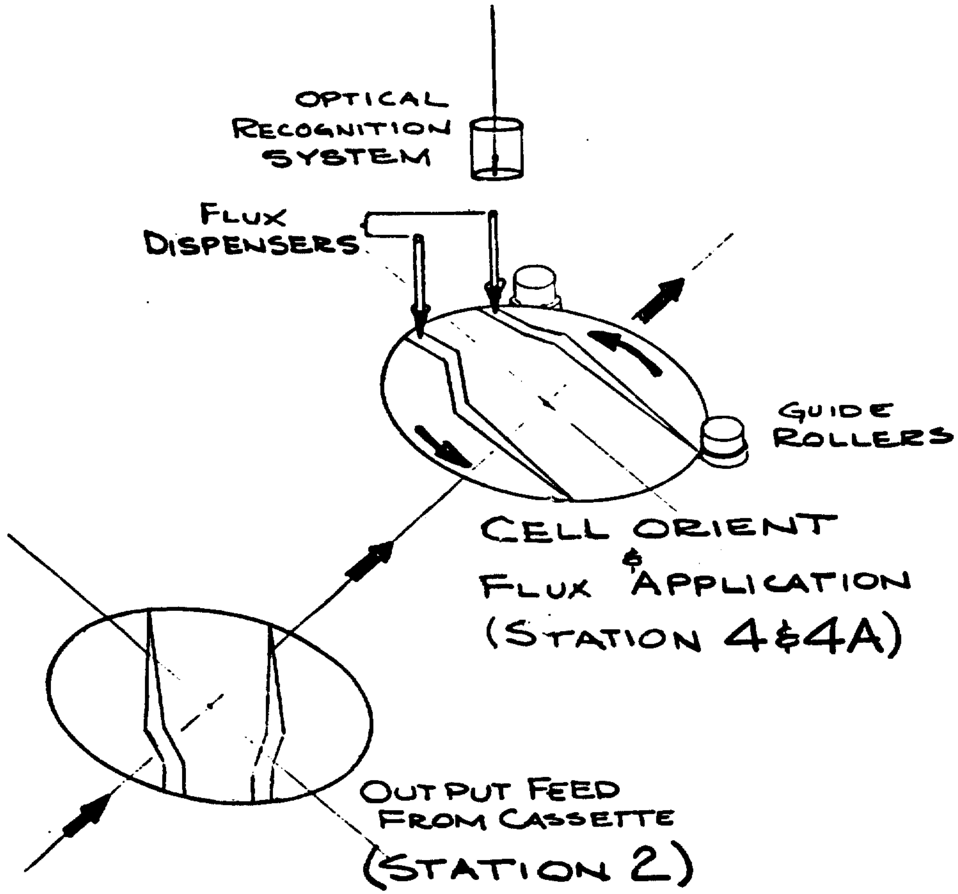


FIGURE 4 - CELL ORIENT AND FLUX APPLICATION STATION

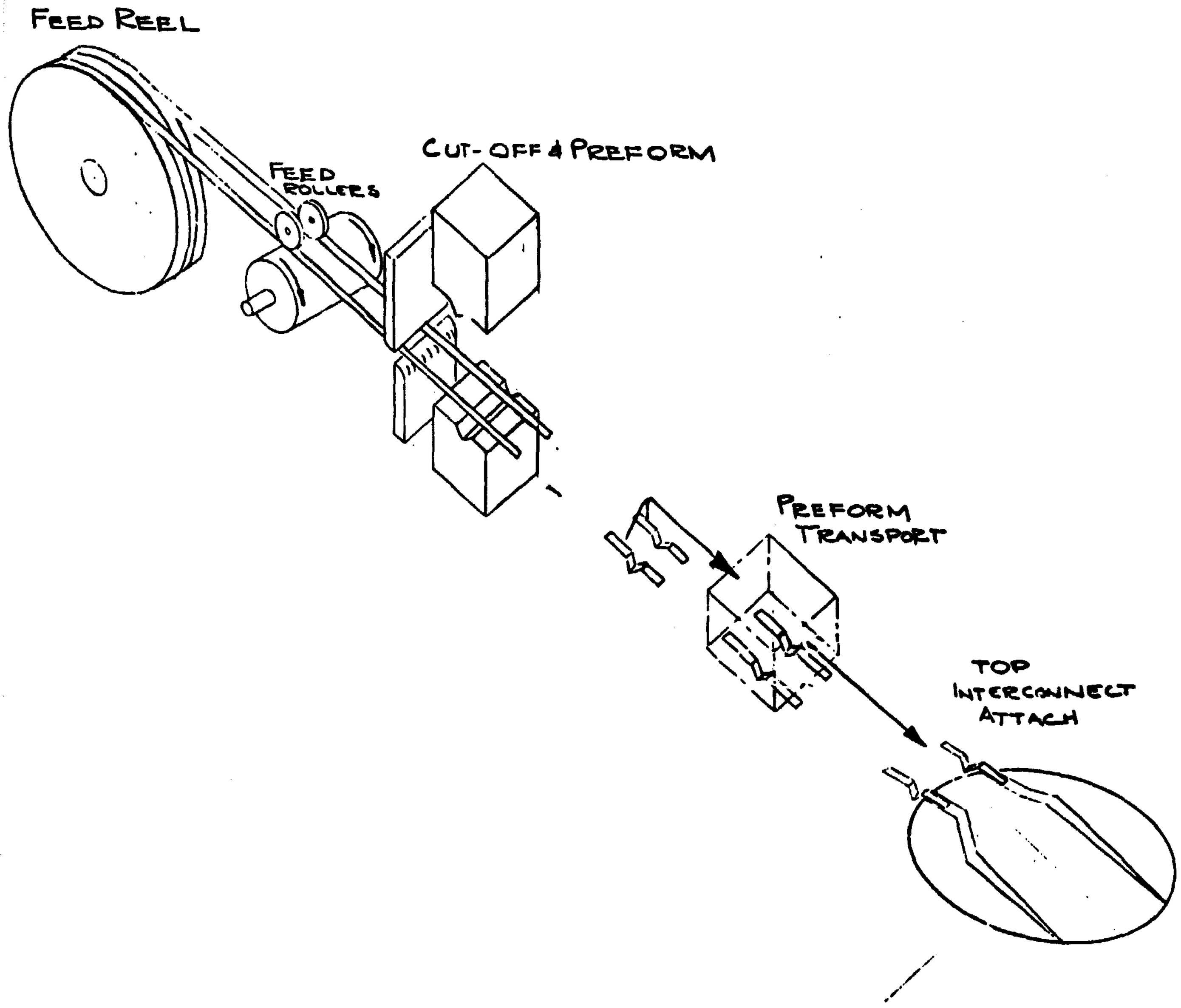


FIGURE 5 - FIRST INTERCONNECT STATION

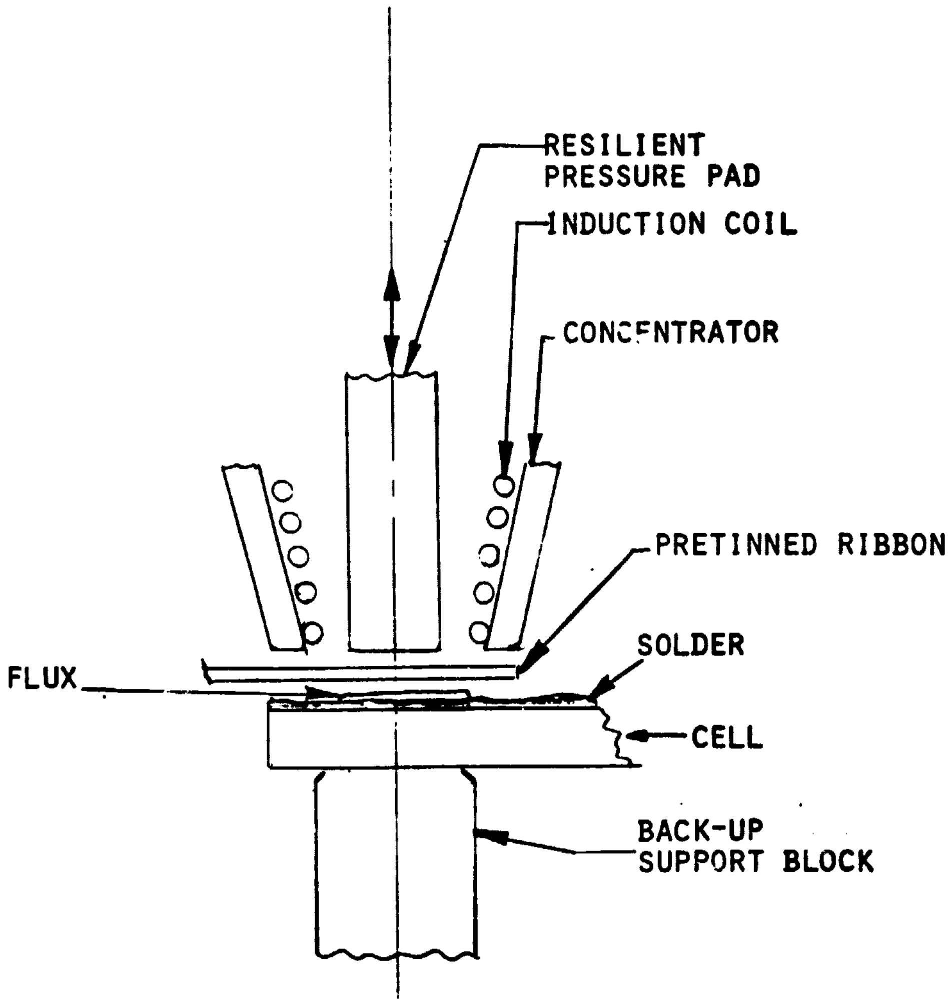


FIGURE 6 - BOND SOLDERING METHOD- 1ST INTERCONNECT

INDUCTION HEATING

will feed, cut off and form the strain relief as part of the ribbon feed operation. The station will be designed to feed and bond one or two ribbons per cell.

2.4.6 Station Six - Flux Application for Second Interconnect. After the cell is indexed into this station by the walking beam conveyor, flux is applied to the tabs in preparation for accomplishing the stringing interconnects (see Figure 7).

2.4.7 Station Seven - Transfer to String Conveyor. This station will utilize a walking beam indexing mechanism that will pick up the tabbed cell from the last position on the walking beam conveyor and transfer it to the string conveyor without loss of orientation (see Figure 8). In Step A, the first cell of any string is placed in position 1 on the string conveyor. In Step B, the next cell of the string is placed in position 2 where its leading edge overlies the tabs that project out from the cell in the first position on the string conveyor. This eliminates the need for tucking of the cells prior to the accomplishing of the second interconnect. Step B is repeated for the remainder for the cells in any particular string.

2.4.8 Station Eight - String Conveyor. The string conveyor holds the location of the cells and maintains their registration between each other within each string. The string conveyor will be able to handle the cells active side up or active side down. The positioning fixtures on the conveyor will touch the cells on their edges only (see Figure 9).

The string conveyor will be programmed to advance the cells one intercell pitch after the second interconnect is made. Upon completion of each string there will be a

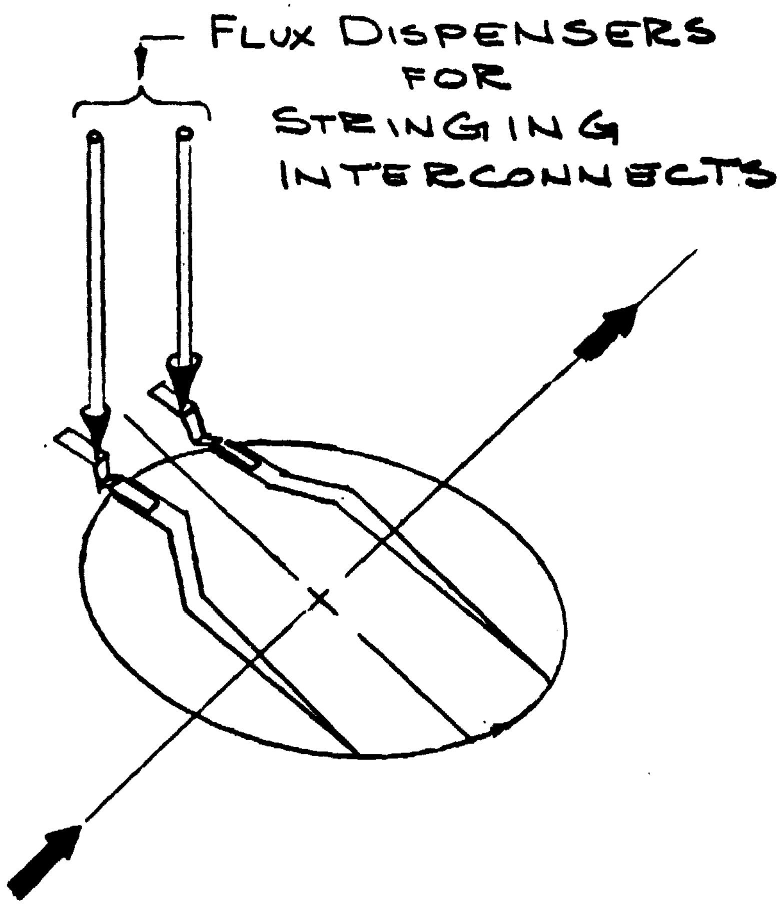
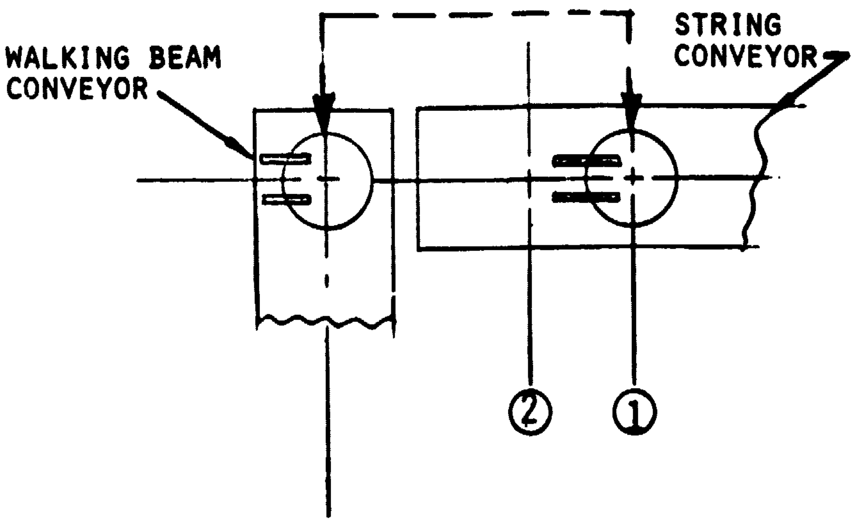
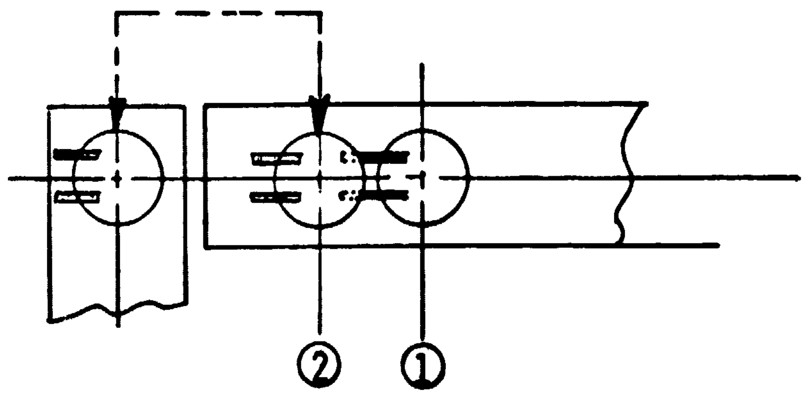


FIGURE 7 - STATION 6 FLUX APPLICATION
FOR STRINGING INTERCONNECTS

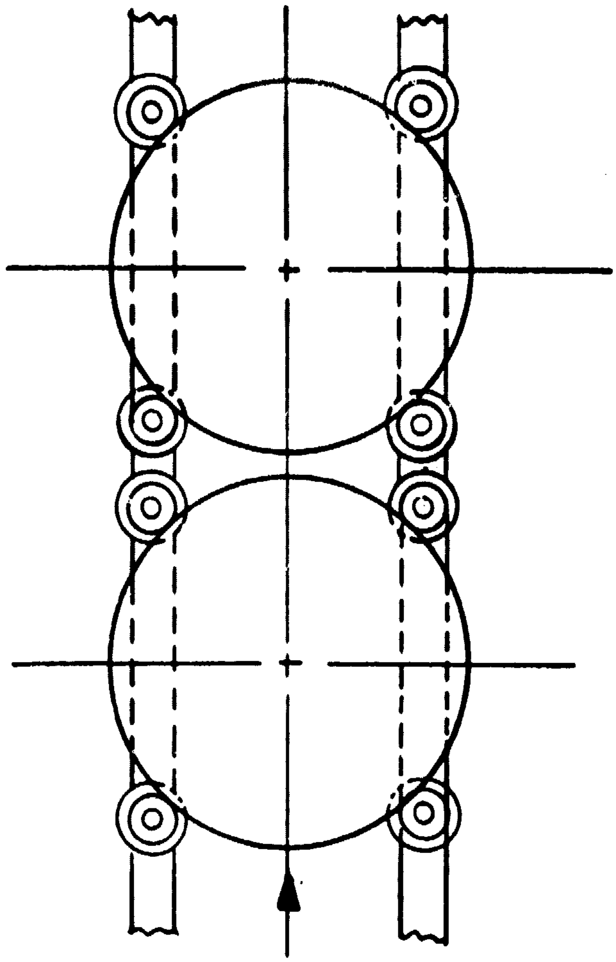


A. FIRST CELL OF STRING IS PLACED IN POSITION #1

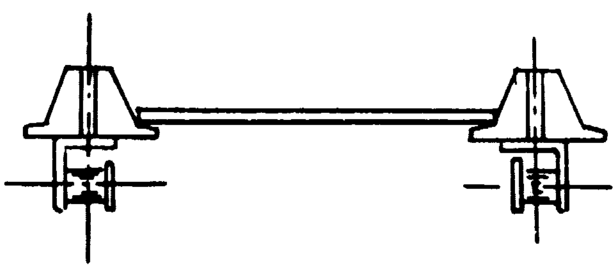


B. NEXT CELL OF STRING IS PLACED IN POSITION #2 TO ELIMINATE NEED FOR TUCKING. THIS IS REPEATED FOR REMAINDER OF CELLS IN A PARTICULAR STRING.

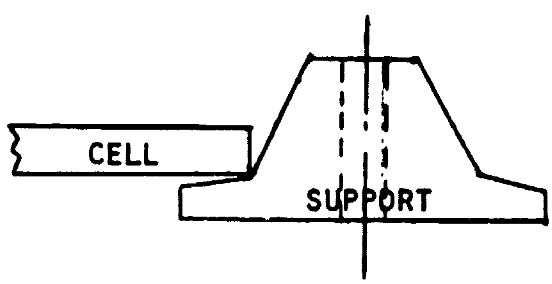
FIGURE 8 - TRANSFER TO STRING CONVEYOR



PLAN VIEW OF STRING CONVEYOR



CROSS-SECTION



ENLARGED VIEW OF CELL SUPPORT

FIGURE 9 - STRING CONVEYOR

double index to create a separation between strings for further handling, such as in the vacuum transfer system (see Section 2.4.11).

2.4.9 Station Nine - Second (String) Interconnect. This string interconnection is made in the first station on the string conveyor. The interconnect technique is the same as in the first interconnect station - induction heating. Since this second interconnect is on the front-to-back preform the interconnect will be made on the bottom side of the cell. Therefore, the tooling will be inverted to accomplish this operation (see Figure 10).

2.4.10 Station Ten - String Test. After the second (string) interconnection has been made, an electrical test is performed to verify that a proper connection has been accomplished between each succeeding pair of cells. This electrical test will be a forward bias test as shown schematically in Figure 11. Any cell not passing this test will be so noted in the microprocessor control system and be placed in the reject station after it arrives at the vacuum transfer station (see Section 2.4.11). The electrical test at this station will be performed in controlled ambient light to minimize any variations that could affect the readings taken in the test.

2.4.11 Station Eleven - Vacuum Transfer. After the string is completed it is indexed into the vacuum transfer system by the string conveyor. At this point it is picked up by a vacuum lance which is then moved manually on a track and the string is appliqued into a fixture or a matrix in the module. The vacuum lance will maintain the proper intercell mechanical spacing of the strings and the track will be provided

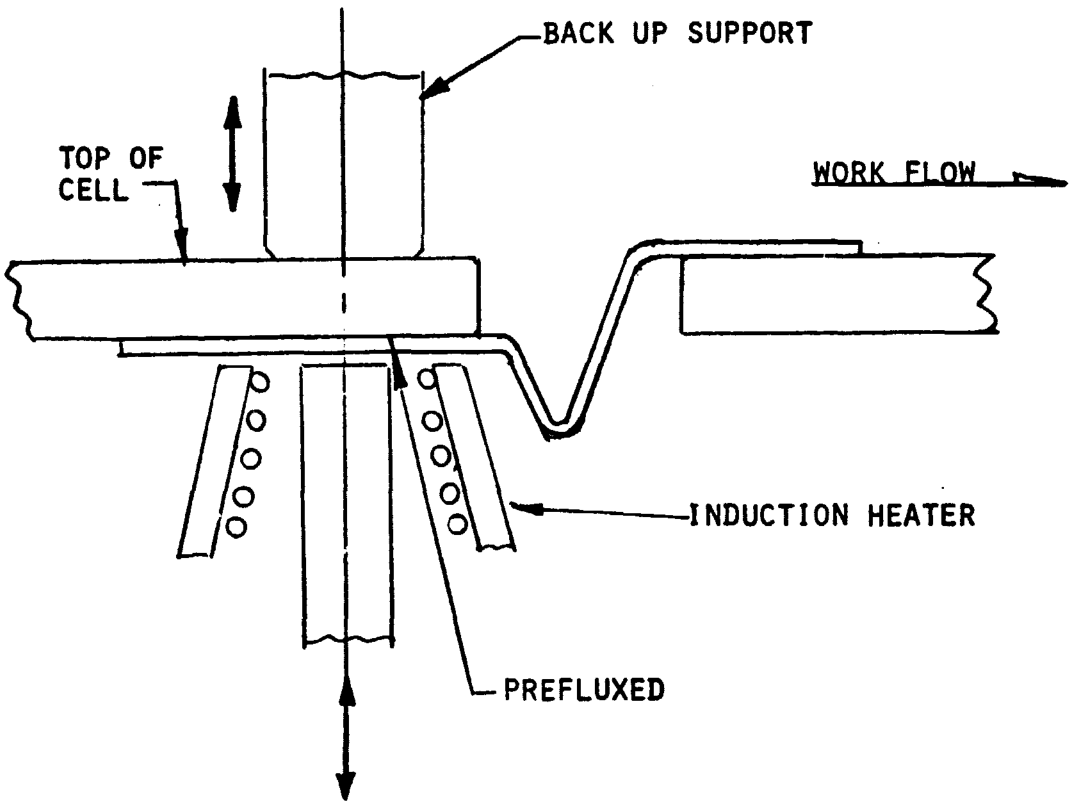
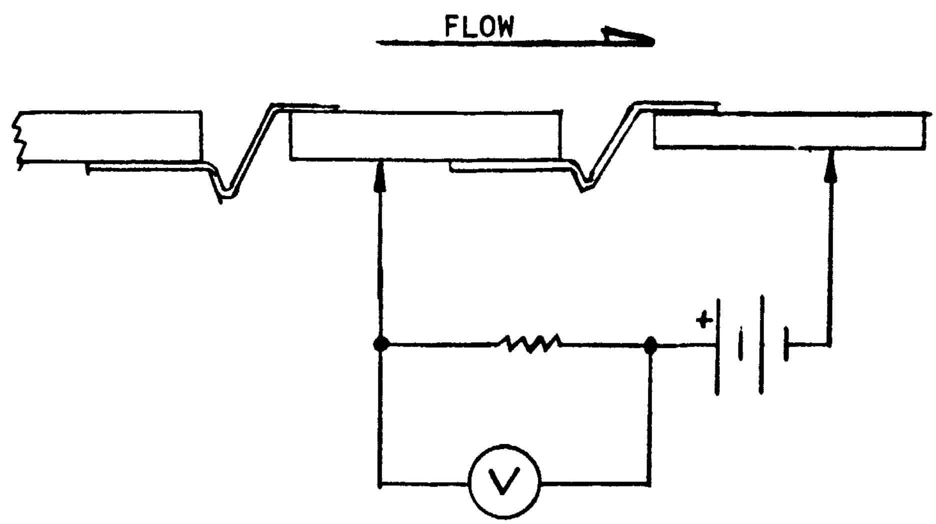


FIGURE 10 - SECOND INTERCONNECT STATION-

-FOR FRONT TO BACK PREFORM

-INTERCONNECT TECHNIQUE SAME AS FIRST INTERCONNECT STATION.



FORWARD BIAS TEST - AFTER EACH 2ND INTERCONNECT IS MADE

FIGURE 11 - STRING TEST

with detents to maintain the correct interstring spacing (see Figure 12). This vacuum lance will also be able to deliver any rejected strings to a reject station which will have its own detent position.

The vacuum lance will allow for two vacuum cups per cell and will be long enough to accommodate up to a four foot string of cells. The vacuum frame will be movable to the detented positions so that the cells can be placed on a matrix of maximum size of 4' x 2'. The matrix will have its work flow in and out from the front of the machine in reference to the vacuum transfer section.

The vacuum lance will be able to accomplish interdigitation of successive strings by being rotated 180 degrees within the vacuum frame (see Figure 13). This half pitch interdigitation is accomplished by having the center of rotation being offset one-quarter cell pitch. The interdigitation will accomplish the string reversals for series strings of a given module.

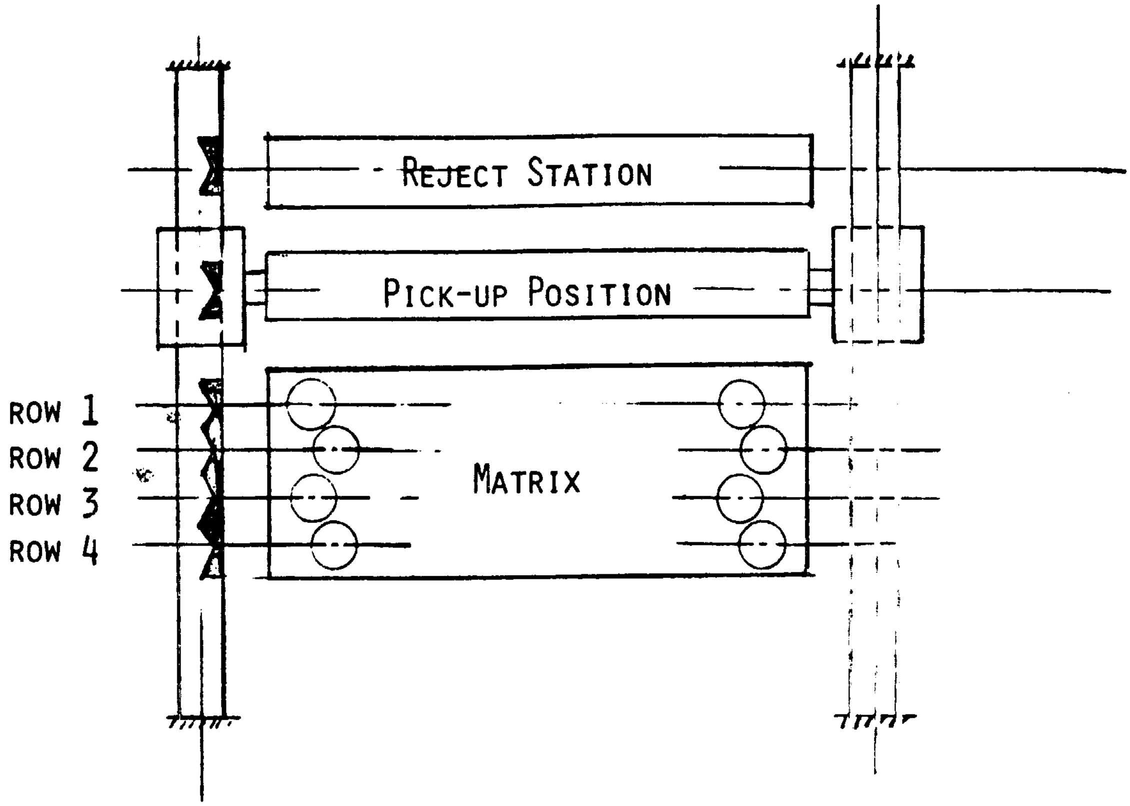


FIGURE 12 - VACUUM TRANSFER SYSTEM
DETENT POSITIONS

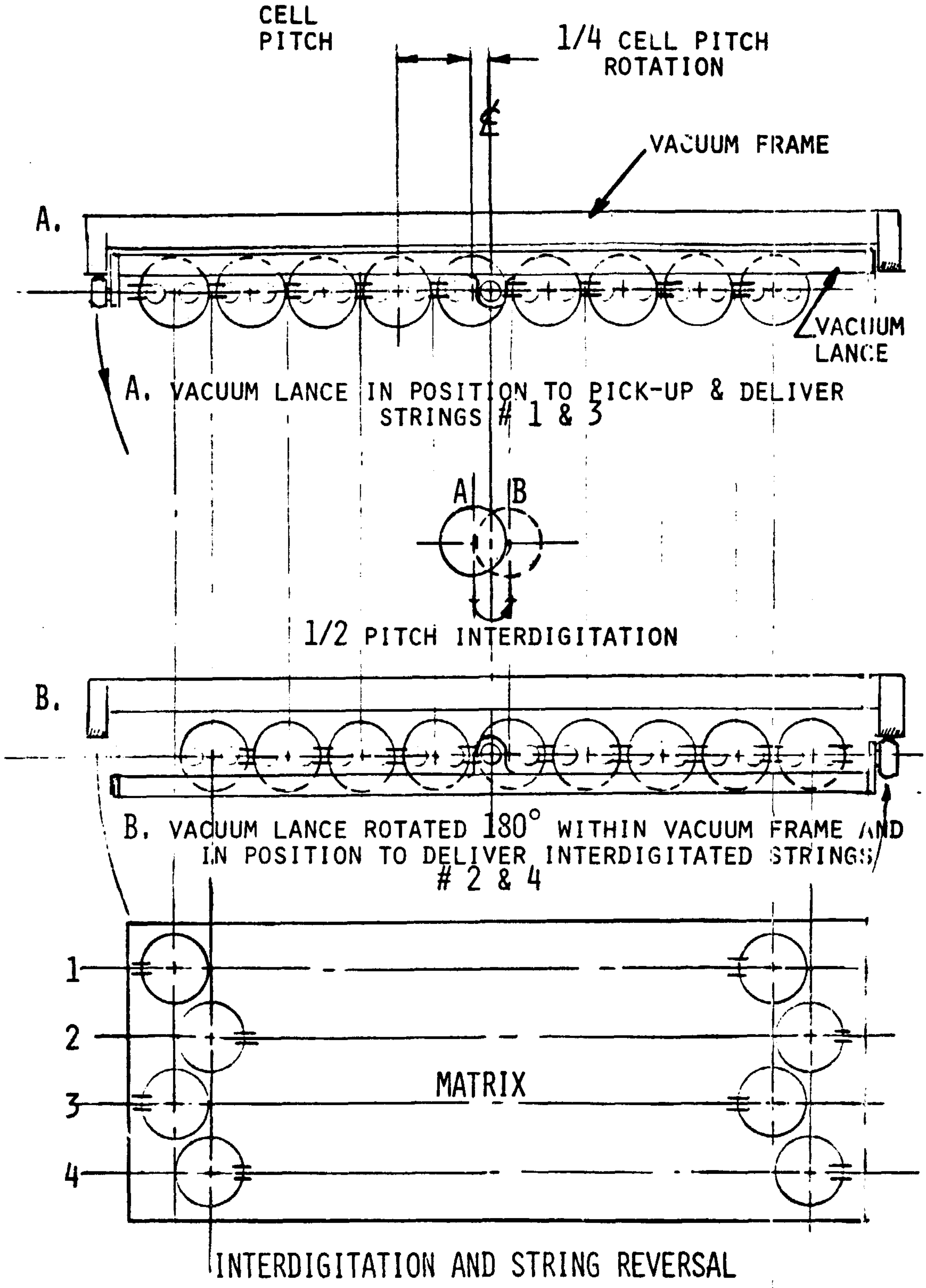


FIGURE 13 - VACUUM TRANSFER SYSTEM
INTERDIGITATION AND STRING REVERSAL

3. WORK PROGRAM FOR SECOND QUARTER

In addition to the design review to take place at JPL on March 21, 1979, K&S will make a presentation at the PIM meeting scheduled for April 3rd and 4th, 1979.

In the technical part of the program, the next quarter will see the completion of the sequence of events of the machine which leads to the determination of control requirements and the start of writing programs for the microprocessor. Development programs and layout design for the machine will proceed with emphasis on those areas that have long development cycles, such as the interconnect stations, string conveyor, cell orient and flux applications and vacuum transfer system.

4. PROGRAM PLAN

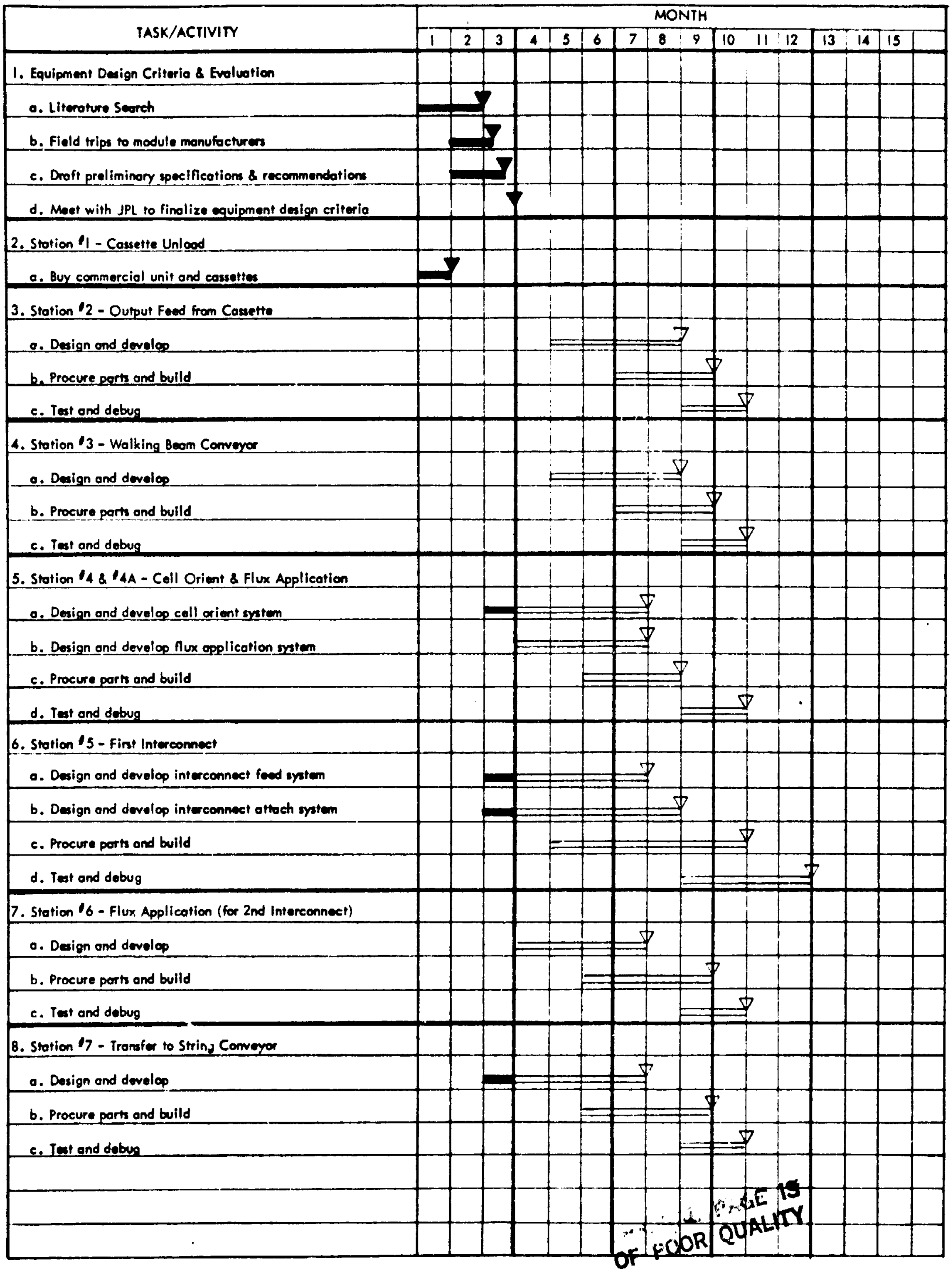
The program plan reflects the proposed machine as a result of the design review, and is broken down into the various general tasks and specific stations of the proposed automated module assembly line. This format was chosen to give a breakdown of tasks, activities, and milestones for efficiency in monitoring the progress of the project. The current status of the program plan is shown on the following pages.

KULICKE and SOFFA
INDUSTRIES, INC.

PROGRAM PLAN

Contract #955287
Sheet 1 of 2

Legend:
- ▽ Projected Milestone
- ▼ Completed Milestone
- Projected Activity
- Completed Activity
- Revised Activity
- ◊ Revised Milestone
- ♦ Completed Revised Milestone



KULICKE and SOFFA INDUSTRIES, INC.

PROGRAM PLAN

Contract #955287
Sheet 2 of 2

Legend:
▽ Projected Milestone
▼ Completed Milestone
Projected Activity
Completed Activity
Revised Activity
◊ Revised Milestone
♦ Completed Revised Milestone