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Summary of Microminiaturization Program - FY 1959 (U)

Israel Rotkin

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4 August 1959 TR-760

SUMMARY OF MICROMINIATURIZATION PROGRAM—FY 1959 (U)

Israel Rotkin

FOR THE COMMANDER
Approved by

Maurice Apstein
Associate Director for
Supporting Research

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CONTENTS

FOREWORD (U)

This report summarizes the miniaturization work at this installation during FY 1959. A brief historical introduction and the status of this work as of the end of FY 1958 are given in reference 1. The current work is aimed at two objectives—first, to meet the immediate needs of the weapons program with effective short-term development efforts; and second, to anticipate and provide for future requirements through research.

When there is an immediate need for miniaturization of a specific system unit, the work is usually accomplished with proven techniques that can be quickly adapted to the problem. Also, techniques under research may be accelerated through development and testing if they appear to offer a solution. There are occasional opportunities to miniaturize entire systems when they evolve from research projects at these laboratories.

The research program to meet future needs has progressed to the point that there is an evident potential for at least a 10-to-1 improvement over the most advanced miniaturization methods now in use. The fabrication of extremely small subassemblies is based on techniques for placing all the elements of a single basic circuit on or just below the surface of a small ceramic wafer. The techniques are adaptable to many low-power circuits. Compared with circuit mountings now in use, even those considered miniature, the individual wafer circuits are essentially two-dimensional, hence the nickname "2D." The basic circuits may then be handled as components, a large number of them being interconnected to perform complex functions.

Volume, weight, and susceptibility to acceleration damage are drastically reduced by 2D techniques, and the power requirements are usually lower. On the other hand, the circuit elements, being thin and of slight mass, are more readily affected by temperature changes and by humidity Therefore, the wafer circuits must be protected from the external environment, either collectively or individually. Since the wafers are so small, even when grouped into a complex, hermetic sealing does not appear to be a serious problem. Techniques for canning or potting, and for sealing the separate elements within the wafers are being developed. Because the dimensions of each element are reduced tenfold or more, the electrical characteristics tend to have broader tolerances than are customary in conventional parts. Systems that incorporate them have to be designed to operate properly with such elements.

While further laboratory investigation of the 2D approach continues, contracts have been let for the industrial production of pilot lots of NOR and binary divider circuits. These contracts develop production methods and supply 2D wafers in quantities large enough to permit extended investigations of reliability and systems design.

Referenced technical reports and monthly letter reports are on file at the Army Ordnance Missile Command, Redstone Arsenal, Alabama, and at the Technical Reference Branch, Diamond Ordnance Fuze Laboratories. Where such reports are still in process, more detailed information is given in this report.

ABSTRACT (U)

The miniaturization work dates back to 1941 and stems from research and development on proximity fuzes and related items. Significant advances in miniaturization during FY 1959 are summarized briefly. Investigations of techniques, components, assemblies and systems are described. References are cited in which detailed information can be found.

1. SYSTEMS

1.1 (C) Light-Weight GM Fuzing System

A light-weight radio proximity fuzing system (figure 1), complete with power supply and safety-and-arming device, has been designed for the Missile-A class of short range tactical missiles. This system, designated "Copperhead," uses dual components throughout for reliable operation, yet weighs only 15 lb.

The low weight has been achieved [illegible]sing (1) a transmitter operating at a frequency which does not require a magnetron, nor the complex and heavy power supply associated with a magnetron or klystron; (2) completely integrated cellular-aluminum structure; (3) microstrip r-f head; (4) simplified antennas (new slotted types or spiral); (5) an extremely compact safing, arming, and programming device (figure 2); and (6) transistors, wherever possible, to replace vacuum tubes.

Further research will emphasize the development of more sophisticated arming systems to accommodate correspondingly more sophistocated firing and guidance systems.

1.2 (U) The Cigarette Fuze

During this period a subminiature proximity fuze was developed. Because of its small size, it has been named the "Cigarette Fuze" (figure 3). Since performance details are classified "SECRET", further information cannot be given in this report without upgrading the classification of the entire document. Additional technical data is contained in references 2 and 3.

1.3 (U) Rangefinder

The first model of a man-portable, battery-powered radar rangefinder is now under test. It should have wide application wherever

Figure 1. Model of light-weight Copperhead fuze system.

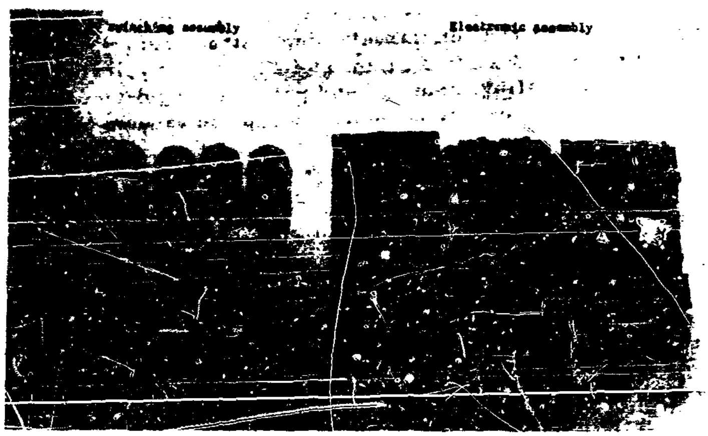


Figure 2. Copperhead fuze system electronic programmer.

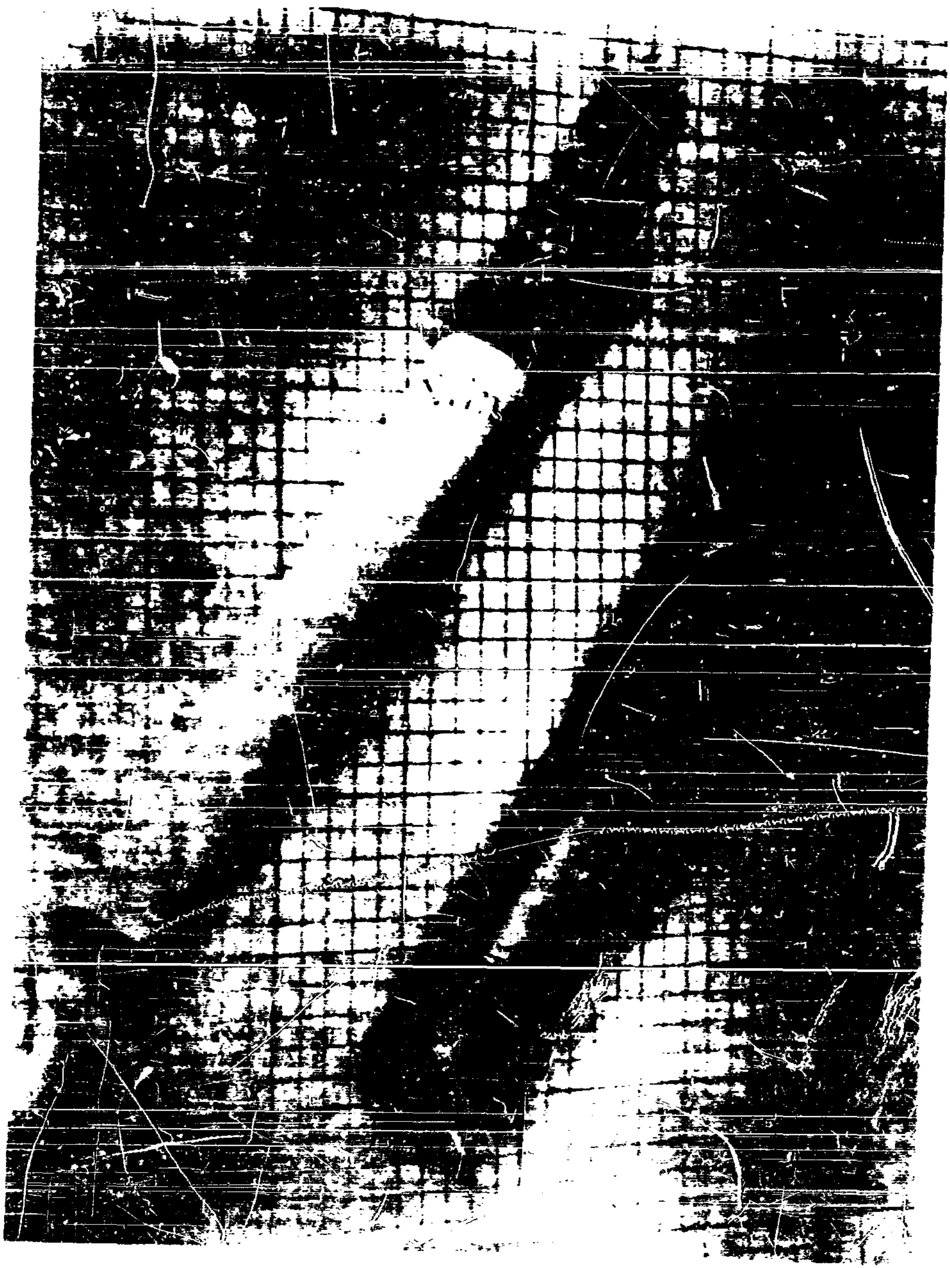


Figure 3. Cigarette fuze package.

accuracy and light weight are premium requirements, as in artillery and weapon systems of the Davy Crockett type. An earlier version of the Short Pulse Radar Rangefinder, showed an accuracy of 0.02 percent. The research model, employs a new statistical averaging technique and a direct digital readout. In 200 measurements of ranges from 100 to 3500 ft, the deviation of range error was 0.6 ft.

The short-pulse radar operates with a 10 mμsec 100 w pulse developed and processed in an electronic package that is smaller than a shoebox and weighs only 7 lb. Antennas, power supply, and oscilloscope used in the above-mentioned tests were laboratory accessories.. These auxiliary units are now undergoing specialized development. Two methods for increasing capability for target identification are included in this development: first, a mapping capability of the radar with a narrow-angle B scan; and second, a delayed and expanded range display showing the target area in azimuthal and distance detail (ref 4).

1.4 (C) Command System Miniaturization

As a result of the assignment to miniaturize a receiver and a decoder used in missile command systems, suitable equipment, already in production, has been located. The first effort of personnel assigned to this project was an investigation of the "state of the art," through correspondence, consultation with other agencies, and visits to commercial firms. Eventually, it was found that a contractor to the U. S. Navy BUAER was producing a 2.75 lb, 36 cu in. model of the decoder, which was originally 10 lb in weight and occupied 254 cu in. By this time, the concurrent experimental work at DOFL had progressed to the point that a two-stage transistor r-f amplifier had been assembled in a shielded box made of copper-clad teflon laminate. Some of the inductors and capacitors for the circuits were formed by etching the copper surface of the laminate box sections before assembly. Parameters of the laminate and the etched components were being studied in detail. Also, considerable effort went into a study of the oscillator requirements and the quest for a miniature crystal.

By March 1959, it was apparent that, considering the advanced status of the BUAER contractor's product, little more could be gained in performance or in volume reduction without changes in basic performance requirements. By agreement between ABMA and DOFL this task was terminated and the remaining funds were transferred to the Radar Altimeter Miniaturization project (ref 5).

1.5 (C) Radar Altimeter

Two models of a simplified trajectory altimeter were delivered to ABMA. They provide an accuracy of ±75 ft. An associated ground system has been completed. The altimeter system employs components of small size, light weight, and simplified circuitry and shows ... improvement in reliability and performance characteristics.

... outstanding feature of the system is that it self telemeters. This was accomplished by making the transmitter repetition rate a function of altitude. Thus, the time and base time comparators are not missile-borne, but are in the ground equipment. This results in increased reliability and decreased volume, weight and power drain in the missile borne portion of the system. (ref 5)

1.6 (U) Radar Beacon

Of prime importance in the development of a radar beacon for ABMA is the realization of an appreciable reduction in the size and weight of the entire system. This is being done by applying the most recent advances in microminiaturization (ref 6). It has been found that much transistorization of circuits which can be used for this application has already been done by industry. Work on the development of a magnetic modulator and a triode transmitter for this system is in process in-house.

1.7 (U) Transistorized Temperature Telemeter

A unit utilizing miniature components (ref 7) has been developed for monitoring and telemetering the skin temperatures of 20-mm and 40-mm projectiles in flight. It will be very helpful in determining the effects of environmental heating on fuzes and other components used in very small projectiles. This unit, which has a telemetering range of 50-60 ft, consists of a VHF transistor oscillator, a thermocouple, and a power supply. The oscillator is frequency modulated in response to the nose temperature by the output of the thermocouple. The item has survived impacts in air gun tests in excess of 40,000 G. (See figure 4.)

1.8 (C) Transistorized Two-Gate Digital Velocity Computer

A transistorized digital computer for measuring the velocity of projectiles was developed and a breadboard model fabricated (ref 8). The unit was tested with both ideal waveforms and with simulators

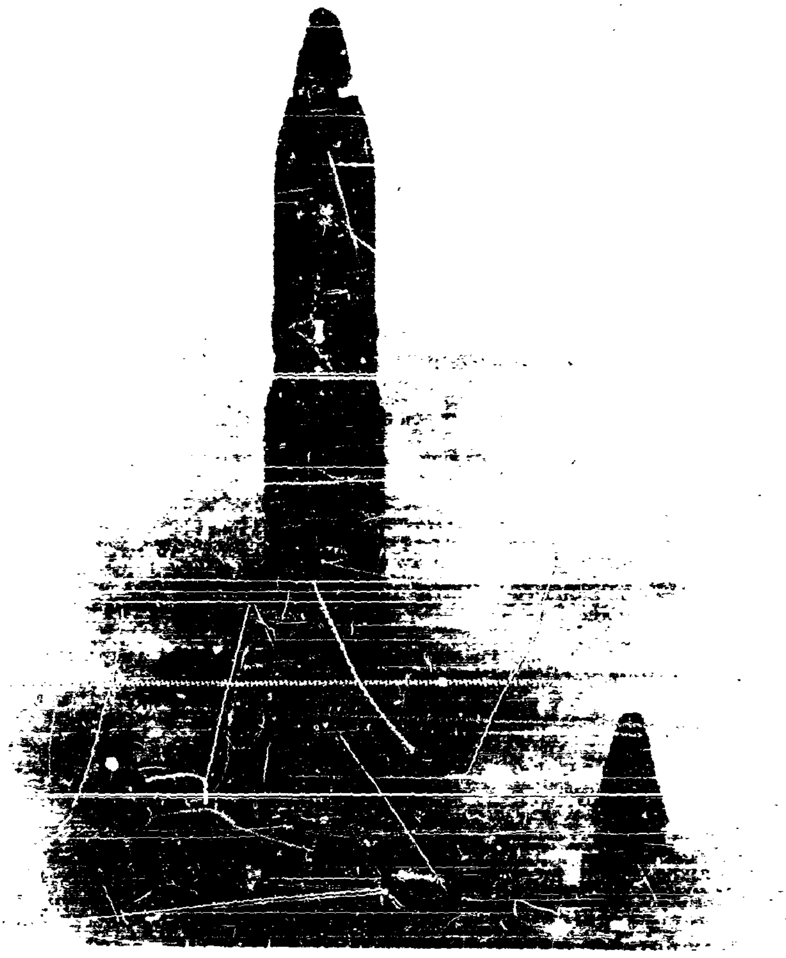


Figure 4. 20-mm Temperature telemeter.

reproducing the output pulses from optical detectors, and performance was within the computed maximum error. The system was synthesized from basic digital building blocks such as high-speed reversible binary counters, low-level voltage comparators, and high-speed coincidence circuits. Since the system consists of a number of these independent logical blocks which are merely tied together in a pattern, it should be readily adaptable to microminiaturization.

1.9 (U) Transistorized Sampling Pulse Oscilloscope

By exploiting the avalanche phenomenon in transistors to produce extremely short sampling pulses, it is possible to display on an oscilloscope of rather limited bandwidth the waveform of pulses having rise and fall times as short as 1 mμsec. Such an oscilloscope, called SPOUT (Sampling Pulse Oscilloscope Unit, Transistorized), has been developed as a by-product of work in microminiature pulse circuitry (ref 9). The sampled pulses may recur at pulse repetition rates between 500 and 10,000 cps and have an amplitude as small as 0.1 v. The oscilloscope sampling unit gives a more convenient display of repetitive pulses than more conventional means such as the traveling-wave oscilloscope.

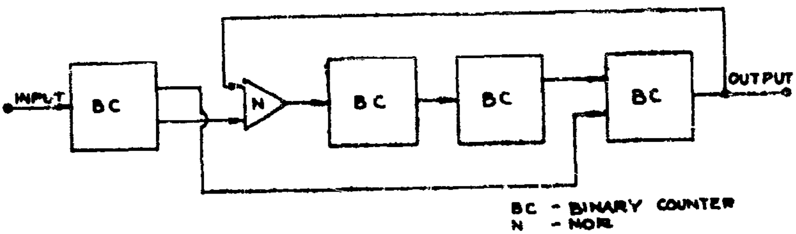
1.10 (U) Transistorized Ordnance Stethoscope

A completely transistorized-tape recorder and a single battery for supplying power have been incorporated into the transistorized electrical ordnance stethoscope previously designed (ref 10 and 11). The stethoscope, which is now more rugged, versatile, and reliable, replaces the much larger, standard vacuum-tube type of stethoscope for use in explosive ordnance disposal. Other modifications were made to improve the electrical performance, reliability, and environmental capability.

2. COMPONENTS AND ASSEMBLIES

2.1 (U) Improved Decade Counter

An inherently more reliable decade-counter circuit has been developed as part of the microminiaturization program. Decade counters for computer and control network applications are basically stacked binary counters, which unmodified, would produce an output pulse whenever 16 input pulses had been accumulated. Feedback circuits are added to restore the initial circuit condition after the tenth input pulse to produce the desired decade-counter performance. Unfortunately, in customary design, signal delay in the feedback circuit has made for marginal performance due to the feedback pulses arriving too late to perform their proper function, requiring more than ten input pulses to produce one output pulse. The improved decade counter (see block diagram below) includes a blocking NOR gate circuit in the feedback loop so that delays do not affect proper operation.



Novel Decade Counter

2.2 (U) Compact Ferrite Duplexer-Detector

A duplexer-detector has been designed and built which has advantages of small size, light weight, few component parts, no external circuitry, and at least 35-db receiver isolation over a frequency range greater than 200 Mc (ref 12). This duplexer utilizes the nonlinear properties of spinel-structure materials (ferrites) to permit simultaneous transmission and reception of short pulse radar signals. Use of this duplexer-detector should greatly simplify many microwave systems.

2.3 (C) Miniature Magnetron

A miniature millimeter-wave magnetron producing 1-kw peak output at 10-percent efficiency with 3500 v applied was successfully operated recently. The design is based on low-field operation first reported by Columbia University. The weight of the package is only 2.5 lb. Because of the low voltage, it should be possible to short pulse the 70-kMc source, and hence this magnetron is the first step toward highly accurate, portable range-finder and battlefield-surveillance systems with sufficient angular resolution -- less than 0.5 deg -- for radar presentations of television-type definition. This further opens the door to fuze systems operating in the secure band, and to recognition devices based on exact electrical signatures of vibration and motion (ref 13).

2.4 (U) Amplifiers

A miniaturized, wide-band amplifier, occupying a volume of 0.7 cu in. and weighing 0.5 oz has been developed (ref 14). This small package consumes 0.2 w at 12 v and has 65 db gain, 50 kc to 60 Mc bandwidth and 1-v output across a 1000-ohm impedance. It replaces wide-band distributed amplifiers of relay-rack dimensions. The amplifier is to be used in a miss-distance indicator and other short-pulse radar equipment, and as a general purpose amplifier where bandwidths of this order are required (figure 5).

Another transistorized amplifier, for use in short-pulse, high-resolution equipment, has 26-db gain, and a 50-Mc bandwidth at a center frequency of 425 Mc. It uses mesa-type transistors, and has a noise figure of 11 db (figure 6).

2.5 (U) Miniature Oscillator

A miniature pulse oscillator (figure 7) has been developed which produces 2-w peak power and requires less than 3 w to operate. Its expected use is in short-range fuze systems (less than 1000 ft) and in guidance beacons.

2.6 (C) Microwave Strip Line

Components (photo-etched, flat coaxial, transmission line) are being substituted for standard rectangular microwave circuit components in the r-f head assembly for the Littlejohn T-2074 (XM7) fuze (ref 15). The use of these strip-line components will enable more than 50 percent reduction in size and weight of the r-f head assembly while meeting the same performance specifications. Individual strip-line components have been tested and show acceptable electrical performance. Assembled r-f heads are under test. It is probable that the strip-line fabrication methods will be adaptable to other radar fuzes of similar design.

2.7 (U) Antennas

Two approaches toward reducing the size of telemetering antennas are being investigated. In both cases, linear dimensions are cut approximately in half. One approach uses capacitance loading; the other uses ferrite materials for inductive loading.

Figures 8 and 9 show an experimental model built to test the first approach. Essentially, it is a re-entrant cylindrical cavity cut in half at the

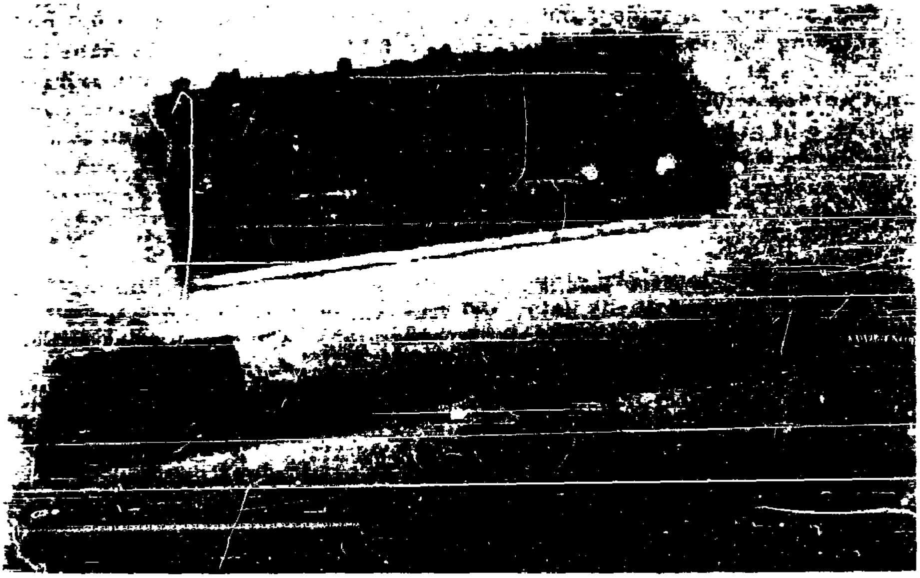


Figure 5. Transistorized wideband video amplifier.

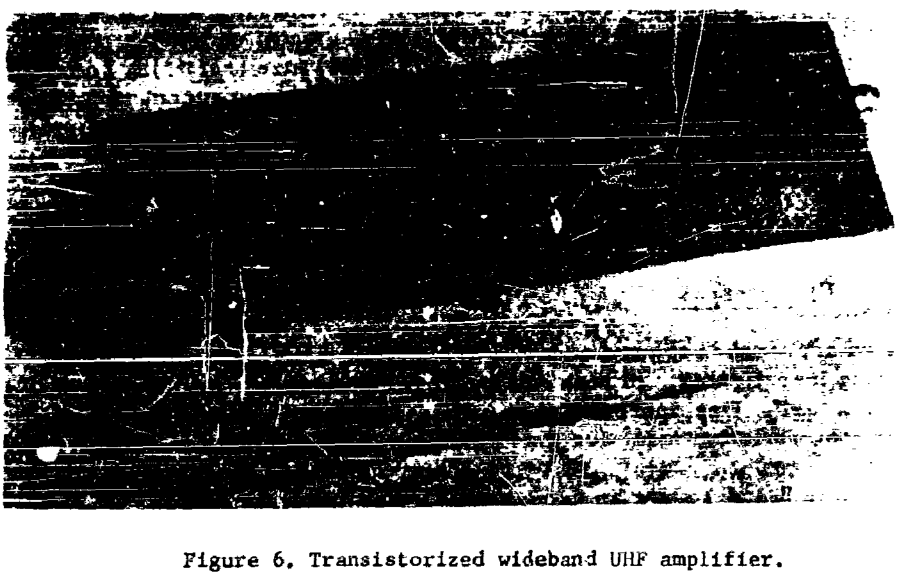


Figure 6. Transistorized wideband UHF amplifier.

Figure 7. Miniature 2-KMc oscillator.

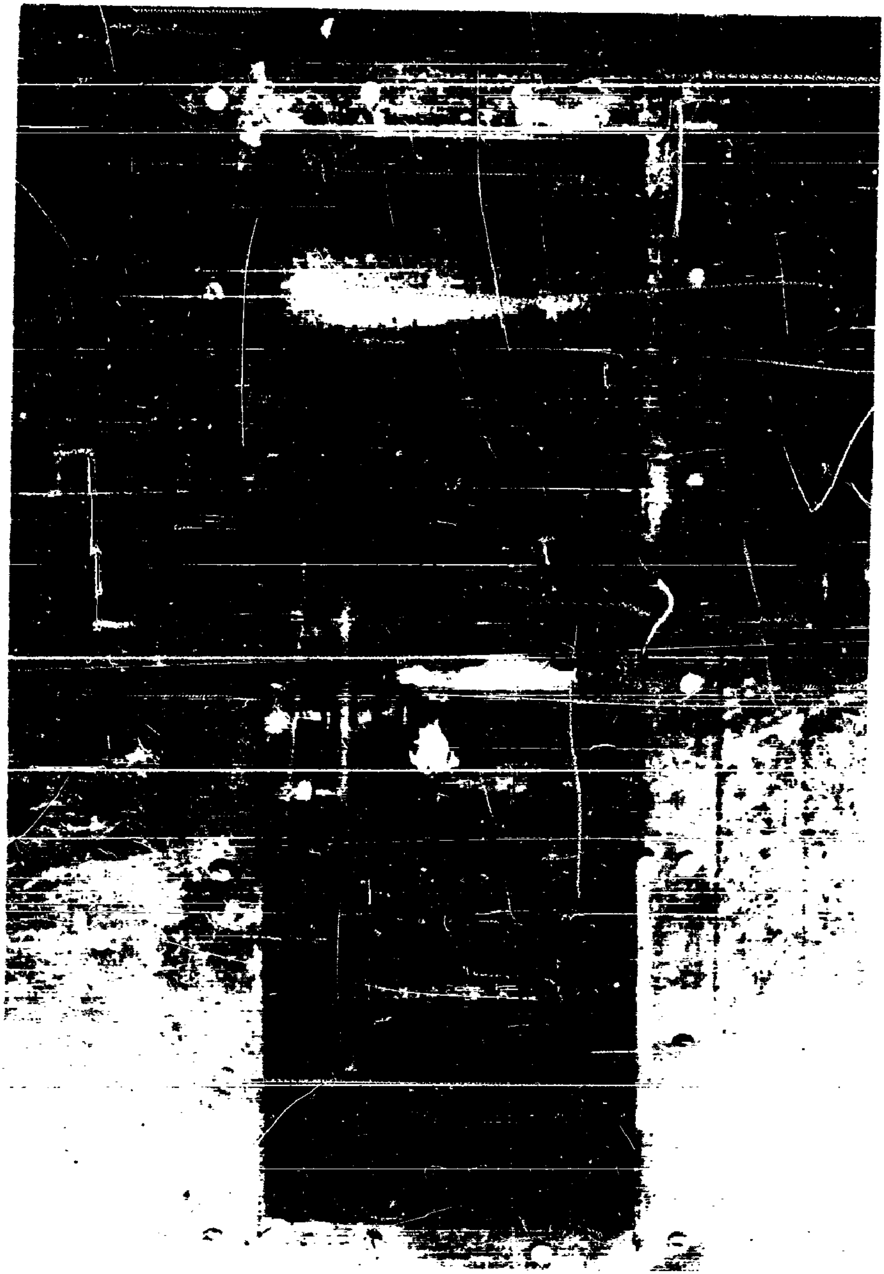


Figure 8. Experimental capacitance-loaded antenna.

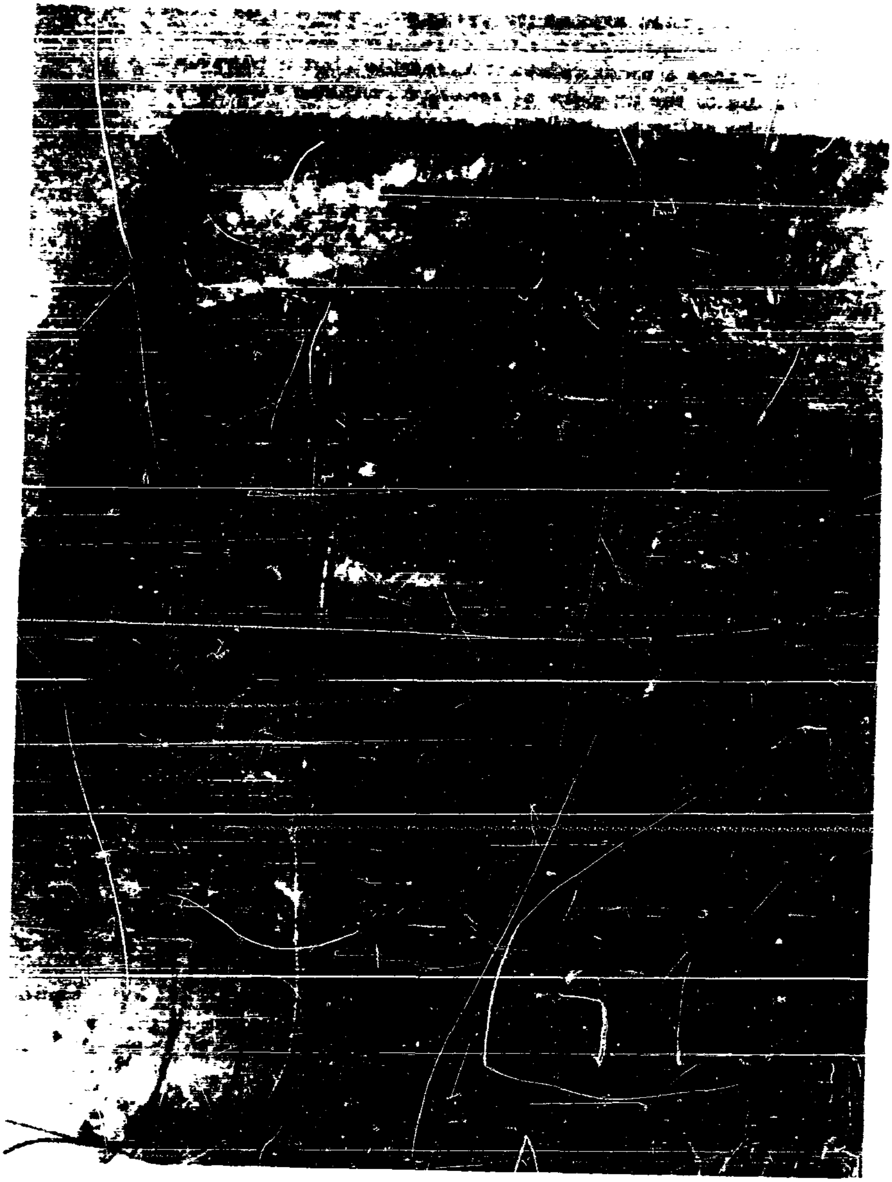


Figure 9. Tube mounting, capacitance-loaded antenna.

missile skin through the axis of the cylinder. The r-f oscillator or power amplifier tube is mounted across the capacitive loading space of the cavity. This not only makes a most compact assembly, but it results in a broad band antenna due to the absence of reactive coupling elements. Measurements of antenna pattern, bandwidth, etc., have yet to be made. This amplifier/antenna combination should have wide application in missile telemetry.

Figure 10 shows an experimental model built to test the second approach, and delivered to ABMA. This model has a VSWR of less than 1.5 over a 70-Mc bandwidth centered at about 250 Mc. However, the output is about 15 db below that of corresponding unloaded antennas due to losses in the ferrite.

A contract has been let to obtain ferrite loading materials with much lower losses than those available on the open market. This should lead to the construction of antennas having the same broad-band characteristics but much more output.

2.8 (U) Standard Transistor Switching Circuits

A compatible set of standard transistor circuits has been designed for use in experimental breadboard systems (ref 16). Thus far available are inverters, binary counters, flip-flops, monostable and free-running multivibrators, NORS, indicator lamp controls, and power switches, all designed for low-frequency (15 kc) switching operations over a moderate temperature range (45°C). Extending these limitations and investigations of linear circuits such as amplifiers could provide standardized compatible elementary circuits specifically designed for microminiature fabrication techniques as system building blocks. One of the first packages to be attempted will be an 18 BIT shift register for ABMA operating at a 100-kc rate. Illustrating the application of the presently available standard circuits, an electronic timer generating 5, 10, and 15 second intervals (following an initiating trigger) has been built and performed satisfactorily.

A computer program is being developed which will provide an exact solution to the electrical behavior of a binary divider. If the requirements of the binary are defined, then an automatic computor can use the program to design the divider. It will also predict the distribution of performance of large numbers of dividers if the statistical distribution of the components is known. This program will provide material for a quality control program for 2D wafers.

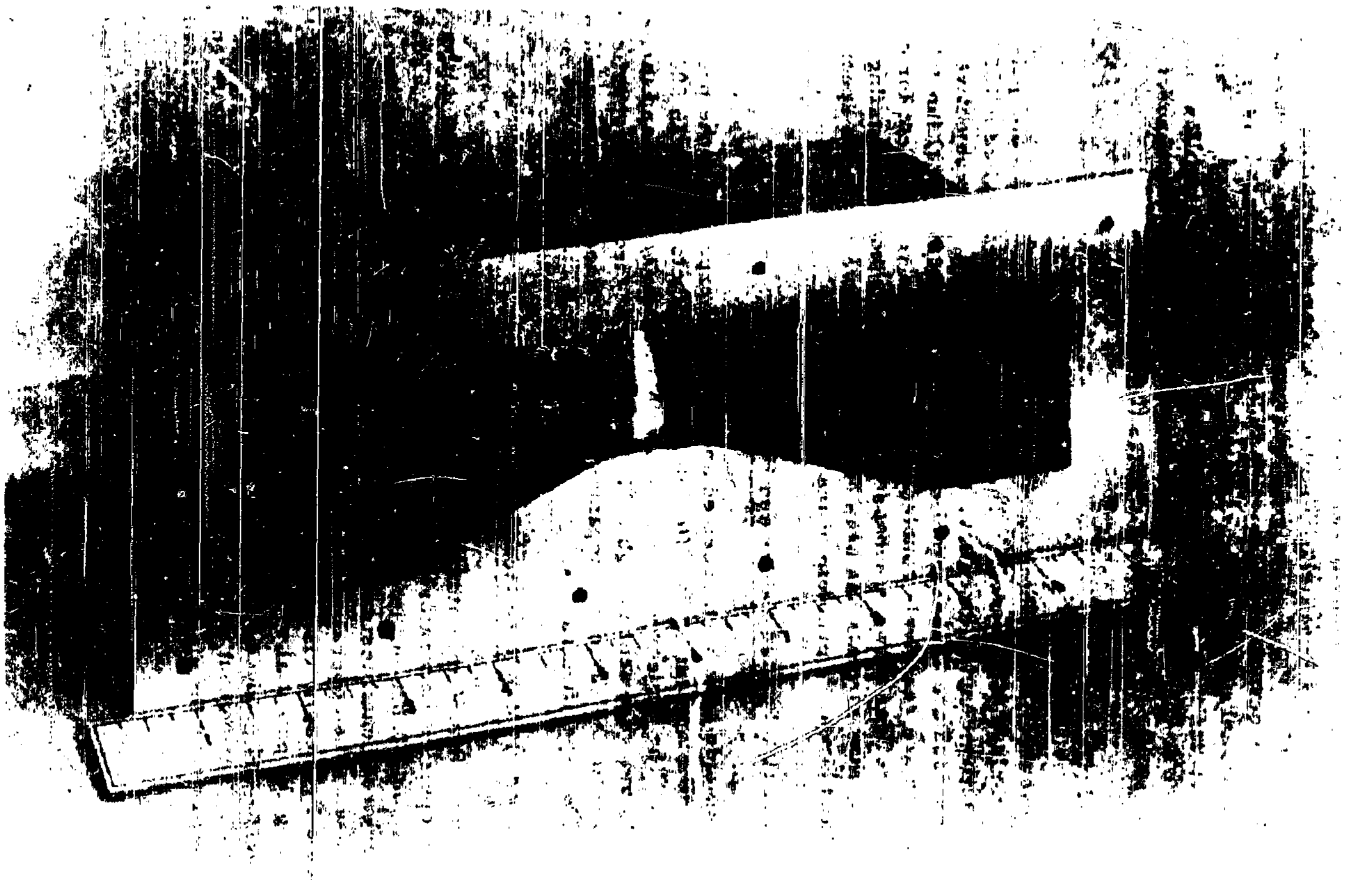


Figure 10. Experimental ferrite-loaded antenna.

2.9 (U) Transistors as Oscillators

Mesa-type germanium transistors have been tested as oscillators up to frequencies of 200 Mc. Up to 100 Mc they have exhibited efficiencies of 40 percent or more. The electrodes used for emitter and base are 4 x 12 mils - the germanium wafer constitutes the collector. This is a significant advance in the effort to devise a rugged transistor specially designed for use in microminiature circuits for ordnance applications. There are no loose parts and the transistor as well as the connections to it constitute an integral solid mass (figure 11).

2.10 (U) ARCSAP

Research is continuing on circuitry which employs AC and pulse power in place of DC power. This type of circuitry is called ARCSAP, "all reactive coupled circuitry, signal and power." The objectives of this approach are subassemblies which can perform logical functions and which are reactively coupled and thus have no requirement for ohmic interconnections between subassemblies. A breadboard consisting of 12 ARCSAP NOR circuits has been constructed to investigate the special logic and circuitry problem of the system.

2.11 (U) Printed Cables and Harnesses

Two bids have been received and a third is expected on the proposal for the development of flat, flexible, multi-conductor cables in 500-ft lengths. The project was discussed with 12 manufacturers, and invitations to bid were sent to eight. The physical and electrical properties of cables from the various companies will be determined and compared with the ABMA specified values.

2.12 (U) Miniature Incandescent Lamps

More than 50 miniature incandescent lamps were provided to the Jet Propulsion Laboratories for use in the Juno II Moon Probe. These lamps, only 0.030 in. in diameter and 0.090 in. long (figure 12) met all the environmental tests made by JPL to establish their suitability for this use. When operating at 1 v and 35 ma of current these lamps produce a light easily visible from any point in a normally lighted room. Raising the potential to 1-1/2 v increases the current to about 40 milliamperes and produces a very bright, and a very small source of illumination. Throughout the normal range of operation these lamp currents are well below the upper limit of about 50 ma available in miniaturized

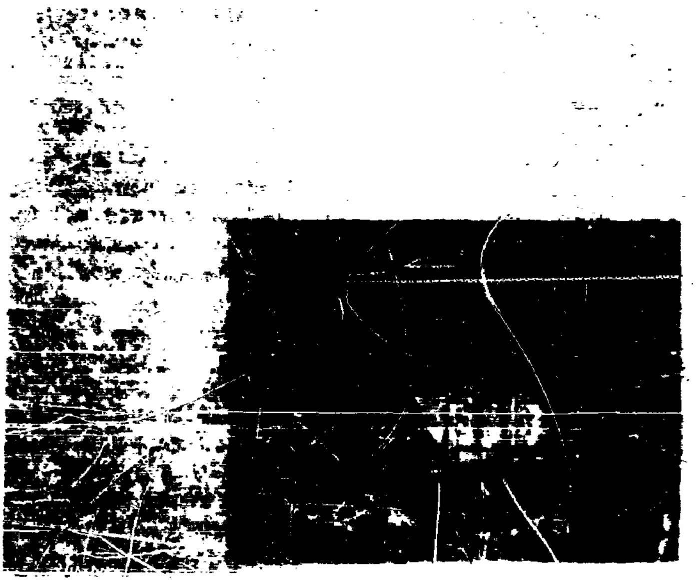


Figure 11. Printed transistor with evaporated leads.

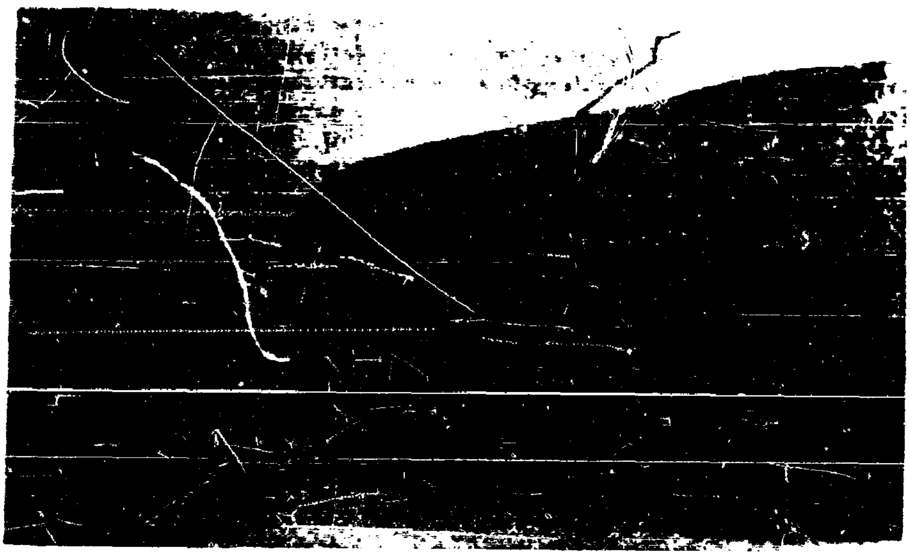


Figure 12. Micrcminiature incandescent bulb.

transistor circuits currently under development in these laboratories. By suitably changing the size of the filament wire and the number of turns, it is possible to design lamps of similar geometry to meet different voltage and current requirements.

Although these lamps were originally designed as indicator devices for transistor circuits, their usefulness is not limited to this application. They can be used for illumination in very confined quarters; i.e., for endoscopes, for inspecting inside of small waveguides, or as nonlinear resistors -- in microminiature Wein-bridge oscillators and as ballasts in filament and heater circuits.

2.13 (U) Miniature Silver Oxide-Zinc Batteries

Miniature silver oxide-zinc batteries have been built and tested successfully for missile use. They supply the required current densities at low environmental temperatures without auxiliary heating (ref 17). The major remaining problem is slow build-up of voltage at the very low temperatures and several solutions are being investigated.

3. METHODS, PROCESSES, AND TECHNIQUES

3.1 (U) Protective Hermetic Sealing of Transistors in 2D Circuits

Achievement of a hermetic sealing technique for transistors in 2D wafers means that these units can now be used without external sealing. The transistors that are incorporated into the 2D wafers must be protected from contamination and subsequent deterioration. One method is to enclose a group of the wafers in a hermetically sealed can; there remains the problem of contaminants enclosed in the can or generated by other wafer elements during operation of the circuit. Recently, a 2D NOR circuit consisting of a transistor and four resistors was constructed in which the transistor is hermetically sealed within the wafer. This is the first 2D circuit in which the active element has been hermetically sealed (figures 13 and 14). The unit is 0.25 x 0.25 x 0.030 in. Units fabricated in this manner have been exposed to ammonia vapor for several hours and to an atmosphere of 95 percent humidity at 71° C for a period of 32 hours without degradation of transistor characteristics, although ammonia causes a rapid change in the characteristics of unprotected transistors.

3.2 (U) Dip Soldering

Various techniques of dip soldering several small components to etched wiring boards in one operation have been investigated. A method

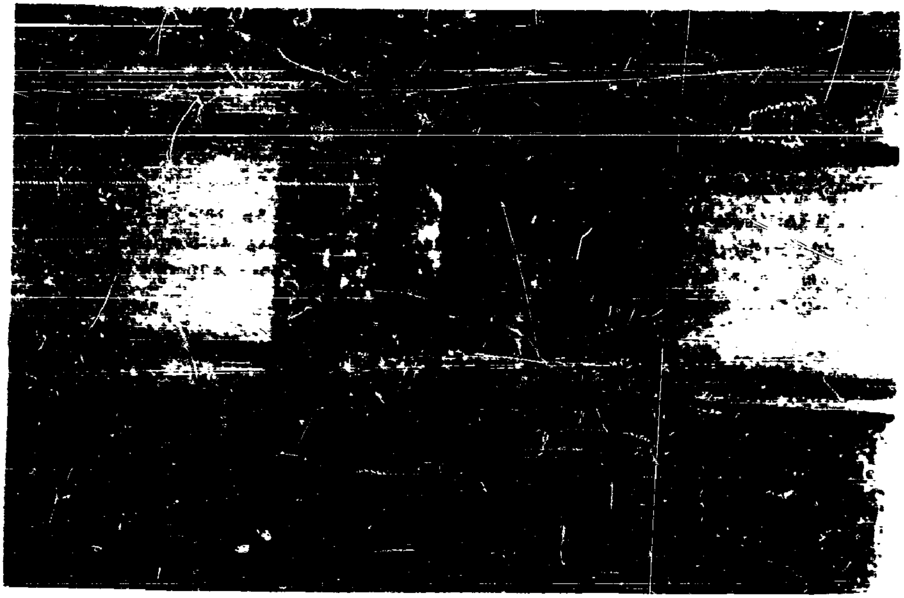


Figure 13. "NOR" circuit with hermetically sealed transistor.
This view shows emitter and base contacts and three resistors.

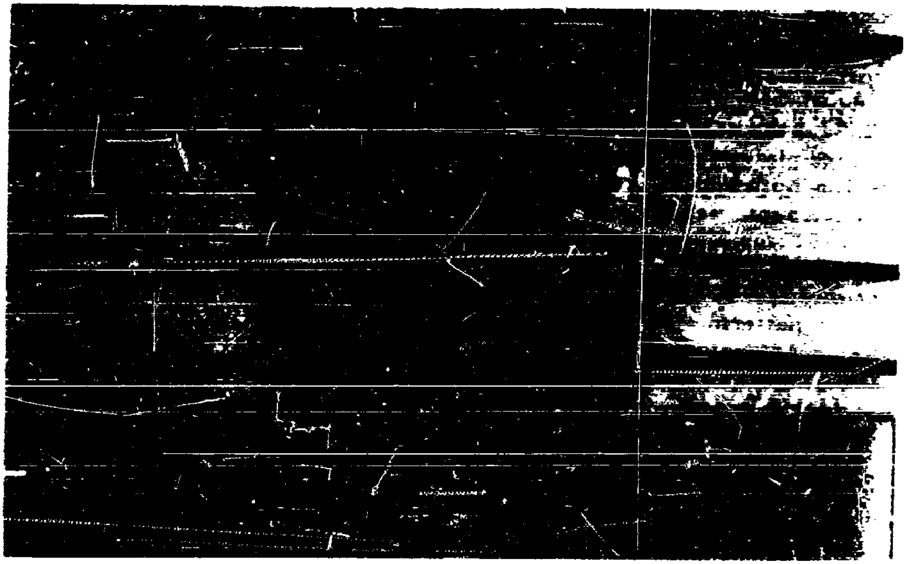


Figure 14. "NOR" circuit with hermetically sealed transistor.
This view shows collector contact and one resistor.

has been developed which eliminates some earlier problems, such as solder bridging of narrow spaces between conductors, heat damage to laminated circuit boards and sensitive components, excessive flux residues, and uncertainties regarding dip timing (ref 18).

3.3 (U) Vacuum Deposition of Films

The usefulness of presently available as well as new materials in microminiaturization work depends upon the facility with which they can be utilized in fabrication of microminiature components and circuits in exactly the location and configuration required.

Vacuum evaporation and deposition is one of the most effective methods of producing thin films of a large variety of materials.

During the past year DOFL has been successful in vacuum deposition of silicon monoxide capacitors with thicknesses from 0.46 to 2.23 microns, with capacitance per unit area 0.0019 to 0.0099 $\mu f/cm^2$, breakdown 1100 to 3500 volts per mil, d-c insulation resistance 10,000 megohms, dielectric loss one percent, average dielectric constant 6, and has done preliminary work on vacuum evaporation and deposition of fused silica for capacitor dielectrics (ref 16).

3.4 (U) Spray Etching Apparatus

Two new types of spray etching apparatus were developed to overcome limitations of commercially available equipments which produced non-uniform etching of plates. Previous investigation and development of bubbler type etching apparatus had revealed unsatisfactory uniformity (ref 19). Both of the new units permitted etchant to be sprayed upon horizontally positioned plates from above, and the second unit also from below the plate, enabling better control of uniformity. The first unit, employing ferric chloride etchant, was made largely of polyethelene, rubber, and phenolic operational components. A number of limitations to successful use were discovered. Primarily, distortion of components at operating temperatures caused leaks, and the spray nozzle assembly produced an unsatisfactory spray pattern. The second unit, employing ammonium persulfate etchant, was constructed largely of stainless steel operational components, and although not as yet completely evaluated, promises to be a most useful tool in determining the variables which affect spray etching (ref 20).

3.5 (U) D-C Glow Discharge Cleaning

This work was undertaken to determine the optimum conditions for the cleaning of glass substrates by exposure to a d-c glow discharge in order to improve the adherence of thin films subsequently to be vacuum deposited upon the substrates (ref 21). Glow discharge cleaning theory was analyzed, assumptions were considered, problem areas determined, experimental apparatus assembled, and a series of tests resulted in the following conclusions:

1. The charge in substrate temperature varies inversely with both the electrode diameter and the residual pressure for bombardment either by ions or by electrons.

2. The change in substrate temperature is practically independent of the electrode spacing for ion bombardment, but it varies inversely with the spacing for electron bombardment.

3. Ion bombardment gives higher substrate temperatures than does electron bombardment over a part of the pressure range 5 to 75 μHg and over the entire range when smaller electrodes are used.

4. Presuming that the higher substrate temperatures are indicative of more effective cleaning of the glass, bombardment by ions is the preferable technique.

3.6 (U) Pilot Lot Production of 2D Wafer Circuits

The feasibility of mass production of the two-dimensional wafer circuit has been demonstrated by the successful fabrication of 250 NOR wafers by a contractor. About 90 percent of the units met the DOFL requirements when tested individually. Binary counters formed by combining the units performed satisfactorily. Some counters were made up just after the lot was received, and some were made with units that had been stored for a few months. Although the transistors in the wafers are protected only by a coat of developed photo-resist, little deterioration of characteristics has been noted in the several months that have elapsed since their manufacture. A contract has been let for the manufacture of 200 2D binary dividers incorporating improvements in conductor and terminal materials, derived from the experience with the NOR wafers.

3.7 (U) Mechanization of Fabrication of Microminiature Electronic Assemblies

Machinery for both hand and automatic fabrication of microminiature electronic assemblies has been studied and developed (ref 15). Utilizing mechanization techniques in processing and orienting each element in the circuit during assembly operations promises more efficient production with increased reliability due to minimizing the human element. Mechanization considered included the placement of conductors, resistors, capacitors, transistors, diodes, inductors, and protective coatings on dielectric base plates. After fabrication of some experimental machines, it was concluded that caution should be exercised in deciding the degree of mechanization which is economically desirable at this time. A certain amount of mechanization is essential to production of large quantities of assemblies; however, since microminiature technology is so new and almost day-to-day changes occur, machine development should not be undertaken unless it can be adapted to meet future requirements and there is a reasonable presumption of cost amortization.

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