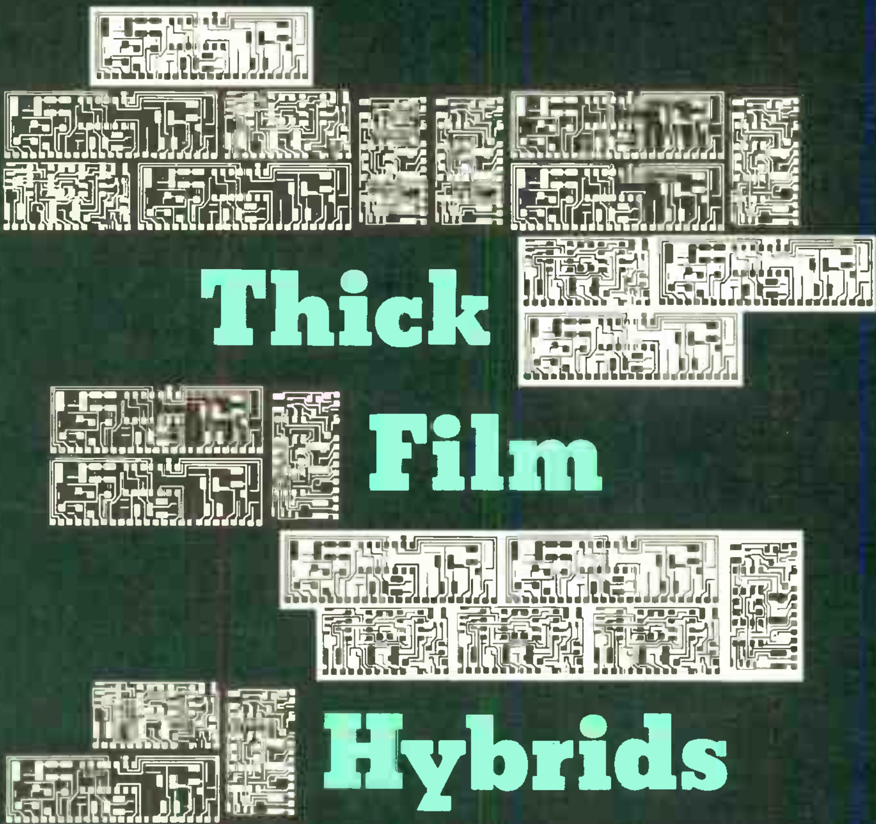
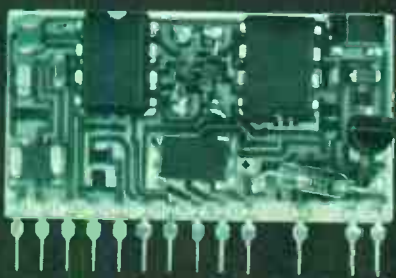
GTE LENKURT

DEMODULATOR

MARCH/APRIL 1977



Thick Film Hybrids



Also in this issue:

Solar Energy for Telecommunications

GTE LENKURT DEMODULATOR ENTERS 26TH YEAR

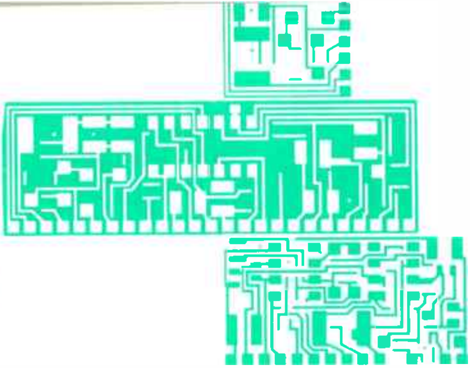
In 1976, the one-hundredth anniversary of the invention of the telephone was celebrated. With this issue, the *GTE Lenkurt Demodulator* marks a quarter-century of service to the telecommunications industry that has evolved, in all its complexities, from that invention.

When the *Demodulator* was introduced as a new publication in March 1952, it was with the stated objective of selecting the important facts from available data on carrier subjects and presenting them in a readily understandable manner. In the 25 years that have since passed, the scope of the *Demodulator* has broadened to include virtually any topic of interest to the telecommunications industry. Thus, while the titles of early articles included, "Carrier System Wave Filters," "Transmission of Signals Over Carrier System Channels," and "A Discussion of 'Levels' and 'Powers' in a Carrier System," more recent articles have been, "Anomalous Propagation," "Switching and PCM System Interfaces," and "International System Metrics." Along with this greater diversity of subject matter have come gradual changes in format and editorial policies that, hopefully, have made the *Demodulator* more useful to its readership, which ranges from technicians to company presidents.

Unchanged, however, has been the committment of the *Demodulator* to keeping its readers abreast of developments in the telecommunications industry, and informed in areas of special interest, through the presentation of readily understandable tutorial articles. How successful this effort has been is reflected in the longevity of the "new publication," and in the continued support and interest of the industry, for which the *Demodulator* staff expresses its gratitude.

In the telecommunications industry, the focus is normally on the daily challenge of keeping products ahead of technological changes, and on meeting growing service demands with increasingly sophisticated systems. When there is time for contemplation, it usually centers on the seemingly unlimited possibilities of the future, and such retrospective reveries as this are, of necessity, limited.

As it enters its twenty-sixth year, therefore, the *GTE Lenkurt Demodulator* looks forward to recording and reporting on the new developments that must surely occur. And, as it has been for the first quarter-century, the success of the *Demodulator* will be measured by the only standard available: its ability to provide its readers with information on developments in a concise and readily understandable manner.



Although they have been in use for many years, thick film hybrid integrated circuits continue to be an important element in modern telecommunications equipment and systems.

Historically, the electronics industry has sought ways to reduce physical size, lower power requirements, and increase reliability through the miniaturization of components. Developments in integrated circuit technology now make it possible, for example, to realize an entire computer system on a single silicon chip. Such monolithic devices, however, have typically not operated well at the microwave frequencies, nor at the power levels, generally used in the telecommunications industry. Their initial design and production are also relatively expensive, and circuit changes are difficult to make once production of a particular configuration has begun. Hybrid integrated circuits evolved to circumvent such problems without resorting to bulky, discrete-device packages; they continue to be widely used, despite advances in monolithic technology, because of their economic advantages, especially in small- and medium-volume production.

As the term implies, hybrid circuits utilize certain aspects of both microelectronic and discrete circuit technology (see Figure 1). They are, in general, fabricated by depositing conductive and resistive patterns on ceramic substrates to form such passive elements as conductors, resistors and, in some instances, capacitors. Discrete active components — where possible, integrated circuits containing a number of transistor elements — are then attached to complete the circuit. Although capacitors can be formed directly on a substrate by alternate applications of conductive and dielectric materials, they occupy large amounts of real estate in this form, and their capacitance is limited. More commonly, chip capacitors of monolithic, multilayer ceramic, or tantalum slug design are mounted as discrete components along with the active transistor and integrated circuit devices. Hybrid circuits thus retain much of the flexibility of the discrete package, allowing certain elements to be readily changed if desired, while benefiting from the space and cost reduction of microelectronics.

Thick Film Fabrication

Thick film is a microelectronic technique for fabricating hybrid circuits wherein metallic pastes are deposited on a ceramic substrate using screen-printing processes. Circuits produced in this manner differ from thin film circuits — which constitute the other major division of hybrid integrated circuitry — both in the thickness of the films themselves and in the method of deposition. While the

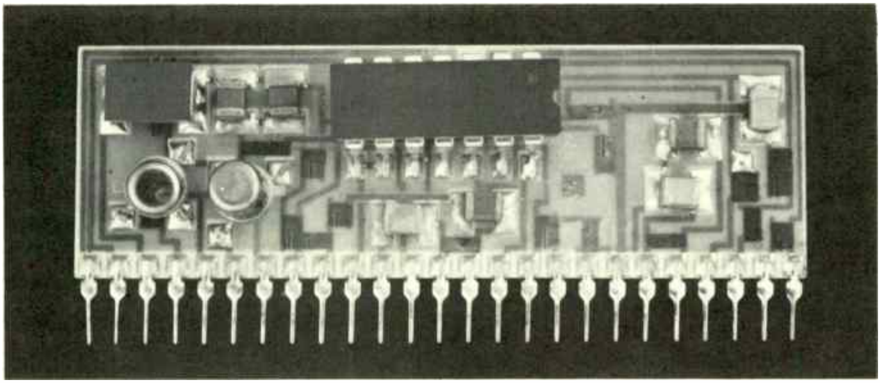


Figure 1. Thick film hybrids combine discrete-component and monolithic technologies to produce circuits that retain many of the advantages of both.

screening process used in thick film production results in resistive and conductive patterns that are approximately one millimeter thick, the deposition of thin films is done by vaporization in a vacuum that forms films typically measured in hundreds of Angstroms.

Process flow in thick film fabrication is a series of interdependent processes. First, the design of the circuit is laid out as original artwork on a precision drafting machine. The artwork is then photographically reduced and a silk-screen replica of the circuit made through which the pastes are applied to a substrate (in practice, the screen is more commonly a fine mesh of stainless steel wires).

The ceramic substrates used in the thick film process are typically polycrystalline compounds. The most common consist of from 85 percent to 99.5 percent aluminum oxide, or alumina, with impurities such as calcium oxide and silicon oxide making up the rest of the material. Conductor patterns are applied to the substrate using "precious inks," which are actually slurries of noble metals and glass suspended in a highly viscous paste. The metals may be gold, platinum, palladium, silver, or an alloy of any of these, while the paste is mostly an organic compound with an evaporative binder added. A resistive ink, using precious metals such as Rhuthenium and glass, similar to that used in some carbon potentiometers is deposited to form resistors.

In a typical thick film process, the conductor pattern that will interconnect the other elements is first screen-printed onto the substrate. A drying and firing cycle is then performed. Drying is accomplished by placing the screened substrate in a temperature-controlled oven until the binder has been driven out of the ink. Firing at high temperature using a sintering procedure causes the ink to adhere to the substrate. When the conductor pattern has been processed, the resistive patterns are similarly deposited, dried and fired. When all of the passive elements have been fired, the substrate is coated with a glaze and refired. If the device is an active circuit, the glazed substrate then has the proper components flow-soldered into place.

Thick Film Resistors

The inks used in forming thick film resistors are specified in "sheet resistance" values of ohms per square. An ink having a sheet resistance of 1000 ohms per square would, when deposited in a square pattern, have a resistance of 1000 ohms from one side to the other, regardless of the size of the pattern.

Typical thick film sheet resistances range from one ohm per square to one megohm per square, with a nominal deposit thickness of one millimeter. The formula for determining the sheet resistance of a resistor is:

$$R_S = kt\frac{l}{w}$$

where R_S is sheet resistance, k is the resistivity constant of the ink, t is the thickness of the deposit, and l and w are the length and width of the pattern. From this, it can be seen that the resistance of a thick film resistor is a function of its shape, and not of its size. For example, a resistor pattern measuring one centimeter on each side might have a resistance of 100 ohms (see Figure 2A). Three such patterns joined to form a rectangle would behave as three series resistors and have a value of 300 ohms (see Figure 2B). However, combining nine patterns into a three-centimeter-per-side square would produce only a larger pattern having a 100-ohm resistance. That this would be the case can be seen in Figure 3, where the nine squares are arranged in one of the possible equivalent configurations; by Ohm's law, the total resistance of these series-parallel elements must be 100 ohms.

Generally, resistors of various values are formed by placing the requisite number of squares end-to-end. A resistor of 80 ohms could be formed in this way by depositing a rectangular pattern equivalent to eight squares of ten-ohm-per-square ink; a 95-ohm resistor could be produced with a pattern equivalent to nine and one-half such squares. The relationship between a thick film resistor's length and its width is given by the "aspect ratio," which is also the number of squares in the pattern. An aspect ratio of 10:1, for example, would describe a rectangular pattern ten times as long as it is wide, corresponding to ten squares placed end-to-end.

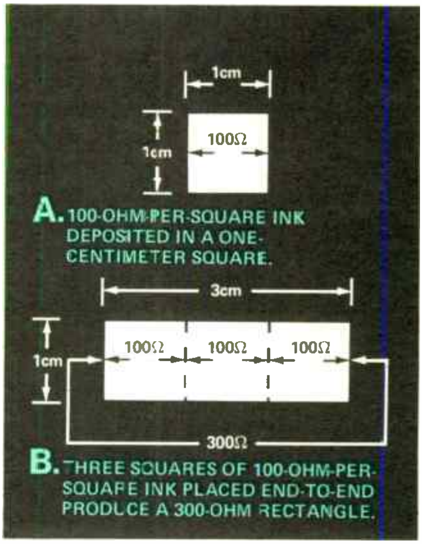


Figure 2. Thick film resistors are formed with special inks whose values are specified in "ohms per square."

Trimming

After firing, the distribution of values for any particular resistor pattern is normally ±10 percent, at best. To obtain the close tolerances required in most thick film circuits, resistors are typically deposited and fired to only about 70-80 percent of the desired value and then trimmed, or selectively altered, to within ±1 percent. Trimming a thick film resistor raises its resistance because, as the formula for sheet resistance indicates, increasing length in relation to width causes a

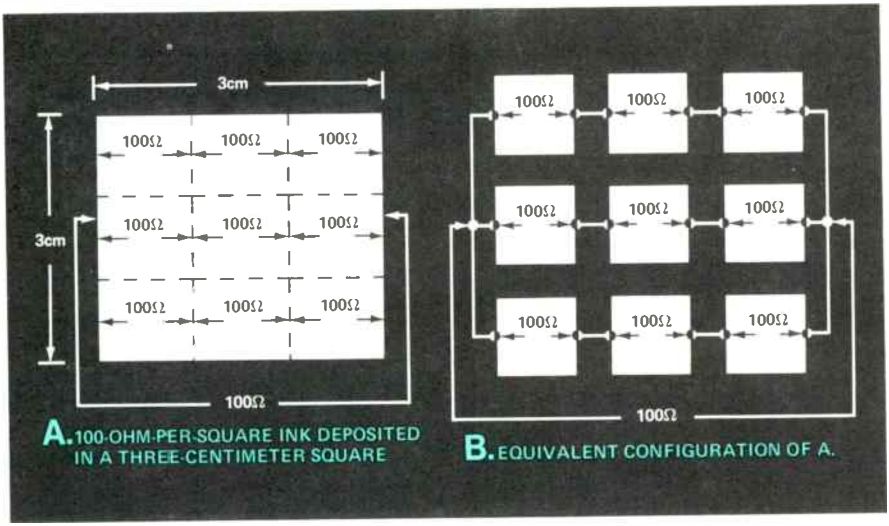


Figure 3. The resistance of a thick film resistor is a function of shape rather than size.

corresponding increase in resistance (see Figure 4).

The three most common mechanisms for trimming thick film resistors are physical abrasion, air abrasion, and laser. The abrasive methods rely upon wearing away portions of the resistive paste, either with a mechanical chipping device or by using a high-pressure air stream to blow fine particles against the pattern. Until relatively recently, air abrasion had been the most widespread thick film trimming process. However, laser trimming is rapidly gaining in popularity because of its greater versatility, the cleanliness of its operation, and the speed with which trimming is accomplished. For example, the abrasive process takes time to wear away material, leaving a large amount of powdery residue that must somehow be removed. The heat applied by a laser, however, vaporizes the ink immediately upon contact, leaving very little residue.

There are two basic approaches to trimming thick film resistors: para-

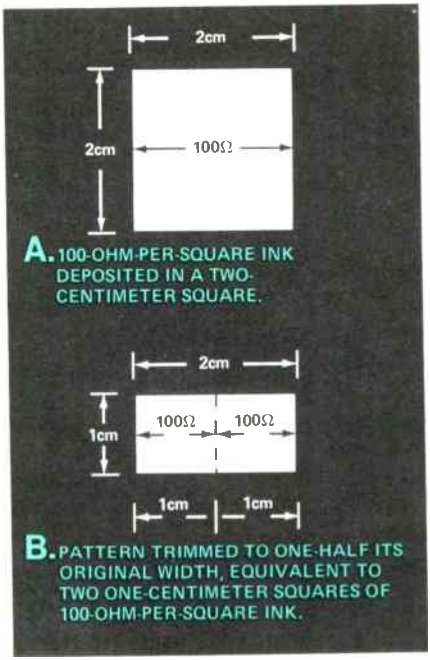


Figure 4. The relationship of length to width in thick film resistors is linear, allowing values to be easily changed by trimming techniques.

metric and deterministic. Parametric trimming requires that the resistors in a circuit be trimmed until some particular function – phase, voltage, gain, etc. – is correct; this is an active trim, accomplished while the device is actually operating. In deterministic trimming, the operation of a complete circuit is measured and compared to a standard; the resistor values needed to bring the two into correspondence are calculated and the trimming accomplished with the device inactive. The two techniques can often be combined to optimize the operation of a complex circuit, as they are in a process developed by GTE Lenkurt for producing a high yield of active resistive-capacitive (RC) filters for pulse code modulation (PCM) applications. In this process, the frequencies of interest (bandwidth, notch and pole), and the resistor values that would allow the circuit to properly respond to them, are known from design criteria. After the complete fabricating process has been accomplished, the response of each circuit is determined during a test phase. The trimmable resistors are then measured and the values needed to produce the desired response calculated. The resistors are then laser trimmed to these target values. After this deterministic trimming phase, a parametric trim is performed on a gain adjustment resistor to achieve the desired output level.

One of the outstanding aspects of thick film technology is its commonality with other microelectronic techniques. Whether the medium is printed circuitry, thick film, thin film, or monolithic integrated circuitry, the goals are essentially the same: reduced space and power requirements, and increased reliability through miniaturization. There is no single technique presently available that will achieve these goals over the wide range of activities with which the telecommunications industry is involved; rather, a supplier of equipment and systems must maintain proficiency in all of the technologies in order to properly meet the varied, and changing, demands of the industry.

BIBLIOGRAPHY

1. Agnew, J. *Thick Film Technology*. Rochelle Park, N.J.: Hayden Book Company, Inc., 1973.

2. "Hybrid Microcuitry, Part 1," *The Lenkurt Demodulator*, Vol. 17, No. 10 (October 1968).

3. Miller, L.F. *Thick Film Technology and Chip Joining*. New York: Gordon and Breach, Science Publishers, Inc., 1972.

4. Sen, D.K. "A Set of Thick Film R-C Active Filters For PCM Application," paper in preparation for International Symposium on Circuits and Systems. Draft: GTE Lenkurt, Inc., February 1977.

solar power for telecommunications

Non-polluting, inexhaustible solar energy is an extremely attractive replacement for conventional power, but solar conversion costs remain high. In spite of this, solar energy is often the only cost-effective source of power for communications systems.

Sunlight beyond the earth's atmosphere contains about 1400 watts of energy per square meter, but by the time the light reaches the surface of the earth the energy level has been reduced to less than 250 watts/m^2 by the atmosphere, clouds and earth shadowing. Still, calculations indicate that the entire electric power requirement of the United States could be met by solar arrays equal to the roof area of all the buildings in the country, provided the arrays were even 30 percent efficient (conventional systems are about 35 percent efficient). The technology required to make solar power a major contributor to the nation's energy needs is evolving rapidly, and some solar products have already found uses in the telecommunications industry.

To date, the most common method of extracting energy from sunlight has been photovoltaic conversion (radiant energy producing an electromotive force) using silicon solar cells, although much work remains to be done before solar cells can compete with conventional power systems in all applications. Efficiencies of 18 percent for silicon cells and 22 percent for gallium arsenide cells have been reported and costs have been reduced by 50 percent in the past two years. However, at $15 per peak watt, solar power still costs 30-50 times as much as power produced by conventional means. The goal of the United States Energy Research and Development Administration (ERDA) is 50 cents per peak watt by 1986, but even optimal application of current silicon

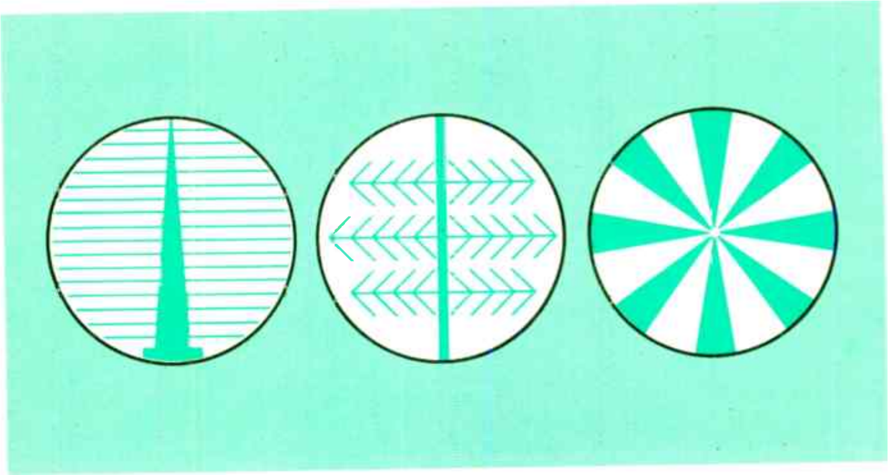


Figure 1. These patterns are typical of collector grids which reduce the cell's series resistance. Square and rectangular cells usually have grids in finger-shaped patterns.

technology is not expected to meet this objective.

In research and development, emphasis is being placed on cost reduction and on demonstrating the reliability of silicon arrays. Some approaches to lowering costs involve new methods of growing single crystals, improvement in encapsulation techniques, automation of high-volume material and cell production, and exploring thin-film photosensors to replace single-crystal wafers. Systems have also been developed which employ lenses or mirrors to concentrate the amount of sunlight falling on the cell, thereby producing thermal power which can be converted to electrical energy, or used for heating and cooling.

Photovoltaic Conversion

A typical solar cell begins as a wafer of silicon sliced from a single-crystal ingot grown from pure silicon, which is a poor conductor and requires the addition of doping agents such as phosphorus and boron to make it conductive. A slice of n-type (phosphorus-doped) or p-type (boron-doped) silicon serves as the base for a diffused or deposited layer of material of opposite charge. At the point where the two dissimilar materials meet, an electrical junction (p-n or n-p) is formed. Because the upper layer of the cell is extremely thin, sunlight in the form of photons can penetrate it and progress beyond the junction. Each photon produces an electron and a positive hole. Because of the electrical field present at the junction, the electrons are forced to the negative side—and the holes to the positive side—of the junction. When collector grids (see Figure 1), contacts and leads are connected to the base and upper layer, and an external load connected between them, an electric current can be made to flow (see Figure 2).

Cells may be connected in series to increase the voltage or in parallel to increase current flow. The larger the cell's surface area, the higher the current will be but the photovoltage is independent of the cell's size. The output of a solar cell is also related to temperature, with a decrease in temperature reflected in an increase in output.

Since solar cells are incapable of storing the energy they produce, it is common practice to include storage batteries as an integral part of each photovoltaic conversion system. The size of the batteries is determined by the average daily load current requirement of the system and the solar conditions at the site where it is to be installed. Solar insolation records, which indicate the amount of energy received from the sun for periods of as much as 40 years, provide reliable information on the number of days each year when a given area may be expected to be without sunlight. This information helps engineers determine battery size for each installation.

The life of a solar cell is virtually infinite when operated under normal conditions, except that the metal electrodes are subject to corrosion and the encapsulating material deteriorates in adverse environments. Solar arrays are generally expected to have an operating life in excess of ten years in terrestrial installations.

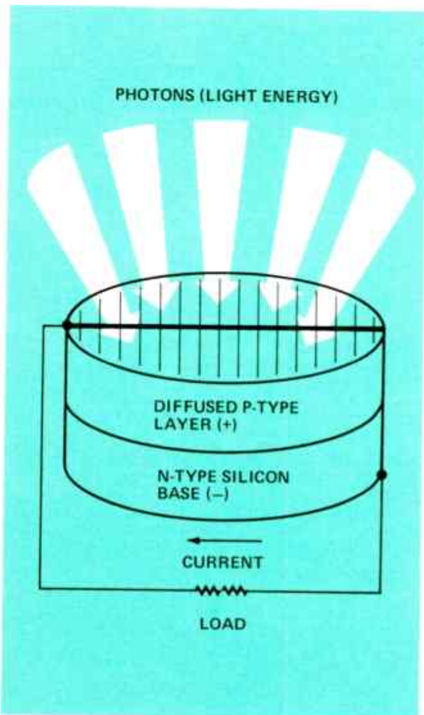


Figure 2. Operation of a typical silicon photodiode. Such cells can be arranged in series/parallel circuits to obtain the desired output.

Cell Structure Types

Silicon cells are produced in three structural forms: nonreflecting, heterojunction and Schottky-barrier. The most efficient is the nonreflecting structure, which is characterized by a textured upper surface that collects a large percent of reflected light. The major faults of this type of cell are low voltage output and a poor response to short wavelengths.

The heterojunction structure employs a thin layer of semiconductor other than silicon deposited on a silicon base, responds well to short wavelengths, and is simpler to process, making it suitable for continuous-flow manufacturing. The heterojunction's major drawback lies in creating the junction itself, which is critical to the device's operation.

Heterojunction devices can be used to create tandem cells consisting of two p-n junctions placed back-to-back with photovoltaic conversion occurring in both top and bottom junctions. If the junctions are properly connected, the conversion efficiencies add to produce a total efficiency of as much as 40 percent.

The Schottky-barrier silicon cell is formed by depositing a thin metallic layer on silicon, and does not require high-temperature processing. It has good short-wavelength response and has the added advantage of using only small amounts of scarce materials, but is still experimental.

Heterojunction and Schottky-barrier cells both hold out the promise of low-cost silicon cells since they involve a deposition process rather than diffusion, which is more complicated and expensive.

Work also has been done on fabricating solar cells from materials other than silicon. For example, cadmium sulfide (CdS) cells, consisting of a layer of CdS deposited on a base of plastic or glass and a coating of cuprous sulfide (CuS), have been produced. Thus far, these have been marked by low efficiency and plagued by instability, but their low fabrication costs and new configurations may make them economically viable. Higher efficiencies have been reported for cells made of gallium arsenide with aluminum-gallium-arsenide coatings, but these are many times more expensive than silicon cells and rely on solar concentration, which requires two-axis tracking to keep them pointed directly at the sun. These arrays operate at temperatures of 100°C or more and usually are water cooled. The water circulating in a system that produces one kilowatt of electrical power can be used to produce an additional five kilowatts of power, or it can be used for interior space heating and cooling.

Recent improvements in silicon cells include a new collector pattern that resembles the spokes of a wheel, which increases efficiency by reducing the shadowing effect. This new shape also provides better contact by using the outside rim as a main electrode, and makes alignment of the photolithographic masks easier in the manufacturing process. In addition, the resistivity of the substrate has been reduced and a p+ diffusion technique on the back produces better contact and higher currents.

Another recent advance in cell technology is the use of thick film techniques to apply contacts to the grids. The thick film process occurs at low temperatures, so the junctions of the cells are not damaged, and is many times faster than vacuum deposition techniques.

Cell Applications in Communications

Solar cells were originally developed to provide power for defense and communications satellites, but today they also power terrestrial communications devices in both industrialized and developing nations. For example, in Niger, solar panels make possible educational television by providing power to remote villages, and in the United States a solar-powered rf repeater (see Figure 3) provides telephone links between isolated small towns in the Southwest.

Other solar-powered repeaters are in operation in New Zealand, the Middle East and other locations in the U.S., but they are either conventional heterodyne or baseband repeaters, which may draw more than three amperes of current and require a large outlay for standby batteries in addition to large solar cell arrays. To provide solar power to a conventional repeater system (see Figure 4) would, therefore, require an expenditure many times the amount spent for the panels which power an rf repeater such as GTE Lenkurt's 700F1 (see Figure 5), which requires only 300 milliamperes.

Conventional repeaters operate in limited temperature ranges and thus require controlled environmental conditions, usually a hut with heating and air conditioning, which adds considerably to the cost of the installation.

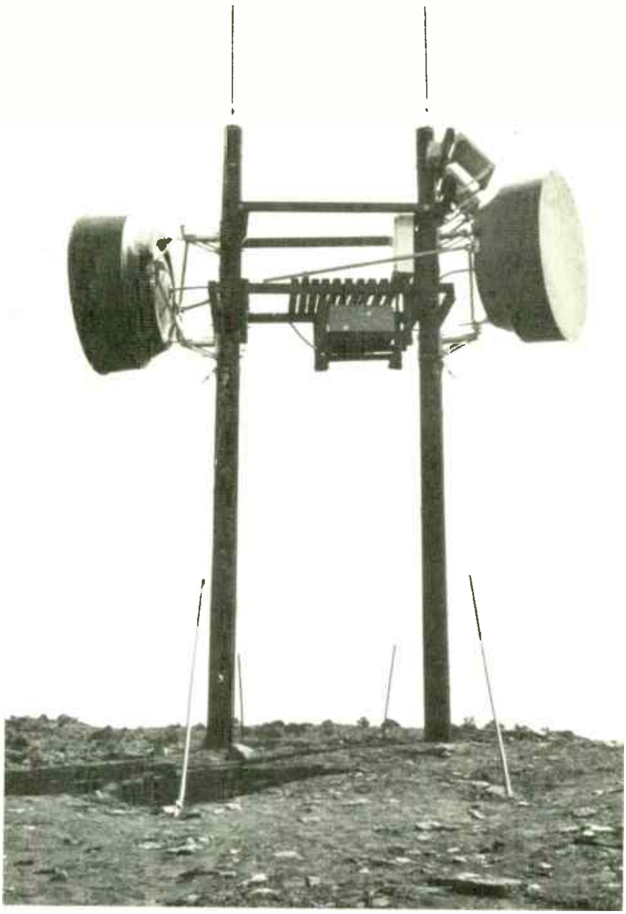


Figure 3. In periods of darkness, the GTE Lenkurt 700F1 RF Repeater consumes just four watts of power from batteries located under the catwalk. In daylight, the repeater is powered by solar cells, which also recharge the batteries.

Expensive housing is unnecessary for the 700F1, which operates over a temperature range of −40°F to +140°F and has all its active components mounted in a weatherproof metal box. Since the 700F1 uses a minimum of components, it is more reliable than conventional repeaters; in addition, the entire system is 100 percent actively redundant.

Another type of repeater which may soon be powered by solar energy is the line repeater used to regenerate the signal in PCM cable systems. Presently, such repeaters are generally powered from dc sources in the telephone company office over one of the pairs of wire in the cable, thus reducing the cable's information carrying capacity. Small solar arrays coupled to rechargeable batteries at each repeater site could provide the necessary power for the repeater and thus free the cable pair for the transmission of information: as the channel capacity of PCM systems increases, this could represent a significant expansion of facilities.

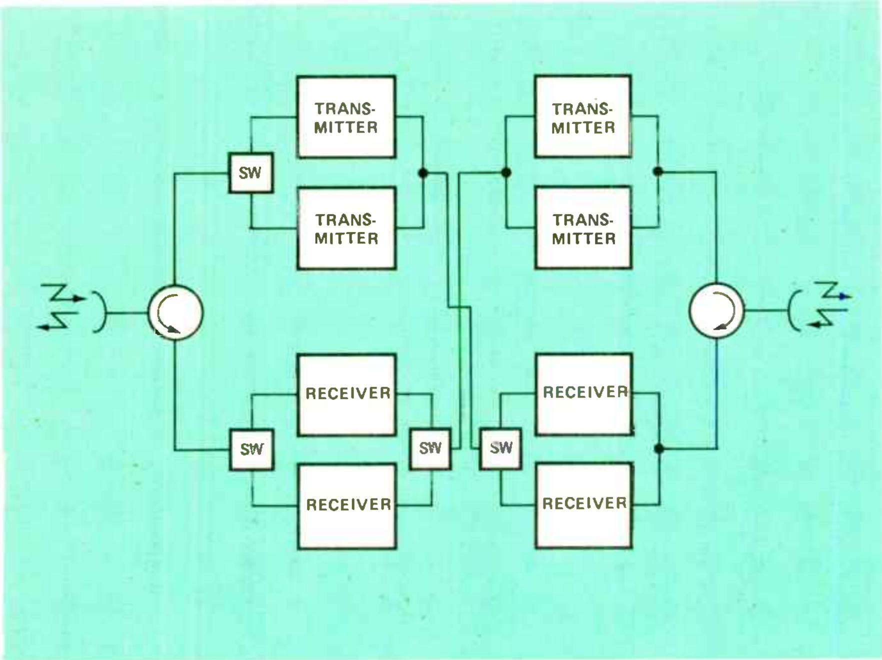


Figure 4. A typical microwave repeater facility including hot-standby protection. Such repeater sites require power for every active element, as well as backup batteries to provide service during power outages.

Although experimental fiber optic transmission systems require regeneration only every seven kilometers (4.2 miles), and their greatest application is expected to be in dense metropolitan areas where regeneration will not be required between offices, solar-powered repeaters offer the possibility of extending such systems over great distances. Current technology requires the use of a pair of copper wires laid parallel to the optical cable but, like PCM cable system repeaters, solar panels may prove to be economically feasible in the near future.

Another communications link that may soon depend on solar energy is the ground station of a domestic satellite system, although the power requirement is considerably greater than for microwave and cable repeater sites. To date, a 900-square-foot solar array has been developed that produces over three kilowatts of electrical power, and an experimental array using Fresnel lenses as concentrators produces one kilowatt of power from slightly over one square foot of collector surface. Therefore, unduly large collector panels would not be required to meet the normal power needs of a ground station. Other solar panels, some as small as 3.25 inches square, provide power for other kinds of devices.

Other Cell Applications

Solar-powered navigation aids, many on oil drilling platforms, are in operation in various harbors and gulfs

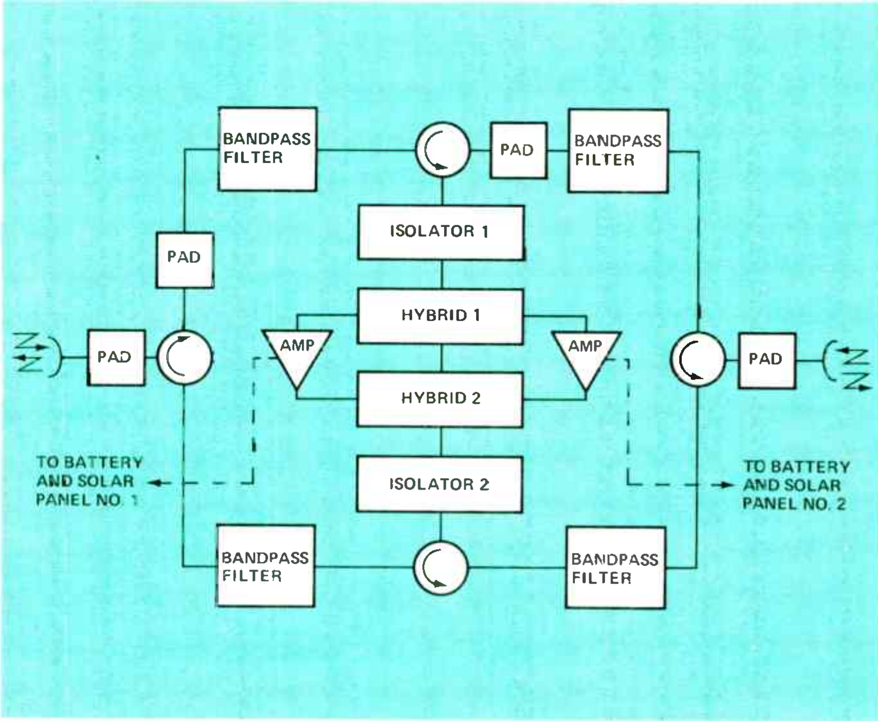


Figure 5. Simplicity of design and the elimination of the frequency conversion process permits the GTE Lenkurt 700F1 RF Repeater to operate on less than four watts of power. Storage batteries provide 10-day backup capability for periods of prolonged darkness.

around the world and off the coasts of Scotland and Venezuela as well.

Solar panels also drive irrigation pumps with a capacity of 2,700 liters per hour. Such applications are expected to increase, since these pumps do not lower the water table as rapidly as gasoline-driven pumps.

Other solar panels provide power for emergency lighting systems on public transportation vehicles, for autopilot systems on yachts, and for charging batteries of many types, including those on boats, in electronic watches, radios and calculators.

Railroads have turned to solar energy to power the warning lights, bells and safety gates at remote crossings, and a company which manufactures water meters uses solar cells to power the outdoor display of a meter located indoors. Many other such uses will develop as solar energy costs are reduced through improved technology.

Future Applications

Large purchases of solar cells by Federal Government agencies such as the Department of Defense and the Energy Research and Development Administration help to drive down the per unit cost, and thus permit a wider range of applications. Immediate possibilities include VHF/UHF repeaters, environmental and pollution monitors, traffic and security systems, paging systems and television translators. Also, railroads can be expected to expand their use of solar energy to power track warning lights, hot box detectors and caboose radios.

Oil companies are expected to be interested in an experimental solar-powered hydrogen-sulfide detector to protect their oil field workers. When operational, the system would include a central control box monitoring four sensors placed around an oil well and capable of shutting down operations if it sensed the poisonous gas. Pipeline companies may soon use electrical power from photovoltaic cells to provide cathodic protection to their underground pipelines.

Experience gained from these applications will surely lead to an even broader range of uses. Likewise, improvements in efficiency and lower cell costs will stimulate further substitution of solar energy for conventional power in telecommunications applications.

BIBLIOGRAPHY

1. Curran, L. "Companies Look for Ways to Raise Solar-Cell Output," *Electronics*, Vol. 49, No. 23 (November 11, 1976), 91-99.

2. duBow, J. "From Photons to Kilowatts: Can Solar Technology Deliver?," *Electronics*, Vol. 49, No. 23 (November 11, 1976), 86-90.

3. Goodenough, J.B. "The Options for Using the Sun," *Technology Review*, Vol. 79, No. 1 (November 1976), 63-71.

4. Kaplin, G. "For Solar Power: Sunny Days Ahead?," *IEEE Spectrum*, Vol. 12, No. 12 (December 1975), 47-52.

5. Morrow, W.E. Jr. "Solar Energy: Its Time is Near," *Technology Review*, Vol. 76, No. 2 (December 1973), 31-42.

6. "RF Repeaters," *GTE Lenkurt Demodulator*, Vol. 25, No. 5 (May 1976).

7. "Solar Photovoltaic Conversion Subprogram," definition report of the National Solar Energy Research, Development and Demonstration Program, ERDA, Washington, D.C. June 1975, III 14-19.

8. "Solar Cell Offers 21% Efficiency with GaAs," *Electronics*, Vol. 48, No. 11 (May 29, 1975), 41-42.

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