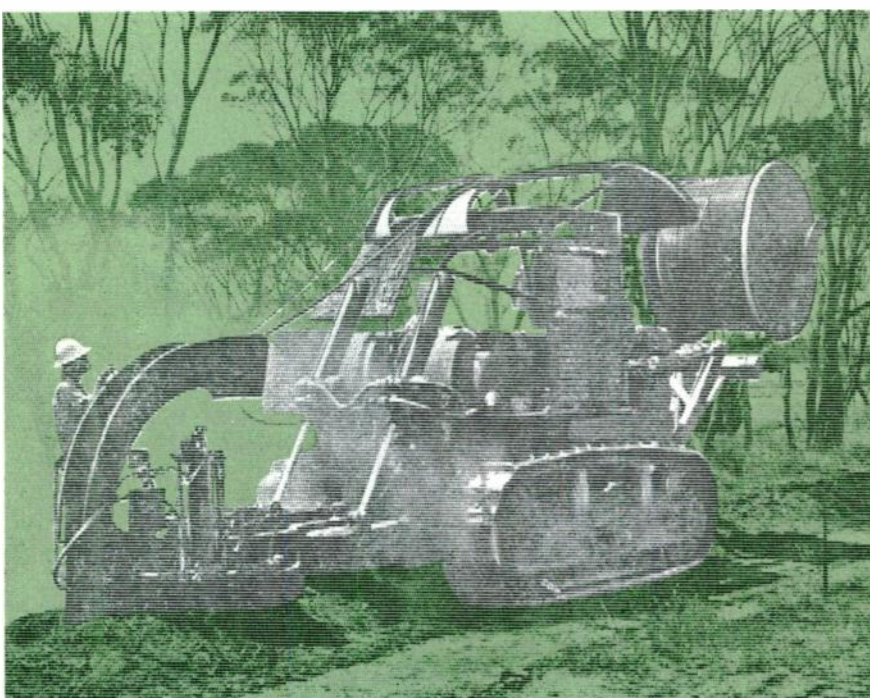
GTE LENKURT

DEMODULATOR

MAY 1971



coaxial communications

Cover photo courtesy of "The Telecommunication Journal of Australia."

Coaxial cable communications can provide short-haul, as well as long-haul, high-density communications facilities.

Over the years, microwave radio systems have become well established as a primary communications network component because of their economy, flexibility, and general availability. In certain applications, these advantages are no longer valid. Therefore, new considerations are being given to cable transmission, particularly transmission via coaxial cable.

A major factor for this interest in coaxial cable in the United States is that congestion in the lower and more desirable frequency bands is making it increasingly difficult to select clear microwave channels for new systems. In areas not suffering from microwave congestion, underground coaxial cables can provide high-density systems with room for expansion.

Radio vs. Cable

Frequently, a microwave system operator will find that a building permit has been granted that blocks one of his metropolitan paths. With microwave frequency congestion increasing, it may be difficult to engineer a radio solution to this dilemma.

The obvious solution to these problems is to select the less congested, higher frequency bands. However, these higher bands impose such restrictions as shorter path lengths due to rainfall attenuation, and more costly equipment, antennas, and towers.

But engineers are still working on systems of the future, which will use frequencies between 18 and 100 GHz and PCM modulation techniques at speeds of 6-600 megabits. It is expected that these systems will be used in applications where the channel densities require sufficient bandwidth to justify the cost per channel on the necessary short path lengths (3-6 miles). But this is still in the future.

Coaxial cable transmission systems, on the other hand, are available and provide short-haul as well as long-haul, high-density communications.

Such coaxial cable systems have been employed in the United States by the Bell System for many years, beginning with the L-1 system; and likewise in Europe by the various governmental entities responsible for the communications network in Europe. Considerations in planning coaxial cable systems must include such factors as right-of-way acquisitions; cost of the cable to be placed; installation expenses, such as earth burial and splicing costs; and lastly, the electronics investment. The initial costs per channel-mile vary widely depending upon the effect of these various factors. But, regardless of initial costs, coaxial systems usually have lower maintenance expenses than their microwave counterparts.

The microwave system and the coaxial system have many basic similarities. Both systems require a means of stacking message channels. This is typically done using the frequency division multiplexing mode, but PCM systems are also under development. In most circumstances, the same channelizing equipment is used for both systems. For example, GTE Lenkurt's 46A radio multiplex system is also used for coaxial cable systems. Slight differences may occur because of specific requirements of the coaxial system.

Figure 1 shows a typical terminal equipment installation.

Cable Characteristics

Communications coaxial cable provides the two necessary electrical paths by having a solid copper tube for the outer-conductor and a concentric solid copper inner-conductor. Coaxial cables with spaced insulators approach the ideal condition of having the conductors separated by a dielectric of air. The concentric conductors minimize external interference that can affect the information being carried on the inner conductor. These conductor pairs are called "pipes" or "tubes."

The extremely broad bandwidth of coaxial cable is limited by the presently available multiplex equipment to about sixty megahertz. This bandwidth permits up to 10,800 two-way voice channels to be frequency-multiplexed and simultaneously transmitted over a pair of coaxial tubes. However, the effective bandwidth of a coaxial cable is limited by the required gain needed to maintain good signal quality. With different modulation techniques it may be possible to lower the required gain and increase the acceptable bandwidth.

Although a coaxial line will transmit signals down to zero frequency – dc – a higher lower-limit is usually set. This is because the coaxial line does not provide good shielding at low frequencies and because it is difficult to equalize the line at low frequencies.

The upper frequency limit for a given coaxial system is determined by cable dimensions and construction, and permissible attenuation. All of these factors interact; therefore, a compromise must be made to find the optimum upper limit.

The attenuation of a coaxial cable is given by the following:

$$A = 2.12 \times 10^{-5} \frac{\sqrt{f}\,(1/a + 1/b)}{\log (a/b)}$$

where

A = *attenuation in dB/mile*

a = *radius of inner conductor in millimeters (Figure 2)*

b = *inner radius of outer conductor in millimeters (Figure 2)*

f = *frequency in hertz.*

This illustrates how frequency and cable dimensions interact with cable attenuation. The attenuation varies directly with the square root of frequency and inversely with cable size.

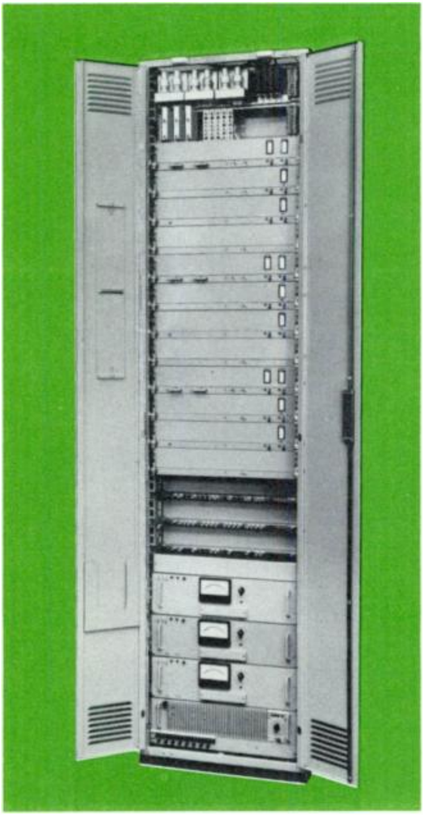


Figure 1. GTE Lenkurt's 46V coaxial cable systems can provide four different capacities – 300 channels, 960 channels, 1200 channels plus TV, and 2700 channels.

Coaxial Equipment

While terminal equipment for microwave and coaxial cable systems is essentially the same, the coaxial line equipment differs for the two systems. For example, in a microwave system, an external power source must be provided at each repeater. But, with coaxial cable systems, the repeaters are powered over the coaxial tube center-conductors; therefore, the repeaters may be located in less accessible areas. For a typical system operated from 24-volt or 48-volt office batteries, the voltage is stepped up to a higher dc potential by means of inverters, and applied to a number of repeaters using constant current regulation. The exact voltage required will depend upon the number of repeaters in series, and with the low-voltage requirements of today's all solid-state repeaters, it is not unusual to have as many as 24 repeaters (with spacings of from 1 - 12 miles) powered from a common power feed.

A nominal value for the attenuation between repeaters is on the order of 40 dB, which will still provide a high signal-to-noise ratio. Both transmit and receive attenuation equalizers are commonly employed to permit wide repeater spacings and still keep the attenuation within 40 dB. This arrangement performs approximately the same function as pre-emphasis and de-emphasis in a microwave system.

In addition to the transmit and receive attenuation equalizers there are "mop up" attenuation equalizers provided on the receive side to correct for any minor irregularities in the response of the cables, or the repeater equalizers on all but the shortest of systems. Pilot stop-filters eliminate any signals at the coaxial pilot frequencies from the multiplex signals to prevent the interaction of the coaxial repeatered-line pilots and the multiplex signal. Figure 3 shows the block diagram of a coaxial cable system.

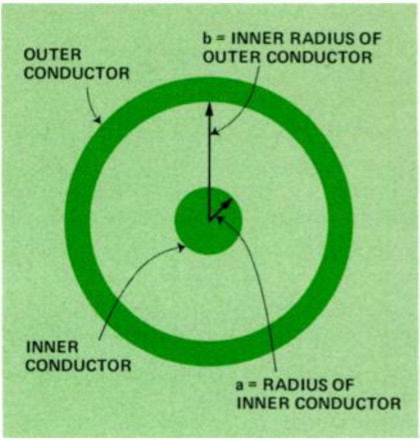


Figure 2. A coaxial pipe or tube consists of two concentric conductors.

Buried System

The frequency response and insertion loss of a length of coaxial cable is a function of the temperature of the cable. The temperature coefficient of coaxial cable is 0.2% per °C, in the carrier frequency range of interest. As the temperature of the cable increases, the attenuation of the cable increases, and it is necessary for the repeater gain to be varied to maintain the proper operating levels for succeeding repeaters and the terminal equipment. In coaxial cable systems this is handled by periodically placed pilot-regulated repeaters. Figure 4 shows the watertight containers for pilot-regulated repeaters.

In the planning of cable systems where the cable temperature varies over wide ambient ranges, it may be necessary to place these pilot-regulated repeaters as often as every other repeater. In conventional systems the placement of the coaxial cable underground reduces the temperature fluctuations and the pilot-regulated repeaters may be spaced further apart with up to six or seven fixed-gain repeaters between the pilot-regulated repeaters.

Some predistortion is usually desirable in these cases, to stay as close as possible to the design operating point for the intermediate fixed-gain repeaters. For example, when the loss is higher than normal, the pilot-regulated repeater makes up for this loss, and also transmits at a higher level, to distribute the deviations from the normal fixed-gain repeaters.

An interesting variation in the control of repeater gain is to have the gain dependent upon the temperature of the repeater. Siemens AG of Munich, Germany, has developed such a repeater which is used in the GTE Lenkurt 46V coaxial cable system. This temperature-dependent repeater employs a semi-conducting element of indium-antimonide in its feedback circuit. By selection of the proper proportions of this compound and doping with nickel-antimonide, it is possible to change the resistance of the semiconductor and thus match the temperature and gain quite accurately. Vernier adjustments are provided for slight variations in repeater spacing. This variable gain repeater automatically matches the gain and temperature

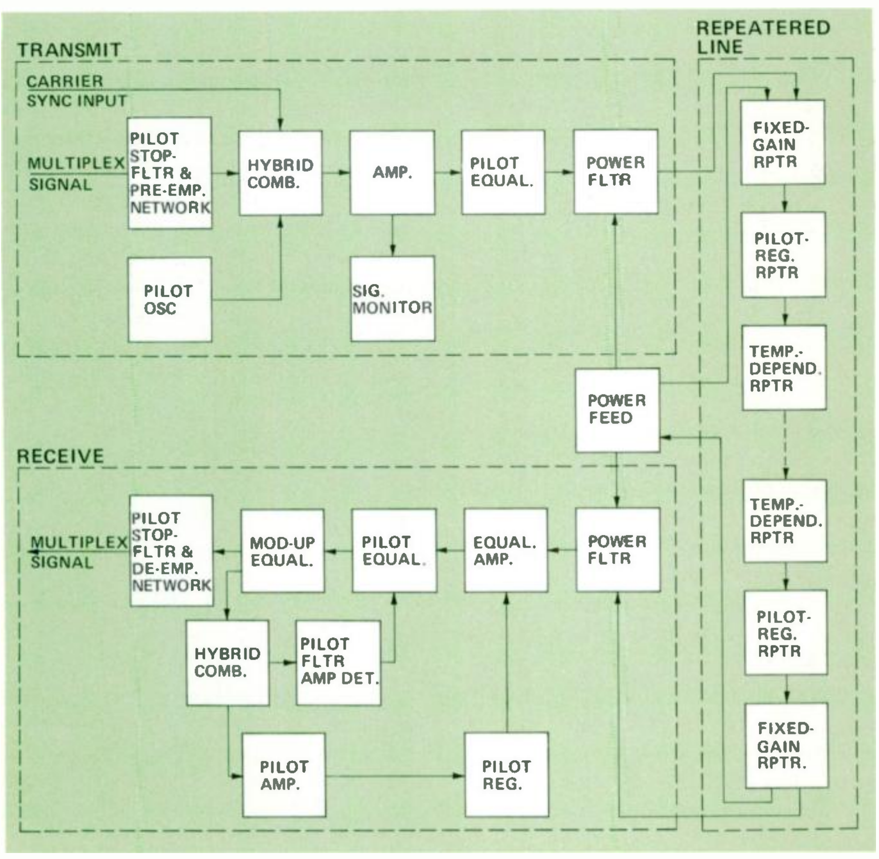


Figure 3. The simplified block diagram of a representative coxial cable system illustrates the functions of the terminal and line equipment.

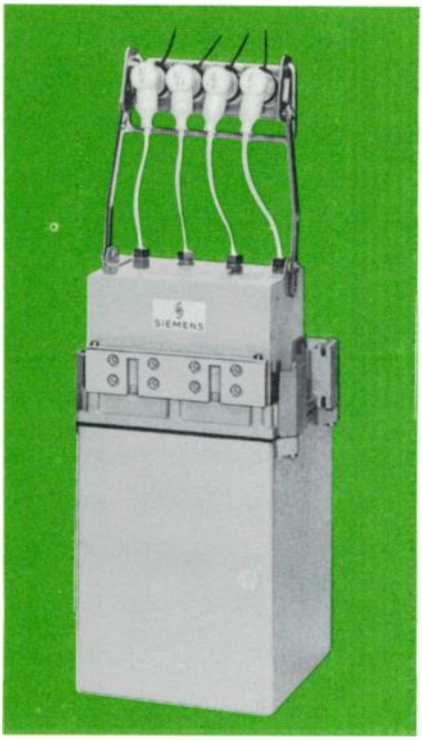


Figure 4. Highly reliable temperature-dependent and pilot-regulated repeaters are packaged in water-tight containers for underground installations.

to maintain proper level stability. These temperature-dependent repeaters have a low power requirement which helps to increase the number of repeaters that can be powered from a common power feed.

Since temperature-dependent repeaters are partially regulating, it is possible to have as many as twelve temperature-dependent repeaters between pilot-regulated repeaters. It is necessary, however, to provide good correlation between the temperature of these repeaters and the coaxial cable temperature.

These temperature-dependent repeaters are outstanding in simplicity and reliability. Only three highly reliable transistors are needed per repeater, and MTBF (Mean Time Between Failures) figures of 500,000 hours per repeater are not unusual. Because of this high reliability, the coaxial cable and repeaters can be put underground without planned access and planned maintenance. Figure 5 illustrates two repeater housings, one with access and one without.

Repeater Spacing

The spacing between repeaters is dependent upon the bandwidth transmitted and the diameter of the cable and associated attenuation characteristic. Standard size coaxial cables can be described in terms of the inner diameter of the outer conductor. Therefore, standard large diameter cable is expressed in inches as 0.375 inch cable, or in millimeters as 9.5 mm cable. Small diameter coaxial cables are described in similar terms as 0.174 inch cable, or 4.4 mm cable. Figure 6 lists CCITT (International Telegraph and Telephone Consultative Committee) channel capacities and repeater spacings as a function of cable diameter.

The small diameter cable (0.174 inch) is generally used where the ultimate growth of the communications

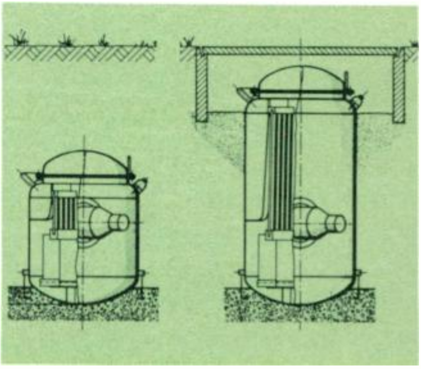


Figure 5. Underground repeater housings are available without access (left) and with access (right).

System Channel Capacity	Repeater Spacing .375 in (9.5mm) cable		Repeater Spacing .174 in (4.4mm) cable	
	Miles	Kilometers	Miles	Kilometers
300	11.6	18.6	5.0	8
960	5.8	9.3	2.5	4
2,700	2.9	4.65	1.25	2
10,800	0.97	1.55	Not recommended	

Figure 6. The CCITT has established channel capacities and repeater spacings for coaxial cable systems as a function of cable diameter.

system can be limited in terms of maximum channelization and system length. Extra cable loss and more frequent repeater spacings cause the noise performance for systems employing 0.174 inch cable to be higher than that obtained with 0.375 inch cable

A general rule that has been followed is that the communications capacity can be tripled when the repeater spacings are halved. By always cutting the spacings by a sub-multiple for expansion, reuse of existing buildings, repeater housings, and other auxiliary features is possible. This reuse keeps expansion costs down, making the long term investment in coaxial cable more attractive.

Applications

Recent interest in wideband communications has also directed attention to coaxial cable transmission systems. Video-phone, facsimile, and television are some of the areas of communication that are bringing more attention to coaxial cable. In order to provide the necessary bandwidth, higher microwave frequencies can also be used, but there are some transmission restrictions with these higher frequencies (these will be discussed in a future Demodulator article). In metropolitan areas, even if a clear frequency allocation can be obtained, it is not always possible to obtain a transmission path clear of obstacles – buildings, other towers, etc. With coaxial cable, wideband services are not affected by the obstacles experienced with radio transmission, but right-of-way acquisitions may be difficult to obtain.

Communications are increasing efficiency in industrial and municipal operations. The availability of a frequency band of a megahertz or so on a coaxial cable system can offer a sufficient number of communications channels to serve these users' needs for many years in the future. A small size cable without repeaters can provide an extremely reliable, short-haul transmission system. The cost is not great considering the capacity and versatility provided. Applications could include emergency alarm signaling, voice communications, data, and slow-scan television.

The next break-through in coaxial cable transmission will come when equipment for PCM on coaxial becomes readily available. New techniques for cable burial are also rapidly being developed which should lower cable installation costs.

Coaxial cable transmission can provide even better transmission quality and wider channels than microwave systems. So, it may not be long before the user can freely choose between coaxial cable and microwave depending upon which best fits his needs and physical environment.

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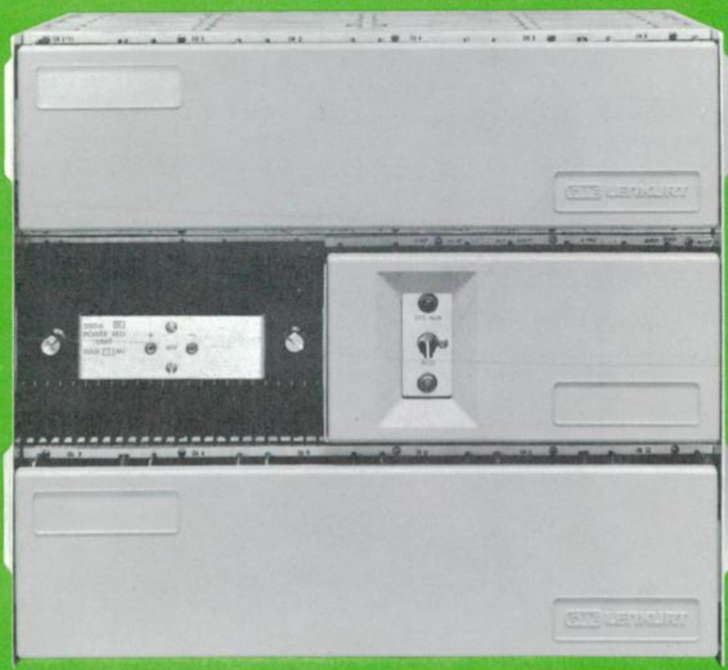

GTE LENKURT

VIDEO, VOICE & DATA
TRANSMISSION SYSTEMS

The GTE Lenkurt Demodulator is circulated monthly to technicians, engineers and managers employed by companies or government agencies who use and operate communications systems, and to educational institutions. Permission to reprint granted on request.

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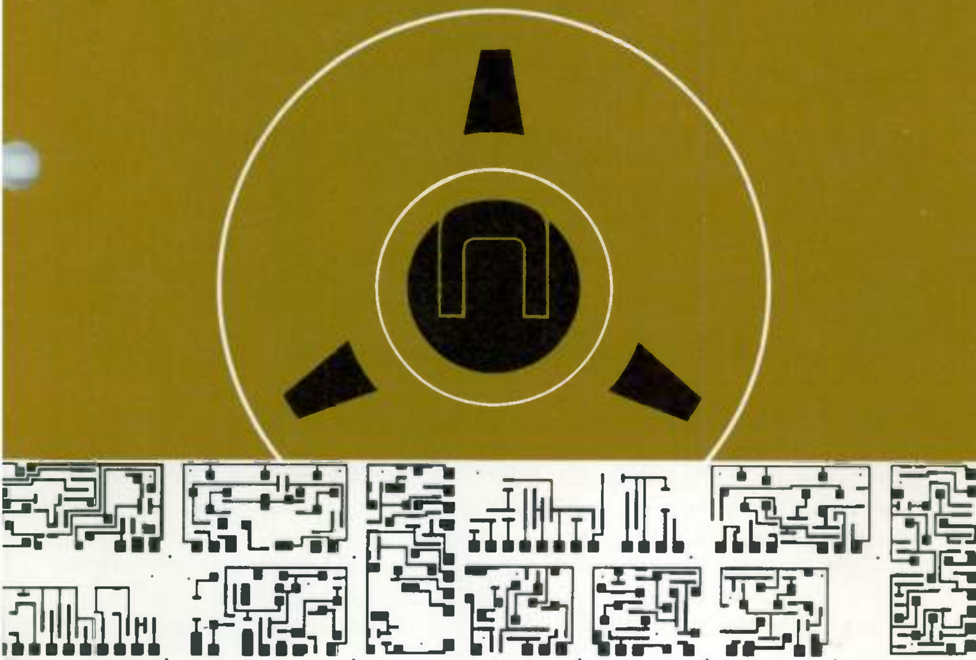
APRIL 1971



the computer in industry

Computers play an integral part in the design, manufacture, and installation of communications systems, and in dispensing with the associated paperwork needed to carry out these processes.

The new generation of digital computers – the third generation – stresses user conveniences. The associated input-output devices are designed to make man-machine communication as convenient as possible. This third generation has introduced the idea of computer graphics which can convert pages of data into meaningful and useful design concepts. The cathode ray tube and the x-y plotter are the two primary input-output devices that have made these computer graphics possible.

The computer graphics of the third generation complement the capability of the previous generations rather than making them obsolete. This developing and expanding use of the computer is helping industry keep up with rapid changes in all areas of technology.

Engineering Design

Starting with the initial design of a communications system, the computer is a significant aid. One common computer use is in network design and analysis of both passive and active filters. The computer can perform many functions in carrying out the filter design. Synthesis, optimization, performance analysis, and sensitivity analysis are some of these functions.

Knowing the desired input and output characteristics of the filter, the engineer uses a synthesis program to design the filter circuit. With the designer supplying sample frequencies in the stopbands and passbands, the computer calculates the loss at each of these frequencies from which an accurate loss curve can be plotted. According to mathematical equations specified by the computer program, the computer can design a filter circuit to match this loss curve.

If the designer is satisfied with the circuit and predicted performance, an optimization program determines the component values necessary to optimize the circuit parameters.

Once the proper circuit and respective components have been selected, filter performance is checked using the computer. In the performance analysis step, the computer "predicts" such parameters as total loss, phase shift, envelope delay, reflection coefficient, and input impedance.

In order to complete the network design, the computer uses a sensitivity program to study network performance when the components go out of tolerance, the temperature changes, an inductance changes, or any other predictable change occurs. The results of this program give the engineer some idea of how valid his chosen tolerances are and allows him to adjust his tolerances to meet performance requirements while minimizing cost.

When the total system is designed and ready for pre-production and manufacturing, the computer comes into serivce again. Sheet metal template layout, printed wiring card artwork and thick film circuits are some of the areas covered by computer aided design (CAD).

Sheet Metal Templates

Sheet metal template layout by computer is another time saving operation both from the standpoint of prototype layout and production runs – even with design changes. The use of the computer to make a master template eliminates the need to hand scribe a sheet of metal that has been covered with a thin coat of paint. In the hand scribe method, the layout man scribes the sheet according to the dimensions given on the engineering drawing for the various items to be reproduced on an actual manufactured sheet metal part. This operation is time consuming and requires a skilled layout man to produce the needed accuracy.

Using this hand scribe method, it becomes even more costly if it is necessary to make an identical template if the first has become worn or because the part is being made in more than one location. And, if design changes are required, an updated engineering drawing is needed before a new template can be scribed.

The major advantage of computer assisted template layout is the ease with which identical templates can be scribed. If instead of scribing lines the layout man puts his time and effort into coding the layout for use with a suitably programmed computer, the second template can be scribed in an average time of 15 minutes, on a flatbed, x-y plotter.

If any changes or modifications are required in the original design, the appropriate changes or modifications are made in the input data before the new template is produced. This input deck is made up of the information from the engineering drawing of the sheet metal part. The mnemonic coding language for template layout uses single letters to designate standard fabrication operations, such as arc, band, countersink, and notch. An added advantage is that the engineering drawing to be coded can show the formed sheet metal part, and the computer can be programmed to compensate for the necessary bend allowances in laying out the flat, unformed template.

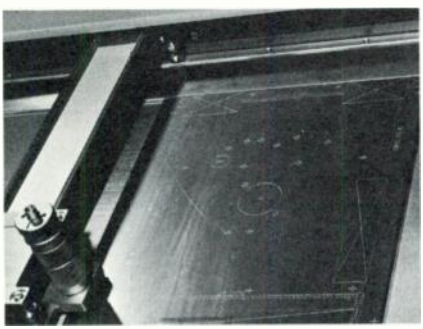


Figure 1. An x-y plotter scribes directly on a painted metal plate to make a sheet metal template.

Using the computer assisted layout procedure, the designer can check the input data before making the template. This is done by plotting the layout on paper before scribing it on metal. Once this paper plot has been checked, the painted metal for the template is put on the plotter to be appropriately scribed, as shown in Figure 1. Necessary written instructions are scribed right on the template so they are legible and cannot be misplaced.

The coded information used to generate the sheet metal template can also be programmed to generate a punched tape for use on a numerically controlled milling machine for machining holes, slots, counterbores, and other machined operations.

Printed Wiring Cards

Another area of computer aided design helpful in getting a product into production is printed wiring card (PWC) layout. Under non-computer aided conditions, four different steps are involved after the circuit designer has completed his design. First, a mask must be drawn or taped for the circuit, designating all the wires and component pads. Second, a reverse side mask must be made indicating component designations and locations. A third mask is a solder resist mask. And fourth, a tape is punched for numerically controlled drilling of the card.

In order to achieve the necessary accuracy, the masks are made at twice the desired finished size and then camera reduced to the proper size. The reduced masks are then used to make silkscreens for printing acid resistant material on the cards. After screening, the cards are acid etched to remove the unwanted metal leaving only the printed wiring circuit on the card.

Using the computer to generate the final artwork, the designer makes a rough sketch of the circuit to be placed on the card. This sketch indicates the placement of components and the routing of the paths. To facilitate coding, the designer usually does the routing of wires on a grid.

To save time in the computer coding process, each component is listed giving a standardized description which is referenced to a drawing of that part. These reference drawings give the component dimensions and pad locations and can be called from the central processor memory when needed. Each component in the list is then coded for position and angle of rotation from the orientation of the reference component. Each pad is then given a number so that a path connection list can be compiled, without knowing the pads' x-y coordinates.

From this input data and a suitable computer program, the same x-y plotter that was used to make sheet metal templates can be used to draw the three masks necessary for making PWC's. This same program and data deck provide the information neces-

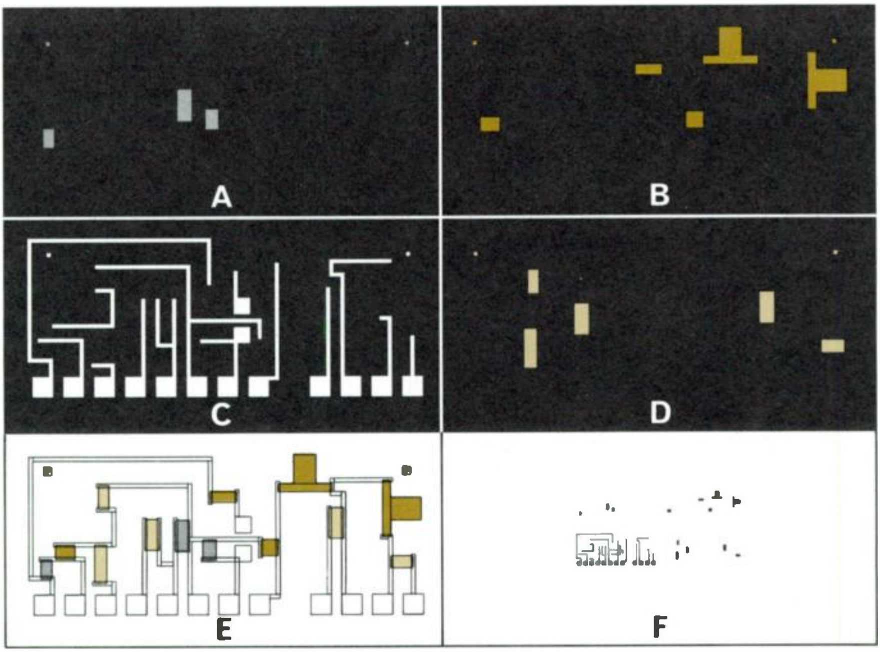


Figure 2. In the production of thick film circuits, mask cutting is done on an x-y plotter (A,B,C,D), a composite mask is also drawn by the plotter (E), and then the masks are photographically reduced to the proper size (F).

sary for punching the tape for numerically controlled drilling of the cards.

One of the most obvious savings experienced using the computer for PWC artwork is that the output from the plotter is to scale; therefore, eliminating the camera reduction step. Updates and changes are easily made to the input data and new photographic masks plotted. The new masks can be plotted on paper if updated drawings are necessary for documentation.

Thick Film Circuits

Computer assistance is provided at two points in the design and production of masks for thick film circuits – ceramic substrates with electronic circuit elements desposited in layers. The computer in conjunction with the plotter, is used to generate the proper resistor shapes for the needed values. These shapes are then plotted on paper as aids to the designer for the final circuit design.

Using these paper aids the designer lays out a separate mask for each layer of the thick film circuit, in much the same way a PWC might be laid out. In order to achieve the required accuracy, the artwork for these masks is drawn at ten times the desired size by a skillful draftsman. Or, using a coding process similar to PWC coding, each layer can be put into a form acceptable for the computer. The computer/plotter combination uses this coded information to produce a mask for each layer of the thick film circuit. These masks are cut five times oversize and reduced down by camera – a savings of 50% in material alone. Registration accuracy for all layers is also guaranteed using the computer technique. Figure 2 shows masks generated by the plotter.

Production

Statistical analysis can be a tedious process, but it can be helpful in checking the quality assurance of incoming parts. When receiving shipments of components such as capacitors, inductors, and crystals a random sample of these items is tested to see how they fall within the specified tolerance range. Using the computer, statistical analysis can be carried out to predict the tolerance variation of the total shipment. From this analysis a decision is made as to accept or reject the shipment. Such a technique saves inspection time and assures fewer system failures caused by components not meeting specification.

If a shipment is accepted, the parts are processed through a computerized inventory system. The flow of all parts

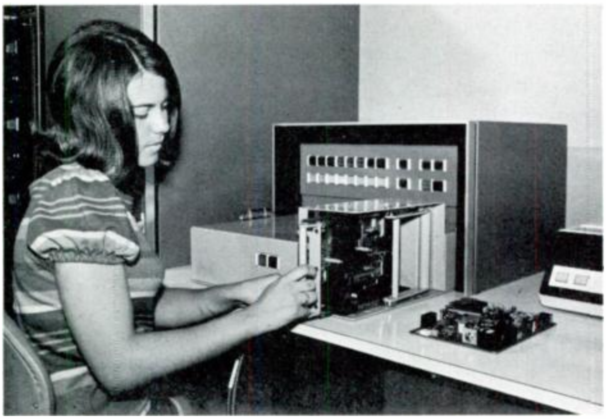


Figure 3. Finished systems are quickly and easily inspected using a computer-controlled test procedure.

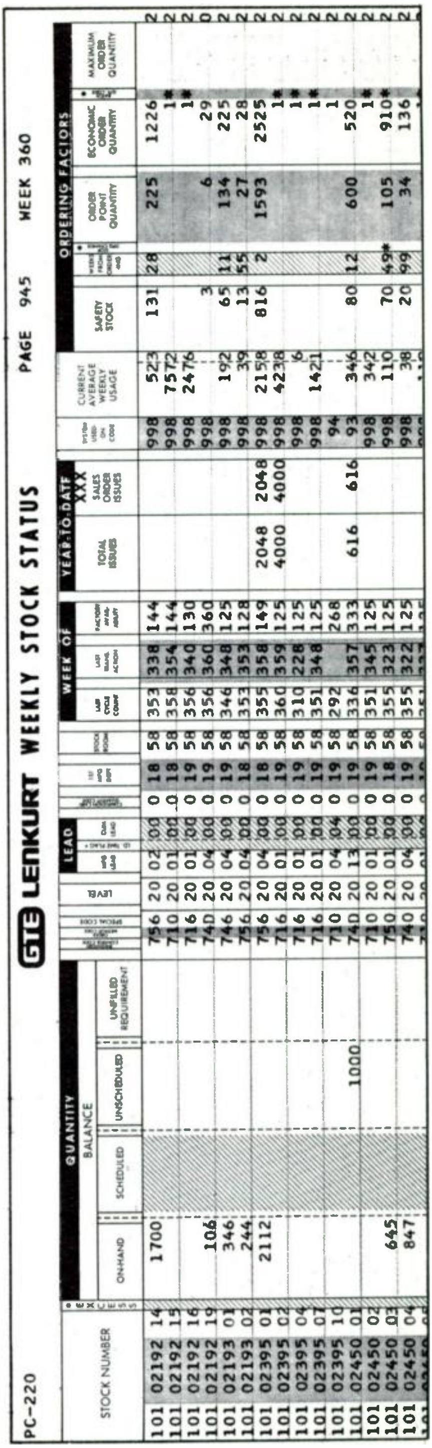
and material is monitored by computer. This inventory control system has been designed to show what parts are used in what products and in what quantities, as well as the number of parts available. This same system records the parts as they go into production and as they are returned as subsystems and then total systems.

At this point the finished systems are given a final inspection. Such systems as the GTE Lenkurt 91A PCM channel units are inspected with a computer-controlled test device (see Figure 3). The previous 20-minute non-computer-controlled routine which includes 25 tests takes only one minute with the aid of the computer. If any of the tests performed on the channel unit indicate a problem, the test set begins an automatic trouble-shooting sequence. In order to locate the fault, as many as 75 additional tests may be made, taking only one additional minute. When the fault is located, a printout device records the fault location data on paper tape, and at the same time the failure data is stored in the computer's memory. This information is tabulated in order to discover possible design weaknesses.

System Planning

When a customer wishes to purchase and install a communications system, he sometimes only knows that he wants to get information from one point to another and he does not necessarily know what equipment is required to install this desired communications link.

Computer technology and programming skill has helped to make this information more readily available. For example, microwave site calcula-



PC-220 GTE LENKURT WEEKLY STOCK STATUS PAGE 945 WEEK 360

STOCK NUMBER	EXCESS	ON-HAND	SCHEDULED	UNSCHEDULED	UNFILLED REQUIREMENT	SPECIAL CODE	LEVEL	MFG LEAD	CUM LEAD		1ST MFG DEPT	STOCK ROOM	LAST CYCLE COUNT	LAST TRANS. ACTION	FACTORY AVAIL-ABILITY	TOTAL ISSUES	SALES ORDER ISSUES	SYSTEM USED-ON CODE	CURRENT AVERAGE WEEKLY USAGE	SAFETY STOCK	WEEKS FROM ORDER	ORDER POINT QUANTITY	ECONOMIC ORDER QUANTITY	MAXIMUM ORDER QUANTITY	
101 02192	14	1700				756	20	02	00	0	18	58	353	338	144			998	523	131	28	225	1226		2
101 02192	15					710	20	01	00	0	18	58	358	354	144			998	7572				1*		2
101 02192	16					716	20	01	00	0	19	58	356	340	130			998	2476				1*		2
101 02192	19	106				740	20	04	00	0	19	58	356	360	360			998		3		6	29		0
101 02193	01	346				746	20	04	00	0	19	58	346	348	125			998	192	65	11	134	225		2
101 02193	02	244				756	20	04	00	0	18	58	353	353	128			998	39	13	55	27	28		2
101 02395	01	2112				756	20	04	00	0	18	58	355	358	149	2048	2048	998	2158	816	2	1593	2525		2
101 02395	02					716	20	01	00	0	19	58	360	359	125	4000	4000	998	4238				1*		2
101 02395	04					716	20	01	00	0	19	58	310	228	125			998	6				1*		2
101 02395	07					716	20	01	00	0	19	58	351	348	125			998	1421				1*		2
101 02395	10					710	20	04	04	0	19	58	292		268			94					1		2
101 02450	01			1000		740	20	13	00	0	19	58	336	357	333	616	616	93	346	80	12	600	520		2
101 02450	02					710	20	01	00	0	19	58	351	345	125			998	342				1*		2
101 02450	03	645				750	20	01	00	0	18	58	355	323	125			998	110	70	49*	105	910*		2
101 02450	04	847				740	20	04	00	0	19	58	355	322	125			998	38	20	99	34	136		2

Figure 4. Stock status reports provide statistical information used by production control to aid their scheduling of production.

tions can and are being made by computer. By making measurements of the geography of the area, it is possible to determine, for a given transmitter/receiver combination, the antenna placement and orientation as well as such performance information as free space loss. This information must be documented and sent to the FCC for approval before it can be installed; therefore, the sooner it is submitted, the better. All approved installations could be recorded in a central memory system so that any proposed system could be checked against the memory for conflicts.

If it is a cable repeater installation rather than a microwave system that is under consideration, the computer is also of assistance in laying out the communications link. Such information as the system length, the lengths and types of existing cable, and the type of information to be transmitted is fed to the programmed computer which prints out the optimum repeater spacing and the repeater slope and voltage settings. The specified repeater locations are then checked to determine if it is possible to place the repeaters exactly as specified. If not, due to physical obstructions or other causes, the necessary adjusted spacings are fed into the computer which then calculates voltage drops and repeater slope settings to accompany these new spacings. The printout of the spacings and voltage drops and slope settings is used as an installer's document for the proposed system.

Actual system design is also aided by the computer. Using a series of decision tables programmed into the computer, complex systems are optimized for performance and manufacture. Where there are many options available, such a program assures the best arrangement of the system parts and also guarantees consistency of design if the same set of options are ordered at another time. Once the desired system has been designed and laid out, the computer, by searching its master parts list generates a parts list for this particular system.

Paper Work

When a customer places an order for equipment, the computer checks the inventory list to determine what equipment, subsystems, parts, and raw materials are available to fill the order. If the order cannot be filled with the materials at hand, the computer prints out the items and quantities to be built or purchased and a list of vendors and their respective lead times.

Using the inventory information from a computerized production control record (see Figure 4), the customer shipping date is established.

The computer that is used for inventory and production control is also used for accounting and other business applications. It is used for ordering and check writing for paying for materials, billing customers, and writing paychecks. In general, the computer can be and is being used to keep track of the company's assets and liabilities.

Whether it is a routine bookkeeping matter or a tedious statistical analysis, the computer can only do what it is programmed to do and its computations are only as accurate as the data that is fed into it. Therefore, the computer can save time, effort, and money only if the assigned jobs are properly designed and programmed. With this in mind, it is necessary to have personnel familiar with the tasks to be performed and with systems design and computer programming expertise in order to take full advantage of the computer's capacity.