July-August 1962

Bell Laboratories

RECORD

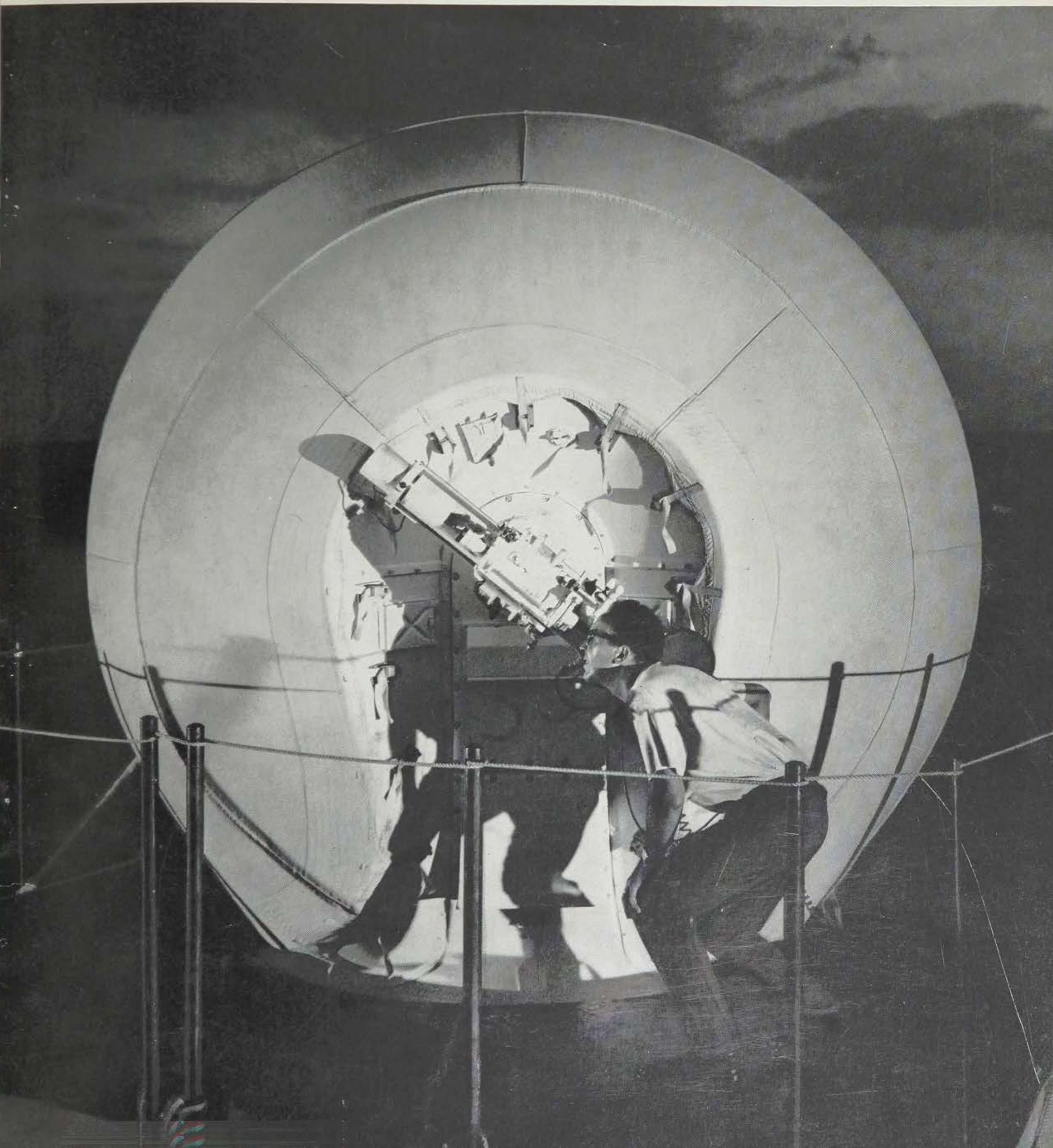
TWX Goes Dial

Symbolic Logic: Part II

Growing Oxide Crystals

Packaging the E6 Repeater

Telstar Success



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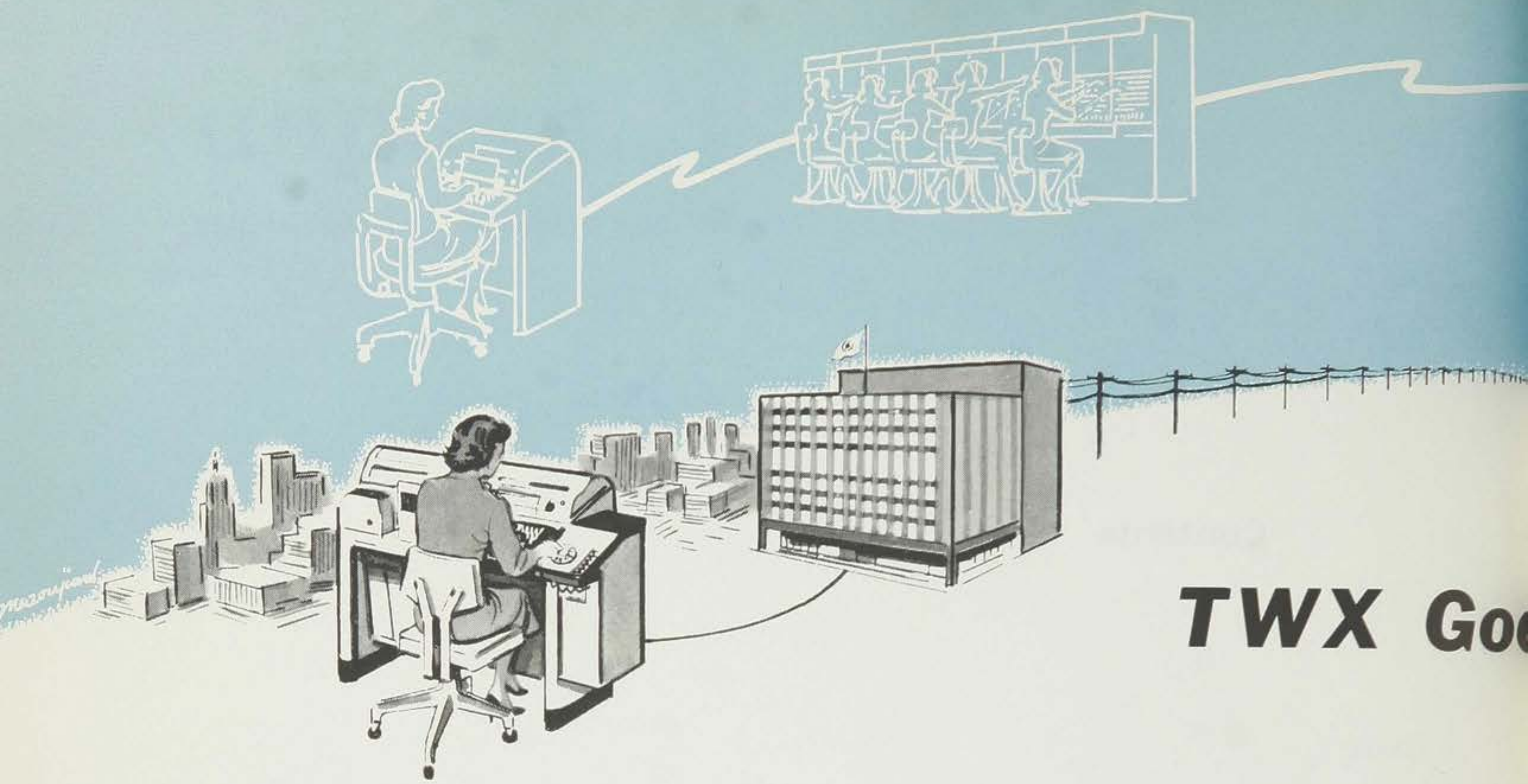
Cover *In the predawn gloom at Cape Canaveral, Bell Laboratories engineer sights through telescope attached to the radar antenna at the Delta rocket carrying Telstar satellite into orbit. (See story page 250.)*



TWX Go

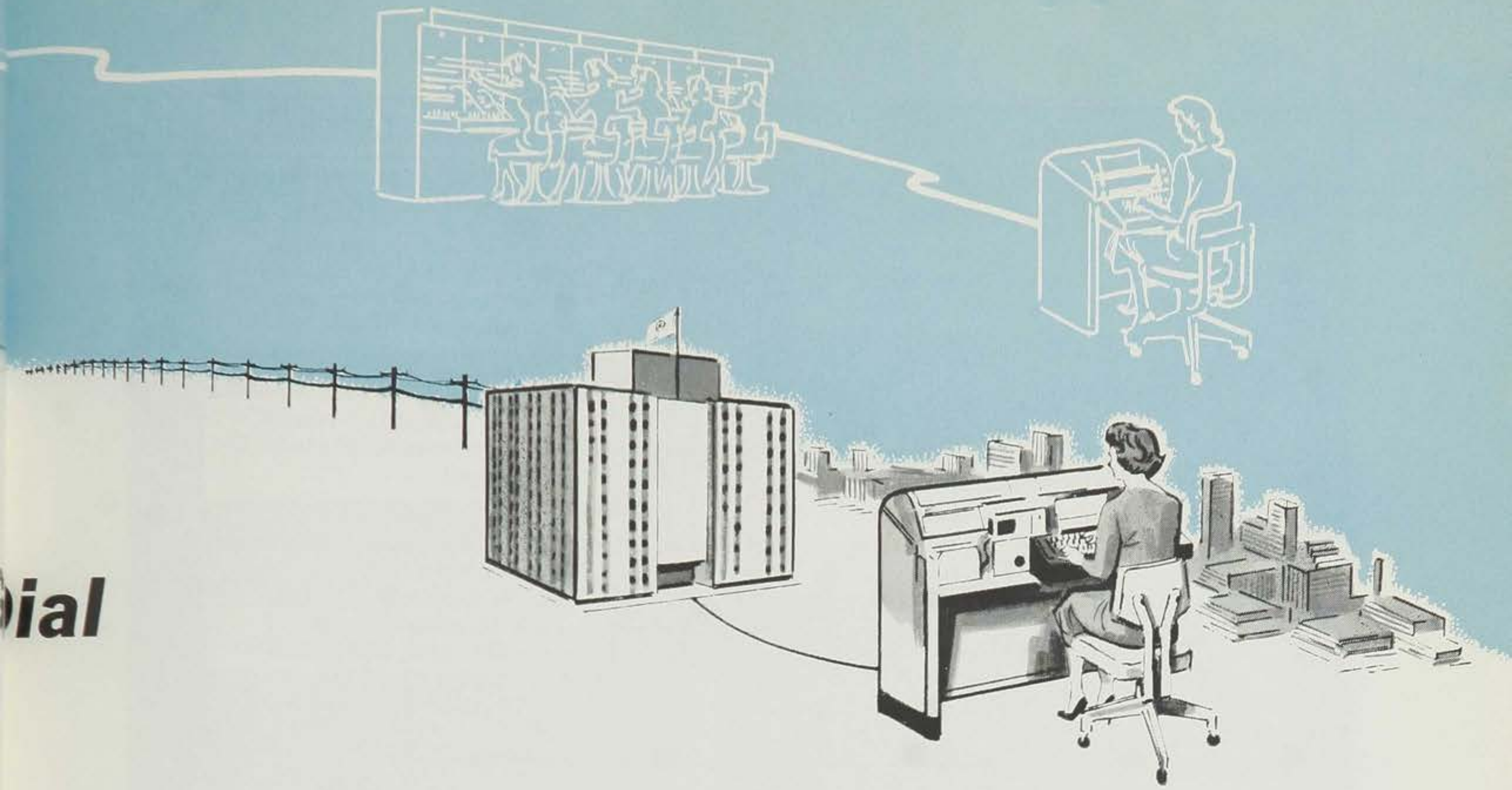
The first nationwide cutover in the history of telephony—one that will involve every operating company in the Bell System and many independent telephone companies—will take place on August 31, 1962. When it is accomplished, some 60,000 teletypewriter exchange (TWX) stations in the United States will begin to dial their calls over the Bell System's direct distance dialing (DDD) network. Almost 900 central offices will be switching centers for the TWX stations.

Since TWX service was started in 1931, its calls have been switched manually; at present 100 switchboard locations are needed to handle the traffic. Most of these have trunks to only 10 other locations in the network; none has trunks to all others. These limited trunking paths, and the fact that the average TWX call covers about 800 miles, results in a large number of multi-switch connections that must be handled by operators. Manual handling of calls is a costly procedure and it requires about two and a half minutes to set up a call. These and other considerations made it desirable to mechanize TWX service as soon as possible.

Tying TWX stations into the DDD network permits the telephone industry to convert them to dial operation in the minimum of time and TWX service will benefit in a number of ways. First, the DDD network will reduce the average time to set up a call to about one-half minute. Second, it will permit customers to place calls in the same manner as telephone calls. Thus, a minimum of customer training will be required. Third, it will reduce the interval from receipt of an order to service because ordinary telephone loops can be used rather than special telegraph loops.

Each TWX station will be assigned a ten digit telephone number. TWX stations will complete calls over the DDD network in much the same manner as telephone stations, but two-way voice communications with telephone stations or to other TWX stations will not be possible. Assistance, collect, conference and similar calls will be handled through switchboards recently designed at Bell Laboratories which will be located at 16 operating centers throughout the country (see the map on page 236), and reached from any TWX station by dialing a special seven digit number. There will also be one information center located in St. Louis, Missouri. All communication with TWX operators will be by teletypewriter machine.

TWX transmitting and receiving stations will



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E. J. Tyberghein

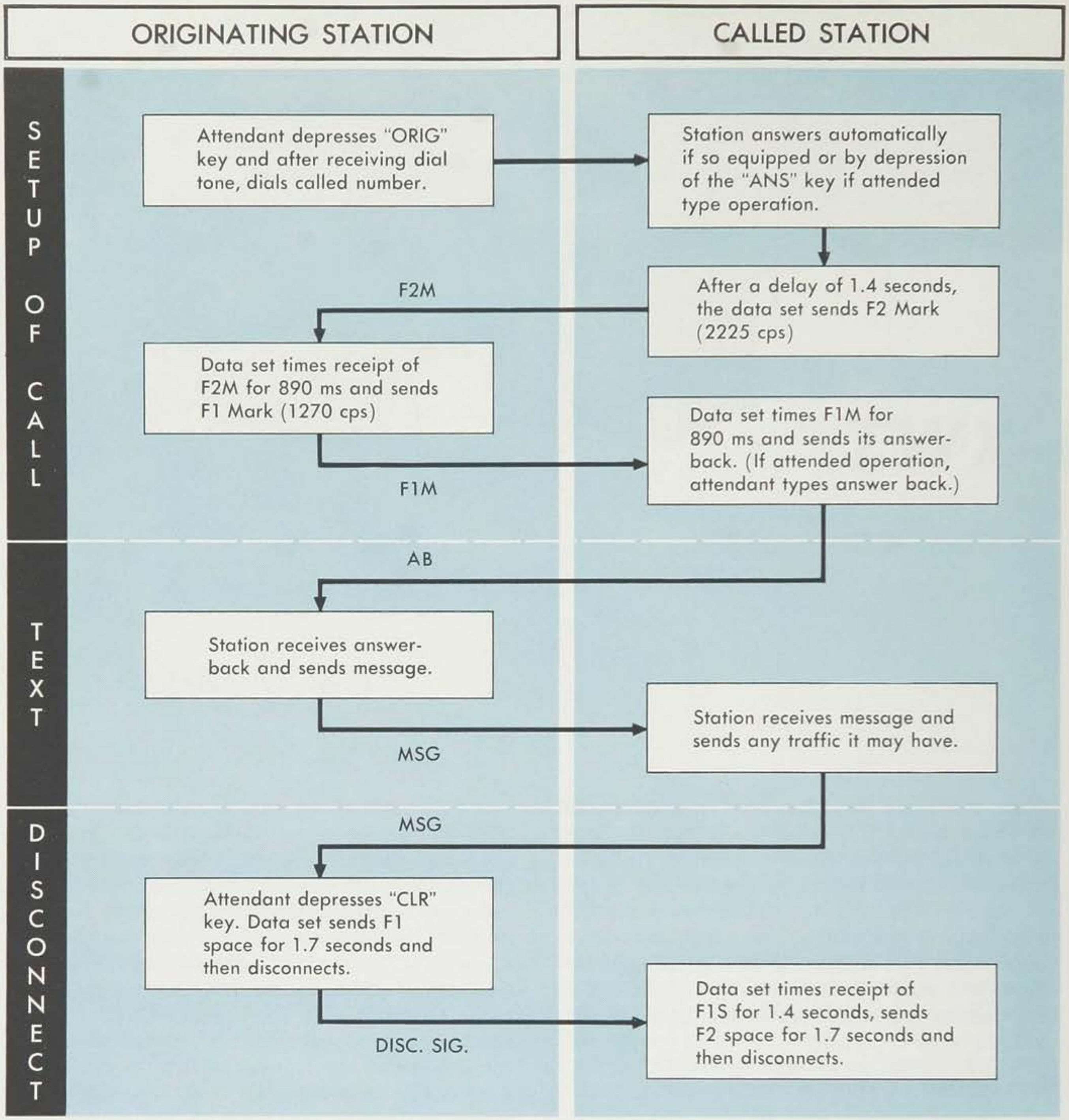
retain the same teletypewriter machines that are in use today: Types 14, 15, 19 and 28. Each machine will provide either manual or automatic answer service. Automatic answer 15 and 19 type machines will answer by sending the letter "V" to indicate to the calling station that they are ready to receive. Automatic answer 28 type machines will send a multicharacter answer which will identify the called station and indicate it is ready to receive.

New Station Equipment

A newly developed data set and an attendant set are intermediate equipment between TWX stations and their serving central office loops. Together, they will (1) convert the dc teletypewriter signals into mark and space carrier frequencies in the voice frequency band; (2) provide all necessary machine control functions; and (3) provide assurance that the transmission circuits are functioning. (If the signal in either direction is lost for approximately one second, both stations will be disconnected.) In addition, the attendant set will provide a means of dialing into the serving central office, and of listening to call progress tones such as dial tone, busy tone, reorder, etc.

A very natural sequence is followed in setting up a call as shown on the next page. The TWX attendant originates a call simply by depressing the ORIG key on the attendant set. Dial tone is returned, and the attendant dials the station she wishes. The called station answers and, after a slight delay to permit off-hook supervision to propagate back to the originating central office, sends F2 mark tone. The F2 tone (2225 cps) disables any echo suppressors in the path and enables the data set at the originating station. The originating station returns F1 mark tone (1270 cps) which enables the data set at the terminating station. When both stations are enabled, the called station sends its multicharacter or "V" answer-back. At this point, both stations are ready to send or receive messages in turn. The originating station always sends its data signals in the F1 band and receives in the F2 band. The called station sends in F2 and receives in F1. An attendant at either station can end the call simply by pressing a CLR (clear) key on the attendant set. For a disconnect signal, the originating station sends F1 space tone (1070 cps) and the called station sends F2 space (2025 cps).

TWX calls will continue to be billed on an



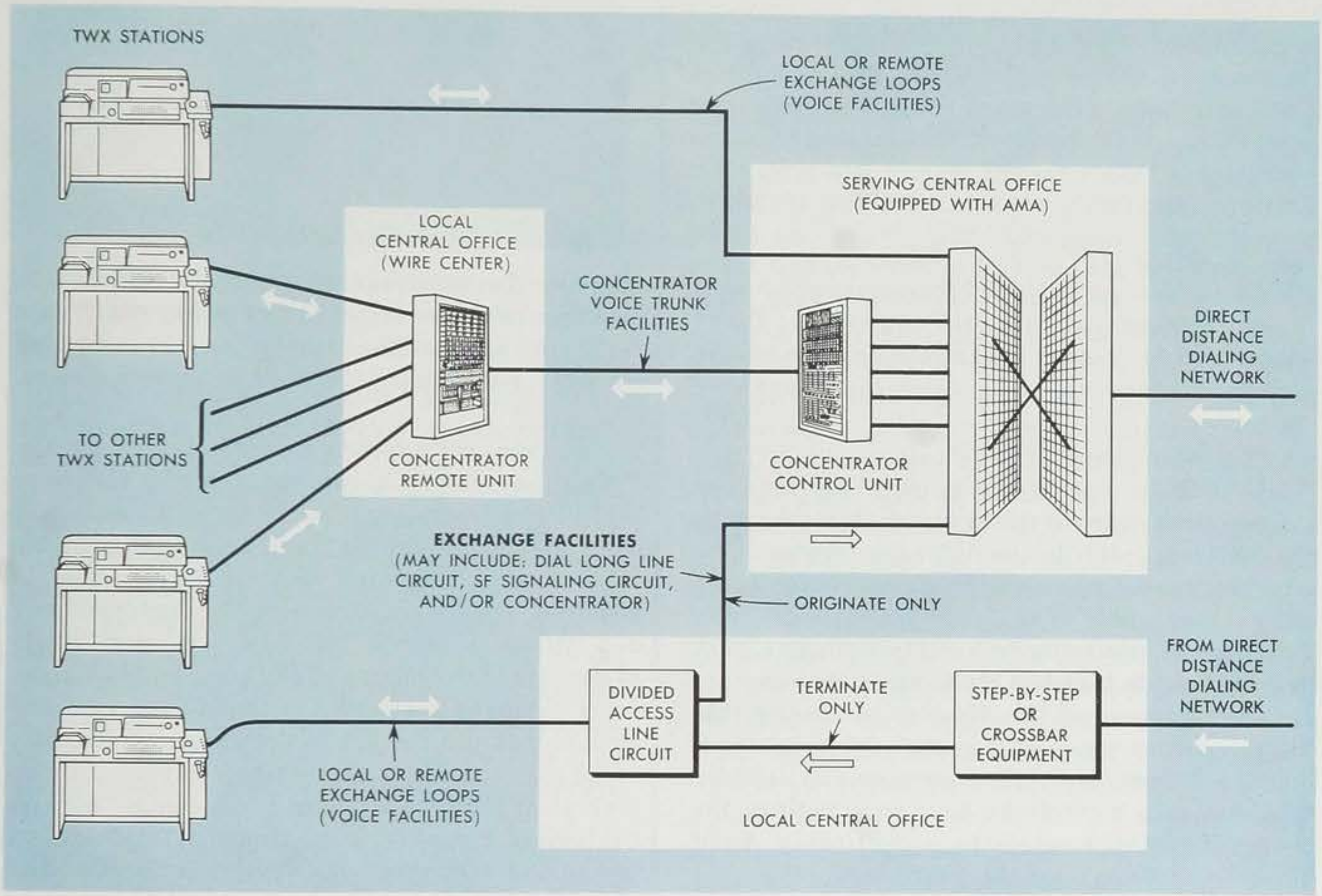
A call between teletypewriter stations will be set up in the steps shown in this drawing. When a teletypewriter console is unattended at a dial TWX *station, an answerback mechanism indicates automatically to the calling party that the station has answered and that it is ready to receive messages.*

individual message basis and therefore automatic message accounting (AMA) records of all calls will be kept. Centralized AMA equipment with operator identification of the calling customer cannot be used because voice communication is not possible. No. 5 crossbar offices with local AMA are preferred for this service, but they do not exist in all areas serving TWX stations. Consequently, some step-by-step offices with automatic number identification (ANI) and CAMA, and some No. 1 crossbar offices with LAMA or ANI CAMA will be used.

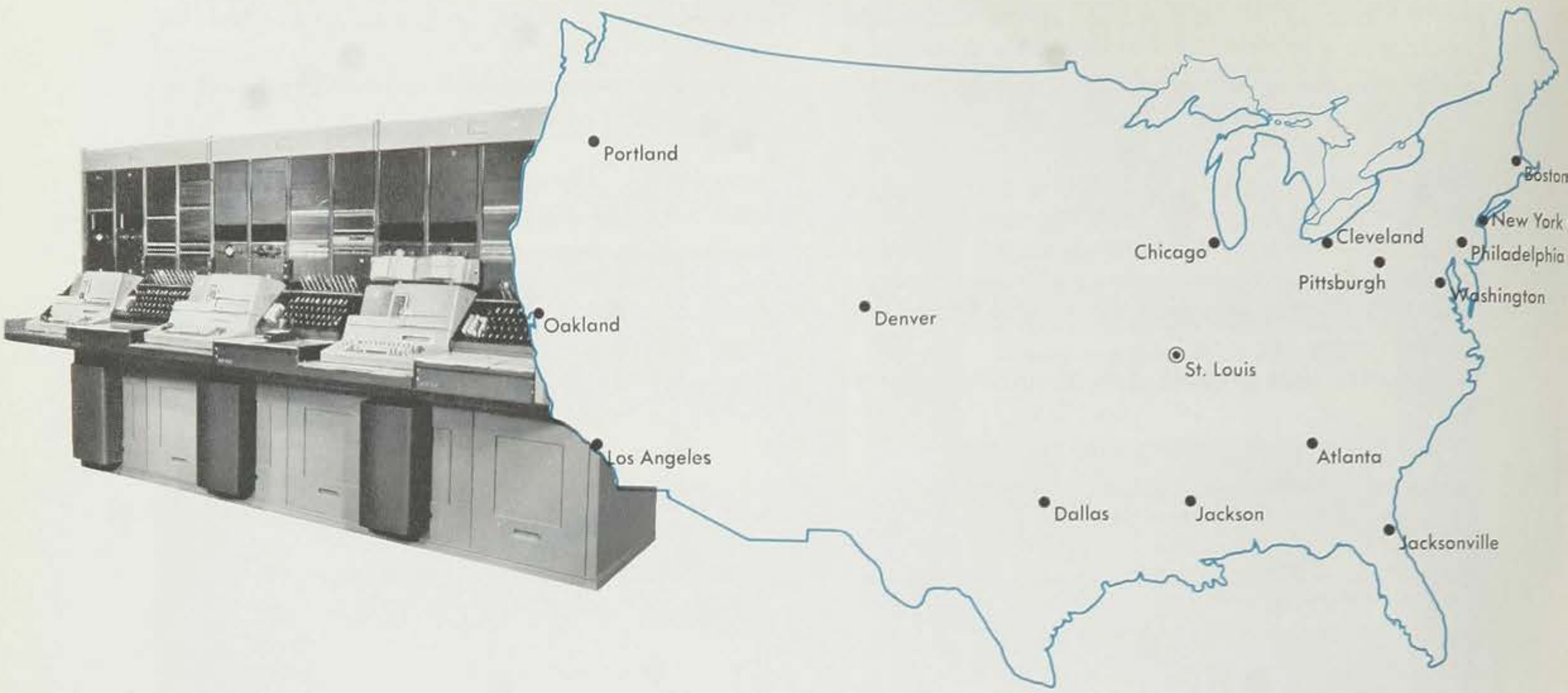
The charge per message depends on the distance and duration of the call. Mileage is determined by the distance between the rate center areas in which the stations are located. In order to keep message sorting at the various accounting centers to a minimum, it is desirable to assign a different central office code for each rate center involved. If separate codes are not assigned, it will be necessary to sort messages from TWX stations by the thousands or possibly even the hundreds digit of the called station's number. However, there are not yet enough AMA and ANI CAMA central offices located in the right spots around the country. Hence, we cannot provide all the rate center codes we need.

To solve this problem, Laboratories engineers developed a divided access line circuit (DALC) which makes it possible for a TWX station to originate messages via one central office (having AMA or ANI CAMA) and receive incoming messages via a different central office which has the proper rate center code. Several typical line and trunking arrangements for serving dial TWX stations are shown in the drawing above. Only voice bandwidth loops are used; loop plant investments are kept to a minimum by using the 1A line concentrator with new arrangements that permit it to operate with carrier transmission trunks.

DDD central offices will be able to handle TWX traffic with the relatively few changes that have been outlined. Some changes also will be made in the interoffice trunk facilities. First, some trunk groups will be enlarged to accommodate the additional load. Secondly, all 2000 cps SF signaling units (a relatively small portion of the single frequency units in plant) will be replaced by 2600 cps SF signaling units. If this were not done, F2 frequencies (2125 ± 100 cps) would cause false operation of the 2000 cps SF receivers. Thirdly, because a receiving TWX station must be able to send a "break" or stop signal while the other station is sending, an echo suppressor disabler will be installed on every echo suppressor that



Shown here are typical line and trunking arrangements that will be used to serve the new dial TWX *stations. The divided access line circuit solves a problem of rate center codes by allowing* TWX *stations to place a call through one central office and to receive through a second central office.*



This assistance switchboard was developed at the Laboratories specially for dial TWX *service. These boards will be located in the cities shown on the map and will share a special seven-digit telephone number. An attendant at any* TWX *station who wishes assistance with collect calls, conference calls, etc., can dial this number and be connected with the switchboard assigned to serve her area.*

may be encountered by a TWX call.

The disabler was developed especially for data transmission over the DDD network. It works with the echo suppressor in the following manner: The echo suppressor monitors the signal energy present in both sides of a four-wire circuit (both directions of transmission) and introduces a high loss in the side that has the lower signal energy. It is the purpose of the disabler to remove this high loss when the circuit is used for data transmission. To accomplish this purpose, the disabler monitors each side of the four-wire facility for energy in two bands—the conditioning band (2000 to 2250 cps) and the guard band (the voice band outside of the conditioning band). Whenever the energy in the conditioning band is sufficiently in excess of the energy in the guard band for 350 milliseconds ($\pm$50 milliseconds), the echo suppressor is disabled; that is, the high loss is removed. If sufficient energy outside of the conditioning band is present on either side of the line, it will prevent the echo suppressor from being disabled. Thus, voice communication cannot disable the echo suppressor. After it is disabled by F2 frequency from the terminating station, the suppressor is kept disabled by energy in either band. A loss of signal for 100 milliseconds causes the suppressor to return to normal.

TWX customers will report trouble by telephone to their local operating telephone companies. A test desk man at the company will analyze the trouble reported and determine what course of action is required. Under his direction, the customer may dial up an automatic test line (ATL) and use it to determine the nature of the trouble. If an operating company craftsman is sent to the TWX station he may use the ATL to determine the trouble, or he may use his portable test equipment, or he may place a call to a manned test center. All test equipment, except for some standard transmission measuring test sets, was developed for the dial TWX system.

Automatic Test Line

The automatic test line permits one-man testing of the over-all operation of a TWX station. After it is reached through a dialed-up connection, it automatically sends standard teletypewriter test signals (the quick brown fox, etc. . . .) under various conditions of carrier signal level and distortion. The condition of the teletypewriter machine and that of the data set and loop is determined from the printed copy at the teletypewriter. After the station is thus checked for its ability to receive,

An attendant uses the new subscriber set on a teletypewriter console equipped for dial TWX *service.*

it gets a typed request from the ATL to transmit. Any distortion in transmission is automatically measured by the ATL and a "TRAN OK," indicating good transmission, or "OUT LIM," indicating a fault, is automatically typed back.

All the automatic features of the new system would be of little value to TWX customers if they did not assure an error performance at least as good as, and preferably better than, that of the present manual system. Field tests conducted jointly by the A.T.&T. Co., the operating companies, and the Laboratories indicate that there is a 99 per cent probability of sending a ten line message without errors due to transmission. Usually an error affects only one character; occasionally one will affect several characters. The rate of errors will vary depending on the kind of facilities a call is routed over and the number of links involved. Some customers will have a slightly higher rate, some lower.

Many customers will find dial-operated TWX service attractive for their data traffic. Customers with a very heavy traffic load will, of course, require much more sophisticated station equipment than has been offered in TWX service. In anticipation of this, new station equipment is being designed, so that, like dial-operated TWX, services can be offered with all the facilities customers may need.

Eastern Third of Blast-Resistant Cable System Nears Completion

The Bell System will complete the eastern third of its blast-resistant transcontinental cable system late this summer as part of its continuing program to insure the survivability of communications.

All the cable, amplifier stations and communications centers are being constructed underground, engineered to withstand any nuclear blast short of a direct hit. The system will be completed to the west coast by 1964.

The buried cross-continent system will transmit telephone calls, data and other communications and will interconnect with existing microwave and coaxial express routes. These criss-cross the nation and include bypass routes around potential target areas. The underground system, which also avoids large cities and major target areas, will represent a Bell System investment of about $200 million when completed.

The subterranean complex will include almost 4,000 miles of coaxial cables, more than 900 intermediate amplifier stations and nine communications centers linking the new route to conventional facilities. The cable is being buried deep underground, and all amplifiers and terminal equipment are housed in reinforced concrete buildings protected by thick earth cover. Manned stations are protected from radioactive fallout.

The communications centers, buried one to two stories deep, have reinforced concrete floors, ceilings and outer walls 18- to 24-inches thick. In emergencies, each center can generate its own power and has reserve water and fuel supplies. Food is stockpiled, and there are emergency living facilities for operators, technicians and maintenance men. Each center's ventilation system is controlled by a sensing device which would react immediately to nuclear blast. Blast valves in the underground buildings would close automatically, filtering equipment would cut in to prevent fallout from entering, and other equipment would constantly check radioactivity.

The only part of each building above ground is a small entrance structure. Personnel enter through a guarded two-door "entry lock" and pass through a fallout decontamination room before reaching the operations areas.

When fully equipped, the new transcontinental system will add about 9,000 telephone circuits to the 15,000 now spanning the country.

Symbolic Logic: The Extende

Symbolic logic is the root structure of mathematics and like many parts of mathematics it finds interesting practical applications. Some of these were pointed out in "Symbolic Logic: The Propositional Calculus" (RECORD, *June*, 1962), particularly in connection with the Boolean algebra. The gateway to symbolic logic is the Propositional Calculus, discussed in that article. Certain symbols such as p, q, or r stood for whole sentences, and other symbols ("and"), ("or"), and so on, stood for the common connectives whereby simple sentences are compounded into complex ones. The Propositional Calculus offered methods with which complex sentences could be systematically analyzed for their truth or falsity in terms of the truth or falsity of their component sentences.

To make any progress beyond this point it is necessary to start taking sentences apart. A simple declarative sentence, for example, consists of (or can be tortured into consisting of) a noun (or substantive phrase), the copulative verb "is" or "are" and a predicate adjective or adjectival phrase—for example, "the moon is blue."

Now let us specify some nouns a, b, c . . . , and some adjectives—or as we shall call them "properties" — which can be applied to these nouns or "objects." Properties will be symbolized by capital Roman letters, F, G, H . . . For example, the symbol "Fa" means that the object "a" has the property "F." If we define "a" to mean the moon, and "F" the property of being blue, then "Fa" is the sentence stated above.

One needs to call a halt here and inquire in what direction we are heading. It would be absurd to try to abbreviate and symbolize the whole English language; we would soon run out of letters of the alphabet. Rather, there is in each application of these techniques some appropriate "domain of discourse" which determines what part of the language is to be symbolized. If arithmetic were the subject matter, then "a" might be a number and "F" the property of being a prime. If genetics were the realm of discourse, then "a" might be a fruit fly and "F" the property of possessing a mutant characteristic. In this article, however, we will not specify any particular application but will let the examples range broadly in subject.

In addition to "properties" that characterize a single object, we are often interested in "relations" which connect two or more "objects." For example, if a and b are people, we might define Sib(a, b) to mean "a is a sibling of b." Here we use the three letter relation symbol "Sib" merely as a memory device. It is easier to remember than a single letter, say S. Similarly, if a and b are numbers, we might define Gr(a, b) to mean "a is greater than b."

Three-place relations are also of interest. For example, Par(a, b, c) could be defined to mean "a and b are the parents of c" (if a, b, and c are people); and Sum(a, b, c) as "a is the sum of b and c" (if a, b, and c are numbers).

D. P. Ling

Language

Symbol	Name	Use	Meaning
$\sim$	Denial	$\sim p$	"not p" (p is false)
$\cap$	Conjunction	$p \cap q$	"p and q"
$\cup$	Alternation	$p \cup q$	"p or q"
$/$	Disjunction	p / q	"neither p nor q"
$\supset$	Implication	$p \supset q$	"if p then q" or "p implies q"
$\equiv$	Equivalence	$p \equiv q$	"p is equivalent to q" ie $(p \supset q) \cap (q \supset p)$

If we have a sufficient vocabulary of this sort appropriate to some desired realm of discourse, we can describe and analyze succinctly the properties and relations which apply to the individual objects of this realm. But we can go an important step further. We can treat the properties of interest and ask how we may describe or characterize them. For example, what sorts of things can we say about "binary" (two-place) relations, such as R (a, b) ("a has the relation R to b"). Let us start by defining three particular relations:

- Equ(a, b) means "the numbers a and b are equal";
- Bro(a, b) means "the males a and b are brothers";
- Acq(a, b) means "the people a and b are acquaintances."

Relations of this sort are often characterized as being reflexive, symmetric, or transitive. They may have more than one of these properties. We may denote these properties by the abbreviations Refl, Sym, and Trans.

A relation is *reflexive* if every object "a" bears that relation to itself. For example, the relation Equ(–, –) is reflexive since, whatever the number "a," Equ(a, a), that is, "a" is numerically equal to itself. On the other hand, Bro(a, a) is not true in any usual sense to the word brother; and thus Bro(–, –) is not a reflexive relation.

A relation R is *symmetric* if, whenever R(a, b) is true, then R(b, a) is also true. Bro is certainly a symmetric relation, so is Equ, and Acq may be presumed so. The relation father-son, on the other hand, is not symmetric.

A relation R is *transitive* if, in the notation of the Propositional Calculus $R(a, b) \cap R(b, c) \supset R(a, c)$. The relation Bro is transitive since if "a" is brother to "b" and "b" brother to "c," then "a" is also brother to "c." In other words, I cannot avoid being my brother's brother's brother. The relation Acq is not transitive, however, and this is probably a good thing. Now we may say

$\sim$ Refl Bro
Sym Acq
Trans Equ
$\sim$ Trans Acq.

The important thing here is that we are no longer discussing the characteristics of objects, but rather the characteristics of the *properties* that objects may display. We are actually building up a whole hierarchy of "types" of predicates. Quantities like the "a" and "b" are said to be of "Type 0." To these can be applied predicates like Blue, Bro and Acq, which are "Type 1." The properties of Type 1 predicates, such as Sym and Trans, are said to be of "Type 2." And so on.

At first thought, this typing of predicates seems pretty academic. This is not the case, however. Bertrand Russell introduced the theory of types to free logic from a host of confusions and paradoxes that otherwise arise. Russell himself invented the paradox that bears his name and that first confronted logicians with this uncomfortable aspect of their art.

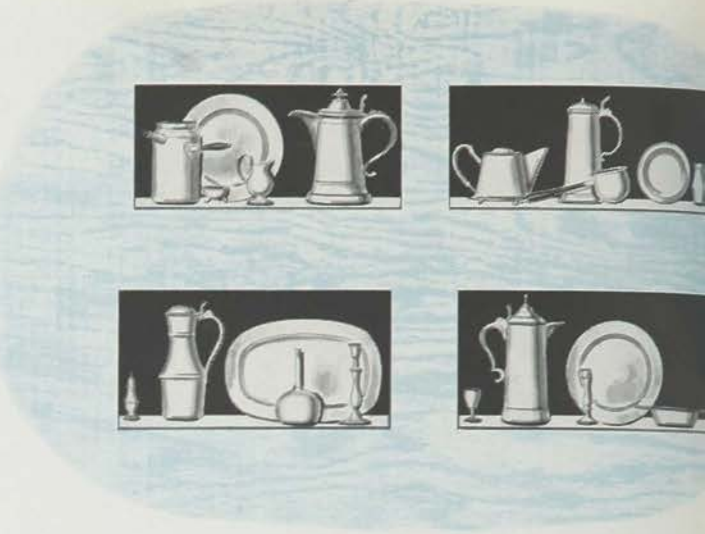
This paradox asks us to consider collections of things—for example, collections of early American pewterware. Now consider a collection of such collections: the collection of all collections of early American pewterware. It seems reasonable to suppose that this super-collection can itself be regarded as a collection of early American pewterware—in fact, a rather handsome one. If we so regard it, then this ultimate collection is a member of itself, since it was by definition the collection of all collections of early American pewterware, and we have agreed that it is one of these.

On the other hand, there are certainly collections which are not members of themselves, for example, the collection of all boathooks is certainly not itself a boathook. Let us proceed a step and consider the collection of all those collections which are not members of themselves. Is this collection a member of itself? If it is, then it contains a member (namely itself) which is a member of itself, contrary to its original definition. If it is not a member of itself, then by its very definition it must be a member of itself. So there you are.

Russell's Answer

You may comfort yourself to some degree in the fact that Russell himself found this argument unacceptable and he set out to find why. In logical terms his answer came to this: Suppose we ignore the distinction of predicate types, and suppose, for example, we allow a certain (say, Type 1) property, F, to apply to itself: F(F) ("the property of being blue is blue"). If this is a legitimate statement, then so too, presumably, is its denial $\sim F(F)$. If a property F possesses this characteristic, then I shall say it possesses the property Q—that is, in our notation, $Q(F) \equiv \sim F(F)$. In words, F possesses the property Q if and only if F does not itself possess the property F. This is a definition of Q, and I can substitute for F any other relation I choose and the definition remains valid. In particular, I choose to substitute Q for F, and thus I obtain $Q(Q) \equiv \sim Q(Q)$ and this is a contradiction.

The trouble is that we have been trying to apply a Type 1 predicate, F, to another Type 1 predicate, also F. Russell concluded quite simply that this sort of thing would simply have to stop. He insisted that logical quantities must be

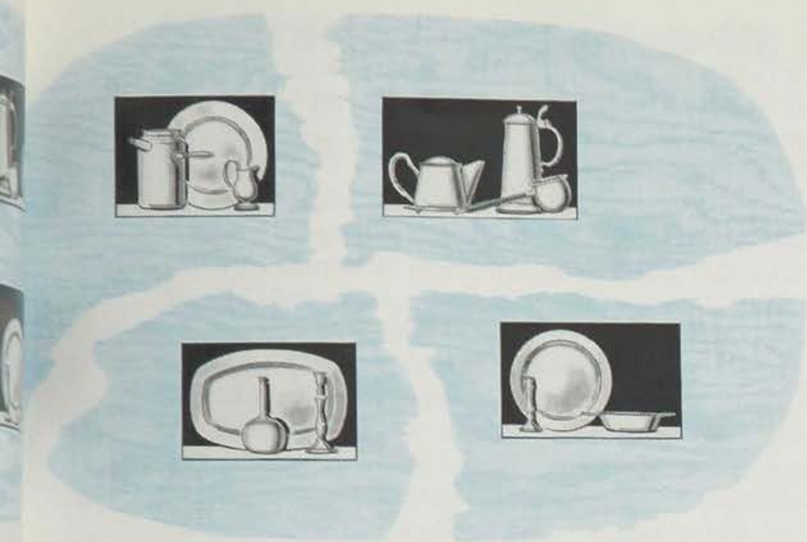


Russell's paradox deals with the notion of selfmembers of classes—some classes are members of themselves; so are not. For example, the class of all collections of pew (symbolized in the left-hand drawing) is clearly itsel

"typed" and that quantities of Type n could only be qualified by predicates of Type $(n+1)$. Thus, we must eschew sentences which declare "the quality of being straight is crooked." With the introduction of the theory of types, all the known paradoxes disappeared. (This, nevertheless, by no means implies that there may not be more paradoxes still unborn.)

Problems and prohibitions of the sort we have been considering are part of what is called the "syntax" of such a language as we are in the process of building. The function of syntax is to determine whether a given string of symbols is or is not a legitimate sentence or expression of the language. It does not concern itself at all with matters of meaning or interpretation, the province of "semantics." We have made numerous remarks on both the syntax and the semantics of the present language. Our recent prohibition of the sentence F(F) is syntactical; our interpretation of Bro(a, b) as "male a is the brother of male b" is semantical. These prohibitions and interpretations have to be carried out in a language broader than the one under discussion. This is called the "metalanguage"; in the present paper, it is English. Metalanguages can themselves be formalized, but no attempt to do so will be made here.

Let us return to the main stream of symbolic logic. Our present array of syntax is not yet complete enough to yield an adequately flexible language. We have symbols only for individual



collection; therefore it is a member of itself. However, the class of all collections of three pieces of pewter (symbolized in the right-hand drawing) certainly consists of many more than three pieces and thus it cannot be a member of itself.

objects or for individual properties of various types. Just as mathematics requires variables—x, y, and z—to represent unspecified numbers, so logic requires variables to denote unspecified individuals or properties. For example, x might stand for some arbitrary object in a specified class of objects, possibly for some unspecified man or some unspecified star. We would also like to have variables denoting properties as well, say P, Q, and R (where we have to say which are to be one-place and which two-place properties, and of what type).

Now, if F is the property of being blue, and x is an arbitrary person, then the symbol Fx seems to convey little meaning. Syntax will not admit it as a *sentence*, but will allow it as an admissible *expression*. It is logical to talk about it and it can be "completed" into a legitimate sentence by replacing x by some individual constant "a" (say John Quincy Adams). "Free" variables, such as the "x" in "Fx" are important constituents in logical formulas as they are in other mathematical formulas. We have a different—and equally important—use of variables in logical expressions that permits the notion of "quantification."

So far we have no way of expressing the quantitative notions associated with the words "all," "some" or "none." In logic this is done by the so called "quantifiers." For the "universal quantifier" we use the symbol (x) and write (x) Fx. (The admission of this expression as a legitimate sentence is purely a matter of syntax.) By it we mean "for every individual object, x, x has the property F," or for short "all x is F." (This interpretation is semantics.) In making sentences like this we normally have in the backs of our minds some domain of discourse, or class of things, from which x is to be selected. Alternatively, we can specify the domain within the sentence itself. For example, if Hum is the property of being human, and Mort is the property of being mortal, then we can write (x) (Hum x $\supset$ Mort x) "all humans are mortal" without having to say much about the domain of x.

Now, we observed earlier that Fx did not appear to be a sentence—not until x was replaced by the name of some specific object. On the other hand (x) Fx ("all x is F") sounds like a perfectly good sentence—and indeed it is. In this case, the occurrence of "x" in "Fx" is not "free;" it is "bound" by the quantifier (x).

The Existential Quantifier

Another important quantifier is the "existential quantifier" $\exists$x. We write $\exists$x Fx (syntax) and interpret this sentence to mean (semantics) "there exists an x such that x is F" (or loosely "some x is F," where "some" has to be interpreted liberally as meaning "at least one"). Again, the x's that appear are not free—they are bound variables. Actually, (x) and $\exists$x are by no means independent notions. For in the expression $\exists x\ Fx = \sim(x)\ (\sim Fx)$, the right member says "it is false that every x fails to possess the property F."

The symbol "=", which has appeared in no logical sentence heretofore, is the "identity" symbol. It means that the two members are identically the same—the same object, the same property, the same sentence. Thus (George Washington) = (first President of the U.S.). This explains "=" in our metalanguage, English. It can be defined, however, within the structure of our formal language. Thus if x and y are unspecified objects and P a *variable* property of Type 1, then $(x = y) \equiv (P)\ (Px \equiv Py)$ which says that "x is identical with y if and only if every property of x is shared by y and vice versa." (In rough paraphrase, "anything you can say about George Washington goes for the first President of the United States."). This is our first use of a variable property as a quantifier. Actually, however, the definition remains valid if we take x and y to represent unspecified properties of Type 1 and P to represent a variable property of Type 2. And so on up the ladder of types.

We have now arrived at a subtle and flexible language involving individual symbols, properties, and relations, of various logical types, and the notion of quantification. It can be "axiomatized" in the same way as the Propositional Calculus was, though no attempt to do so will be made here. The resulting language is powerful enough to serve as a foundation for arithmetic, the cornerstone of mathematics.

Truth and Provability

This language, however, or other logical languages of similar nature and power, have some surprising and in some cases disquieting features. Let us hark back to the Propositional Calculus. Here there were two ways of establishing a proposition as true. One was via the "Truth Table." If the proposition had the truth value T for all possible truth values of its component sentences p, q, r, . . . , then the proposition was said to be "logically true." A second method was to "prove" the statement. We did this by beginning with the axioms and forging a logical chain which led validly from these to the proposition in question. Then the proposition was said to be "provable."

It is a happy circumstance that in the Sentential Calculus the two methods are truly equivalent: a logically true proposition is provable and vice versa. An even happier circumstance is that the truth table method can always be carried through and the logical truth of a proposition established or refuted. If it is true, its proof can then be sought with the assurance that it exists, and in fact the truth table provides a constructive guide to its determination.

Now let us see how these matters stand with respect to our extended language. The notion of "logical truth" still persists. However, the truth table may now have infinitely many rows, and hence may be of little practical comfort. Consider the famous (and so far unproved) "Twin Primes Conjecture" to the effect that there are infinitely many consecutive odd prime pairs. We begin the list, to give a sense of the meaning of the conjecture: (3, 5), (5, 7), (11, 13), (17, 19), (29, 31), . . . Either the list gives out at some point—in which case the conjecture is false—or else it doesn't. But the process of carrying through this evaluation is clearly impossible. There are indeed special situations whereby legitimate mathematical trickery allows such an infinite evaluation to be made, so the notion of a "Truth Table" is more than an academic one. However, the present case is not one of these.

Similarly the notion of "provability" carries through as before in our extended language once it has been given suitable axioms. At this point, however, the similarities abruptly end, and the dissimilarities take over.

First, it is no longer true that "logically true" and "provable" are equivalent notions. It is still true that a provable statement is always logically true; the converse, however, fails to hold. There are theorems of arithmetic which can be shown to be logically true but which are not provable —not merely for which no proof has been found, but for which no proof can possibly exist. Such propositions (often called the "unprovable theorems of arithmetic") have been actually written down, but they are not—as might be guessed —very easy to state. Second, even if a proposition is provable, there is no systematic way of constructing a proof. There not only is no such a way known at present, but Church has shown that it is impossible that there could ever be one.

Mathematicians have, of course, always been humbly aware that something of this sort was so. These relatively recent results merely made the score official. Indeed, part of the savor of mathematics was the devising of proofs in an uncharted land, and part of the genius of mathematicians consisted in their passionate belief in the right theorems. However, the part about nonprovability has been a little unnerving to mathematicians. Some have even speculated that Fermat's Last Theorem may be true but unprovable. (Fermat in the margin of a book stated he had found a proof that $x^n + y^n = z^n$ could not be solved for positive integers x, y and z if the fixed integer n was greater than 2. Unfortunately he gave no hint as to how the proof proceeded, and no one, despite strenuous efforts, has been able either to supply the proof or to furnish a counter-example which would show the "theorem" false.)

Even more disconcerting, perhaps, is Gödel's result that the extended logic, and the arithmetic that stands on its shoulders, can never be proved free from inconsistency. A valid proof to this effect would be *prima facie* evidence that arithmetic was in fact inconsistent, since Gödel showed that no such proof would be possible within a consistent arithmetic.

Such considerations, troubling as they are, do not weigh heavily on mathematicians. They stick to their last until such time as the final blow may fall, and meanwhile console themselves with the thought that they probably cannot be wholly displaced in function by the computing machine.

Machine Diagnoses its Own Failures: Writes Dictionary for Cures

An electronic telephone switching system that diagnoses its own failures when they occur and tells maintenance men where to look for the trouble in a "dictionary" it helped "write" has been developed by Bell Laboratories. The system also discovered methods of running itself that its human programmers had not considered.

S. H. Tsiang, of the Electronic Switching Laboratory, developed the dictionary for a recently-completed trial of an experimental Electronic Central Office at Morris, Illinois. The dictionary was written for the system's most complex part, a central control unit containing 6,500 transistors and 45,500 diodes. Tsiang described the dictionary's preparation in a paper presented at the Summer General Meeting of the American Institute of Electrical Engineers.

The dictionary helps insure the continuous operation of the electronic switching system, which must be able to handle telephone calls at any time and run 24 hours a day without more than a few thousandths of a second lapse. When the Bell System's first commercial Electronic Central Office begins operation in 1965 in Succasunna, N. J., every control unit will have a duplicate standing by in case any component fails. The duplicates would then take over automatically and, in the thousandths of a second between calls, run diagnostic tests on the defective unit.

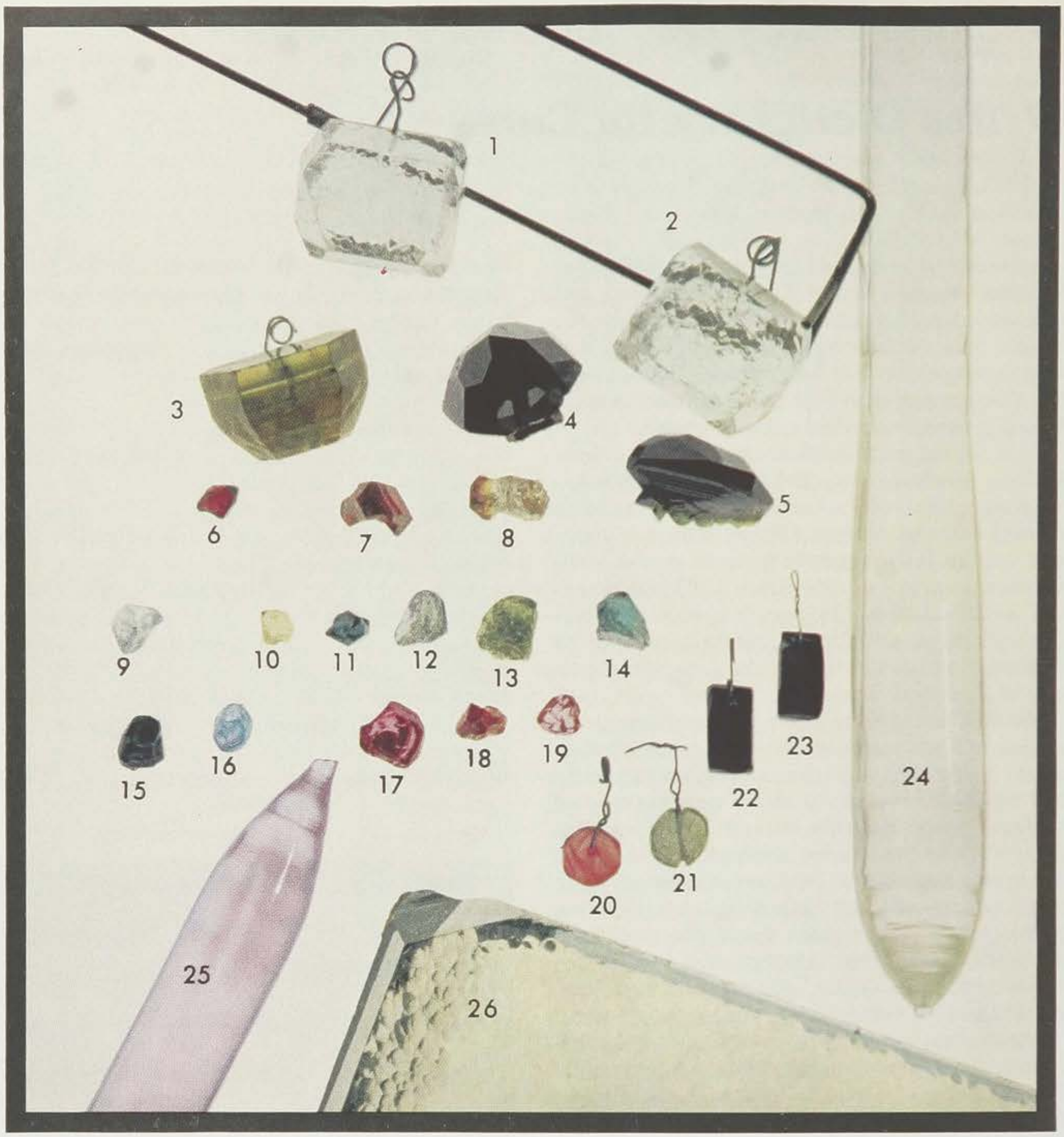
The system prints test results on a teletypewriter. A maintenance man checks these results in the dictionary, which tells him the Circuit Pack to replace. (Components are mounted on small, easily removable units called Circuit Packs.) This way, he usually can locate and clear up trouble in a few minutes.

To prepare the dictionary for Morris, Tsiang had the system programmed to make over 900 different tests on each of 50,000 simulated failures. The system recorded the test patterns for each failure and the identity of the faulty components. Then a computer sorted the patterns in numerical order and printed them in a four-volume dictionary totaling 1,290 pages.

Bell engineers expect a dictionary of this type to locate 90 per cent of the component failures that may develop at the Succasunna office. In the meantime a duplicate of the first commercial Electronic Central Office is being constructed at the Laboratories' Holmdel location. Engineers there will continue to improve diagnostic techniques and the maintenance dictionary.

Programmers gave the system many alternative ways of restarting itself in millionths of a second if a vital component should fail. "However, we noticed the system using a combination we had not programmed into it," reports R. Ketchledge, Director of the Electronic Switching Laboratory. "So we investigated and found we'd accidentally connected a wire to an open terminal. This should have caused the system to stop when it needed to use this wire. But it didn't. It combined several programs into one of its own and avoided using the open wire. This 'motivation' apparently results from our providing the system with many alternative programs aimed at the same result—to keep running."

Dictionary refers R. Ketchledge, director, Electronic Switching Laboratory, to defective Circuit Pack in model of the electronic switching system.



1-2 *Quartz (grown hydrothermally)*
3 *Zinc oxide (grown hydrothermally)*
4-5 *Yttrium iron garnets (grown from flux)*
6 *Calcium tungstate (grown by Czochralski technique)*
7-20 *Yttrium gallium garnets (grown from flux—doped with various types of impurities)*
21-22 *Yttrium iron garnets (grown hydrothermally)*
23 *Ruby (grown hydrothermally)*
24 *Sapphire (grown hydrothermally—doped with iron)*
25 *Calcium tungstate (grown by Czochralski technique—doped with neodymium)*
26 *Quartz (grown hydrothermally—doped with iron)*

Crystals are perhaps the best example of order and symmetry in nature. The artificial growth of crystals provides an insight into the forces which hold solids together and aids in the understanding of how to use solids in technology.

Growing Oxide Crystals

R. A. Laudise

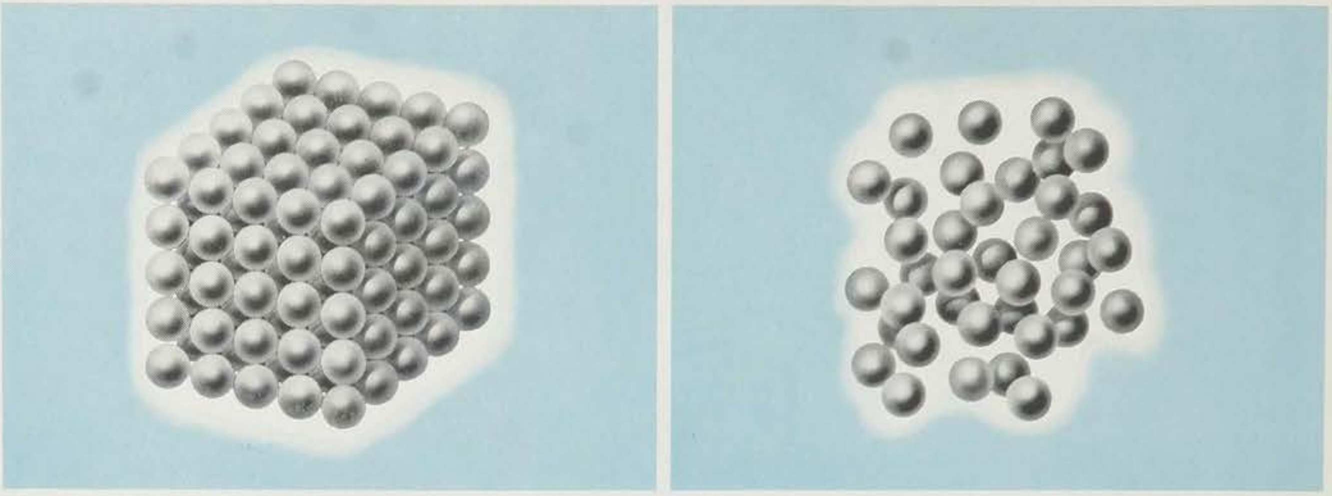
As late as 1927 Sir Arthur Eddington could remark with only a small degree of hyperbole that more was known about the interior of a star than about the interior of a table. Even today, it is not unfair to say that an important limit to the progress of the electronics industry is the lack of understanding of materials in the solid state. Crystalline solids, and relatively large single crystals in particular, are of special importance both to the hardware of telephony and to the research underlying this hardware.

A single crystal is a solid in which the atoms are *ordered*; that is, the atoms line up in some regular pattern or array, and this mode of lining up is preserved throughout the crystal (see left half of diagram on page 246). The right half of the drawing is a schematic representation of a liquid, or, for that matter, of a glass, since both are noncrystalline and have a similar structure. Both liquids and glasses exhibit an almost complete randomness in their structures. In 1912, Max von Laue and his co-workers in Germany, and two years later William Henry Bragg and William Lawrence Bragg in England, used X-rays to determine the spatial arrangements of the atoms of solids (RECORD, *March*, 1962). Until that time, all of our knowledge of their structure was obtained by inferences and guesswork, such as deductions from the external habit of crystals where regularity suggests an internal orderliness.

The crystals shown in the photograph have been grown at Bell Laboratories using hydrothermal, molten salt, and Czochralski techniques.

It is this orderliness that makes single crystals so attractive for research and so useful for devices. For example, ceramics, although they are cheaper and easier to make than single crystals, are not suitable for some research and for specialized applications. The reason lies in the nature of ceramics, which are solids composed of many tiny single crystals or grains. Each of these grains possesses order throughout itself but is misoriented with respect to its neighbors. Many properties of crystals depend on the direction in which the property is measured. If one is interested in studying or making use of this anisotropy, or directional dependence of properties, a ceramic whose grains are randomly oriented will obviously not be satisfactory.

As an example, quartz is a piezoelectric crystal. That is, if it is stressed in a particular crystallographic direction, an electrical charge develops on certain of its faces. This property, which depends on the lack of symmetry in the structure



Schematic representation of the ordered atomic structure of solids compared to the randomness exhibited by liquids. The regularity of crystals makes them ideal for laboratory experimentation.

of the crystal, is difficult to study in a polycrystalline quartz ceramic and is not present in vitreous quartz glass. Similarly, ferromagnetic materials have anisotropies in their magnetic properties which are of research interest and of practical importance. Such anisotropies are usually not observable in, for example, ceramic ferrites.

Each of the grains in a ceramic is separated from its neighbors by a discontinuity called a grain boundary. This is a region characterized by much disorder, strain, and often by high concentrations of impurities. Very often the properties of the grain boundaries in a ceramic obscure the properties of the single crystal regions. In a polycrystalline semiconductor, the electrical properties are essentially those of the grain boundaries. Many of the characteristic properties of the crystalline semiconductor can only be studied and made use of in a single crystal. Such single crystals are often formed in nature, and large grains may sometimes be chosen from a ceramic for study. In most cases, however, requisites on purity, perfection, and availability decree that we synthesize single crystals.

Semiconductor crystals have been grown extensively for more than ten years and indeed form the basis of a rather large industry. Recently, the Laboratories has focused its attention on magnetic, piezoelectric, and luminescent crystals, most of which are refractory oxides. The growth of these oxide crystals presents the chemist and metallurgist with severe challenges and causes them to devise new and revitalize old techniques. To appreciate these techniques, let us review some of the general principles involved in crystal growth.

A crystal may be grown by taking advantage of any one of the following methods:

(1) solid polycrystal $\rightleftarrows$ solid single crystal, or polycrystal, of larger grain size.
(2) gas $\rightleftarrows$ crystal.
(3) melt $\rightleftarrows$ crystal.
(4) chemical reaction $\rightleftarrows$ crystal.
(5) solution $\rightleftarrows$ crystal.

An example of method (1) is the grain growth which occurs during the annealing of cold-worked metals. Although it has been used for the growth of certain single crystals, this method has not yet been applied to the growth of oxides and need not concern us here. The growth of iodine by sublimation typifies method (2), and method (3) describes the growth of crystals by freezing their melts.

In methods (1), (2), and (3), the composition of the solid, liquid, or gaseous phase in equilibrium with the crystal is nearly identical in composition to the crystal itself. However, it is often advantageous to add another chemical entity or component to the system. For instance, in the case of method (2), if the vapor pressure of the crystal never reaches a high enough value at temperatures we can attain experimentally, it is sometimes possible to add a component which reacts with the crystal to form a volatile compound and thus grow the desired crystal by means of a chemical reaction—method (4). A crystal can be grown by this technique if the reaction can be reversed in some manner to cause the crystal to be deposited. An example is the growth of germanium:

$$2GeI_2(\text{gas}) \rightleftarrows Ge(\text{single crystal}) + GeI_4(\text{gas})$$

The reaction tends to go to the right as the temperature is reduced.

In growing a single crystal, gaseous germanium tetraiodide (GeI_4) reacts with polycrystalline germanium at a given temperature to form the volatile compound germanium diiodide (GeI_2). This compound moves in an inert carrier gas stream (or by convection and diffusion) to a cooler single crystal germanium substrate or seed. The GeI_2 decomposes to GeI_4 on this seed and germanium atoms attach themselves to the seed and cause it to grow. Then the GeI_4 moves back to the polycrystalline germanium, and the cycle repeats itself. Of course, growth by this type of reaction might take place in the liquid or even in the solid state almost as well as in the gaseous state.

If the added component does not interact strongly with the crystal but does permit it to grow at a temperature below its melting point, it is usually convenient to consider this method as growth from solution—method (5). Such growth may occur at temperatures and pressures near ambient or, as in hydrothermal crystal growth, at rather high temperatures and pressures. The solvent may be water, an inorganic salt, or an oxide at or above its melting temperature.

Most oxide crystals suitable for devices must possess high chemical and physical stability over wide environmental ranges. These requisites generally focus our interest on high-melting, nonvolatile, chemically inert, water-insoluble, refractory oxide crystals. Usually, such crystals can be grown best by means of method (3) or (5) since their lack of reactivity and nonvolatility often rules out methods (2) and (4). Whenever possible, it is advantageous to grow crystals by means of a crystal-melt equilibrium. Since no other chemical entities besides those making up the crystal to be grown are present in appreciable concentrations, the purity of such crystals will be high, and the rate of crystallization usually can be high.

To crystallize from a pure melt, the following criteria must be fulfilled:

(1) The crystal should not decompose at or below its melting point.

(2) The crystal should not undergo any destructive (polymorphic) phase change between room temperature and its melting point.

(3) The vapor pressure at the melting point should not be excessive.

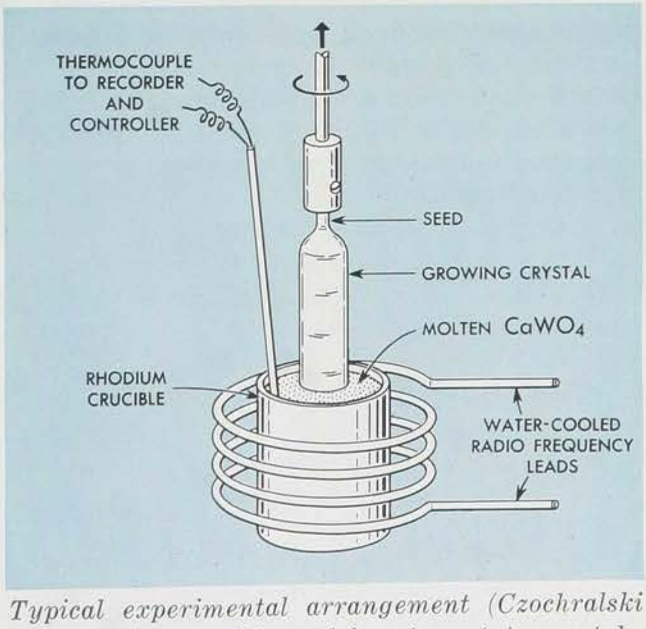
(4) A suitable heating arrangement should be available to bring controlled regions of the melt through the melting point in such a way as to induce single crystal growth.

(5) An inert container for the molten material should be available.

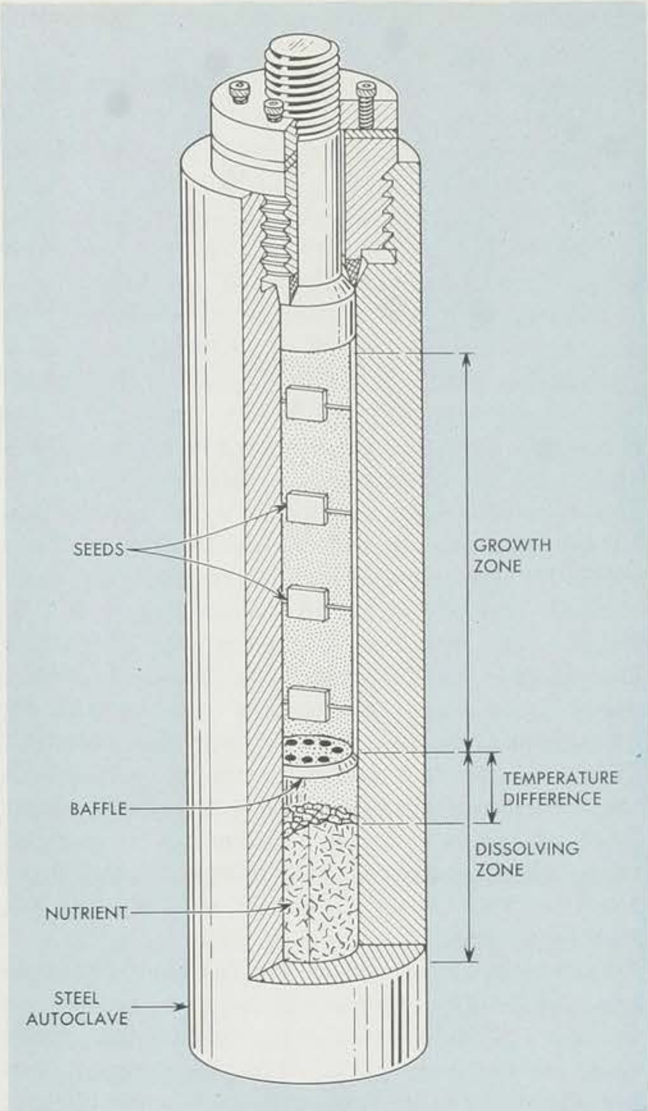
A number of experimental arrangements have been devised to achieve criteria (4) and (5), but perhaps the most useful method is the Czochralski, or crystal-pulling, technique. G. K. Teal, J. B. Little, and E. Buehler pioneered in the use of this technique in the growth of silicon and germanium at Bell Laboratories.

More recently, the technique was applied with notable success to the growth of the tungstates. Calcium tungstate ($CaWO_4$) occurs in nature as the mineral scheelite and was shown to be a promising host lattice for a variety of rare earth and transition metal impurities for microwave and optical maser applications by L. G. Van Uitert. The growth and doping of calcium tungstate by the Czochralski technique has been studied extensively by K. Nassau and A. M. Broyer who prepared large crystals of quality suitable for optical maser experiments. When doped with rare earth ions and excited by ultraviolet radiation, $CaWO_4$ fluoresces strongly. This emission of radiant energy is used in the optical maser where $CaWO_4$ doped with about 0.5% of the rare earth, neodymium, is pumped with ultraviolet light and coherently emits at 1.065 microns in the infrared region (RECORD, *February*, 1962).

A typical experimental arrangement for pulling tungstate crystals is shown below. A number of tungstates and molybdates doped with various rare earths have been grown, but perhaps $CaWO_4$, which melts at about 1600°C, is typical. Because $CaWO_4$ is too reactive to be contained in anything except a noble metal and



Typical experimental arrangement (Czochralski technique) for pulling calcium tungstate crystals.



Cutaway diagram of hydrothermal system developed at Laboratories for growing quartz crystals.

too high melting to be held in the more common platinum or gold, it is best contained in the molten state in a rhodium crucible. The crucible is placed within the work coil of a radio-frequency generator of the sort ordinarily used in metallurgical heating operations. The rf field induces currents in the crucible which heat it and its contents to the desired temperature.

A mechanically rotated seed is then placed in the melt and is slowly withdrawn. Since the temperature falls off sharply above the crucible, the liquid freezes onto the seed as it is extracted. If temperature profile, pulling rate, pulling direction, and melt purity are properly controlled, the added growth will be a single crystal. If the crystal is to be doped with a rare earth, enough of the oxide of that rare earth is added to the melt to achieve the desired concentration of dope in the solid. Very often careful purification of the starting materials and annealing of the grown crystal are required to achieve a satisfactory crystal. Calcium, strontium, and barium tungstates and molybdates have been prepared using this technique.

There are other solid-liquid methods of crystal growth such as the Verneuil, or flame-fusion, technique. This is the method used to grow sapphire protection windows for satellite solar cells and ruby for microwave and optical maser applications. Both crystals are prepared for the Laboratories by the Linde Co.

The Stockbarger and "boat" methods developed at the Laboratories by H. J. Guggenheim for the growth of $CaF_2:Sm^{+2}$ are other examples of method (3). These techniques, although different in detail, are similar in many principles to the Czochralski technique and will not be discussed further here.

Where the criteria for growth from an essentially pure melt cannot be met, it is necessary to crystallize from solution. In general, it might be said, one pays the price in lowered purity and decreased rate for the privilege of crystallizing at a lower temperature. The solvent may be thought of as lowering the melting point of the crystal so that it will not decompose, undergo undesired polymorphic phase changes, or develop too high a vapor pressure.

At Bell Laboratories, J. P. Remeika pioneered in the use of molten inorganic oxides and salts as solvents, or, as they are often called, "fluxes," for the growth of refractory compounds. By this technique, he grew the first single crystals of the butterfly-twin modification of the ferroelectric crystal, barium titanate ($BaTiO_3$). This modification could not be formed at the melting temperature, so Remeika grew the crystal from solution at a temperature below the melting point. His technique involved saturating a solution of molten potassium fluoride (held in a platinum crucible at a temperature of 1200°C) and then slowly cooling the crucible and its contents. Crystals of barium titanate form on the walls of the crucible and grow during the cooling period. When the whole melt freezes, the crucible is cooled more rapidly to room temperature, and an aqueous solvent (which does not dissolve $BaTiO_3$) leaches away the frozen melt.

This same technique was applied at the Laboratories by J. W. Nielson and E. F. Dearborn to the growth of the ferrimagnetic garnet, yttrium iron garnet ($Y_3Fe_5O_{12}$). Because garnet decomposes as it melts, it was necessary to grow it from solution. The flux was molten lead oxide. Later work showed that a mixture of lead oxide and lead fluoride was in some respects a better solvent for garnet. More recently, R. C. Linares of the Laboratories has shown that a mixture of barium oxide and boron oxide is an even more effective solvent for garnet.

Recent interest has centered on experiments directed at growing garnet on a seed crystal. The supersaturation necessary for garnet growth is caused by slowly dropping the temperature. Rates of crystallization as fast as 0.020 inches per day are common. These rates are, of course, slow compared to the rates obtainable in the tungstate growth. This is understandable when we consider the nature of the process which limits the rate in the two cases. In crystal growth, a number of steps must occur sequentially for matter to be deposited in the crystalline state. The over-all rate will be controlled by whichever step is slowest. In growth from the pure melt, the rate-limiting step is generally thought to be dissipation of the heat of crystallization; that is, the heat given off by a material when it goes from a liquid to a solid state.

Czochralski growth takes place by conduction of heat along the grown crystal and by radiation and convection from the grown crystal to the furnace walls. The process is rapid, and tungstates may be pulled at rates as great as three inches per hour. In growth from solution, the rate-limiting step probably involves diffusion of the solute to the growing seed crystal and diffusion of solvent away from the growing solid-liquid interface.

Diffusion is a comparatively slow process, and growth rates so far have not been much in excess of 0.010 to 0.020 inches per day. The principal advantages of seeding are that it permits unique nucleation in a controlled manner and stirring of the growth interface by means of rapid oscillatory rotation of the seed. This helps to accelerate diffusion so as to speed up the rate of crystallization and to decrease the amount of frozen flux in the crystal.

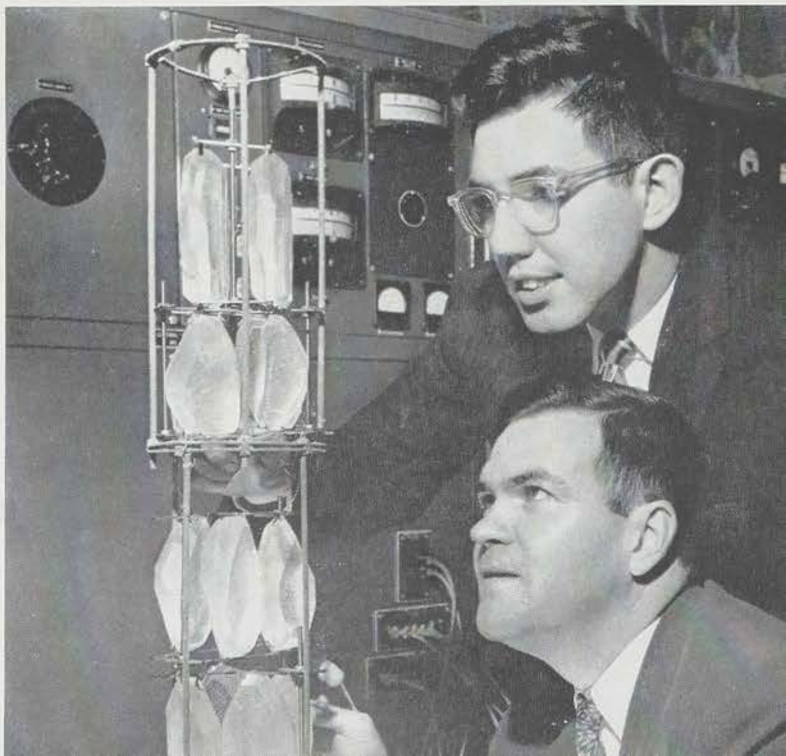
The molten-salt technique has been applied to the growth of a variety of other refractory oxides. As part of the Laboratories investigations into the nature of ferrimagnetism in solids, optical absorption spectra of transparent garnets have been made by R. Pappalardo and D. L. Wood. The nature of the crystallographic environment of the transition metal cation can sometimes be deduced from absorption spectra analysis of transparent yttrium gallium garnet ($Y_3Ga_5O_{12}$) to which has been added a small quantity of a colored transition metal cation such as iron, cobalt, nickel, or titanium. A knowledge of the crystallographic environment of the various transition metals in gallium garnet sheds light on the environment of iron in garnet, for example, which is structurally nearly identical to gallium garnet.

In spite of the efficacy of molten salts as solvents, a great many crystals cannot be grown satisfactorily by this technique. The primary reason for this is that molten salts generally require a rather high temperature for crystallization (more than 1000°C). Many materials decompose, evaporate rapidly, or undergo destructive phase changes in this region. In general, the lower the melting point of a solvent, the lower the temperature at which crystallization from it can take place, provided the solvent has a reasonable solvent power or tendency to interact with the solute.

Water has very good solvent power for many solutes and melts quite low, especially in comparison with molten salt solvents. Up to 100°C, however, water is not an effective solvent for refractory oxides. Water at say 300 to 400°C is an excellent solvent provided its density can be kept fairly high. At reasonable densities, water exerts a substantial pressure at elevated temperatures. For instance, for a density of 0.8 g/cc at 400°C, the pressure is above 20,000 psi. Consequently, high-pressure autoclaves must be used as the containers for crystallization. Crystal growth from high-temperature, high-pressure water has come to be called hydrothermal crystal growth and was first applied to the growth of quartz at Bell Laboratories by A. C. Walker and E. Buehler (RECORD, *January*, 1959).

A schematic of the system used to grow quartz crystals hydrothermally is shown opposite. Small particles of quartz are placed in the bottom

R. A. Laudise (top) and R. A. Sullivan, Western Electric, stu[dy] quartz crystals grown at Western's Merrimack Valley pla[nt]



of a cylindrical, steel autoclave; a perforated metal disc, or baffle, is arranged above this quartz nutrient and suitably oriented seed plates of quartz are suspended in the upper region. It was discovered early in hydrothermal quartz growth experiments that the solubility of quartz in water was never more than a fraction of a percent even at elevated temperatures and pressures. However, in 2 to 3 weight percent solutions of certain alkaline compounds, such as sodium hydroxide (NaOH), the solubility of quartz at say 400°C and 20,000 psi will be about three weight percent. Crystals grow best from solvents where their solubility is relatively high. Consequently, the vessel is filled to some predetermined fraction of its free volume with a dilute NaOH solution and sealed. The problems of sealing hydrothermal vessels are unique, and much effort has been devoted to vessel and closure design. The most commonly used closure is based on a design suggested by the late P. W. Bridgman and is called a modified Bridgman closure.

The vessel is placed in a furnace designed to maintain the bottom hotter than the top and to keep the dissolving and growth zones isothermal. The interior baffle partly restricts the convective circulation of the solution to localize the temperature differential near the baffle level. The temperature of operation is usually in the range 300 to 400°C with a 20 to 50°C temperature differential, and the vessel is filled to about 80 per cent of its volume. Under these conditions, the vessel is filled with a single fluid phase which is liquid below the critical temperature, 374°C, and an extremely dense gas above that temperature. The solution becomes saturated with quartz in the nutrient region and moves up by convection to the cooler growth region where it becomes supersaturated and deposits quartz on the seeds. The cooled, depleted solution then returns to the nutrient region for re-saturation.

The kinetics of hydrothermal quartz crystallization have been studied extensively, and the process is used by the Western Electric Co. to produce quartz for filters and oscillators (RECORD, *January*, 1959). The technique has been used for the growth of a number of other crystals including zincite, grown by A. A. Ballman and A. J. Caporaso; yttrium iron garnet, grown by E. D. Kolb; and sapphire, grown by A. A. Ballman.

Crystal growth has often been called an art rather than a science, and there is much truth in this viewpoint. The objective of crystal-growth research at Bell Laboratories is to bring understanding and hopefully even scientific insight to this intriguing and important field.

On July 10, 1962, Bell System people wrote a new chapter in communication history, when Telstar was successfully launched (with the cooperation of the NASA), orbited, and tested in broadband communication transmission.

Telsta

Telstar, the experimental communications satellite designed and built at Bell Laboratories, was launched by NASA on July 10, from Cape Canaveral, Florida. Within hours of the launch, Telstar successfully relayed television, voice, data, and facsimile in an historic demonstration of the practicability of active communications satellites. Bell Laboratories command guidance system guided the satellite into a nearly perfect orbit.

A Bell System team effort from concept and design to launching and transmission tests, the 170 pound, 34-inch sphere acts as a "microwave tower in space." Bell Laboratories, Western Electric, Long Lines, the Bell Telephone operating companies, and A.T.&T. together shared in the precedent-setting project which opens a new era in international communications.

From a scientific viewpoint, Telstar is a tremendous success. Britain and France reported that they received video pictures and sound sent from the huge antenna at Andover, Me., via Telstar to receiving stations at Goonhilly Down, England, and Pleumeur-Bodou, France.

First use of the satellite, on its sixth orbit, was

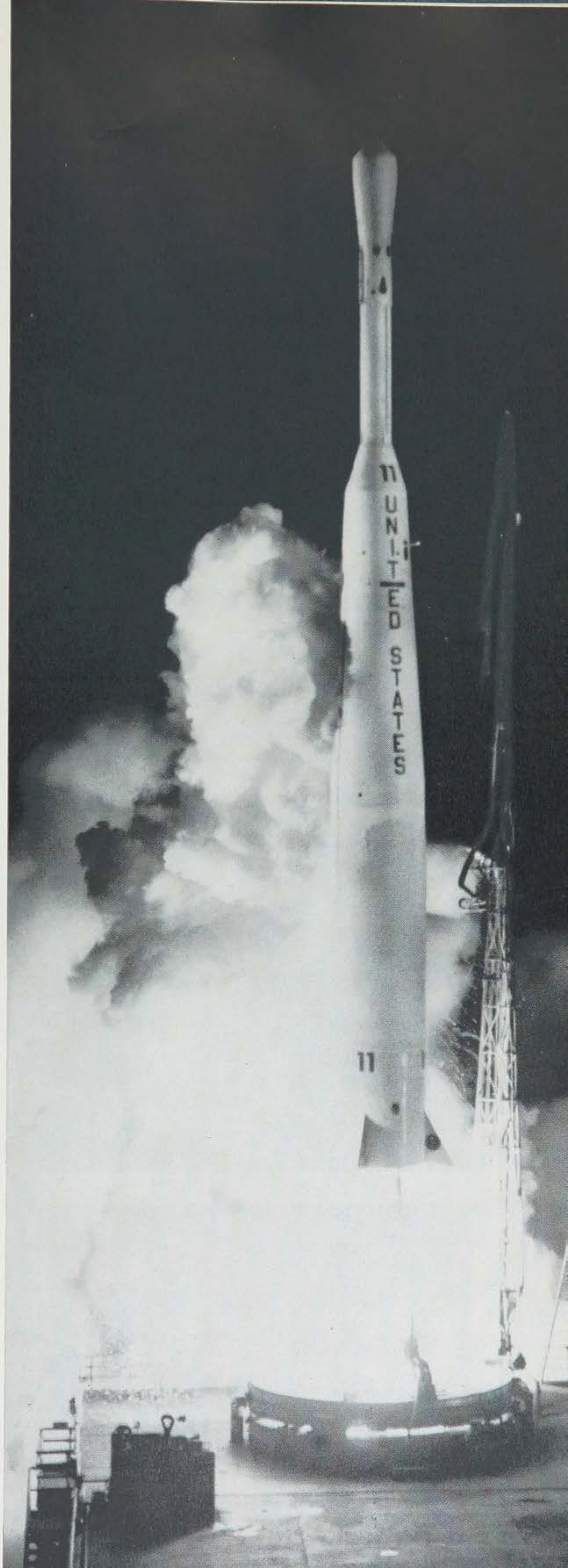
Success

a telephone call from Andover by F. R. Kappel, board chairman of the A.T.&T. Co., to the Vice President of the United States, Lyndon B. Johnson in Washington. Mr. Kappel's voice was sent to the satellite and back, and then by land lines to Washington. Vice President Johnson's portion of the call was by land lines (see photos, page 252).

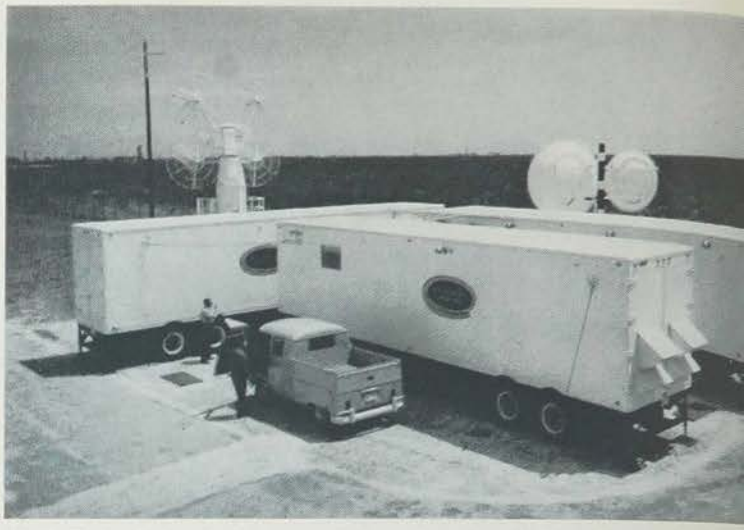
Next, a TV signal relayed via Telstar showed the American flag flying in front of the Andover antenna's "bubble" accompanied by the playing of the national anthem. This was followed by a taped interview between Mr. Kappel and Dr. J. B. Fisk, president of Bell Laboratories.

The Kappel-Fisk interview was followed by a live TV pickup consisting of the introduction of guests at Andover and at Washington, D. C. The portion from the nation's capital was sent via land lines to Andover. The video transmission was from Andover to Telstar back to Andover and also to Holmdel. During this demonstration, the French also reported excellent TV reception.

The TV demonstration was followed by facsimile transmission of a photo of the satellite. The photo was sent from New York to Andover by land line, then to the satellite and back, and



Multi-stage Delta rocket, with Telstar, lifts off.



Bell Telephone Laboratories trailers at Cape Canaveral, Fla. for testing and tracking the Telstar communication satellite.

Technician makes final connections to Telstar in the gantry while it is attached to the rocket which carried it aloft.

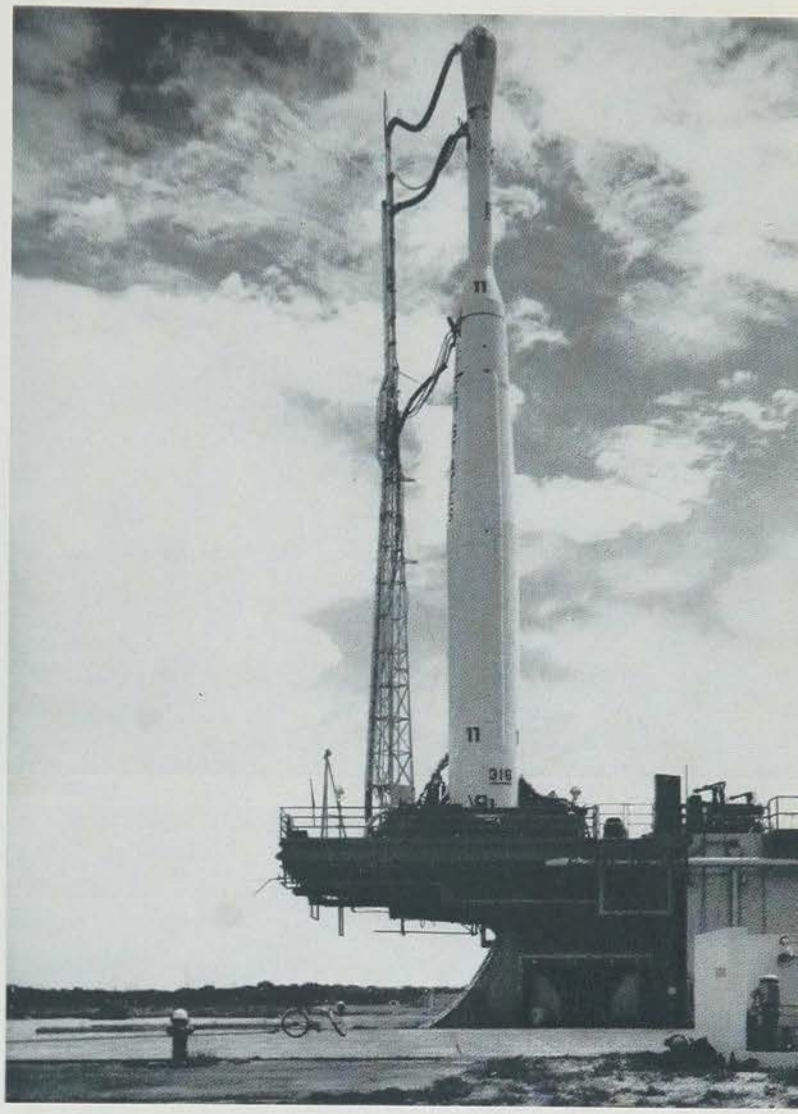
then to New York by land line. The photo was also received at Holmdel. Copies then were made and distributed to newsmen at both Holmdel and New York.

Telstar's work was accomplished with a one-trillionth of a watt signal received at Holmdel, and a one-billionth of a watt signal at Andover. The "better" signal at Andover was due to the larger pick-up area of the Andover antenna.

The seventh pass of the satellite provided opportunity for testing data transmission, simultaneous use of channels, and trans-Atlantic television transmission.

Telephone calls from Washington, New York, Holmdel, and Andover traveled via Telstar, news copy was sent from Andover to United Press-International and the Associated Press in New York, and facsimile photos were transmitted—

Douglas Aircraft launch crew prepares to mate Telstar with third stage of NASA's Delta vehicle.



Delta rocket sits poised on launching pad, prior to launching, with the Telstar satellite in place on nose.

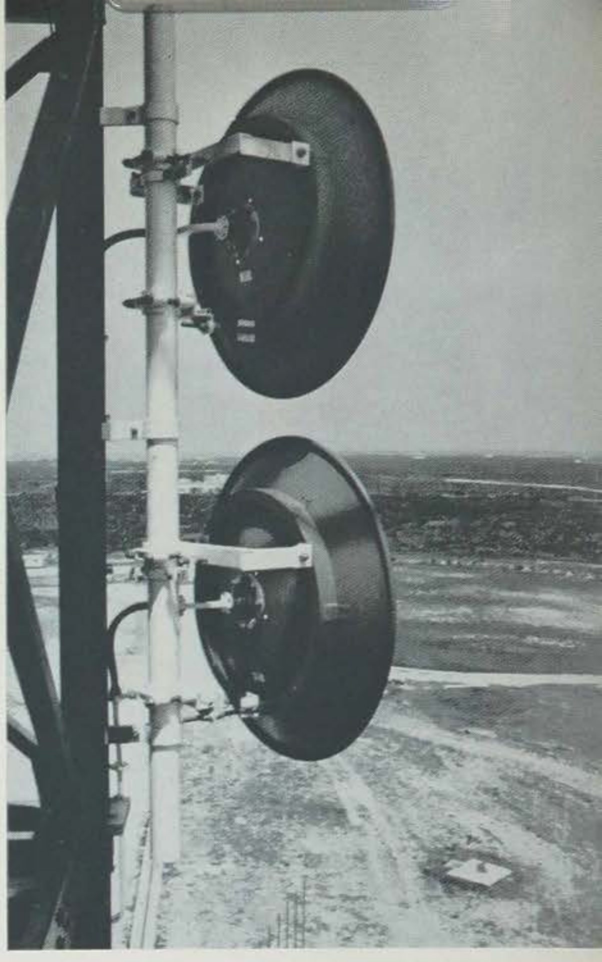
all simultaneously. Five-hundred word news stories had been pre-punched on tape and were transmitted from Andover to Telstar to Andover by Bell System DATASPEED, a high-speed data transmission system which sends at 1,000 words per minute over the regular telephone network. From Andover, the stories traveled via land lines to the agencies' world headquarters in New York.

The last 12 minutes of the seventh pass were devoted to "replaying" the video tapes, and both the French and the British reported good TV reception. The Telstar demonstrations were witnessed by a nationwide audience in this country who saw and heard the satellite's work on their television sets.

In addition to its communication functions, Telstar provided about 115 different types of data by telemetry. After liftoff at Cape Canaveral, the telemetry reports showed that "skin" temperature of the satellite was normal, the internal temperature was normal, and the solar cells showed no damage due to the jar of takeoff. Subsequent telemetry detail indicated that the solar sensors were functioning satisfactorily. The sensors are used to determine the angle of the spin axis to the sun; the axis must not point at Andover because of the radiation patterns of the antenna encircling the satellite.

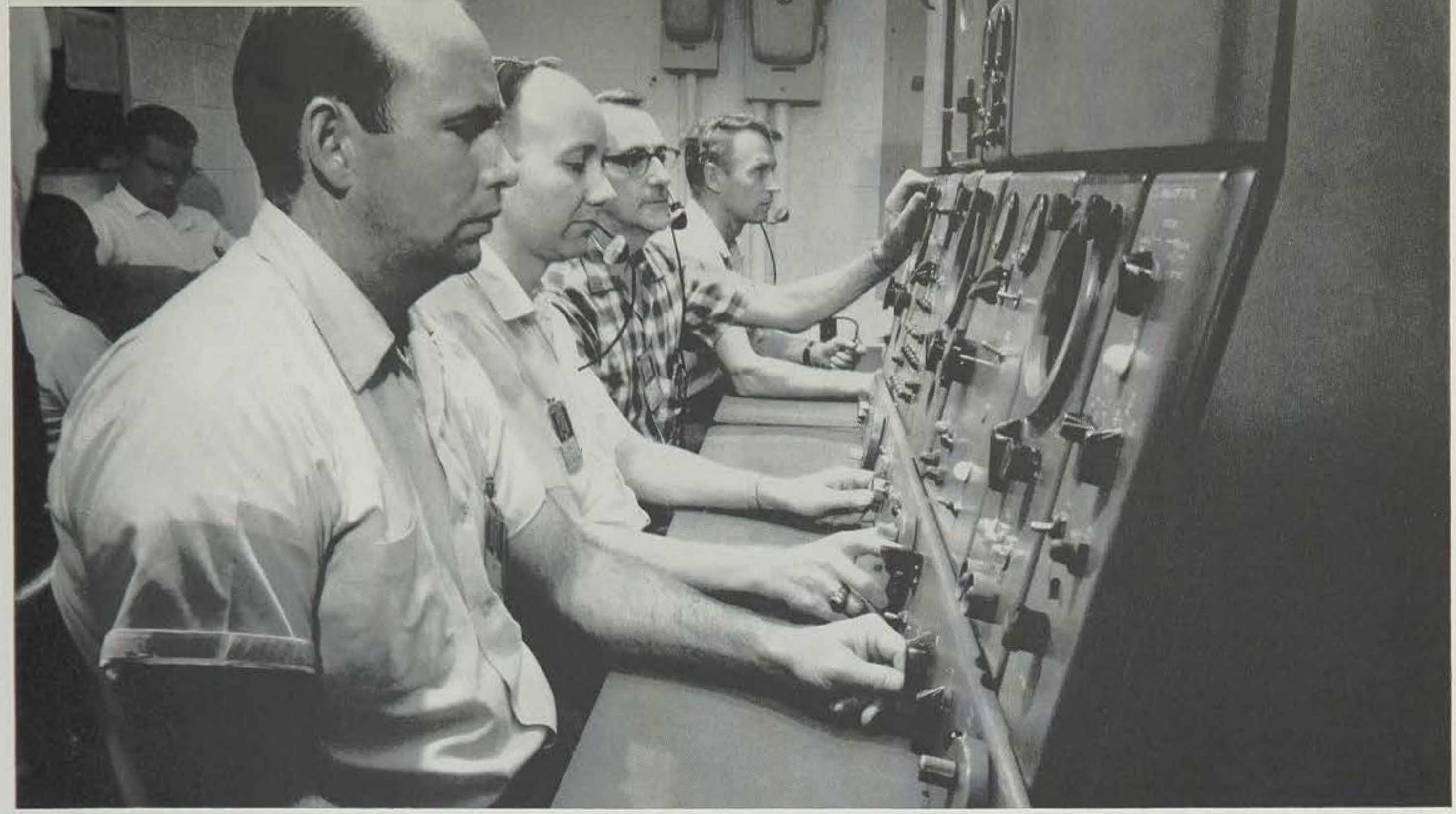
After 17 days in orbit, an analysis of telemetry and other data indicate that the satellite is in excellent condition. The orbital time of Telstar was 157.8 minutes; the perigee of the satellite was 593 statute miles; the apogee 3,502 statute miles; the inclination from the equator 44.79 degrees. The velocity at perigee was 18,352 m.p.h.; at apogee 11,217 m.p.h.

B. A. McLeod (left) and B. Driver discuss command buttons for Telstar satellite in Laboratories telemetry van parked at Cape Canaveral.



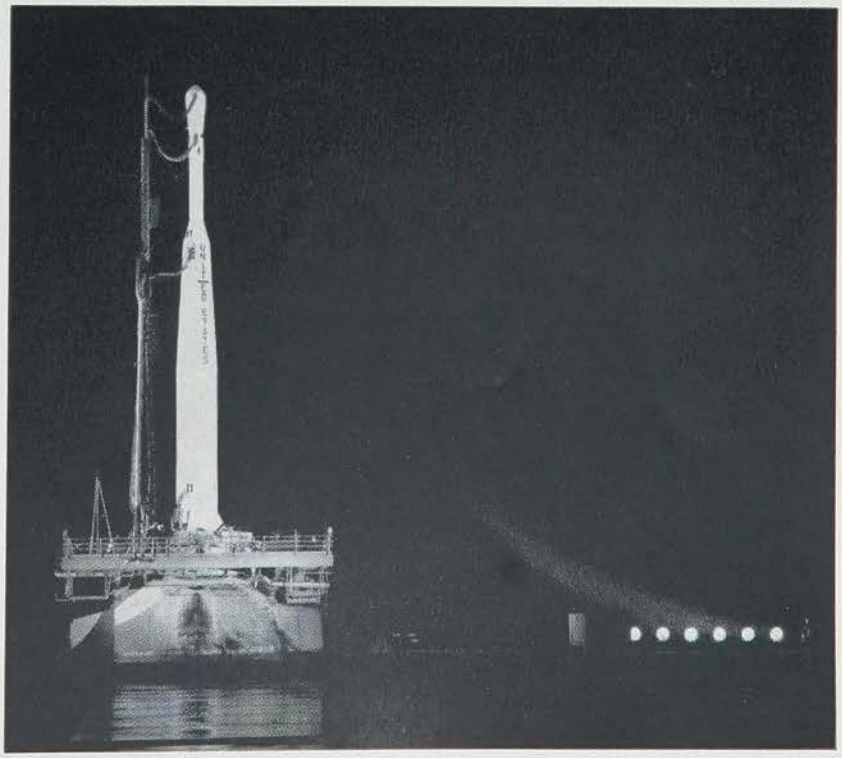
Special antennas mounted on Delta gantry Cape permit Laboratories engineers to check sat ellite's condition from laboratory two miles awa

NASA and Douglas Aircraft engineers at contr console in Delta blockhouse, Cape Canaveral, use in launching the Bell System's Telstar satellit

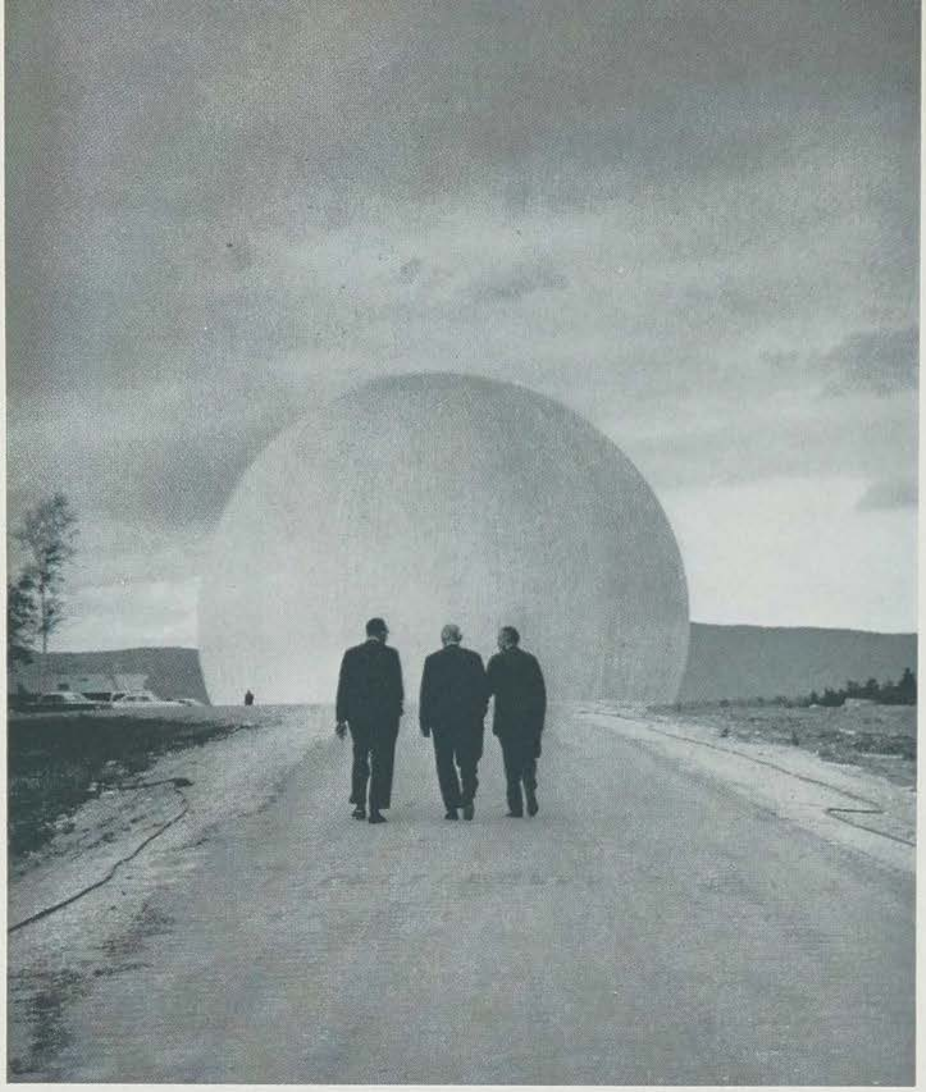


Bell Telephone Laboratories Command Guidance crew at positions for a Delta vehicle launch operation. Command Guidance system guided Telstar to desired orbit.

Douglas Aircraft man pushes "engine start" button to send the Delta vehicle and Telstar satellite on their way into the planned orbit.



In the dark of night, searchlights at Cape Canaveral lit up the Delta rocket and pad as preparations for the launching continued.



Tracking tests of initial passes of the Telstar s
ellite were made from control console at Andov

J. P. Molnar, F. R. Kappel, and J. B. Fisk, (l. to r.), walk from the control building to the horn antenna before the transmission experiments.

R. J. McCune checks out equipment at monit
console before transmission pass at Andove

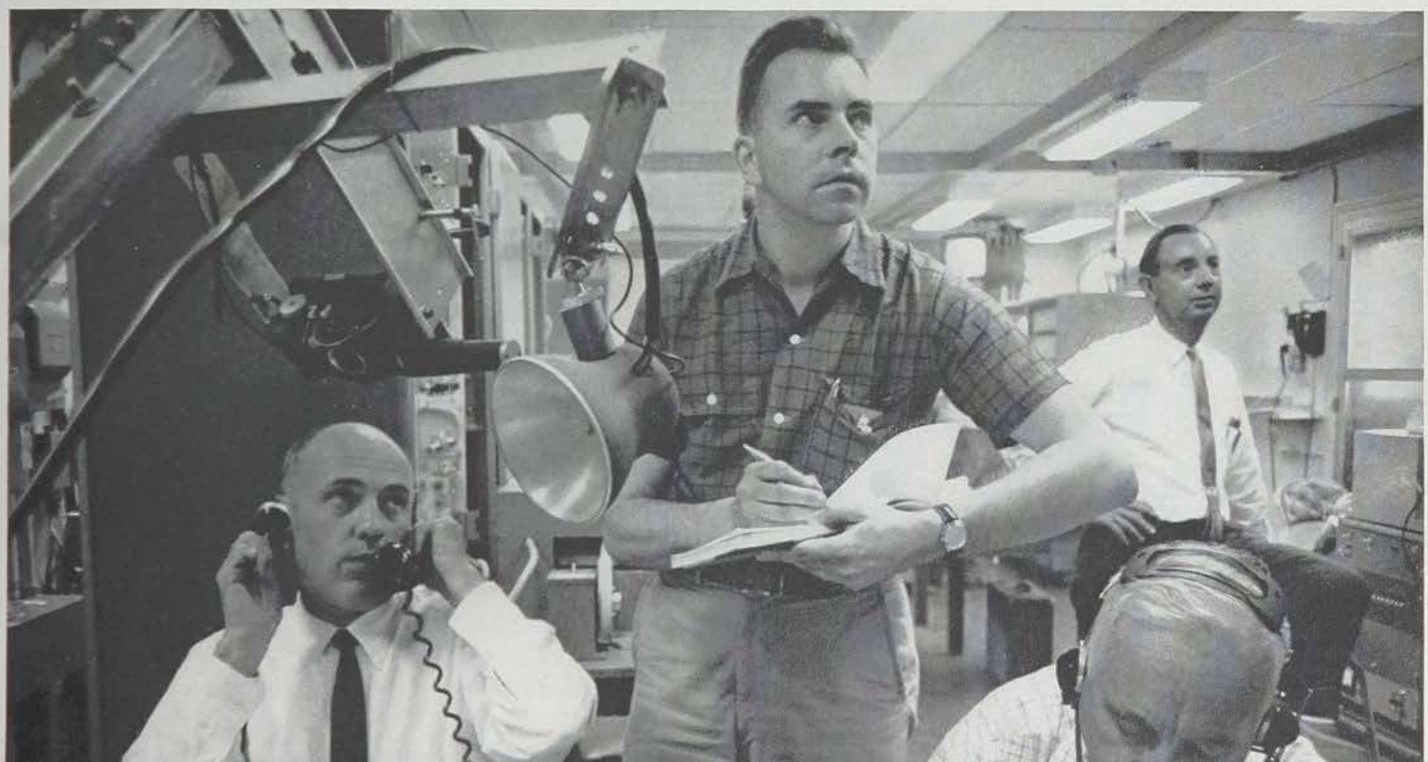
Bell Laboratories engineer evaluates signal levels on television monitors at Andover control room during first transmission experiments.

F. R. Kappel and J. W. Cook, A.T.&T. vi
president-public relations, tape TV intervie

Long Lines engineer at Holmdel displays first photo facsimile transmitted via Telstar.

C. C. Cutler checks received signal characteristics at Holmdel during transmission.

W. E. Legg checks settings of beacon tracking console at Holmdel location before reception tests on Telstar's first pass.



Holmdel test conductor W. C. Jakes (left) and L. R. Lowry wait for Telstar's first signals to appear. Standing between them is R. Klahn; G. J. Stiles in background.

J. D. Rigden, Electron Device Laboratory, checks alignment of helium-neon gaseous optical maser designed to emit coherent radiation in the visible light spectrum.

Greater practical use of gaseous optical masers may soon be realized because of recent discoveries by Laboratories scientists, which permit optical maser action in a variety of pure and mixed gases.

New Developments in Gaseous Optical Masers

Recently a number of developments in the evolution of gaseous optical masers have been announced by Bell Laboratories. One of these is the achievement of optical maser action in five of the noble gases. The masers, made of helium, neon, argon, krypton, and xenon, emit continuous beams of coherent radiation at a total of 14 different frequencies. The availability of this variety of frequencies represents a major step in advancing optical maser technology.

Although Bell Laboratories is exploring the possibilities of using optical masers in future communications systems, Bell scientists say that much more research must be carried out before this potential can be evaluated. Until this achievement in the gaseous maser field, it was generally thought that a wide range of frequencies seemed potentially available only from solid-state masers.

In the August issue of the *Physical Review Letters*, C. K. N. Patel, of the Electronics and Radio Research Laboratory, W. R. Bennett, Jr., W. L. Faust, and R. A. McFarlane, of the Optical Electronics Research Laboratory, describe the investigation of maser oscillations in the noble gases at wavelengths ranging from 1.5 to 2.2 microns.

The studies were carried out by the Laboratories scientists in a two-meter-long quartz discharge tube with windows at a polarizing angle (the Brewster angle) and with external confocal mirrors. A dielectric coating applied to the mirrors makes them strongly reflective at wavelengths near 2 microns.

The results suggest that stimulated emission is a way to improve methods used to investigate spectra in certain cases. Of the 14 coherent emission lines seen in the five gases, three had never before been observed even through ordinary fluorescence. Many transitions exist in the noble gases in the infrared portion of the frequency spectrum. But fluorescent emission accompanying such transitions is generally weak as one goes further into the infrared, and the sensitivity of available photodetectors is poor. When made to operate in an optical maser however, these gases may produce, at specific frequencies, beams of coherent radiation that have enough strength and directionality to be easily observed by shining them on a spectrometer.

Energy Transfer Mechanism Different

The pure gases produce maser oscillations by an energy transfer mechanism differing from that responsible for operation in helium and neon mixtures (RECORD, *March*, 1961). In the latter case, electrons in the discharge created by a radio-frequency generator excite the helium atoms to their metastable state, which is close in energy to an upper state of neon. As a result, the helium atoms can impart their energy to the neon atoms by collisions. The neon atoms then fall to a lower level, creating the maser radiation.

In masers filled with neon, argon, krypton, or xenon, energetic free electrons in the discharge directly excite the atoms of the single gas into an upper energy level. From here they fall to a lower level emitting coherent radiation at characteristic frequencies. It was previously thought that the lower levels, as well as the upper levels, might become filled directly from the discharge. This would preclude the establishment of an inverted population (where more atoms are in an upper maser state of energy than in a lower) sufficient for maser action.

Because helium does not have an electron configuration corresponding to those of the other four gases, it produces maser oscillation by some mechanism other than direct electron excitation. This is believed to be a two-stage process wherein helium atoms are excited into the upper maser level through collisions with directly excited helium atoms.

In addition to this development, Laboratories scientists recently demonstrated that the helium-neon gaseous optical maser can emit continuously a bright red beam of visible coherent light. The radiation has a wavelength of 6328 angstroms, and thus a frequency which is the highest coherent optical frequency yet generated.

The original helium-neon maser, also first demonstrated at Bell Laboratories, operates continuously in the infrared portion of the electromagnetic frequency spectrum. Now it has been made to operate in the visible portion by replacing the dielectric-coated mirrors reflecting in the infrared with mirrors designed to reflect strongly at the new wavelength.

In a recent letter to the *Proceedings of the IRE*, A. D. White and J. D. Rigden of the Electron Device Laboratory described how spectral studies of the helium-neon gas discharge led to the discovery of enhanced emission at 6328 angstroms. This, in turn, led to development of the maser device that produces a coherent oscillation at this wavelength.

The modified helium-neon maser uses a higher metastable energy level of helium which also is close in energy to a series of higher upper-level states in neon. When these excited neon atoms fall to the lower level they radiate at a frequency, corresponding to the 6328-angstrom wavelength, which is higher than from the original device.

A dc discharge imparts energy to the helium, marking a departure from previous radio-frequency methods of excitation of gaseous mixtures. Messrs. White and Rigden demonstrated that with existing gas-discharge tube techniques one can put metal electrodes inside the glass cavity without impairing the efficiency of the maser gas. Advantages of dc over rf excitation are stability and uniformity of the discharge and a more efficient use of input power.

The mirrors in the optical cavity are specially prepared by a dielectric coating technique which makes them strongly reflective at a desired frequency. The mirrors used for this experiment were designed for peak efficiency of reflectivity at about 6350 angstroms. They are placed in the "confocal" geometry which has proved very useful in the operation of optical masers.

Bright Coherent Visible Beam

The coherent beam emerging from the optical maser, although only about 0.2 milliwatts in power, is bright enough to be seen impinging on a white screen, even when the equipment operates in a lighted room.

New physical experiments can be envisioned. For example, the red maser beam will be extremely convenient for interferometric measurements, such as in gaging the surface regularity of a spherical mirror. And, like all optical masers, this one may be useful as a generator of coherent light for experiments in optical communications.

In another announcement by the Laboratories, two new gaseous optical masers—one using a mixture of neon and oxygen, the other of argon and oxygen—were described. Both devices radiate in the near infrared at a wavelength of 8446 angstroms. This marks a major technological advance because the underlying physical principle suggests the advent of a whole family of gaseous optical masers. Also, it provides a new frequency for optical communications.

Optical maser action in neon-oxygen and argon-oxygen is made possible by "dissociative excitation transfer." It is the first time that this excitation mechanism has been used in an optical maser.

A letter in the June 15th issue of the *Physical Review Letters* by W. R. Bennett, Jr., W. L. Faust, R. A. McFarlane, and C. K. N. Patel describes dissociative excitation transfer wherein an excited atom of a noble gas, such as neon, breaks up an oxygen molecule. To operate the masers, the scientists mix molecular oxygen with neon or argon and excite the mixture with a radiofrequency discharge. Energy transferring from the neon or argon to the oxygen molecule results in its dissociation into two atoms. One of these atoms attains an excited state, either immediately or very shortly thereafter, from which it radiates the 8446-angstrom line.

These masers contain a ratio, by pressure respectively, of approximately 70 to 1, neon to oxygen, and approximately 40 to 1, argon to oxygen. In both cases output power is about two milliwatts.

The experiments suggest that the mechanism of dissociative excitation of a molecule by energy transfer from a metastable atom may be more generally useful in optical maser technology than the inelastic atom-atom collisions responsible for maser action in helium-neon mixtures.

Original Design Modified

Maser oscillation takes place in a quartz-tube resonator which is a modification of the one used for the original gas optical maser experiments conducted at Bell Laboratories.

The first maser device consisted of a quartz tube, about 80 cm long and 1.5 cm inside diameter, containing highly reflecting parallel mirrors in metal chambers which terminated each end of the tube. Flexible bellows in the chambers permitted external tuning of the mirrors. At the extremes of the system were two optically flat windows through which the maser beam could leave undistorted. The device was about one meter long.

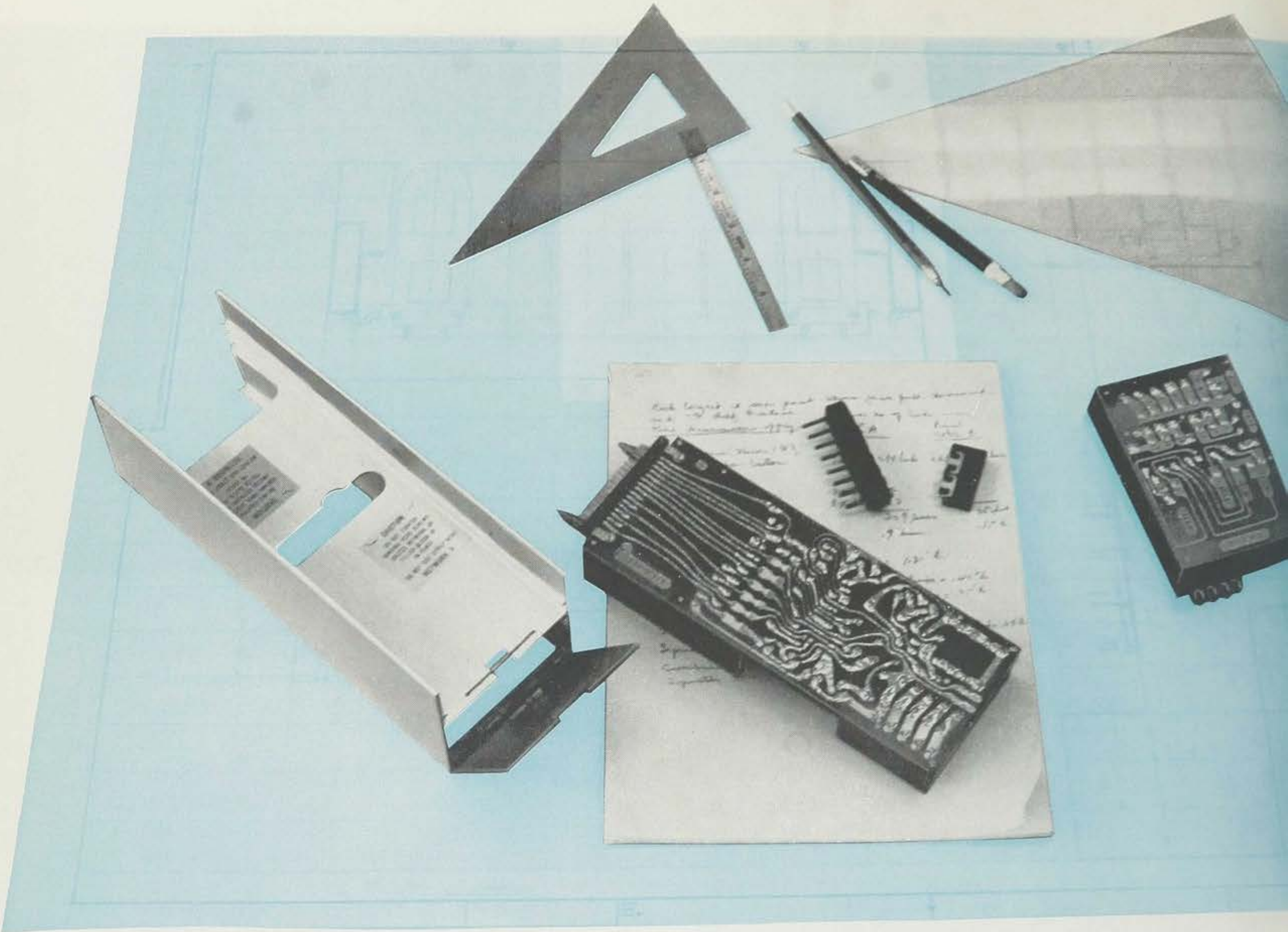
Soon after this maser was made to work, Laboratories scientists began modifying it to ease construction, improve its operation, and extend its experimental flexibility.

Laboratories scientists, C. K. N. Patel and W. R. Bennett, Jr., align the optical maser tubes containing the five noble gases—helium, neon, argon, krypton, and xenon. The new optical masers generate fourteen coherent infrared wavelengths.

Then in a radical departure from the original construction the mirrors were taken outside the evacuated tube. Moreover, their shape was changed from flat to concave with a radius of curvature comparable to the spacing of the mirrors. Other spacings have also been used. In addition, the terminations of the tube, now merely glass windows, were canted at the Brewster angle which minimizes reflection losses for radiation polarized in the plane of incidence. This polarizes the emitted beam.

This redesign provided several advantages over the previous design. It simplified construction of the mirror mounts and the gas-discharge tube. It avoided possible damage to the dielectric coated mirrors due to baking of the tube during preparation and evacuation. It reduced losses arising from diffraction. And it permitted easy readjustment of the mirrors and the ability to replace them with mirrors of different characteristics.

As a result of the developments in gaseous optical masers over the past few months, a large number of continuous coherent optical frequencies ranging from 150,000 kmc to 400,000 kmc provide carrier signals with extremely wide bandwidths for various applications.



A modern version of the negative-impedance type of voice-frequency repeater for the Bell System is now in full production. This repeater, the E6, is more compact, more economical, and more adaptable than any previous model (see RECORD, *October*, 1961). It represents a major advance in applying solid-state devices for amplifying voice signals and reducing frequency distortion in inter-office and exchange-area trunks. In transmission performance, the E6 exceeds previous E-type repeaters in most applications. A plug-in unit with power consumption of about 1.5 watts, the E6 is half the size of its predecessor, the E23. A standard 48-volt central-office battery is the only power source required. By contrast, the E23 repeater uses a total of 7.5 watts from 130-volt and 48-volt supplies for the plate and heater elements of the electron tubes. The 50 per cent reduction in size is largely attributable to the use of transistors, printed wiring and plug-in networks.

An important economic factor in maintaining electrical adjustments of the E6 repeater is the method of matching the impedance of the repeater to the impedance of the line and setting the amount of gain. Previously, such adjustments were made by soldering individual wires to network terminals. With the E6, these adjustments are made by simply turning gold-plated screws on the printed circuits to short-circuit or to connect internal network components. The conductors associated with these circuits are hot-tinned to assure reliable contact; embedded elastic stop nuts prevent the screws from loosening.

The basic parts of the E6 are its converter network, two passive networks known as line-building-out (LBO) networks, and a housing. The heart of the repeater is the converter, which is essentially a negative-impedance amplifier. It consists of 57 components contained in a new type of housing. The resistors and capacitors, *Voice repeaters—the vital force of a transmission network—are used by hundreds of thousands in the Bell System. This means that their size, cost, and efficiency are tremendously important to the Telephone Operating Companies.*

J. K. Jones and W. C. Schmidt

Packaging and Equipment Design For the E6 Telephone Repeater

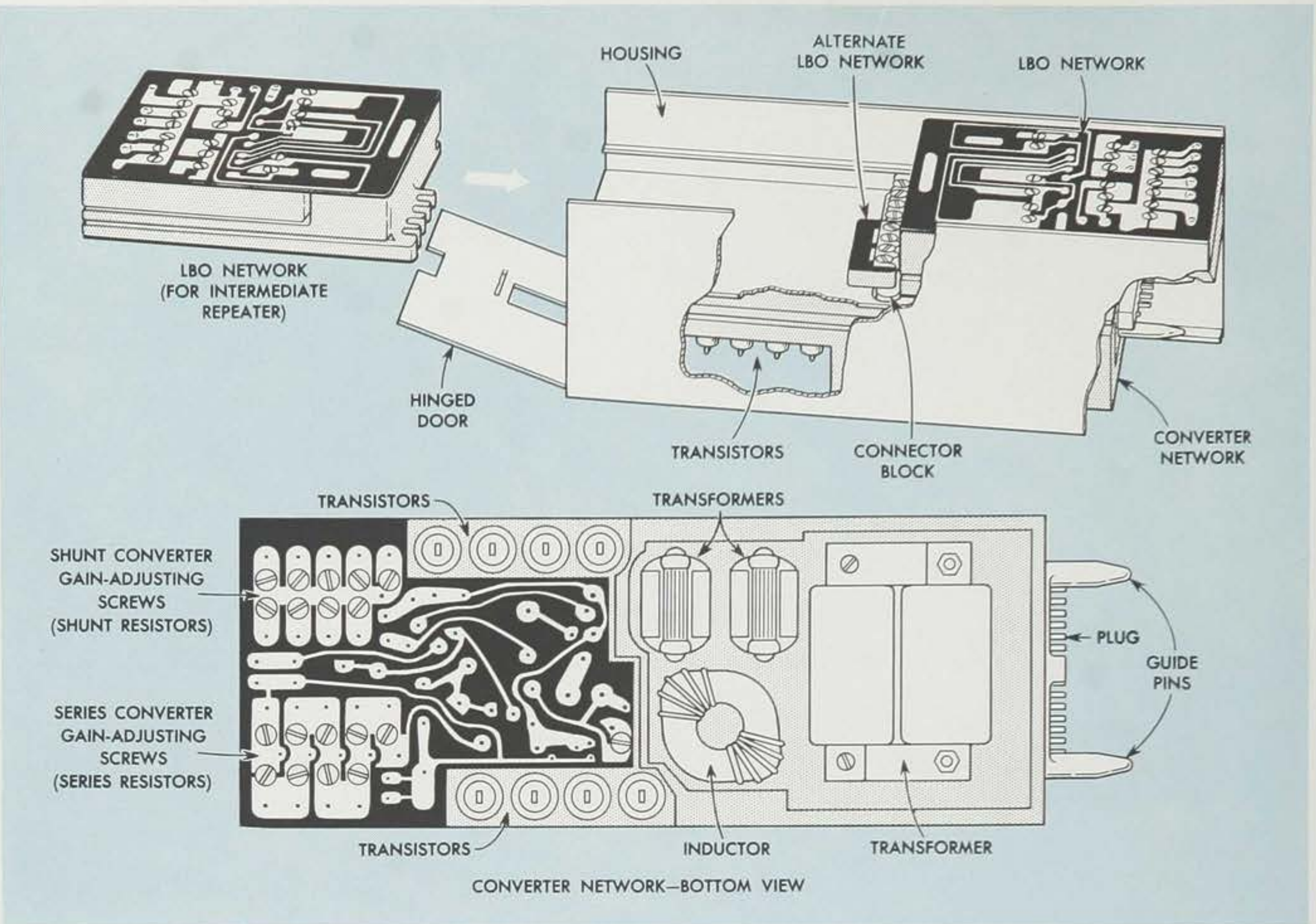
all with pigtail leads, fit into matching cavities in two molded blocks of phenolic resin. These two blocks form a container for all the pigtail components the leads of which terminate on printed-wiring boards.

Funnel-shaped holes in the blocks hold the pigtail components in place. A tapered section at the base of each hole readily guides the pigtails through holes in the printed-wiring board where they are soldered in place. Connections between printed-wiring boards on opposite sides of the converter are made with tinned-copper wire extending through the blocks and soldered to the printed-wiring boards.

Three transformers and one inductor occupy somewhat more space than the resistors and capacitors of the converter network. These four components are mounted in a large cavity within the bottom block, as shown in the drawing on page 264. The transformers and inductor are connected to wires that extend through, and are soldered to, the printed-wiring boards. All of these components are potted in wax; and, for additional protection, a metal plate covers the cavity.

Eight transistors—four on each side of the converter—are mounted outside rather than within the cavity. This arrangement helps to dissipate any heat generated by the transistors. The transistor wires extend through ledges to the printed-wiring board where they are soldered.

The second major part of the repeater is the line-building-out (LBO) network. The LBO, as the name indicates, actually "builds out" the line to match the impedance of the line to the impedance of the repeater. Although physically a part of the repeater, it may be considered an extension of the line. The general shape of the LBO is similar to that of the converter. Here, 24 components, mostly resistors, capacitors, and inductors are assembled in matching cavities in two



The E6 repeater consists of two LBO networks, a converter, and a housing. When used as a terminal repeater, only one LBO is necessary. The converter is a series and shunt element. The LBOs provide resistors and capacitors which match the impedance of the line to impedance of repeater.

molded blocks of phenolic resin. Four screws are used to fasten the LBO network in the housing and also to make electrical connections with the converter.

The housing for the repeater, viewed from the back, is an H-shaped extrusion with a die-cast front door hinged at the bottom. Both the housing and the door are made of aluminum alloy. When the door is opened, contact between the plug on the repeater and the connector on the shelf is broken. In this way, the door disconnects the repeater and also facilitates the removal of the repeater from the shelf. A hole in the door provides access to test jacks on the converter.

Rails along the inside walls of the extruded housing match grooves in the converter and in the LBO networks. These rails guide the networks into position. Rails along the bottom hold the repeater in place while it is installed on an equipment shelf in a central office. A spring lock holds the door closed.

A rectangular opening across the center section of the housing receives a molded phenolic block for insulating and guiding the screws that engage the LBOs. In the converter block, these screws also engage internally mounted terminals which are connected to the plug through the printed-wiring conductors on the converter. The assembly of the converter and the LBOs in the housing is shown in the drawing above.

Disablers that operate on the loop current in the line are available as optional equipment. Basically, the disabler improves transmission by permitting the repeater to operate at higher gain in the talking condition than can normally be supported without singing (oscillations) when the circuit is not in use or when dial pulses are being transmitted to a distant office. The disabler is a plug-in unit similar in size to the repeater except about half as high. The housing is an extrusion with a die-cast front door hinged at the top. When opened, the door breaks the contact between the plug and connector in the same manner as the door of the repeater.

Rails at the bottom of the repeater and rails at the top of the disabler move along grooves on the equipment shelf and permit these units to slide easily into position. The shelf, an assembly of die-castings of aluminum alloy, accommodates six repeaters and six disablers on the upper and lower surfaces, respectively.

The E6 repeater and the disabler plug into position in a central office in a manner similar to E23 repeaters. The plug on each unit is a strip of 16 contact pins. The pins on one side of the plug are soldered to a printed-wiring board. On the outer side of the plug, the pins are arranged to engage 16 contacts of a connector on the equipment shelf. All electrical connections reach the repeater or the disabler through the engagement of its plug and connector. The connector for each repeater, the connector for the associated disabler, and a multi-contact jack with the latter are interconnected. This permits the disabler to be inserted into or removed from the repeater circuit simply by inserting the disabler into or removing it from the shelf; no wiring change is involved. Two tapered guide pins on the back of each unit align the plug and connector prior to engagement.

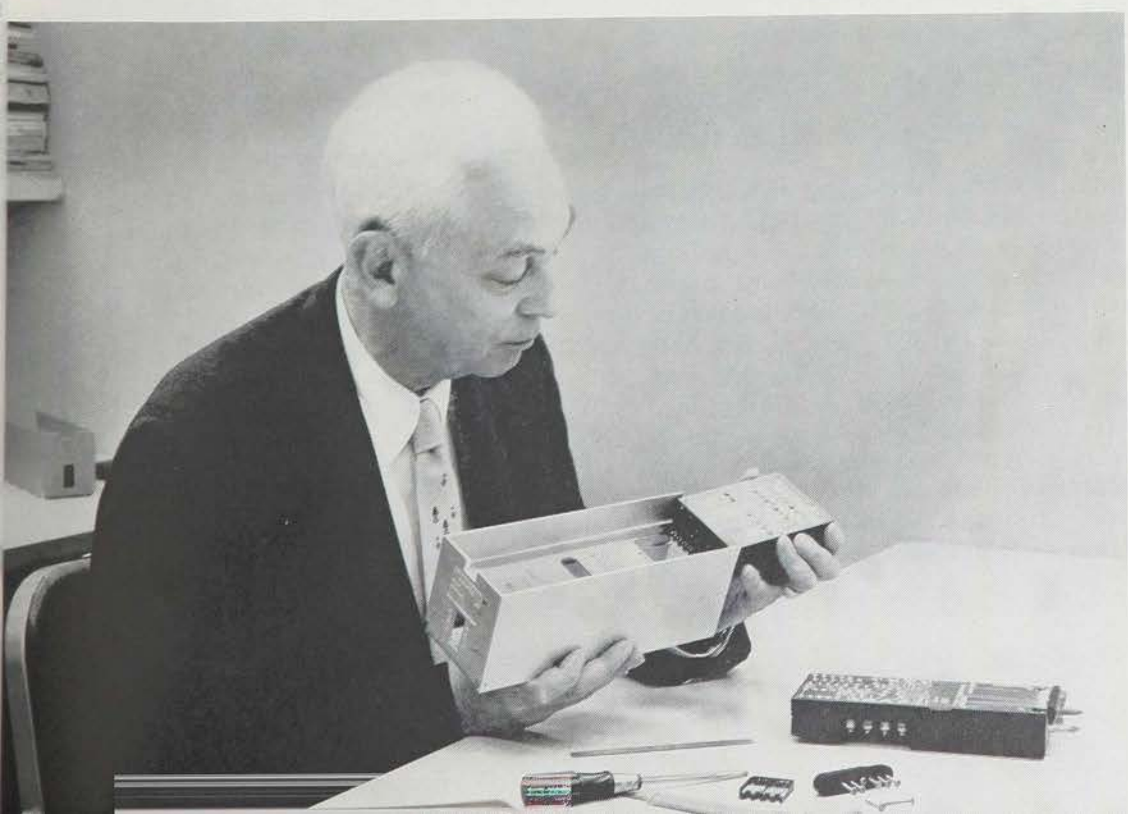
As the repeater or disabler is moved into position, the two guide pins enter holes at the rear of the equipment shelf, and in so doing, guide the plug into proper engagement with the connector on the shelf. The guide pins also relieve the plug and connector of any strain that might be caused by the weight of the repeater or disabler. A small V-notch on each guide pin engages a spring catch at the rear of the shelf and locks each unit in place. A molded plastic comb-like strip across the rear of the shelf supports and channels the wires to the connectors.

Usually, test jacks are installed in the relay rack bays to simplify maintenance and permit the repeater conductors to be readily "picked up" for gain tests while the repeater is on the shelf. The jacks are arranged so that a telephone line automatically bypasses a repeater if the repeater is picked up for tests. The jacks are conveniently located so that an attendant may easily determine whether or not the line is being used. During a simulated call, jacks also help the attendant to determine whether performance is satisfactory.

The power required for the repeaters may be supplied through either of two types of power-distribution panels: one panel supplies power for a bay of as many as 16 shelves of repeaters and disablers; the other panel is for a small two-shelf unit. In addition to the fuses for the repeaters and disablers each panel has a fuse and an outlet to power test sets and an alarm relay and lamp. If a fuse fails, an audible alarm is automatically set off and visual alarms indicate the aisle and bay where the failure occurred.

Shop-wired arrangements for bays minimize installation procedures. In an 11½-foot high, 23-inch wide bay, as many as 96 repeaters and disablers, or as many as 90 repeaters, disablers and test jacks, may be installed. In shorter bays, the quantities are reduced accordingly. A shop-wired two-shelf unit, 23 inches wide accommodates 12 repeaters, disablers, and test jacks.

The E6 telephone repeater is an example of how Bell Laboratories and Western Electric teams utilize design and manufacturing techniques to make high-performance telephone equipment available at lower cost. In a broader sense, it is another step toward better service for the telephone customer.



J. K. Jones slides LBO network into E6 repeater housing. Note converter network (foreground).

PATENTS

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Christensen, H.—*Radiant-Energy Translation System*—3,035,175.

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Mitchell, C. E.—*Subscriber Calling Apparatus*—3,035,211.

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Anderson, L. K., and Shaw, H. J., *The Representation of Waveguides Containing Small Ferrimagnetic Ellipsoids,* PGMTT Symp., Boulder, Colo.

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Barnes, E. G., *Trees and Shrubs on Industrial Properties—Planting and Maintenance,* Nat. Arborist Assoc., Washington, D. C.

Benes, V. E., *Maximum Likelihood Estimates of Fluctuations of Traffic-Intensity,* Columbia Univ., Statistics Dept., N. Y. C.

Bennett, W. R., *Optical Masers,* Bank Street School, New York City.

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E. J. Tyberghein, the author of "TWX Goes Dial" in this issue was born in Detroit, Michigan. He graduated from the Massachusetts Institute of Technology in 1947 and started his Bell System career that same year in the plant and engineering department of the Michigan Bell Telephone Company. He became supervisor of transmission facilities at the Michigan Company before being transferred to A.T.&T. Co. in 1955. After 3½ years with an equipment group dealing with the various suppliers of carrier and radio equipment, Mr. Tyberghein was assigned to work in systems engineering. In August 1960 he was transferred to Bell Laboratories where, as a member of the Data Systems Engineering Center, his major concern is systems engineering.

Donald P. Ling, is executive director of the Military Research Division of the Laboratories. He received the A.B. degree in mathematics from Amherst College in 1933 and the M.A. and Ph.D. degrees in mathematics from Columbia University in 1939 and 1944. From 1944 to 1945, Mr. Ling worked with the Applied Mathematics Panel at Columbia University.

Since joining the Laboratories in 1945 Mr. Ling has been chiefly concerned with systems synthesis and the analysis of weapons systems; the general problem of missile guidance and control; space technology; and the application of mathematical techniques to military situations. He became director of Military Analysis in 1958, and assistant director of Military Systems Engineering in 1959. He was appointed to his present position one year ago.

Mr. Ling has served on various civilian government committees. He is the author of a number of technical articles on missile guidance, space technology and communications, and is a member of the American Mathematical Society and the American Rocket Society.

D. P. Ling

Mr. Ling's article in this issue, "Symbolic Logic: The Extended Language," is the second of two tutorial articles on Symbolic Logic. The first one appeared in the June issue of the RECORD.

R. A. Laudise (author of "Growing Oxide Crystals") was born in Amsterdam, New York and educated in the public schools of that city. He received a Bachelor of Science Degree in Chemistry from Union College in Schenectady, New York, in 1952. Mr. Laudise received an A.D. Little Fellowship to the Massachusetts Institute of Technology, where he

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graduated with a Ph.D. in Inorganic Chemistry in 1956. That year he joined Bell Laboratories where he has been interested in crystal growth, particularly by hydrothermal and molten salt techniques. Mr. Laudise is head of the Crystal Chemistry Research Department in the Metallurgical Laboratory. He is a member of the Society of Sigma Xi, the American Chemical Society, the American Ceramic Society, the American Mineralogical Society, and the American Association for the Advancement of Science.

W. C. Schmidt joined the Laboratories in 1927 where he was initially engaged in the design of equalizers for program transmission circuits. During the war

W. C. Schmidt

years he was engaged in work on data smoothing networks for gun directing systems. In 1951 he joined a development group responsible for packaging and printed wiring techniques. He received his EE degree from the Polytechnic Institute of Brooklyn in 1937. Mr. Schmidt is co-author of "Equipment Design and Packaging of the E6 Repeater" in this issue.

J. K. Jones, co-author of "Equipment Design and Packaging of the E6 Repeater," is a resident of Andover, Massachusetts and is a member of the technical staff at the Merrimack Valley branch of the Laboratories. He received his B.S.E.E. from North Carolina State College in 1921, and began his Bell System career with Southern Bell Telephone and Telegraph Company where he remained for one year and then joined the Western Electric Company. With Western Electric for 10 years at the Hawthorne and Kearny plants, Mr. Jones worked with specifications for central-office equipment and supervised the preparation of standard information for application on specific orders. In 1933, Mr. Jones joined the Laboratories where he has been engaged in equipment design of toll switchboard, voice-frequency carrier telegraph and broadband carrier telephone systems. Since 1954, he has been engaged in the development of voice-frequency repeater equipment.

J. K. Jones

NEWS FROM
BELL LABORATORIES

A simple, highly sensitive microwave amplifier

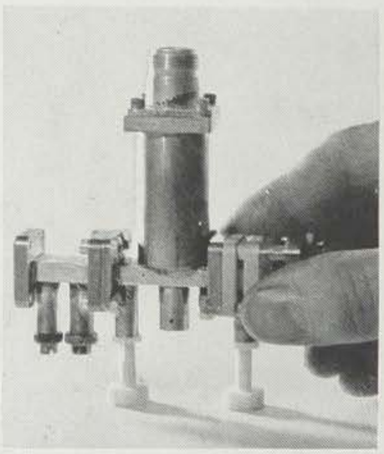
Bell Laboratories engineers have developed an extremely sensitive parametric amplifier which approaches the maser in sensitivity. Both will be used in experiments with Telstar, the Bell System's experimental communications satellite.

Heart of the parametric amplifier is a newly developed semiconductor diode with very low intrinsic noise. Previously, the sensitivity of such amplifiers at microwave frequencies was severely limited by the unwanted noise generated in their diodes. The new diode, no bigger than the eye-end of a needle, solved this problem.

Our engineers also devised new circuitry to stabilize precisely the output of the klystron (microwave generator) supplying power for the amplifier. To reduce further the intrinsic noise of the amplifier, they immersed the diode and its circuits in liquid nitrogen, utilizing a new cooling arrangement which economically maintains a low temperature for many days without attention.

The new amplifier fills a need in the communications field for a simple microwave amplifier of high sensitivity in applications for which the higher sensitivity of the maser does not justify its additional complication.

Bell Laboratories' Michael Chruney adjusts waveguide assembly (in circle) housing the diode. After adjustment the entire parametric amplifier will be immersed in liquid nitrogen in dewar at left. The new amplifier operates at 4170 megacycles (center of band) and provides an almost flat gain of 38 db over a 50-megacycle band with a noise figure of approximately 0.6 db.



Close-up of the waveguide assembly, in which Bell Telephone Laboratories' newly developed diode is located.

Heart of amplifier—a hermetically sealed gallium arsenide diode—is compared with eye of average-sized sewing needle.

BELL TELEPHONE LABORATORIES

World center of communications research and development