Solid state

Special report:

The unijunction transistor

From ball parks to ballistic missiles, it's finding more and more uses. As the market grows, so does competition among manufacturers

By Jerome Eimbinder
Solid State Editor

The electronic scoreboard at Houston's new Astrodome Stadium does more than keep baseball fans apprised of the progress of the game. It dramatizes a trend in the semiconductor industry toward unijunction transistors.

For years, manufacturers conceded the unijunction-transistor market to the General Electric Co. because most applications required just one such device, or a few at most; GE's potential rivals didn't consider a field of this size worth fighting for.

The Astrodome scoreboard employs 200,000 semiconductor devices; of these, 25,000 are unijunction transistors. More displays using unijunction devices are being considered at other ball parks; also, the American Machine and Foundry Co. is developing an automated bowling scoreboard, designed with unijunction transistors. The devices also are finding their way more and more frequently into military and industrial applications.

Sales climbing

With the biggest producer, GE, reluctant to disclose figures, it's difficult to assess the size of the market for unijunction transistors. However, some industry observers estimate that sales will exceed $1.5 million in the current fiscal year and $2.5 million in the year ending in June, 1966. GE says it commands about 80% of the market; other estimates put GE's share as high as 95%. A GE spokesman says profit on these devices is "very healthy."

But competition is growing, particularly from two giants in the semiconductor industry: Texas Instruments Incorporated and Motorola, Inc.

Texas Instruments is no newcomer to the unijunction field. For three years it has been a second source for several types introduced by GE.

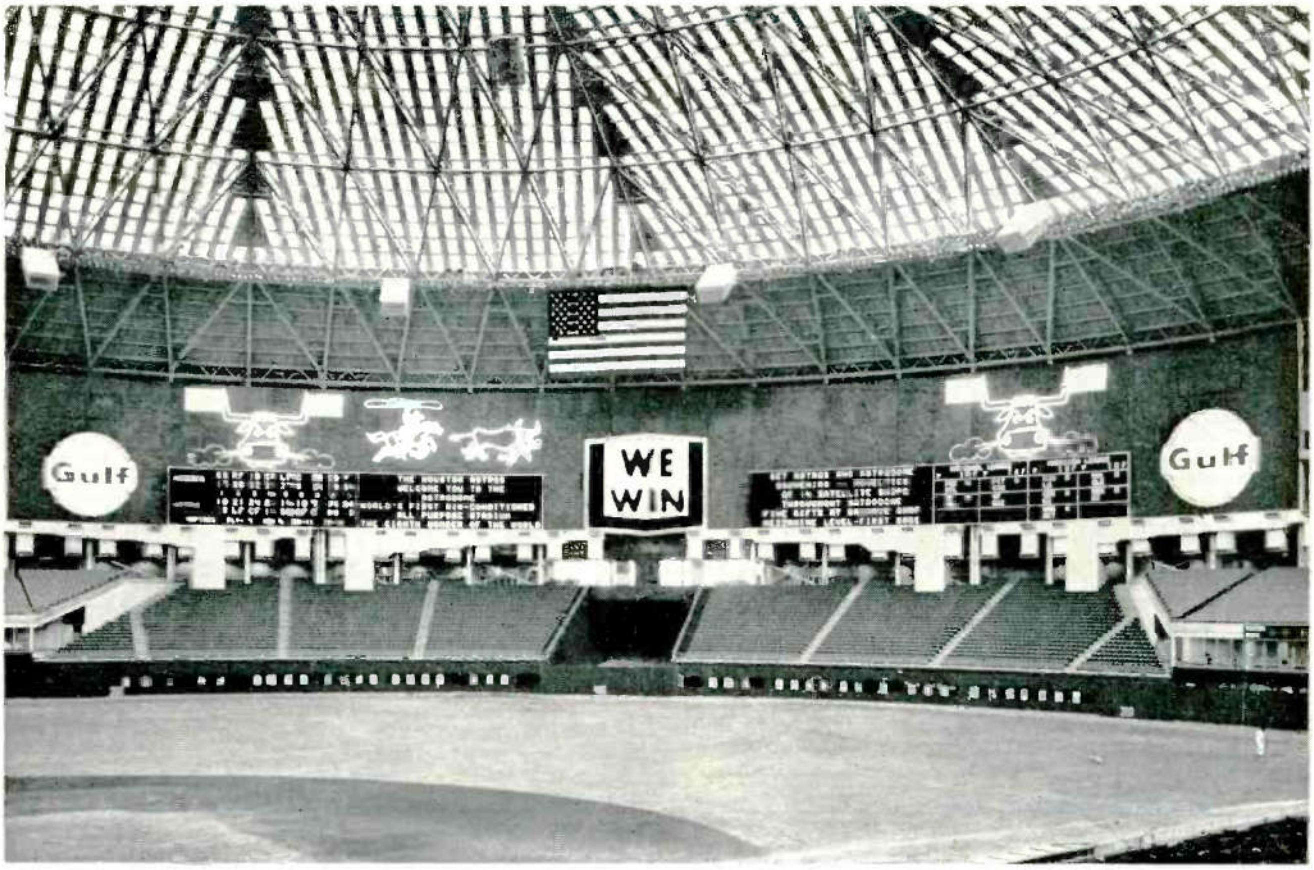
Motorola's decision to enter the competition last summer was prompted by feedback from its salesmen, according to Tom Conners, marketing manager. Conners says, "We've gone into the unijunction field because we've found that many of our customers use unijunction transistors to trigger our silicon controlled rectifiers." He adds, "This will give us the ability to offer the customers a complete package." Undoubtedly, Motorola's decision was also influenced by the presence on its staff of the developer of the first commercial unijunction transistor, I. Arnold Lesk, as director of applied research.

GE has been slow in adapting planar technology to unijunction manufacturing. Besides its high speed and low saturation voltage, the planar device is especially attractive because of its potentially low manufacturing cost.

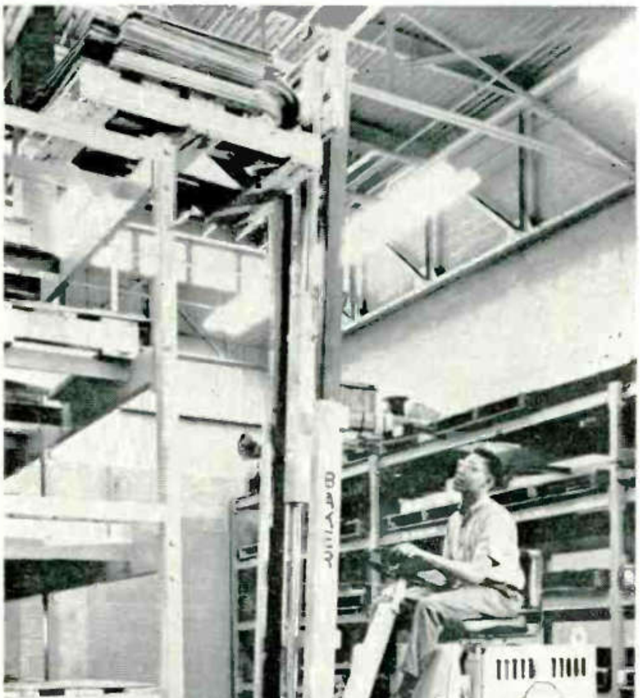
Both Motorola and Texas Instruments brought out planar unijunction devices last fall; GE's planar unit is still on the drawing board. GE may find some consolation, however, in its competitor's problems. Texas Instruments tried at first to make its two planar unijunction devices, the TIS01 and the TIS02, in plastic packages, but reportedly had trouble obtaining good stability and removed both of them from the market. Motorola has, for undisclosed reasons, withdrawn two of the six planar unijunction devices it introduced last October.

Texas Instruments is delivering samples of two metal-can planar diffused devices, the SJ993 and the SJ1127, to replace the two withdrawn silicone-plastic encapsulated units. It is also developing a low-cost line of silicon planar unijunction transistors to compete with General Electric's 2N2646 family, which sells for as little as 60 cents apiece in quantities of 1,000 or more.

One article in this issue (p. 93) discusses alloy and planar unijunction construction and compares



Scoreboard at Astrodome Stadium contains nearly 200,000 semiconductor devices including about 25,000 unijunction transistors. The center section of the scoreboard, showing the message "we win," can also display scenes and pictures of players. The manufacturer is the Fair Play Scoreboard Co.



◀ **Electric-powered fork-lift truck** uses a unijunction transistor in its control system. The transistor supplies a 50-milliampere signal to turn on a silicon controlled rectifier. The rectifier delivers pulses up to five amperes to the d-c motor. By varying the pulse frequency from 45 to 300 cps, the average voltage to the motor can be varied and the motor speed controlled from minimum to maximum. In the photograph, a load of welded transformer parts are being stacked for storage. Truck was built by the Baker division of the Otis Elevator Co.

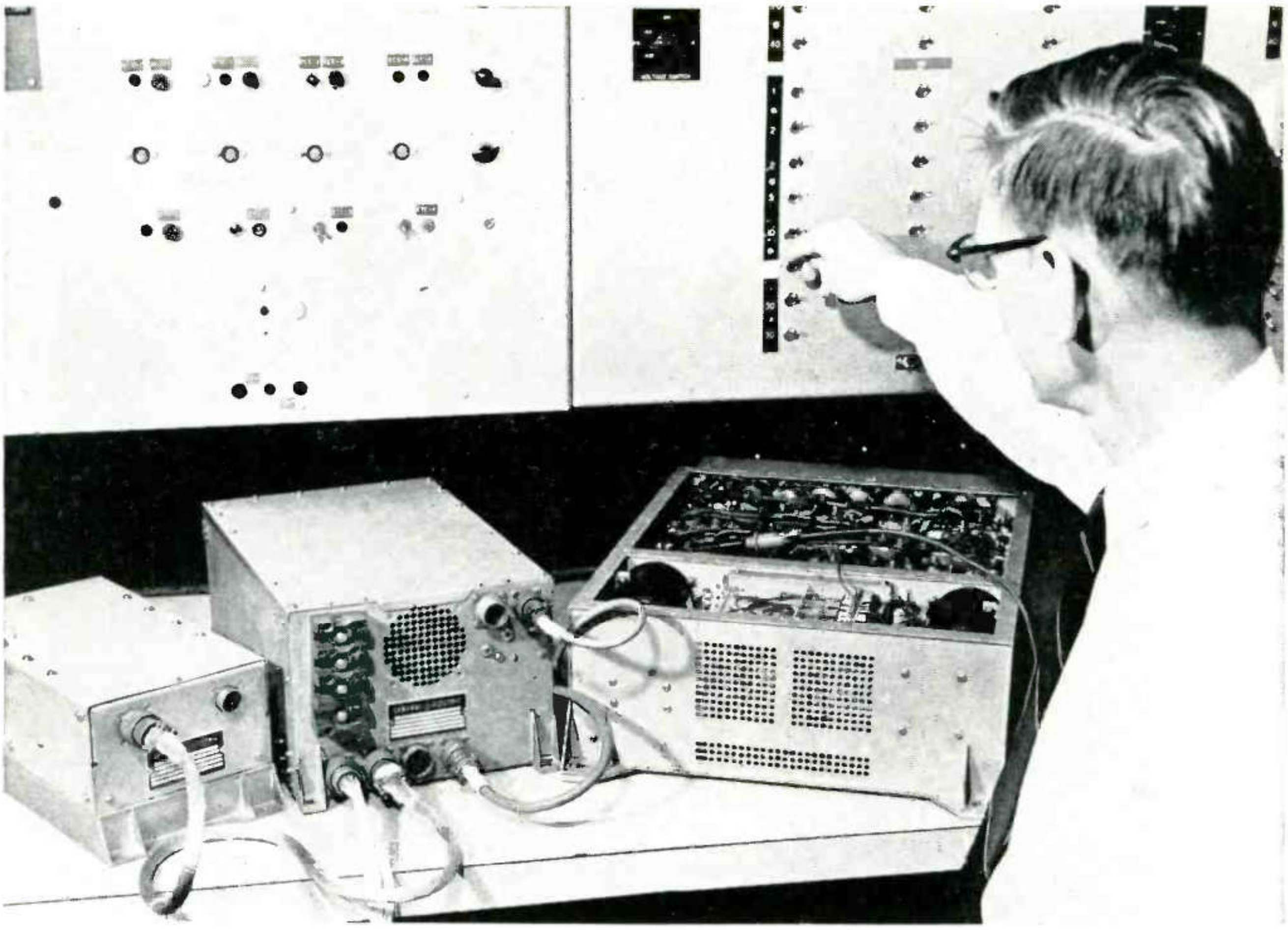
Engineering-laboratory test set for measuring unijunction transistor's characteristics. This instrument whose circuitry contains unijunction transistors, measures seven characteristics including intrinsic standoff ratio and interbase resistance. It is manufactured by the Syracuse Electronics Corp.

Unijunction transistor characteristics chart

TYPE NUMBER	STRUCTURE	ABSOLUTE MAXIMUM RATINGS: Emitter reverse voltage (volts)	RMS emitter current (ma)	Dissipation at 25°C (mw)	CHARACTERISTICS: Emitter reverse current at 30V. (μa) max.	Intrinsic stand-off ratio at 10V. min.	max.	Peak-point emitter current at 25V. (μa) max.	Interbase resistance at 3V. $I_E=0$ (kilohms) min.	max.	Base-one peak pulse voltage (volts) min.	CASE	MFR.
2N489	bar	60	70	450	2.0	.51	.62	12	4.7	6.8	—	TO5	GE, TI
2N489A	bar	60	70	450	2.0	.51	.62	12	4.7	6.8	3	TO5	GE, TI
2N489B	bar	60	70	450	0.2	.51	.62	6	4.7	6.8	3	TO5	GE, TI
2N490	bar	60	70	450	2.0	.51	.62	12	6.2	9.1	—	TO5	GE, TI
2N490A	bar	60	70	450	2.0	.51	.62	12	6.2	9.1	3	TO5	GE, TI
2N490B	bar	60	70	450	0.2	.51	.62	6	6.2	9.1	3	TO5	GE, TI
2N490C	bar	60	70	450	0.02	.51	.62	2	6.2	9.1	3	TO5	GE
2N491	bar	60	70	450	2.0	.56	.68	12	4.7	6.8	—	TO5	GE, TI
2N491A	bar	60	70	450	2.0	.56	.68	12	4.7	6.8	3	TO5	GE, TI
2N491B	bar	60	70	450	0.2	.56	.68	6	4.7	6.8	3	TO5	GE, TI
2N492	bar	60	70	450	2.0	.56	.68	12	6.2	9.1	—	TO5	GE, TI
2N492A	bar	60	70	450	2.0	.56	.68	12	6.2	9.1	3	TO5	GE, TI
2N492B	bar	60	70	450	0.2	.56	.68	6	6.2	9.1	3	TO5	GE, TI
2N492C	bar	60	70	450	0.02	.56	.68	2	6.2	9.1	3	TO5	GE
2N493	bar	60	70	450	2.0	.62	.75	12	4.7	6.8	—	TO5	GE, TI
2N493A	bar	60	70	450	2.0	.62	.75	12	4.7	6.8	3	TO5	GE, TI
2N493B	bar	60	70	450	0.2	.62	.75	6	4.7	6.8	3	TO5	GE, TI
2N494	bar	60	70	450	2.0	.62	.75	12	6.2	9.1	—	TO5	GE, TI
2N494A	bar	60	70	450	2.0	.62	.75	12	6.2	9.1	3	TO5	GE, TI
2N494B	bar	60	70	450	0.2	.62	.75	6	6.2	9.1	3	TO5	GE, TI
2N494C	bar	60	70	450	0.02	.62	.75	2	6.2	9.1	3	TO5	GE, TI
2N1671	bar	30	50	450	12.0	.47	.62	25	4.7	9.1	—	TO5	GE, TI
2N1671A	bar	30	50	450	12.0	.47	.62	25	4.7	9.1	3	TO5	GE, TI
2N1671B	bar	30	50	450	0.2	.47	.62	6	4.7	9.1	3	TO5	GE, TI
2N1671C	bar	30	50	450	0.02	.47	.62	2	4.7	9.1	3	TO5	GE
2N2160	bar	30	50	450	12.0	.47	.80	25	4.0	12	3	TO5	GE, TI
2N2417	bar	60	70	450	2.0	.51	.62	12	4.7	6.8	—	TO18	GE
2N2417A	bar	60	70	450	2.0	.51	.62	12	4.7	6.8	3	TO18	GE
2N2417B	bar	60	70	450	0.2	.51	.62	6	4.7	6.8	3	TO18	GE
2N2418	bar	60	70	450	2.0	.51	.62	12	6.2	9.1	—	TO18	GE
2N2418A	bar	60	70	450	2.0	.51	.62	12	6.2	9.1	3	TO18	GE
2N2418B	bar	60	70	450	0.2	.51	.62	6	6.2	9.1	3	TO18	GE
2N2419	bar	60	70	450	2.0	.56	.68	12	4.7	6.8	—	TO18	GE
2N2419A	bar	60	70	450	2.0	.56	.68	12	4.7	6.8	3	TO18	GE
2N2419B	bar	60	70	450	0.2	.56	.68	6	4.7	6.8	3	TO18	GE
2N2420	bar	60	70	450	2.0	.56	.68	12	6.2	9.1	—	TO18	GE
2N2420A	bar	60	70	450	2.0	.56	.68	12	6.2	9.1	3	TO18	GE
2N2420B	bar	60	70	450	0.2	.56	.68	6	6.2	9.1	3	TO18	GE
2N2421	bar	60	70	450	2.0	.62	.75	12	4.7	6.8	—	TO18	GE
2N2421A	bar	60	70	450	2.0	.62	.75	12	4.7	6.8	3	TO18	GE
2N2421B	bar	60	70	450	0.2	.62	.75	6	4.7	6.8	3	TO18	GE
2N2422	bar	60	70	450	2.0	.62	.75	12	6.2	9.1	—	TO18	GE
2N2422A	bar	60	70	450	2.0	.62	.75	12	6.2	9.1	3	TO18	GE
2N2422B	bar	60	70	450	0.2	.62	.75	6	6.2	9.1	3	TO18	GE
2N2646	cube	30	50	300	12.0	.56	.75	5	4.7	9.1	3	TO18	GE
2N2647	cube	30	50	300	0.2	.68	.82	2	4.7	9.1	6	TO18	GE
2N2840	cube	30	50	300	1.0	—	—	10*	4.7*	9.1*	—	TO18	GE
2N3480	planar	30	50	400	12.0	.56	.75	20	4.7	9.1	3	TO5	MOT
2N3481	planar	30	50	400	12.0	.70	.85	20	4.7	9.1	3	TO5	MOT
2N3483	planar	30	50	400	1.0	.60	.72	5	4.7	9.1	4	TO5	MOT
2N3484	planar	30	50	400	0.2	.70	.85	5	6.2	9.1	6	TO5	MOT
5E35†	cube	30	50	300	12.0	.62	.82	—	4.7	9.1	—	TO18	GE
5E36†	cube	30	50	300	1.0	.62	.82	—	4.7	9.1	—	TO18	GE
SJ993	planar	30	50	300	10.0	.56	.75	5	4.7	9.1	3	TO18	TI
SJ1127	planar	30	50	300	10.0	.68	.82	2	4.7	9.1	6	TO18	TI

† Frequency and period guaranteed in multivibrator test circuit
* At 1.5 volts
Emitter reverse current measured at specified V_{B2E} and $I_{B1}=0$
Intrinsic standoff ratio measured at specified V_{BB}
Peak-point emitter current measured at specified V_{BB}
Interbase resistance measured at specified V_{BB} and $I_E=0$
Base one peak pulse voltage measured in manufacturer's test circuit

GE = General Electric Co.
MOT = Motorola, Inc.
TI = Texas Instruments Incorporated



Aircraft power system developed by General Electric uses circuitry containing unijunction transistors and silicon controlled rectifiers to replace hydraulic constant-speed alternator-drive arrangement. System components shown being tested are protective controls, waveform filters and unijunction-scr converter circuitry.

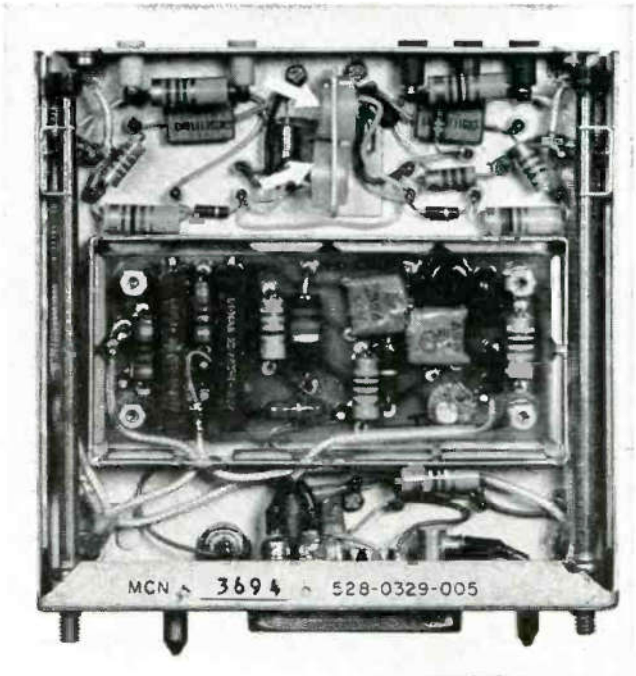
them with the bar structure employed in most currently available unijunction transistors.

The market

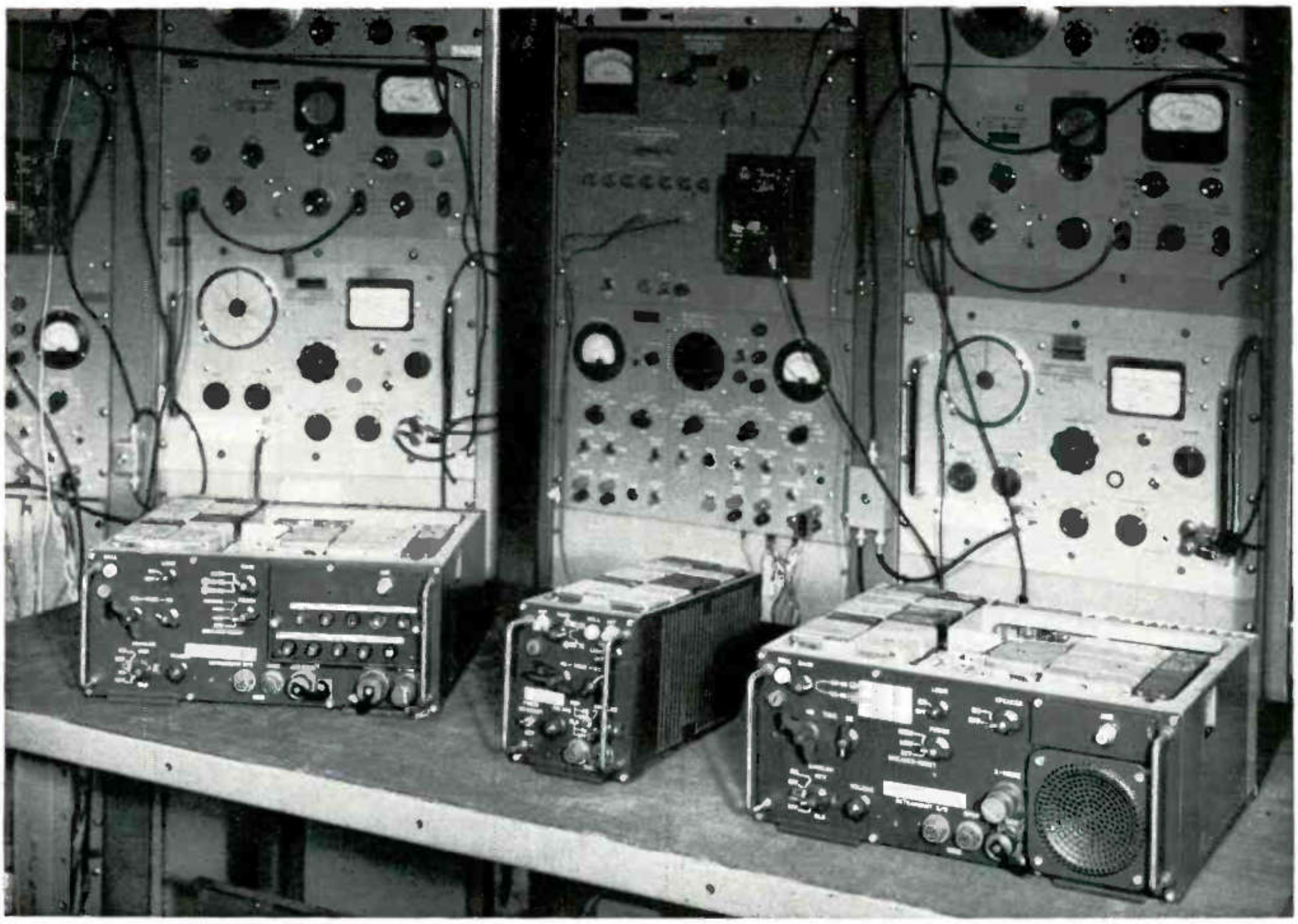
Military applications of unijunction transistors have been considerable. The devices have important functions in the Polaris and Minuteman control systems, and have been used in the circuitry of most space satellites. They are also used extensively in military communications. The Collins Radio Co. uses unijunction transistors in the AN/ARC-80 airborne data-communications system and in the 618T single-sideband transmitter-receiver for level detection, tone generation and frequency division. The Magnavox Co. and Bendix Corp. are also using unijunction transistors in mobile communications systems.

The unijunction transistor has also found its way into a variety of industrial applications—the latest of which is the regulated power-supply circuitry of commercial jet aircraft. More typical of its industrial applications is its widespread use in timing. The Industrial Timer Corp., for example, offers five precision timers using unijunction transistors. Each of the units, which sell for $69.95, has been in the company's line more than four years.

According to GE, the owners of two-engine com-



618T single-sideband transceiver manufactured by Collins Radio Co. uses unijunction transistors for frequency stabilization. Arrows indicate unijunction transistors.



The AN/VRC-12 jeep radio communications system, built by Magnavox Co., employs unijunction transistors as saw-tooth oscillators in frequency-sweep generators. Being tested are the push-button tranceiver RT-246 (lower left), the auxiliary receiver R-442 (lower center) and the manual-tuned transceiver RT-524.

mercial jet aircraft will save about $8,000 a year per plane by using a regulated power supply designed with unijunction transistors. Applications for unijunction transistors also include electronic organs (for frequency division) and a music-light display at the New York World's Fair. The Woods Hole Oceanographic Institution uses a five-unijunction transistor pulse-generator in instruments placed on the ocean floor. This provides a beacon to help the pickup crew find the instruments.

No integrated circuits have been marketed yet with unijunction transistors. However, the practicality of such devices has been shown in the construction of planar unijunction transistors and in work on unijunction integrated circuits at the University of California, financed by an Air Force grant.

The main restriction on the use of unijunction transistors in integrated circuits is that the large pellet size of the unijunction's frequent working companion, the medium- or high-power silicon controlled rectifier, restricts its manufacture in integrated form.

Military types

A military specification for unijunction transistor types 2N489 through 2N494 was issued by the Air Force in July, 1959. The specification, MIL-T-19500/75, calls for a series of environmental tests including moisture resistance, noise fatigue vibration, and stringent electrical tests. Currently both Texas Instruments Incorporated and the General Electric Co. have been approved by the Air Force as qualified to supply these types. Individual military projects, such as the Minuteman and Polaris missiles, also have rigid specifications for unijunction transistors. The Minuteman specification is for the 551B transistor, Polaris the G319.

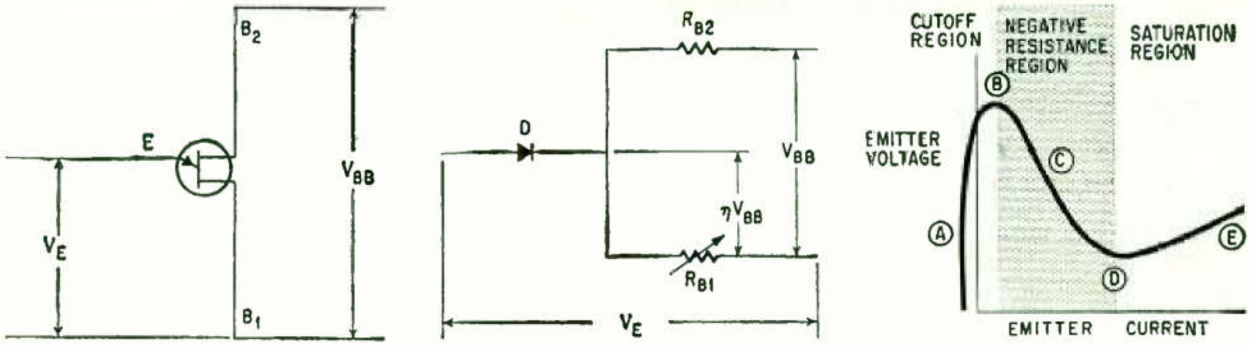
Lead arrangement

Although the chart on page 89 refers to standard TO-5 and TO-18 transistor cases, the basing arrangement for unijunction transistors differs from conventional TO-5 and TO-18 bases. For the unijunction-transistor base, the index tab is between the emitter lead and the base two lead instead of between the emitter and the vacant lead location.

An in-line lead arrangement was used for the discontinued plastic-case unijunction-transistor types.

Family tree

The unijunction transistor is generally considered to have been born in 1952 in the electronics laboratory of the General Electric Co. Its developer was I. Arnold Lesk, then a GE scientist working



Symbol for a unijunction transistor having p-type emitter and n-material base region is at left. Simplified equivalent circuit containing only three components is in center. Emitter-to-base-one voltage current characteristic, at right, exhibits five key points: (A) cutoff, (B) peak point, (C) negative resistance region, (D) valley point, and (E) saturation.

Theory of operation

The simplified equivalent circuit (off condition) for the unijunction transistor, shown in the center diagram, requires only two resistors and a diode, although more complex equivalent circuits have been derived.

The diode represents the junction between the p-material emitter and the n-material base region. Resistor R_{B1} represents the resistance of the base region between the p-n junction and the base-one (B_1) contact; R_{B2} is the resistance between the junction and the base-two (B2) contact.

The fraction of the applied interbase voltage V_{BB} that appears across R_{B1} is designated by η. If the emitter-to-base-one voltage V_E is less than V_{BB}, the p-n junction will be reverse-biased, and only leakage current in the order of a few microamperes (nanoamperes for some types) will flow. This condition is represented by point A on the voltage-current characteristic shown in the diagram at the top, right. By increasing V_E until it is greater than V_{BB}, the p-n junction becomes forward-biased and emitter current starts to flow.

At point B, the emitter voltage reaches the peak-point voltage and the unijunction transistor fires. The majority of the holes, being injected from the p-material emitter, travel to base one, lowering the resistivity of the emitter-to-base-one region. This, in turn, results in a decrease in the emitter voltage as the current rises, and the device exhibits a negative resistance characteristic (B-D). As the current rises, the emitter voltage continues to drop until it reaches the valley-point voltage (point D). The valley-point voltage depends on the resistances in series with base one and base two. It decreases as resistance in series with base two is increased, and rises with resistance in series with base one. The region beyond point E, in which the current-voltage relationship is positive, is called the saturation region.

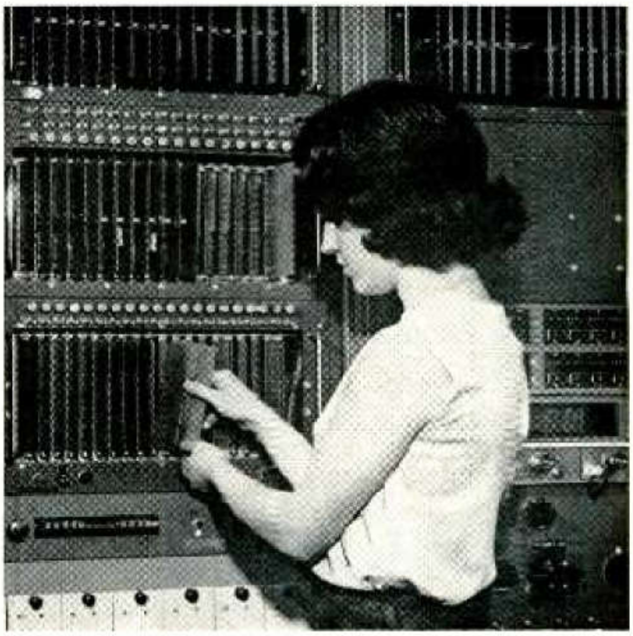
under an Air Force grant to study semiconductor phenomena. But its history goes back further than that.

Its feasibility was demonstrated in 1948 by Heinrich Welker in France. In 1949, William Shockley and J. R. Haynes described the principles governing unijunction action.

The first line of commercial units, using germanium-alloy construction, found limited use in multivibrators, oscillator circuits and filter circuits, and as pulse generators, switches and voltage or temperature sensors. But sales were restricted by high prices and certain technical deficiencies (p. 99).

In 1956, GE changed the name of the device from double-base diode; it also switched from germanium to silicon, and eliminated some technical drawbacks. Two years later, GE made several improvements in the device structure and abandoned the use of silicon produced by the Czochralski method; it switched to silicon made by a floating-zone process. A considerable increase in device uniformity resulted.

In 1960, T. P. Sylvan, working at GE, designed a small unijunction cube structure, more compact than the then-conventional bar structure and with faster turn-on.



Unijunction-transistor classifier at the General Electric Co. facility in Syracuse. Each panel board, such as the one being loaded by the operator, controls a standard go, no-go test. The classifier allows rapid grouping of transistors, according to principal characteristics.