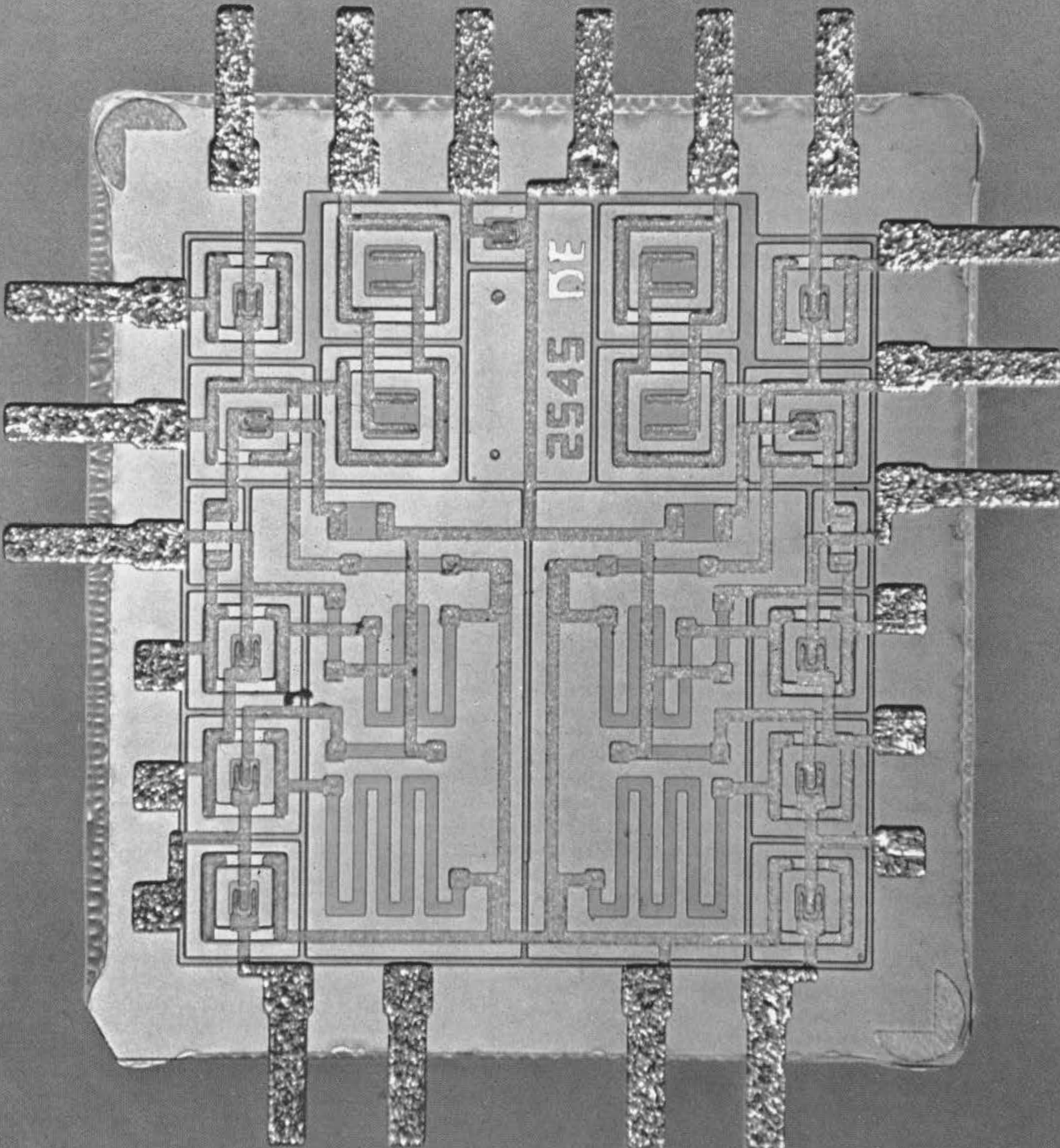
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An integrated circuit for TOUCH-TONE calling weds the major techniques of the new technology. Now being developed for use in the TRIMLINE telephone, the circuit opens the door to the wide use of integrated circuits in customer equipment.

A Tone-Generating Integrated Circuit

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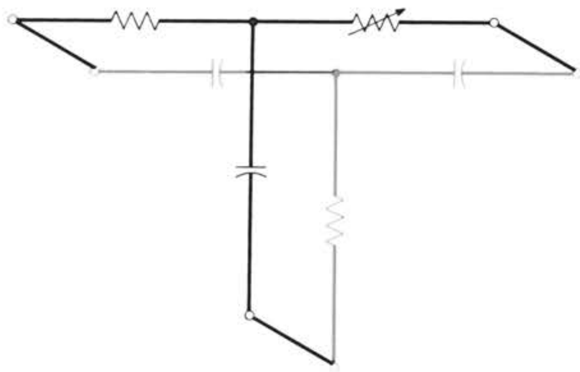
A TONE GENERATOR for the TOUCH-TONE calling TRIMLINE telephone is the first application of the new integrated circuit technology to the telephone set. Taking full advantage of the compatibility of thin films and beam-leaded integrated circuits, the design for this device achieves significant reductions in size, weight, and cost over its conventional predecessor. The new tone generator is based on an old idea—an oscillator with no inductors—which has been made economical by recent advances in integrated-circuit technology.

As a component of the telephone handset, the tone generator for TOUCH-TONE must meet extreme operating conditions. It must be rugged—to withstand repeated drops. It must be light—to make the handset comfortable to hold. It must be stable—to require no readjustment of frequency or amplitude. It must be insensitive to temperature and humidity—to withstand the environment of an outdoor phone booth. It must operate over a wide range of power levels—to be used on customer loops of widely differing length. And, of course, it must be inexpensive.

Most low-frequency oscillator circuits use an inductor-capacitor resonant circuit to determine and control the frequency of oscillation. Resistor-capacitor (RC) networks may also serve these functions and, indeed, their use in tunable laboratory signal generators is quite common. Two principal factors, however, have hampered their use in critical circuits—difficulty in achieving sufficiently economical, precise, and stable capacitors and resistors, and the cost of amplifier gain. For these reasons LC (inductor-capacitor) networks have been generally used in applications such as the original TOUCH-TONE calling dial. (RECORD, *January 1966*) Thin-film resistors and capacitors, however, have the necessary precision and stability; beam-leaded silicon integrated circuits provide the necessary gain economically; and the whole circuit can be tuned after assembly. These advances break through the obstacles to wide use of RC oscillators for fixed-frequency ser-

One of the earlier models of the beam-leaded silicon integrated circuit for the TOUCH-TONE calling TRIMLINE® telephone. Transistors, resistors, and gold beam leads are visible in this microphotograph.



A notch filter in each feedback loop controls the oscillating frequency of the RC tone generator. This "twin-tee" filter is tuned by adjusting the resistor shown in the right arm of the black "T."

vice. The first practical result is the new tone generator—an RC integrated circuit with silicon semiconductor amplifiers.

The new device (see the diagram on page 321) consists of two switchable oscillators which generate a series of tones in prescribed pairs—one pair for each dialed digit. A total of seven tones (four from one oscillator and three from the other) is required. The feedback loop in each amplifier includes a notch filter (a variant of the standard "twin-tee" network) to control the oscillating frequency. (See the drawing above.) Finally, the pair of tones is coupled to the customer's loop by the buffer amplifier stages in the silicon integrated-circuit. In dialing, pressing a digit button selects the corresponding frequency pair by switching a single resistor in each twin-tee network. The oscillator circuit is so designed that tone frequencies can be switched with negligible effect on output level.

Tantalum thin-film resistors and capacitors, deposited on separate substrates and interconnected with gold tape leads, make up the passive network which controls the TOUCH-TONE calling frequencies. The resistors are fabricated from tantalum containing a controlled amount of oxygen (rather than the more common tantalum nitride) to provide a temperature coefficient of resistance equal in magnitude, but opposite in sign, to that of the thin-film tantalum capacitors. This makes the oscillator frequency insensitive to changes in temperature.

The transistors, power supply diodes, and amplifier resistors — 26 components in all — are contained in a single silicon chip about 1/16-inch square. Sealed-junction beam-lead construction eliminates the sealed cans and individual wire leads of the old transistor technology. This means large savings in space and cost and simplification of assembly. (For details of the sealed-junction packaging see *Beam-Lead Sealed-Junction Integrated Circuits* in this issue.) The silicon integrated circuit is attached to the tantalum thin-film substrate to complete the tone generator.

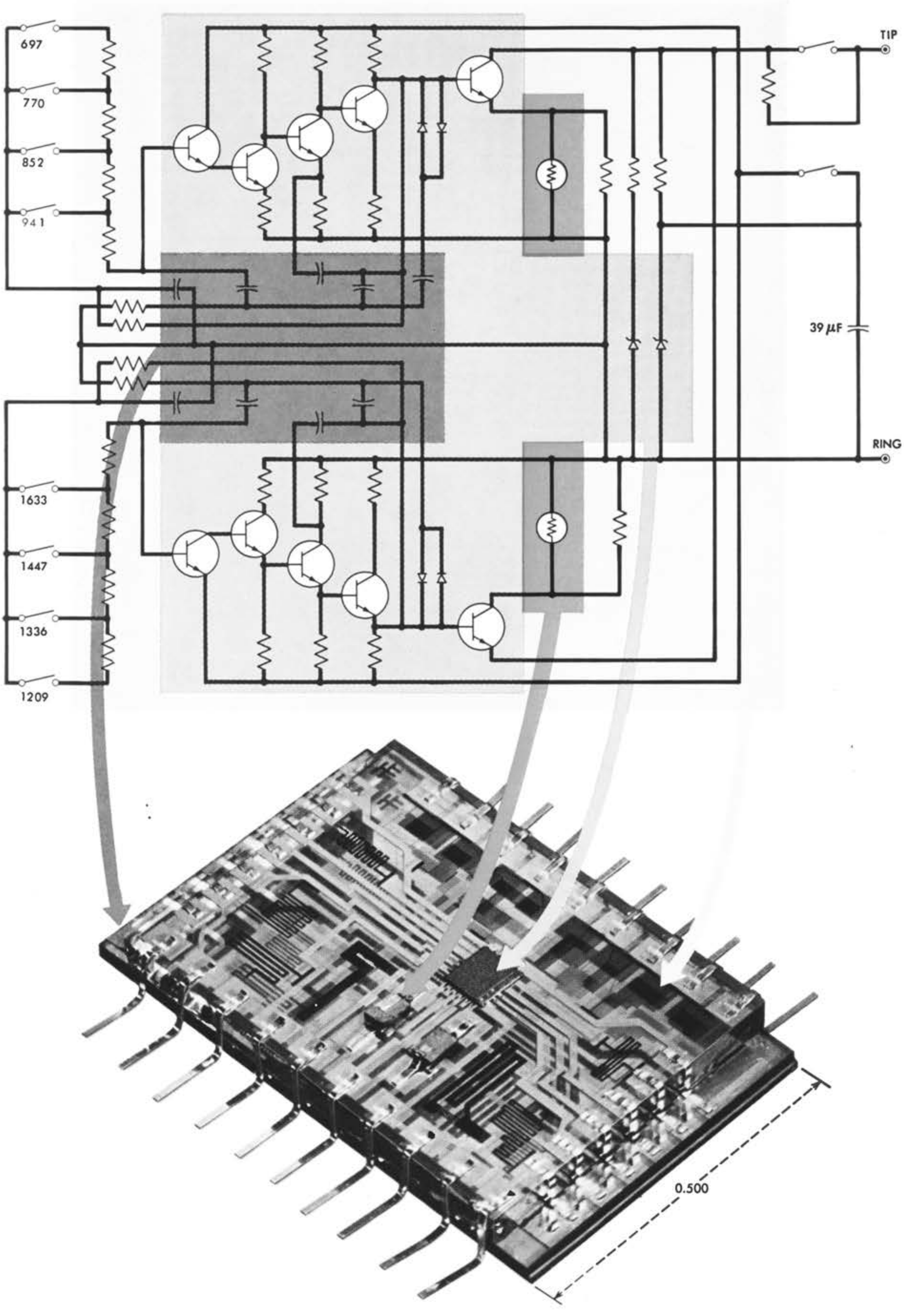
A novel and economical method was developed for tuning the notch circuit to the correct transmission loss and to the desired oscillating frequency. Each frequency is a function of a resistance-capacitance product of the circuit. Because it is not economical to make capacitors with tolerance smaller than ±5 per cent, the frequency-controlling resistors are designed 5 per cent low in value. The frequency is therefore from 0 to 10 per cent above the desired value. It may be adjusted downward by increasing the value of the resistors, using a process called "trimming," until the desired RC product is precisely achieved. (See *Tantalum Integrated Circuits*, this issue.)

The first step in tuning the circuit is to measure the notch's transmission attenuation. This is done by feeding the output of an oscillator into the twin-tee network and adjusting the frequency until the output of the network is 180 degrees out of phase with its input. The attenuation is measured at this point and high or low values are compensated by adjusting one of two resistances in the circuit.

At this point, the beam-lead semiconductor amplifier is thermocompression-bonded to the resistor substrate, and the two tone generators are tuned. Each oscillator is tuned separately by measuring only one output frequency, calculating its ratio to the design value, and then increasing all resistors by that ratio. For example, if the desired frequency is, say, 941 Hz, and the measured frequency 988 Hz, each of the resistors is increased by 5 per cent. The remaining frequencies are attained by adjustment of the resistances associated with the other tones in inverse proportion to each design tone. The whole technique is thus simple enough to be automated.

Because of the large number of gain stages required in the amplifiers, economy dictated the use of a semiconductor integrated circuit. Major

Twenty-six components—transistors, diodes, and amplifier resistors—are contained in a single silicon chip about 1/16 inch square (in the center of the integrated circuit.) Gold tape leads interconnect the resistor substrate and the capacitor substrate, which together comprise the passive network for controlling the TOUCH-TONE *calling frequencies.*


697
770
852
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TIP
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0.500

R. O. Druckenmiller checks liquid diffusion source during fabrication of integrated circuits. Bottle contains a solution of boron tribromide. Gas bubbled through the solution carries boron into the diffusion furnace (at the left) where it reacts in the formation of resistors and the bases of transistors on the silicon slice.

steps in its design were: choosing the actual device structures for the required circuit functions, laying out the topological circuit on the silicon chip, and selecting the precise size, shape, and location of the components on the chip and the interconnections between them. Components were selected that would perform well electrically and that could be fabricated economically.

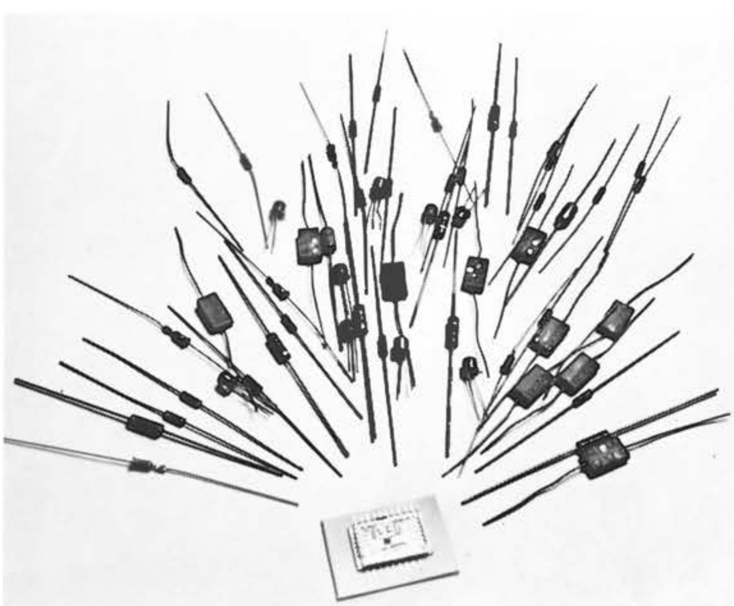
The cost of the silicon integrated circuit depends on the size and the yield of the silicon chips (see *Beam-Lead Sealed-Junction Integrated Circuits* in this issue). Although hundreds of chips are obtained from a single silicon slice, processing of the slice involves an expensive series of operations. Accordingly, it is economical to minimize the size of the chip, to get more chips per slice. The yield often depends on the size of the chip: given a certain number of defects on a slice, a small chip is less likely to contain an incapacitating defect than a large chip. This is another reason for minimizing the area of the chip.

Other concerns in the layout of the silicon integrated circuit were minimization of high-frequency parasitic oscillations and of parasitic coupling between the two oscillators. Parasitic oscillations are a problem even in the layout of a discrete-component amplifier. In semiconductor integrated amplifiers, the problem is intensified because the components and "wiring" of both high-gain amplifiers are densely packed. Considerable protection against oscillation at unwanted high frequencies is afforded by two thin-film capacitors which provide increased loss at high frequencies. (Such protection is needed also with conventionally-built laboratory versions of these circuits.) Parasitic oscillations and coupling are further avoided by generous use of isolating junctions and by spatial isolation (25 mils) of inputs and outputs. Also, diffused crossovers common to the two amplifiers were avoided entirely in the final design, which was judged to be the best of several alternative versions.

The new RC tone generator is a unique product of integrated circuit technology which resulted from the cooperative efforts of both circuit and device design engineers. It demonstrates cost, size, and weight reductions as well as improvements in reliability attained by the application of the new technology. As the first application of integrated circuits in a telephone handset the RC tone generator clears the way for their use in a broad range of customer equipment.

	CONVENTIONAL	INTEGRATED
INDUCTORS	2	0
TRANSISTORS	2	10
VARISTORS	3	2
DIODES	0	2
RESISTORS	4	12 10
CAPACITORS	4	10
THERMISTORS	0	2
TA SOLID CAP'S	0	1
COMPONENT COUNT	15	6

The integrated circuit in the rectangle at the upper right functionally replaces the assembly of discrete components at the left. Only six "components" in the new tone-generating integrated circuit replace 15 components in the conventional LC circuit. The 10 resistors on one substrate can all be tested together and are considered as one component. The same is true of the 10 capacitors on the capacitor substrate. The silicon amplifier chip, a single "component" in integrated circuit technology, comprises the equivalent of 26 conventional solid-state elements.



Performing the functions of the integrated circuit RC tone generator with conventional components would require using all the transistors, diodes, capacitors, and resistors shown here.