MINIATURE TUBES IN WAR AND PEACE*

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Summary—In 1939, a new line of miniature tubes was made available for use in small personal-type receivers. Since that time, the use of miniatures has been extended into electronic equipment of almost every type. This paper describes the design features which account for the versatility and lower cost of the miniature tube and cites several varied applications of miniatures in both military and commercial equipment. A table showing typical present-day applications for miniature tubes is included.

INTRODUCTION

EACH basic receiving tube enclosure has features which make it particularly suitable for specific fields of application. The miniature tube enclosure incorporates most of the desirable features of the other enclosures. It was first introduced by this company in a line of battery-type tubes in 1939 and has since shown a versatility unmatched by any other of the basic enclosures. The miniature tube design was achieved principally through the elimination of non-essential parts. The high standards of performance, low cost, versatility, and small size of tubes incorporating this design are attributable to a large degree to the simplicity of the construction.

In World War II, miniature tubes were first used in war applications to provide more compact equipment and to make available high-frequency tubes which could be mass-produced. Before the end of the war, however, over 50 million of these tubes had been used in nearly every field of electronic application.

Engineering developments and mass-production techniques are now directed intensively toward many peacetime products. The application of miniature tubes to wartime equipment provided a good proving ground to test their performance and dependability, and the promise held for their widespread commercial use is now being fulfilled.

The purpose of this paper is to describe the miniature tube development and the history of its rapid extension to military and commercial use.

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Development of the Miniature Tube

The development of a battery-operated, personal-type receiver having the general size of the average camera and capable of being produced at reasonable cost was begun in 1938. Smaller tubes of high efficiency and low cost were among the first requirements. To provide such tubes, the development of a small tube enclosure was started.

As a result of this work, four filamentary-type tubes in the new miniature envelope were made available in 1939 for use in a personal-type radio receiver (see Figure 1). These tubes were the 1T4 radio-frequency pentode, 1R5 converter, 1S5 diode-pentode, and 1S4 output

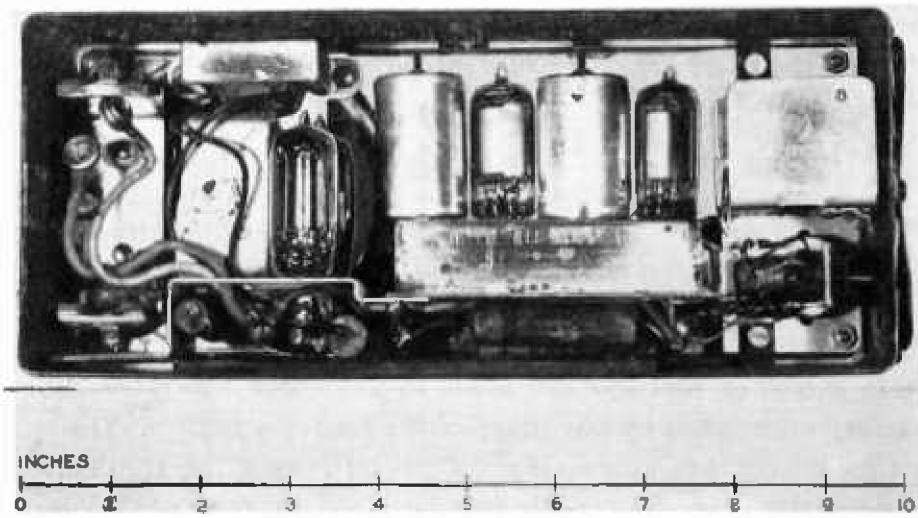

Fig. 1—An early model personal receiver.

pentode. All of the tubes used a 1.4-volt filament with low current drain suitable for small dry-battery operation. The receiver space required for the four tubes was only about one-fifth of the space required for the equivalent tube complement in glass tubular (GT) bulbs.

Although several types of small tubes had previously been available, the new miniature tubes had one very important advantage. The reduction in size was accomplished almost entirely by the elimination or redesign of auxiliary parts, while components of the electrode assembly, or mount cage, were comparable in size to those of the larger receiving tubes. Consequently, the manufacturing techniques for parts and assembly of the mount cage, where the bulk of the labor for tube making is required, were essentially unchanged and high-speed methods developed for standard types were directly applicable to the miniatures.[1]

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[1] N. R. Smith and A. H. Schooley, "Development and Production of the New Miniature Battery Tubes," *RCA REVIEW*, Vol. IV, No. 4, pp. 496-502, April, 1940.

This feature played an important part in the speed with which mass-production of miniature tubes was achieved in World War II.

The reduction in tube size was effected principally by two design features. First, the conventional base was eliminated on the miniature tube by extending the lead wires from the electrodes through the glass seal to serve as base connections. The temper of the external lead wires was carefully adjusted to provide sufficient stiffness for easy insertion into a socket, yet the leads were kept flexible enough so that severe strains were not placed on the glass seal through misalignment of the pins and socket lugs. Secondly, the conventional press-seal stem used in the larger tubes was replaced by a flat button stem with the

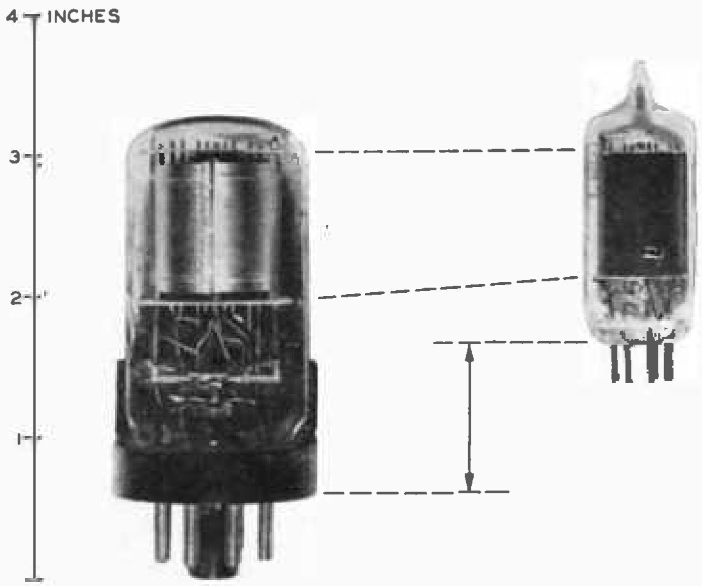

Fig. 2—Comparative dimensions of miniature type 12BE6 and glass type 12SA7-GT.

seven lead wires positioned in a circle and sealed in the same plane as the glass seal between the bulb and stem. This arrangement provided shorter connections to the electrodes, improved the high-frequency performance and the heat conduction through the lead wires, and reduced both the length and diameter requirements of the enclosure. The separation between lead wires in the seal was increased by the circular lead arrangement which reduced the possibility of electrical leakage and minimized the capacitance between lead wires. A wider spacing between pins one and seven gave a positive index for insertion of the tubes in sockets.

Compared to the equivalent GT tubes, the miniatures provided a reduction in diameter from 1 5/16 inches to ¾ inch maximum and a reduction in overall length from 3 5/16 to 2⅛ inches maximum (see Figure 2). The fact that the miniatures do not have a conventional base removed a source of dielectric losses and a costly operation in manufacture. At standard broadcast frequencies, the two types were comparable in performance but the miniatures gave promise of superior performance at higher frequencies.

MINIATURE TUBES IN WAR

With the advent of war, the trend toward more compact, lighter-weight equipment was greatly accelerated. Portable transceivers of smaller size were needed for the infantry. Compact, lightweight units were required for aircraft communication receivers and radar equipment. Balloon transmitters for weather forecasting, detection and trigger equipment for water mines, emergency transmitters for life rafts, and radio controls for guided missiles were but a few of the many applications requiring smaller tubes.

A further war need was for tubes which would operate satisfactorily at higher frequencies. Few GT types are efficient above 100 megacycles, but the military requirements demanded that equipment be made to operate at a frequency of several hundred megacycles.

Anticipating these requirements, work was started in 1940 to develop heater-cathode tubes as well as additional filamentary types in miniature enclosures. Other types of small tubes which were then available required slow, precise assembly by highly skilled operators and could not possibly meet the expected demands.

The most urgent needs in heater-cathode types were for a radio-frequency amplifier, a local oscillator, and a mixer for the conversion of the high carrier frequencies to an intermediate frequency which could be handled by conventional tubes. An early solution to this problem was found by transferring to the miniature enclosure the mount cages of the acorn types 954, 955, and 956, which had already been proven for high-frequency operation. The new miniature heater-cathode types were introduced in 1941 as the 9001, 9002, and 9003 to provide a complement consisting of a mixer, local oscillator, and radio-frequency amplifier. In laboratory tests on the miniature equivalents of the acorn types, some sacrifice in top frequency was observed, but the results were better than predicted. It was evident that small tubes suitable for high-speed manufacture could be made for operation at frequencies of several hundred megacycles.

Using types 9002 and 9003, an Army communications receiver (SCR-522-A) was designed and placed in production for aircraft service. Operating on a frequency band of 100 to 156 megacycles, this transmitter-receiver unit had a working range of 180 miles at an altitude of 20,000 feet. It was used extensively for aircraft and vehicular communications throughout the war.

As the use of high-frequency miniatures was rapidly extended to other equipments, the advantages of their small size became more evident and the development of other miniatures was undertaken for use at frequencies which could be handled by conventional types if space were not a consideration. Additional features, not anticipated originally, became evident with expanding field use. Under climatic conditions of high humidity, the basing cement on conventional types deteriorated, moisture was absorbed by the base, and high electrical leakage resulted. Also, salt water spray during shipboard operation took its toll in corroding external metal parts of conventional tubes. The baseless miniature tube, however, did not absorb moisture, and the nickel external pins and glass enclosure, which were the only surfaces exposed, were practically impervious to corrosion. A further advantage disclosed by field use was that while the miniatures on casual inspection appeared less sturdy than the larger tubes, the lower mass of the miniatures actually gave better shock-resistant qualities to withstand the impact of gun-fire, the high acceleration of units enclosed in missiles, and the rough usage encountered in mobile service.

One question unanswered at the start of the war was whether heater-cathode types with appreciable wattage input could be made to operate with satisfactory life in the smaller miniature enclosure. Since the size of the electrodes was not reduced appreciably and the short lead connections provided good heat conduction to the socket, the possibilities for higher dissipations appeared favorable except for limitation of increased bulb temperatures, resulting from the greatly reduced radiating area of the miniature enclosure. If higher dissipations could be tolerated, miniature types having better transconductance and higher peak currents could be designed.

In answer to this, the 6C4 oscillator, introduced in 1942, was found to be capable, in Class C oscillator service, of dissipating five watts in the plate with approximately one watt cathode input. At 150 megacycles, the average power output obtainable was 2.5 watts. As a result, this miniature triode found wide use in both local-oscillator service and pulse-modulator applications where higher dissipations were required. One model of aircraft interrogation equipment (AN/AP-2), for example, used nineteen miniature 6C4 tubes out of a total complement of forty-four tubes, of which all but three were miniatures.

With the knowledge that higher wattages were practical in miniature tubes, work was concentrated on the design of a mixer tube and an intermediate-frequency amplifier to complete a high-frequency miniature complement having transconductances of the same values as the comparable larger receiving types. These types were made available during the latter half of 1942 as the 6J6, a twin triode mixer-oscillator with a transconductance of 5300 micromhos at 8.5 milliamperes for each triode section, and the 6AG5, a radio-frequency pentode with a transconductance of 5000 micromhos at a cathode current of 9 milliamperes. The 6J6 was used in pulse-oscillator service at frequencies as high as 450 megacycles and the 6AG5, although used principally in 30-megacycle intermediate-frequency amplifiers, was employed in some applications at frequencies as high as 200 megacycles.

It was soon found that many equipment designers were using the 6J6 connected as a diode for a second detector to conserve space and gain higher perveance than could be obtained with standard types specifically intended for detector use. To provide for this service, the high-perveance, miniature twin diode 6AL5, was introduced in 1944. This tube has a voltage drop in each section comparable to a diode-connected 6J6. For narrow band applications requiring less perveance, the twin-diode high-mu triode 6AQ6 was introduced during the same year.

The introduction of these tubes gave receiver designers a complete miniature complement of heater-cathode types through the second-detector stage for equipment operating up to 400 megacycles. In 1943, the 6AK6 output pentode was introduced to complete the receiver complement.

The rapid development of heater-cathode type miniatures was paralleled by a similar program to provide filament-type miniatures for dry-battery, portable communications equipment for the infantry. The original miniatures introduced for the personal receiver formed the nucleus for a receiver complement, but there were no existing types suitable for a transmitter. In the early part of 1942, the 3A5 twin triode, giving 2-watts output at 40 megacycles with a filament input of only 0.3 watt, was introduced. A radio-frequency power pentode type 3A4 was also made available for class C transmitting service. The 1L4 sharp-cutoff pentode and the 1A3 diode for frequency-modulation detection use completed a working complement of filamentary miniatures for portable transceiver applications.

With these new types and the personal-receiver tubes developed before the war, a "walkie-talkie" frequency-modulation transceiver, SCR-300-A (Figure 3), was developed and became the first radio field telephone which was truly portable. With the necessity for telephone lines eliminated, the "walkie-talkie" made possible the maintenance of communications between fast-moving combat units and proved to be one of the most important tactical weapons of the war. The "walkie-talkie" contained eighteen miniature tubes in a unit 5 by 11 by 17 inches with total weight, including batteries, of thirty-eight pounds. Operating at a signal frequency of 40 to 48 megacycles, the quick-heating miniatures gave instant switch-on service and a working radius of three miles.

The first large-scale test of the filament-type miniature tubes was provided by the SCR-300-A in the invasion of Sicily. The records of tubes replaced in equipment used by combat divisions during this

Fig. 3—Walkie-talkie transceiver (SCR-300-A).

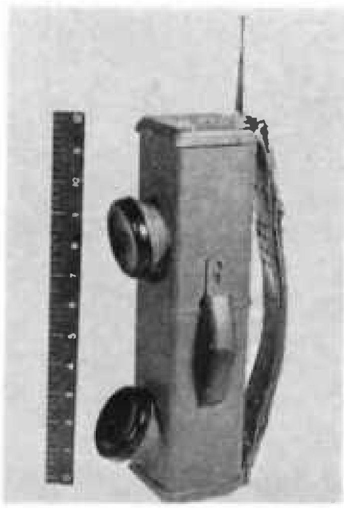

Fig. 4—The handy talkie (SCR-536).

campaign showed that despite the rough usage of battle service the tube replacements for all reasons were less than three per cent of the total number in service. The results firmly established the ruggedness and dependability of the miniature tubes.

A still smaller transceiver of lighter weight, the "handy-talkie" SCR-536 (see Figure 4), was employed in the Pacific during the latter months of the war. Using a total complement of five miniatures and weighing less than six pounds, this unit was only 4 by 6 by 16 inches in size and could be held conveniently in one hand during operation.

The applications of miniature tubes to war equipment were so many and so varied that only a few can be cited. The best indication of their contribution to the war effort can probably be given by production figures. Although this compay was the only manufacturer of miniature tubes in 1939, the end of the war found all of the seven principal suppliers of receiving tubes producing miniatures in large quantities. Figures available from the War Production Board records from September 1943 to July 1945 show that over the twenty-three month period a total of more than 50 million miniature tubes were produced by the industry for military use (see Figure 5). The monthly production rate for all companies increased from a total of 800,000 tubes in September 1943 to over 3,500,000 tubes in May 1945.

Miniature Tubes in Peace

The promise of widespread commercial use of miniatures was evident at the end of the war. The shift in frequency allocations to establish frequency modulation in the band of 88 to 108 megacycles,

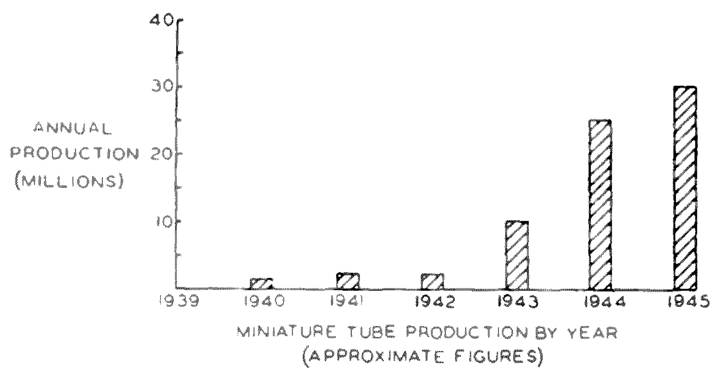

Fig. 5—Miniature tube production by year.

the higher-frequency requirements for television, and a general trend toward more compact ac dc and battery-portable receivers all indicated that miniature tubes would eventually carry the bulk of the peacetime production load for the new designs of broadcast receivers.

In September 1945, a complete miniature complement of tubes for ac dc receivers were made available. These tubes include the 12BA6 radio-frequency pentode, 12BE6 converter, 12AT6 twin-diode-triode, 50B5 output pentode, and the 35W4 rectifier (see Figure 6). This complement is comparable in performance and cost to the tube complements used for pre-war ac/dc receivers. Their use has made possible the more compact receivers now available. Coincident with the ac/dc line, the 6.3 volt equivalents 6BA6, 6BE6, and 6AT6 were introduced, together with a sharp-cutoff radio-frequency pentode, the 6AU6.

In order to provide for operation at both amplitude- and frequency-modulation frequencies, the miniature radio-frequency amplifier and the converter were designed to have higher gain and improved high-frequency characteristics as compared with the pre-war equivalent larger types intended for the lower frequencies only. As a result, the combination amplitude- and frequency-modulation receivers now in production are using the same miniature tubes for both bands. In addition to the savings in receiver cost, a lower unit cost for tubes is made possible by the resulting concentration on fewer tube types.

In December 1945, the new miniature rectifier 117Z3 provided, with existing filamentary types, a complete miniature complement for portable ac/dc-battery receivers. A miniature line for automobile receivers was also provided for with the availability of the 6X4 rectifier, the 6BF6 twin-diode medium-mu triode, and the 6AQ5 beam power amplifier. High-frequency types 12AW6 radio-frequency pentode and the

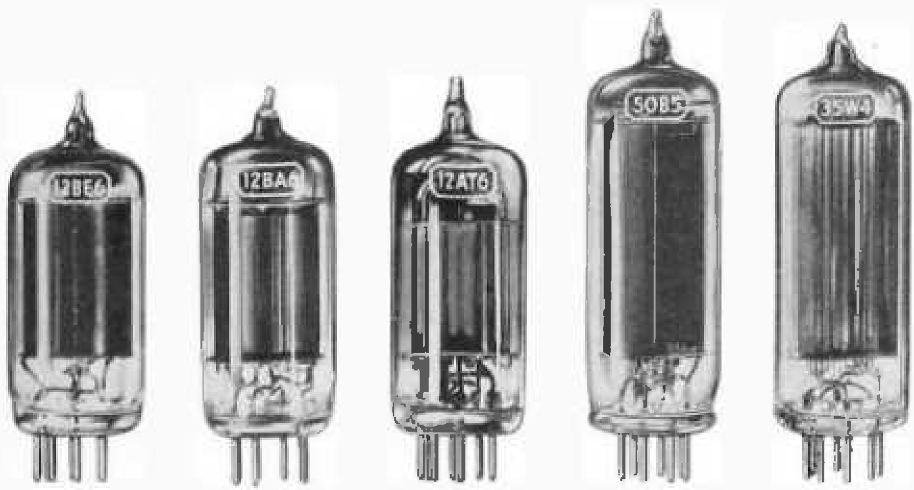

Fig. 6—AC/DC miniature tube kit.

12AL5 twin-diode detector are recent additions designed for use in ac/dc receivers for frequency-modulation reception.

In the television field the space saving and performance afforded by miniatures are particularly desirable because of the large number of tubes required for each receiver and the high frequencies of operation. The current 10-inch table-model television receiver of this company uses 15 miniatures out of a total complement of 30 tubes.

In addition to their use in the field of broadcast entertainment, miniatures are rapidly being extended into industrial applications. The 2D21 thyratron, OA2 voltage regulator, and 1654 high-voltage rectifier are employed in many industrial applications where their small size and ruggedness are of advantage. Recently, a nine-pin miniature twin-triode, 12AU7, was made available in a slightly larger envelope for industrial applications as well as for home-receiver use. Although intended primarily to provide the additional pin connections required for multi-unit tubes, the nine-pin miniature envelope also opens up possibilities for higher-wattage types to supplement the seven-pin miniature line, since bulb temperatures are the present limiting factor in the extension of seven-pin types.

CONCLUSION

The four miniature tubes first introduced in 1939 were designed to fill the need for tubes which could be produced in quantities and at reasonable cost for a compact personal-type receiver. In the intervening years, however, the practical experience with miniatures has shown them to be adaptable for general receiving tube use with an exceptional range of capabilities. The versatility of miniatures holds promise for higher performance and lower costs in electronic equipment of the future.

Typical Applications for Miniature Tubes

(See Table on opposite page)

Table 1—Applications for Miniature Tubes

Application	ac/dc Receivers (AM)	ac/dc Receivers (AM-FM)	ac Receivers (AM-FM)	Automobile Receivers	Television Receivers	"Personal" & Three-way Portable Receivers	VHF, Industrial & Low-Power Transceivers
RF Amplifier	12BA6	12BA6 12AW6	6AG5 6BA6	6BA6	6J6, 6AG5	1U4, 1T4	6J4, 9003
Converter or Mixer	12BE6	12BE6	6BE6, 6AU6	6BE6	6J6	1R5	6J6, 9001
Oscillator			6C4, **6BE6		6J6		9002, 3A5
Sound IF Amplifier	12BA6	12BA6	6BA6	6BA6	6BA6	1U4, 1T4	9003
Picture IF Amplifier					6AG5		
Limiter or Driver		12AU6	6AU6		6AU6		1L4
Detector & AF Amplifier	12AT6	6AQ6, 12AL5, 12AT6	6AL5,* 6AT6	6AT6, 6BF6	6AL5,* 6AT6	1S5, 1U5	1A3*
Power Output	35B5, 50B5	35B5, 50B5	6AQ5	6AQ5	6AQ5	3V4, 3S4, 1S4	3A4
Rectifier	35W4	35W4		6X4		117Z3	
Video Amplifier					6AU6		
DC Restorer					6AL5		
Phase Inverter			6AT6				
Thyratron							2D21
Voltage Regulator							OA2
High-Voltage Rectifier							1654

** Triode Connected

* Has diode(s) only