Solid State Devices

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This paper describes the electrical and physical characteristics of the solid-state devices developed for the L-4 system. These include new high frequency, planar, epitaxial, silicon transistors with low noise figures and intermodulation distortion for use in the various amplifiers. New diodes for power supply, surge protection, and modulation use were also developed.

I. INTRODUCTION

New solid state devices were developed to meet the stringent requirements of the L-4 system. Since the intermodulation distortion and noise are additive over the thousands of miles of system, low noise figure and very low intermodulation distortion limits are placed on the transistors. A low capacitance surge protection diode was developed to provide secondary surge protection for the repeater input. A multiple low capacitance diode was developed as an 18 MHz modulator in the terminal; four diodes were developed for the terminal.

II. TRANSISTORS

Concurrent with the conception and design of the L-4 system, major advances were achieved in transistor technology which have been exploited to reduce system noise, to reduce distortion, and to improve system reliability.

These advances resulted in the development of two families of high frequency, planar, epitaxial, NPN silicon transistors for use in the various amplifiers of the L-4 system.

2.1 *Description*

Two families of transistors were developed to meet the requirements of various L-4 system applications. The first family consists of

the 45-types, which were designed for low power, low noise, and low distortion. The second family includes the 46-type transistors, which were designed for medium power, low distortion applications.

The transistor wafers are encapsulated in metallic ceramic packages which were designed for these devices in order to minimize parasitic capacitance and lead inductance, and to provide low thermal impedances while electrically insulating the transistor from the heat sink. The 45-type transistors are encapsulated in an aluminum oxide ceramic-kovar package designated the JETEC TO-112 and the 46-types are encapsulated in a similar package except that a beryllium oxide ceramic was substituted for aluminum oxide to achieve a 20°C per watt thermal impedance required for the medium power operation.[1]

2.2 *45-Type Transistors*

The stringent requirements of the L-4 system amplifiers determine the critical transistor parameters such as low noise figure, high gain, high gain-band product, and low distortion. The 45D transistor is an example of the 45 transistor family; it illustrates how the stringent parameters are met.

The 45D transistor, shown in Fig. 1, consists of eight emitter stripes, $15\mu \times 50\mu$ each. The eight emitter stripes are connected in parallel by the aluminum metalization as are the ten base stripes. The design of the device was dictated by the circuit requirements listed in Table 1.

A typical use of the 45D is in the input stage of the basic repeater, in which a low noise figure is required at a bias current of approximately 20 mA. The relatively high bias current is required in order to avoid distortion in this stage. A noise figure of less than 4.0 dB is achieved by a base resistance of less than 25 ohms. This value of base resistance is achieved by using the eight emitter stripes. The gain-bandwidth product of 900 to 1,300 MHz was achieved by making the width of the base approximately 0.5μ; the variation of the gain-bandwidth product with collector current is illustrated in Fig. 2.

Other transistors in the 45 family are similar to 45D but vary in size, in order to vary current handling ability.

2.3 *46-Type Transistors*

The 46-type transistors fulfill the L-4 system requirements for a medium power transistor which has low distortion, high gain-bandwidth product, and tightly controlled dc gain. The 46E is a good example of the 46 family.

The 46E transistor, shown in Fig. 3, consists of 72 emitters, $15\mu \times$

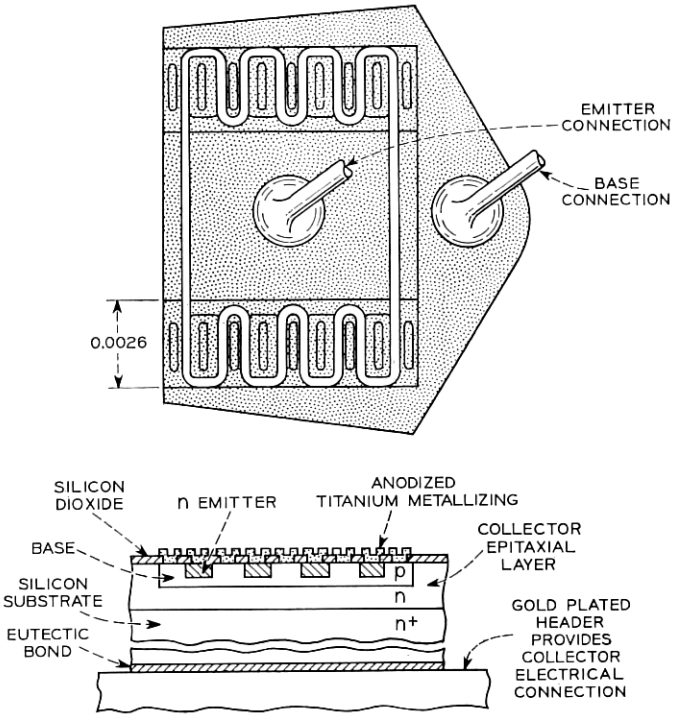

Fig. 1 — The 45D transistor.

15μ, connected in parallel by the aluminum overlay. Base contact is provided by low resistance p-type diffusions under the emitter metalizing instead of metallic stripes as in the 45D. This overlay structure yields a transistor with a large emitter periphery to emitter area ratio and balanced current flow in each of the emitters.

TABLE 1 —TRANSISTOR REQUIREMENTS

Parameter	45D	46E
$V_{CE(SUS)}$	>14 V	>30 V
h_{FE}	100–300	35–75
Noise figure	<4.0 dB	—
f_t	900–1,300 MHz	600–850 MHz
M_{3E} (f = 17.0 MHz)	—	−99 dBm
M_{2E} (f = 17.0 MHz)	—	−53.2 dBm
I_C max	160 Ma	500 mA
I_C typical	20 mA	170 mA

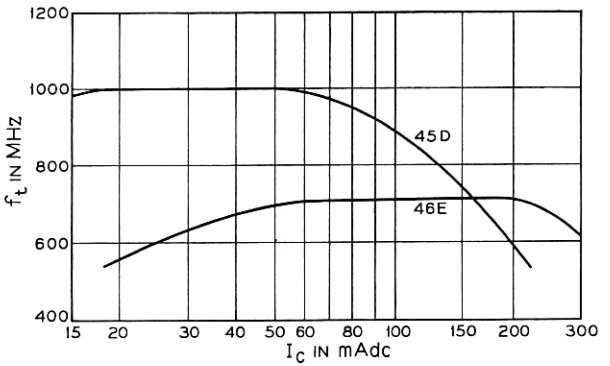

Fig. 2 — Variation of the gain-bandwidth product with collector current.

Important transistor requirements are illustrated in Table I. The dc gain and gain-bandwidth product ranges are required to achieve amplifier gain and phase margins. The stringent third harmonic distortion requirements were met by designing the 46E with a large region of constant gain and gain-bandwidth product as a function of the collector current. This gain-band product characteristic is illustrated in Fig. 2.

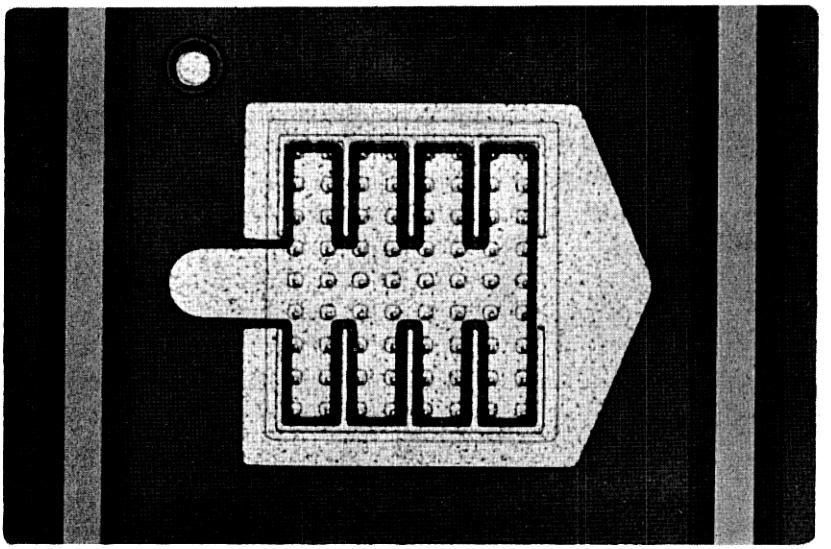

Fig. 3 — The 46E transistor.

2.4 *Transistor Reliability*

During the development of the L-4 transistors several thousand units were subjected to accelerated aging under conditions of both power and temperature stress. Extrapolation of these data predicts a transistor failure rate for both the 45 and 46 types of less than 10 FITS* over a twenty-year period at junction temperatures of 125°C. Reliability information obtained from system use agrees with the extrapolated results.

2.5 *Conclusion*

The 45 and 46 families of transistors have been developed and manufactured to meet the stringent requirements of the L-4 system for low noise, low distortion, and highly reliable transistors.

III. DIODES

Six new diode codes were required for the L-4 carrier system. In general, these break down into three use categories: power supply, surge protection, and modulation. The 460B, 464C, 478B, and 496A diodes were developed for power supply use. The 495A was developed for primary repeater surge protection; the 458E was developed for secondary repeater surge protection. The 460C multiple diode was developed for the mastergroup multiplex terminal (MMX).

3.1 *460 B Diode*

The 460B diode is four high-speed p-n junctions connected in a full wave bridge configuration sharing a single TO-55 type encapsulation (shown in Fig. 4). This device is a full wave bridge rectifier in the 20KHz dc-to-dc converters used to power the repeater in the L-4 carrier system.

Design requirements were: breakdown voltage (V_B), > 60 V; output current (I_o), $\leqq 100$ mA ($\leqq 1$ A for lms trouble condition); reverse recovery time, (t_{rr}), $\leqq 100$ ns; saturation current (I_s), $\leqq 15$ μA; and packaged in a four leaded TO-55 package. The breakdown voltage and output current are consistent with the load requirements for the power supply; the reverse recovery time and saturation current are requirements necessary to meet the converter efficiency. The package requirement meets the need for a small easy-to-mount diode package. These requirements were all met by using four gold doped planar epitaxial

* 1 FIT = 1 failure per 10^9 device operating hours.

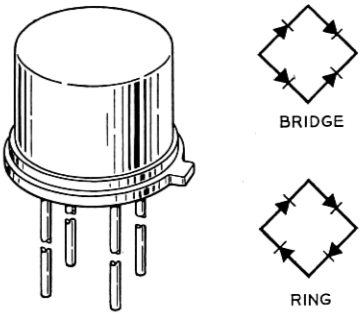

Fig. 4 — Mounting arrangement.

p-n junctions mounted in a metallized ceramic header of a TO-55 package.

3.2 *464 Diode*

The 464C diode is a molded diode assembly consisting of four high-speed high-voltage one-watt diodes (426 Type) connected in a full wave bridge configuration and molded in epoxy. This device serves as a high voltage rectifier for the converter power stages in the terminal station of L-4 carrier system. Design requirements were: breakdown voltage, (V_{BR}), $\geqq$ 800 V; output current (I_o), $\leqq$ 500 mA (650 mA for several hours under trouble conditions); reverse recovery time (t_{rr}), $\leqq$ 100 ns; and packaged into a single molded assembly. The V_B and I_o are consistent with the power supply requirements, whereas t_{rr} was low to improve power supply efficiency.

The molding of completed packages (426 types) served two functions, first to minimize any corona problems and, second, to make an easy to mount package. These requirements were met by molding four 426 type diodes into a four terminal bridge configuration. The structure is shown in Fig. 5.

The silicone resin serves as a high dielectric insulator across the glass seal area of the metal diode package and also mechanically decouples it from the epoxy resin. The epoxy serves as a support for the diode and wiring structure and seals the diode from moisture. An alumina filling agent in the epoxy lowers the thermal impedance of the package. The shell, although not required for the design of the molded assembly, was used to reduce the cost of fabrication. In order to avoid corona, care is exercised during fabrication to avoid pinholes and voids in the molding materials and sharp projections on the metal parts.

3.3 *478B Diode*

The 478B diode is a molded diode assembly consisting of four high-voltage one-watt diodes (426 type) connected in a series string and molded in epoxy. This device goes directly across the output terminals of each power converter to provide a current path for the other series connected converter should that converter's output voltage fail. Design requirements were: breakdown voltage (V_{BR}), $\geqq$ 3,500 V; $I_o \leqq 650$ mA (in trouble condition only for a period of several hours); and molded into a single package assembly. Under normal operating conditions this diode is in the back biased (blocking) condition with no forward current flowing. The requirements were met by molding four 426G diodes into a series string. The diode assembly was fabricated in the same manner as the 464C molded assembly.

3.4 *496A Diode*

The 496A diode consists of two 425L diodes matched for forward voltage drop. This diode is used as a full wave rectifier in the 2.5 KHz dc-to-dc converter to power the terminal bays of the L-4 carrier system. Design requirements were: breakdown voltage (V_{BR}), $\geqq$ 200 V; output current (Io), $\leqq$ 1.25 A (6A peak current); forward voltage drop (V_f), $\leqq$ 1.2 V at 2.5 A dc; and forward voltage unbalance (V_f (unbal)), $<$ 50 mV at 2.5 A dc. The V_{BR} and I_o requirements are consistent with the power supply requirements and are easily met by the 425L ten watt diodes. The upper limit on V_f is to prevent inefficiencies and power loss in the converter. The forward voltage matching requirement was designed to reduce the second harmonic distortion (5 KHz) and thus further assure its complete removal by filtering. If not completely removed, this signal would appear as noise in the audio band.

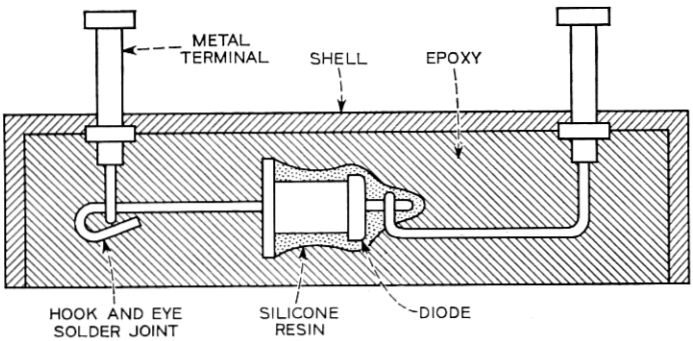

Fig. 5 — Schematic of assembly cross section.

3.5 *495A Diode*

The 495A diode which is used as primary surge protection at the input and output terminals of the L-4 repeaters has a low capacitance. It is a multiple diode consisting of two p-n junctions connected in series with a center tap and encapsulated in a three leaded package. When used at the input of the repeater, the terminals of the 495A diode are wired so that the two p-n junctions are connected parallel-opposing, and act as a bidirectional surge protector. When used at the output of the repeater the center tap of the two p-n junctions is connected to the collector terminal of the output transistor; the other two terminals are appropriately connected to the most positive and to the most negative terminal of the power supply. This configuration thus protects the amplifier by limiting the voltage swing on the collector of the output transistor should a voltage surge be induced in the cable.

Design requirements for this diode were: breakdown voltage (V_{BR}), $\geqq$ 50 V; forward voltage drop (V_F), $\leqq$ 1.0 V at 100 mA dc; saturation current (I_s), $\leqq$ 200 nA dc; capacitance (C), $\leqq$ 12 pf; and nonrepetitive forward current surge of 8 A for 500 μs and 25 A for 10 μs. The breakdown voltage, forward voltage drop, and saturation current are consistent with the diode requirements for this end use. The capacitance requirement was necessary to minimize any attentuation in the transmission path. The nonrepetitive current requirement was necessary to assure that the diode would effectively absorb the surge currents which could be transmitted down the cable. These design requirements were met by using two planar p-n junctions in a three leaded TO-18 package. Figure 6 shows the device outline.

3.6 *485E Diode*

The 458E diode, which has a low capacitance, is used as a secondary surge protector at the input to the L-4 repeater amplifiers. Two 458E diodes are used, connected parallel-opposing, to act as a bidirectional surge protector. These units are connected across the emitter base terminals of the input transistor in the solid state amplifiers. Design requirements were: breakdown voltage (V_{BR}), $\geqq$ 50 V; forward voltage drop (V_F), $\leqq$ 1.0 V at 100 mA; saturation current (I_s), $\leqq$ 50 nA; capacitance (C_o), $\leqq$ 4.0 pF; and nonrepetitive forward voltage (v_f nonrep.) $\leqq$ 2.10 V at 1.0 A peak, t_p = 30 ns maximum. The breakdown voltage, forward voltage drop, and saturation current are consistent with the diode requirements for this end use. The low capacitance requirement was necessary to avoid introducing any attenuation in the transmission path. The nonrepetitive forward voltage requirement was necessary to assure

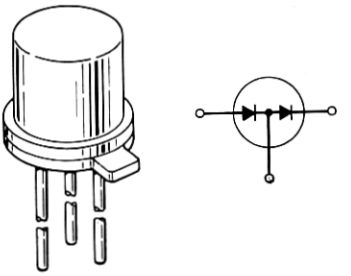

Fig. 6 — The device outline for the 459A diode. All dimensions are in inches.

that the maximum voltage at the input terminals of the solid state amplifier would not exceed one volt (either polarity). All of these requirements were met by using an epitaxial wafer mounted in the small glass diode, package (see Fig. 7).

3.7 *460C Diode*

The 460C diode is a multiple of four p-n junction diodes used as an 18 MHz modulator in the mastergroup multiplex terminal in L-4. The four closely matched p-n junction diodes are connected in a ring configuration and mounted in a four-leaded TO-55 package. Design requirements were: saturation current (I_s), $\leqq$ 20 nA dc at 20 V; capacitance (C_o), $<$ 4.0 pF; reverse recovery time (t_{rr}), $<$ 4.0 n.s. The saturation current requirement is consistent with diode requirements for this end use. The low capacitance and reverse recovery time requirements are necessary to assure that no imbalance in these parameters will result in leakage of the carrier frequency into the output of the modulator. Because the four p-n junctions are wired into a ring configuration these three parameters are measured on the individual diodes before they are mounted in the package.

The carrier leak test is a final test made on the finished 460C diode to

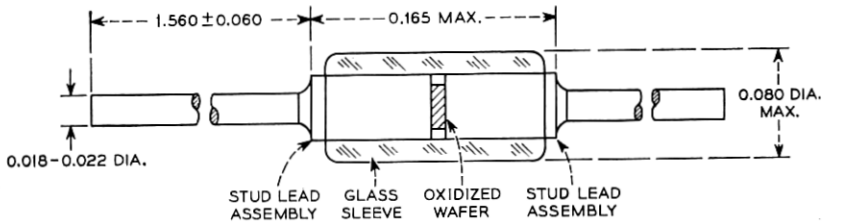

Fig. 7 — Mounting and wiring arrangement.

assure that all parameters, including forward voltage drop, are in balance and the device is functioning properly. These requirements were all met by using four gold doped planar epitaxial p-n junctions mounted in a TO-55 package.

3.8 *Diode Reliability*

Accelerated aging of L-4 system diodes during system development has indicated junction temperature to be the primary failure stress for diodes used within their maximum rated voltage. As indicated in the preceding sections, many of the L-4 diodes are used as protectors during either surge or trouble conditions and hence are called into operation for relatively brief and infrequent intervals of system operation during which they may be safely operated near or above their nominal maximum rated power and temperature.

Diodes not so used are operated at relatively low power levels or are located at system terminals where adequate cooling is available. Information from system use indicates satisfactory system reliability.

REFERENCE

1. Elder, H. E., "Active Solid-State Devices," B.S.T.J., *47*, No. 7 (September 1968), p. 1326.