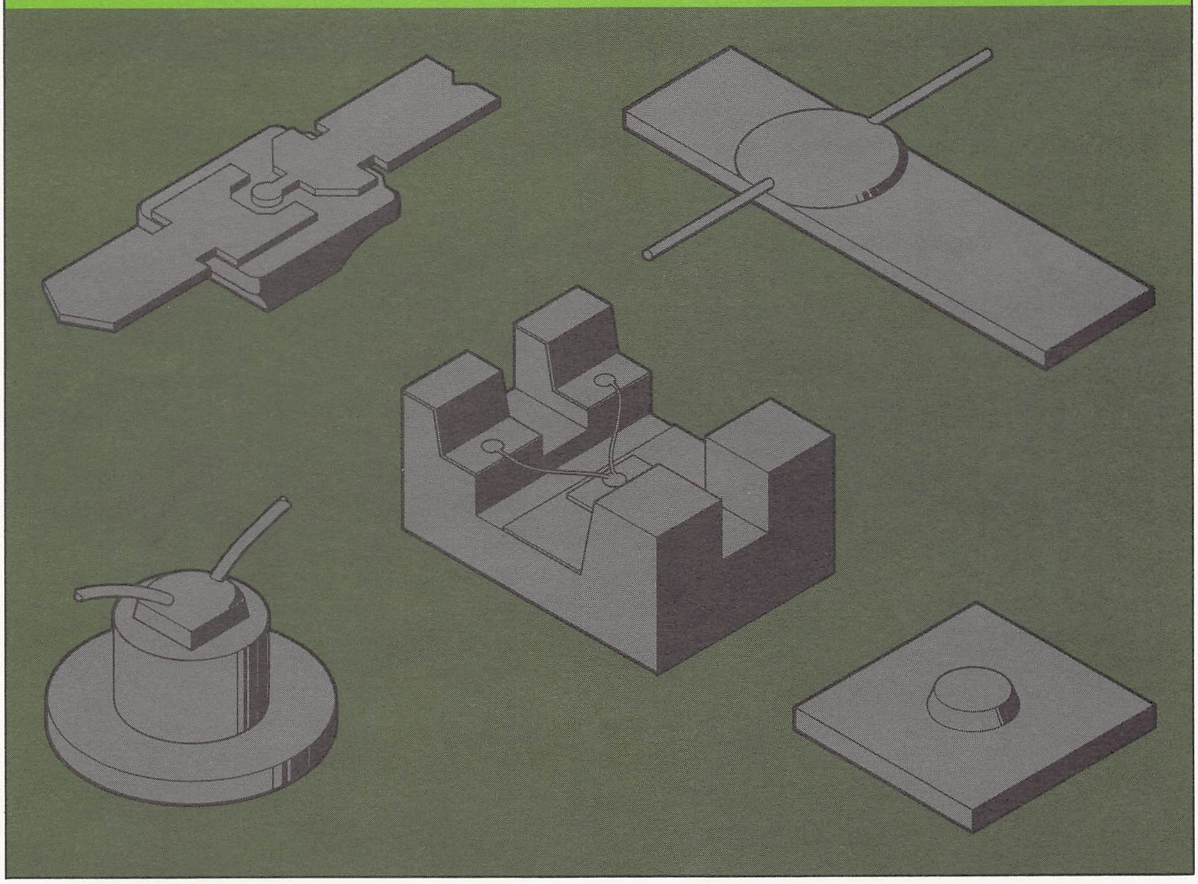
APPLICATION NOTE 940

HEWLETT PACKARD

COMPONENTS

DIODES for HYBRID INTEGRATED CIRCUITS



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DIODES for HYBRID INTEGRATED CIRCUITS

CONTENTS

INTRODUCTION

Package parasitics introduce fundamental limitations on the bandwidth of circuits using packaged semiconductor devices. The difficulties of designing around these parasitics have stimulated the development of microwave integrated circuit techniques. The accompanying advantages of better reproducibility, lower cost, and smaller size are often more important than the parasitic considerations. In fact, these advantages are now being recognized by designers of lower frequency systems, and, as a result, circuit boards with packaged diodes are being replaced by hybrid integrated circuits using semiconductor chips, beam leads, or other forms of diodes designed for these circuits.

Figure 1 shows the package styles for hybrid integrated circuits presently available from HPA. The characteristics of each type will be discussed. For further details, see HP Brochure "Chips and Carriers for Hybrid Integrated Circuits"; available from your local HP Sales Office.

HYBRID PACKAGE STYLES

Chips

Diode chips would appear to be the ultimate form for elimination of parasitics and for size reduction, however, the need for specialized equipment for die attach (connecting the base of the chip to the circuit) and wire bonding (connecting the chip top contact to the circuit) limits the use of chips. The number of assembly operations is less for other hybrid package styles so assembly costs are usually higher for chips. High volume production can be an exception because automatic equipment for die attach and bonding becomes economically feasible.

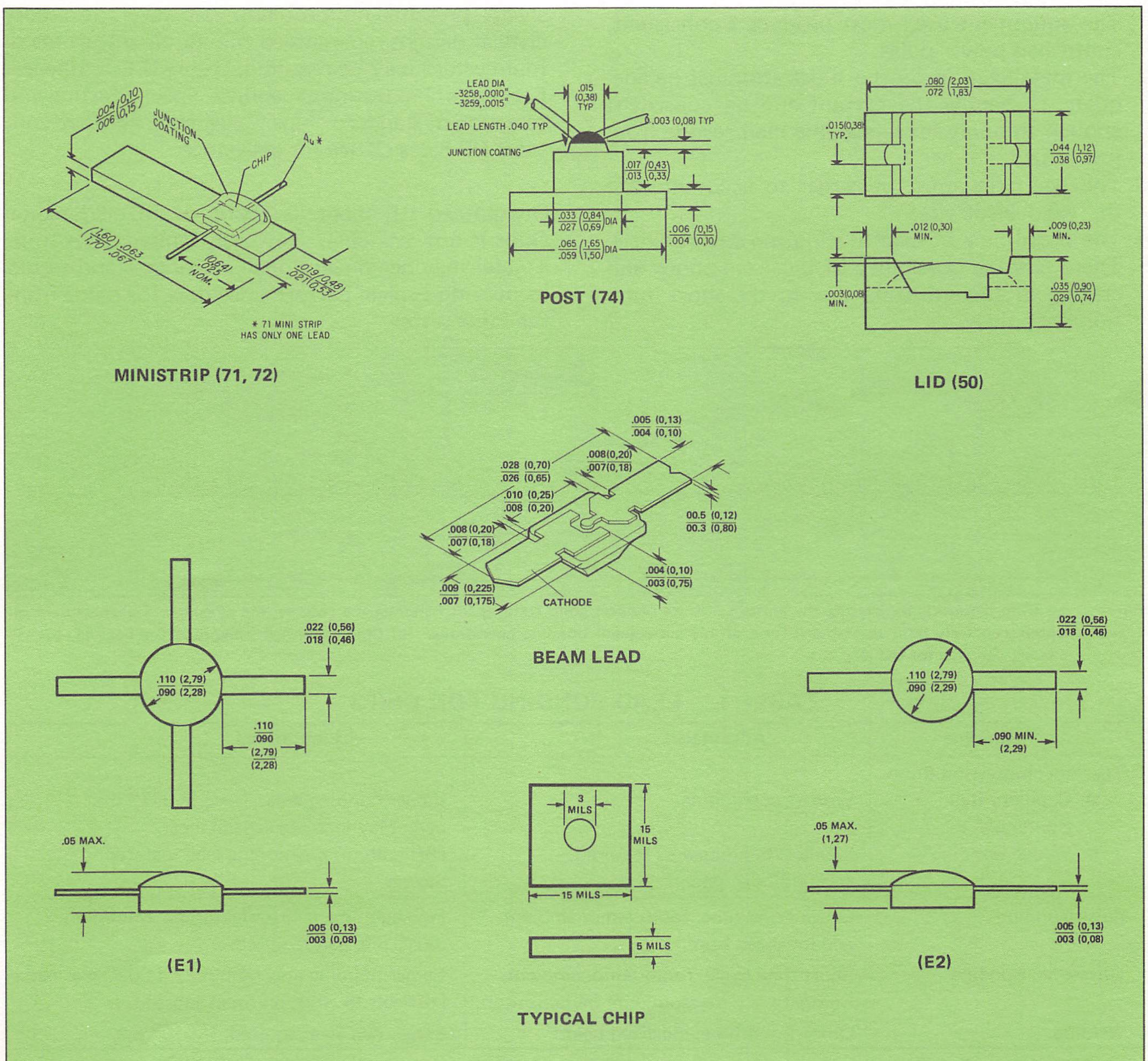

Figure 1. Diode Packages for Hybrid Integrated Circuits.

Chips may be mounted using conductive epoxies, or soldered using either substrate heating (Figure 2a) or localized heating techniques (Figure 2b). Substrate heating or epoxies allow a smaller pad area for mounting the chip than do localized heating techniques. Generally a 5 mil border around the chip is adequate.

In the localized heating method (using parallel-gap resistance heating techniques, Figure 2b), controlled current flows between the electrodes as shown. This heats the area under the chip so the solder preform melts and wets both the substrate metallization and the chip. This method offers ease of handling, as the chip pick up can be integrated with the weld electrodes. It also offers speed of the melt cycle, the use of localized atmosphere controls, and most importantly, the use of room temperature ambient for the substrate. Some of the disadvantages are:

1. The equipment used must produce a consistent, controlled power pulse.
2. The metallization on the substrate must be adequate to handle the current and be consistent enough to allow for repeatable melt results from pad to pad.
3. The pad area must be larger to accommodate the weld electrodes.
4. The possibility of over-heating the device exists.
5. There is some possibility of localized shock and crazing of the substrate due to the short duration heat pulse.

Perhaps the biggest deterrent to using chips is the yield factor. In packaged devices the high temperature critical-yield steps of die attach and wire bond are performed by the supplier and then tested after assembly to screen out any rejects. In performing the operations of die attach and wire bond on a substrate (perhaps made more expensive by the addition of other devices previously attached) one risks the loss of considerably more investment, if the chip is destroyed during these operations, than the cost of the chip itself.

The techniques,[1] advantages, and limitations of bonding to chips are summarized in Table I. The criteria for choosing a specific technique are generally the size of the contact area on the chip, sensitivity to temperature, and the equipment available. For most applications, the normal spread in dc parameter values around "typical" values given in spec sheets presents no problem. However, for more critical designs, guaranteed minimum and/or maximum values may be required. Table II lists Hewlett Packard's chip testing capability. Special testing and selection of standard chips is available; contact your local HP Sales Office for assistance.

Guaranteed RF characterization of mixer/detector chips is not available. However, sample chips from a wafer may be conventionally packaged and tested to provide typical performance data for chips from the same wafer.

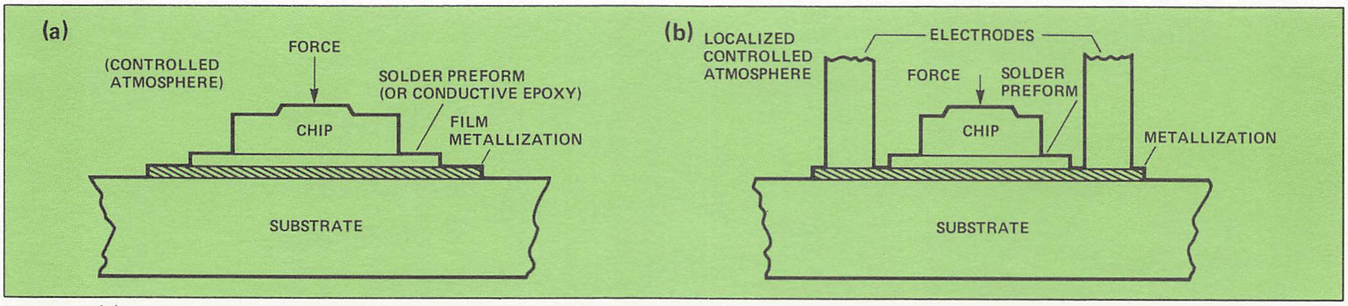

Figure 2. (a) Chip mounting by heating the entire substrate requires good fixtures for handling the chip as well as good atmosphere control. Epoxies severely limit the temperatures of any subsequent bonding operations. (b) Chip mounting using localized heating requires a larger pad area for the chip.

TABLE I. LEAD BONDING FOR CHIPS

Technique	Advantages	Limitations
Thermocompression Bond		
A. Capillary Ball Bonding**	Ease of positioning	Larger bonding area. Need >.002" dia. pad. May increase capacitance.
B. Wedge Bonding**	Smallest bonding area required, ≈ .0005" dia. pad	Difficulty in positioning lead material. Slower.
Pulse Bonding	Quick bond time, room temp. ambient and localized heat.	Few equipment manufacturers. Minimum .001" dia. pad required.
Ultrasonic Bonding	Short time cycle, room temp. ambient. Compatible with aluminum metallization.	Larger bonding area required, >.002" dia. pad. Difficult to work on small substrates.
Welding	Quick bond time, localized heat.	Larger pad size required, >.010" dia.

** Both A and B require high temperature ambient. Temperature must be carefully controlled when working on temperature sensitive devices such as Schottky Diodes.

TABLE II. CHIP TESTING CAPABILITY

Chip Type	Breakdown Voltage V_{BR}	Junction Capacitance C_j	Forward Current I_F	Series Resistance R_S	Lifetime τ
Schottky Barrier Diode	Yes	Yes	Yes	Yes*	No
PIN Diode	Yes	Yes*	Yes*	Yes*	Yes*
Step Recovery Diode	Yes	Yes*	Yes*	Yes*	Yes*
Impatt Diode	Yes	Yes*	n/a	n/a	n/a

*Special test. Specified minimum and/or maximum parameter values available upon request. Contact your local HP Sales Office.

Beam Lead

The beam lead device is a silicon chip with co-planar plated gold tabs that extend parallel to the top surface of the chip approximately 10 mils beyond the edge. If size is the major concern, beam lead diodes, not chips, are the correct choice.

Handling must be done with care, since the leads may be distorted by the pressure of tweezers. However, the diodes will stick to the tip of a tweezer point or to the rough edge of a broken Q-tip. A vacuum pickup may be used, but the needle must be small enough to prevent passage of the diode. Schottky barrier beam lead diodes are easily damaged by static electricity, just as packaged diodes are. Contact to the circuit should never be made with the free side of the diode because this would allow static electricity from the operator's hand to flow through the diode. Instead, the side of the diode to be attached should be contacted first. If there is any chance that the two circuit attachment points are at different potentials, they should be brought together with a grounding lead before contacting the diode.

Thermocompression bonding is a satisfactory joining technique. The device is placed face down with the tabs resting flat on the pad area and bonded using either a heated wedge (and/or substrate) or parallel-gap (step-welding) technique. (See Figure 3)

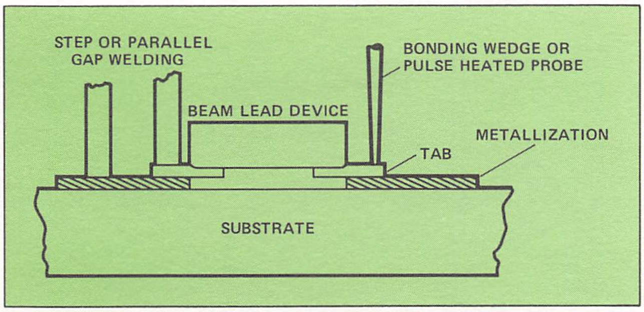

Figure 3. Beam lead attachment requires thermocompression bonding to the substrate metallization.

The heated wedge may be continuously heated, as in most standard equipment, or it may be pulse resistance heated where a high current short duration pulse is used to raise the wedge to the required temperature. In the step-welding operation, current is passed through the substrate metallization and the device lead. Most of the heat is generated at the interface between the two, which is exactly where it is needed. Many new bonders have recently been announced and are specifically designed to bond beam leaded devices. Some of these use ultrasonic, rather than thermocompression techniques.

The major advantage of the pulse heating techniques is that a cold ambient may be used, generating only localized heating in the vicinity of the bond itself. The electrodes (or wedge) can be placed on the device lead when the bond area is cold and can maintain a constant force through the heating and cooling cycle.

If a soft substrate is used, there is some danger of breaking a lead by pressing it into the substrate. Bonding pressure should be adjusted to prevent this. With properly trained assemblers, beam lead diodes permit a rapid and inexpensive assembly procedure. Only a microscope and thermocompression bonder are needed.

Beam lead mixer diodes with guaranteed noise figure at X-band are available upon special request, so that the performance of the mixer circuit can be predicted.

Ministrip

If the ultimate in size reduction is not needed, the ministrip design may be preferable. A chip is soldered to a molybdenum tab and covered with a protective coating. Either one or two leads can be provided. The ministrip may be soldered to the circuit on a hot plate, belt furnace, or with a gap welder, or epoxy may be used. Thermocompression bonding is recommended for attaching the leads. This package style is particularly well suited to shunt diodes, but series applications are possible by soldering the ministrip to the conductor on the substrate and bonding the lead across a gap in the conductor.

TABLE III. MINISTRIP TESTING CAPABILITY

Device	Noise Figure NF	IF Impedance Z_{IF}	VSWR	Voltage Breakdown V_{BR}	Total Capacitance C_T	Forward Current I_F	Series Resistance R_S	Lifetime τ
Schottky Barrier Diode	Yes*	Yes*	Yes*	Yes	Yes	Yes	Yes*	No
PIN Diode	n/a	n/a	n/a	Yes	Yes*	Yes*	Yes*	Yes*
Step Recovery Diode	n/a	n/a	n/a	Yes	Yes*	Yes*	Yes*	Yes*

*Special Test. Specified minimum and/or maximum parameter values available upon special request. Contact your local HP Sales Office.

Full RF characterization of ministrip mixer diodes is available upon special request. Typical measured admittance of the 5082-2710 X-band ministrip mixer diode is shown in Figure 4. Ministrip PIN diodes are also available with guaranteed values of series resistance, lifetime, and capacitance. Table III lists HP's testing capability for ministrip devices.

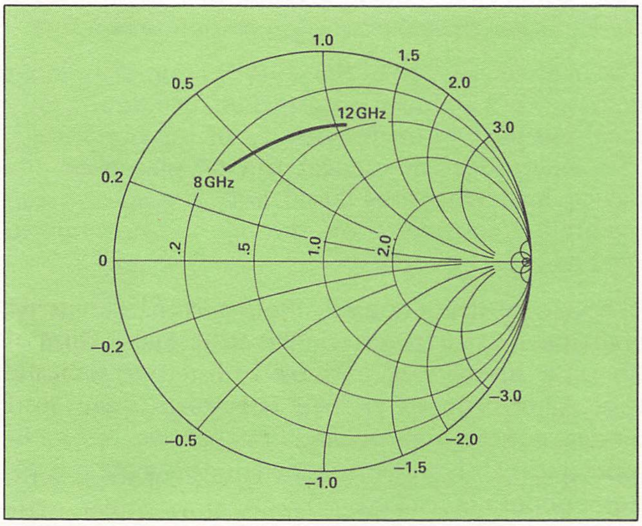

Figure 4. Typical admittance of 5082-2710 Ministrip Schottky Diode. 1 mW power level.

Leadless Inverted Device (LID)

LID diodes are favored in many applications because soldering, rather than bonding, is used for attachment to the circuit. The chip is attached to a ceramic carrier and bond wires connect the chip contact to pads or "feet". The feet of the LID may be attached to the circuit in a simple soldering operation. The preferred method would be to prewet both the feet of the LID and the metallization on the substrate and then use a flux (that is not harmful and can be rinsed away) or a controlled non-oxidizing atmosphere. A weight can then be used to apply equal force to the legs of the LID. The assembly is brought up to temperature where the solders will melt and flow together, then cooled to re-solidify and to form a continuous solder fillet (See Figure 5).

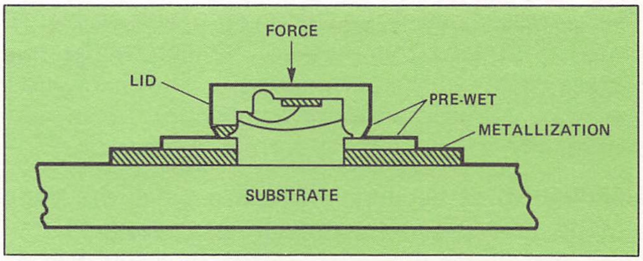

Figure 5. LID mounting is the easiest type to perform in hybrid microcircuitry. It can generally be accomplished with a single solder operation.

It is also possible to use localized heating and attach one side of the LID at a time. This can be done with a soldering iron, but extra care must be taken and the proper equipment used (controlled temperature irons, extra fine points, good optics, and a good positioning fixture). It is also possible to obtain a good solder joint by prewetting either the substrate or the LID. In general, it is easier to get an adequate amount of solder on the substrate than on the feet of the LID.

If more than one LID device is to be attached to the substrate, a template can be made, the parts prealigned, and all devices reflow soldered in one batch operation (Figure 6). This can save considerable costs, as well as eliminate the headache of destroying (or unsoldering) one part while trying to attach another.

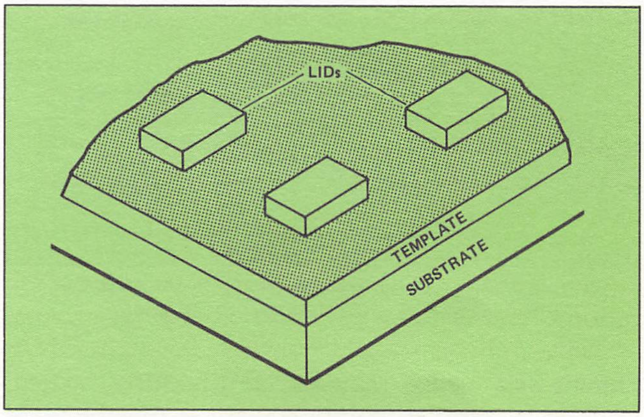

Figure 6. Batch reflow soldering is suited for bonding several LIDs to a substrate.

TABLE IV. LID TESTING CAPABILITY

Device	Noise Figure NF	IF Impedance Z_{IF}	VSWR	Voltage Breakdown V_{BR}	Total Capacitance C_T	Forward Current I_F	Series Resistance R_S	Lifetime τ
Schottky Barrier Diode	Yes*	Yes*	Yes*	Yes	Yes	Yes	Yes*	No
PIN Diode	n/a	n/a	n/a	Yes	Yes*	Yes*	Yes*	Yes*

*Special Test. Specified minimum and/or maximum parameter values available upon special request. Contact your local HP Sales Office.

Full RF characterization of LID mixer diodes is available upon special request. Preliminary measurements of the 5082-2705 X-band LID mixer diode are shown in Figure 7. LID PIN diodes are also available with guaranteed values of series resistance, lifetime, and capacitance. Table IV illustrates HP's testing capability for LIDs.

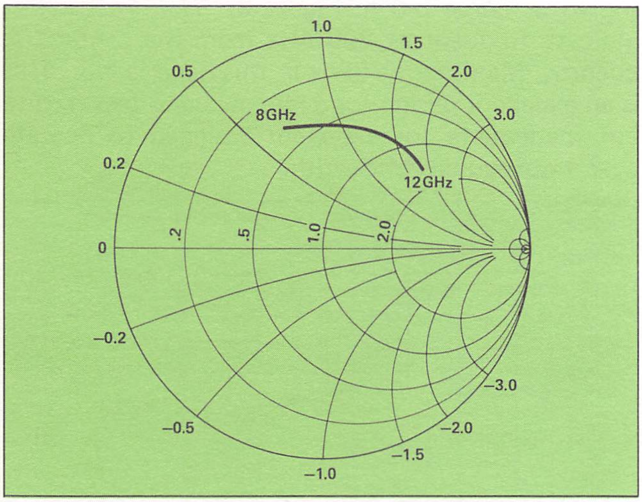

Figure 7. Admittance of 5082-2705 LID Mixer Diode. 1 mW power level.

E-Series

Another hybrid package requiring only a single assembly operation is the E-Series. In this case either soldering, spot welding, or parallel gap welding can be employed. The E-2 mixer applications are similar to the beam lead applications, with the main difference between them being the much larger size of the E-2 package. The E-2 package is much easier to handle, but it does take up more room on the substrate and has larger parasitics than the beam lead device.

Full RF characterization of E-2 mixer diodes is available upon request. Figure 8 shows the typical admittance of the 5082-2217 X-band E-2 mixer diode.

A four lead E-Series package (E-1) is available with Schottky diode quads for mixer or modulator applications. These units are made in the ring and the crossover arrangement. They are characterized for capacitance and for forward voltage match, as well as for series resistance. In addition, conversion loss at S and X bands can be guaranteed.

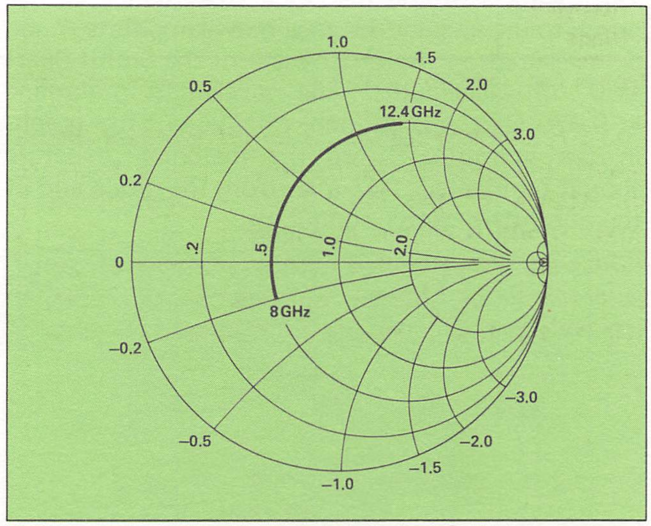

Figure 8. Impedance of 5082-2218, E-2 Mixer Diode. 1.5 mA detected current.

Microstrip Post

The microstrip post was developed for PIN switches and phase shifter circuits. The accurate location of the chip center (within .003 inch of the pedestal center) makes this model useful for phase shift circuits at frequencies as high as 20 GHz.

The pedestal may be attached to the substrate with conductive epoxy or low temperature solder. The temperature must be kept below 280°, the soldering temperature used to attach the chip to the pedestal. The wires may then be thermocompression bonded to the substrate metallization pattern.

IMPEDANCE MATCHING

In many applications of these diodes, it is desirable to add circuit elements to match the impedance of the diode to the impedance of the transmission line. This is particularly true of mixer diodes where mismatch reflections may be directly related to loss of noise figure performance. The remaining section of this note will discuss a technique for designing impedance matching elements.

The measured admittance of the LID mixer diode shown in Figure 7 will be used as an example of a simple matching technique. This method of matching to mixer diodes can be used with other package styles as well.

The diode admittance shown in Figure 9 was measured in a 50 ohm microstrip transmission line on 10 mil thick alumina. The reference plane is the inside edge of the cathode feet and this also corresponds to the end of the microstrip center conductor on the test circuit. To determine the location of the matching structure for a narrow band match at 9.375 GHz, measure the radial distance to point A, the diode admittance at that frequency. Find point B on the unit conductance circle at the same radial distance on the opposite side of the chart. The location of the matching susceptance corresponds to the angular distance between points A and B, measured on the outer scale of the Smith Chart as 0.178 wavelengths. The wavelength in alumina at 9.375 GHz is 0.49 inch, calculated from graphs in the literature [2], so the matching structure should be located .087 inch from the diode end of the microstrip center conductor.

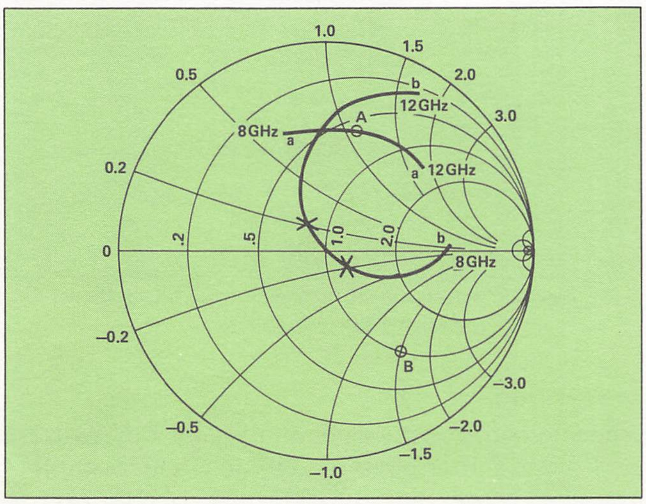

Figure 9. Matching the LID Mixer. a a = Diode Admittance, b b = Mixer Admittance.

The required matching susceptance is 1.6 x .02 = .032 mhos, the negative of the susceptance at Point B on the Smith Chart. This susceptance can be provided by a single stub, or preferably, by two open stubs symmetrically located about the 50Ω line at the proper distance (.087 inch) from the end of the line. The length of each stub is determined by the relationship: $B = \tan\theta / Z_O$ where B is the susceptance of an open stub, Z_O is the characteristic impedance of the line used in the stub, and θ is the electrical length of the stub. A convenient value of Z_O is 34Ω, corresponding to a line width to substrate thickness ratio of two. [2] Since each stub must provide half the matching susceptance,

$\tan\theta = 34 \times .016 = .544 \quad \theta = 28.5^\circ$

The stub length ℓ is related to θ by $\ell/\lambda = \theta/360^\circ$, so

$$\ell = \frac{28.5^\circ}{360^\circ} \times 0.49 = .039 \text{ inch}$$

This method of matching is suggested for narrow band mixers. The location and length of the tuning stubs should be adjusted experimentally to allow for fringing capacitance and junction corrections.

Figure 10 shows the microstrip circuit used to test the LID mixer at 9.375 GHz on a 10 mil thick alumina substrate. The I.F. circuit consists of high impedance lines, equivalent to series inductances, and large pads, equivalent to shunt capacitances. They form a low pass filter to pass the 30 MHz I.F. without disturbing the microwave signals on the main line. The wider lines across the 50Ω transmission line are the stubs providing the matching susceptance. This test circuit is used with a coax to waveguide transition. The dimensions differ from the calculated design to compensate for the transition admittance as well as for fringing corrections. [3, 4]

The calculated admittance of the tuned mixer is shown as curve b-b in Figure 9. The cross marks indicate frequencies 200 MHz from the center frequency. Maximum VSWR in this band is 1.3. This is an excellent design for a narrow band test fixture but inadequate for a system designed to operate over a waveguide bandwidth.

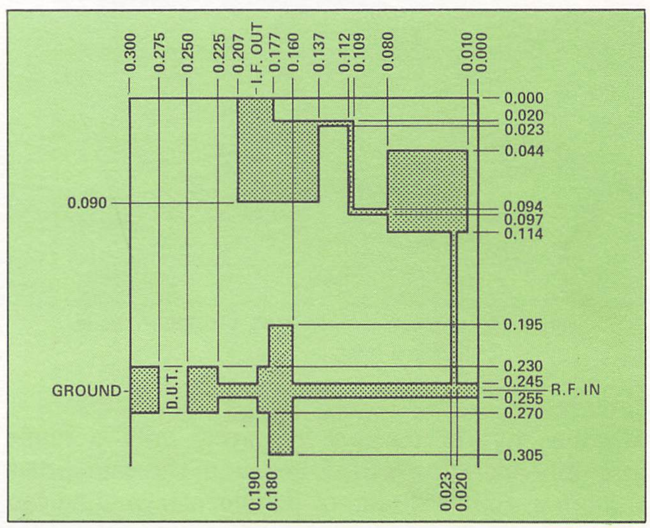

Figure 10. LID Mixer Test Circuit

NOTES:

1. N. Tarowsky, "How to Assemble Hybrid Microwave IC's", MICROWAVES, August, 1969.
2. A. Presser, "RF Properties of Microstrip Line", MICROWAVES, March, 1968.
3. Microwave Engineers Technical and Buyers Guide, Horizon House, 1969, p. 72.
4. L.S. Napoli and J.J. Hughes, "Foreshortening of Microstrip Open Circuits on Alumina Substrates". IEEE Trans. MTT vol. MTT 19 pp. 559-561, June, 1971.

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