

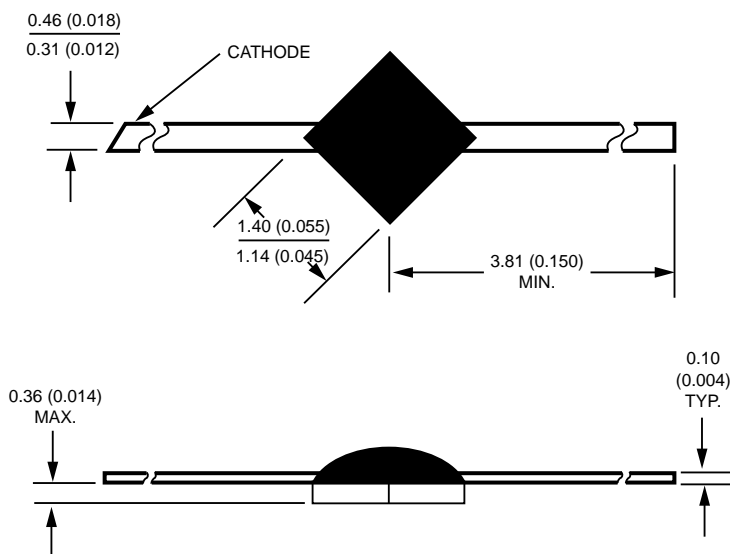
Broadband Microstrip Mixer Design – The Butterfly Mixer

Application Note 976

Introduction

In Hewlett-Packard Application Note 963, *Impedance Matching Techniques for Mixers and Detectors*, a technique for designing broadband matching circuits was developed and illustrated with circuits for matching the H5CH-5318 beam-lead Schottky diode. The shunt elements in these circuits are shorted transmission lines with low characteristic impedance – as low as 8 ohms. No attempt was made to realize these circuits.

This Note concerns the application of this matching technique to the design and construction of a microstrip mixer using a 5082-2207 diode (outline C2, Figure 1) for the frequency range from 8 GHz to 12 GHz. The problem of realizing low impedance shunt lines was solved by using radial lines.



DIMENSIONS IN MILLIMETERS AND (INCHES).

Figure 1. Outline C-2

Diode Model

The equivalent circuit for the diode was found by measuring the impedance from 2 GHz to 12 GHz and then finding a circuit with calculated impedance equal to this measured impedance. Figure 2 shows the test circuit. Figure 3 shows the diode model. The impedance measurement is made with enough incident power to produce 1.0 mA of rectified current at each frequency. This approximates the rectified current for 1.0 mW of absorbed power, the usual condition for mixer applications. The element values were obtained with the help of a computer optimization program.^[1]

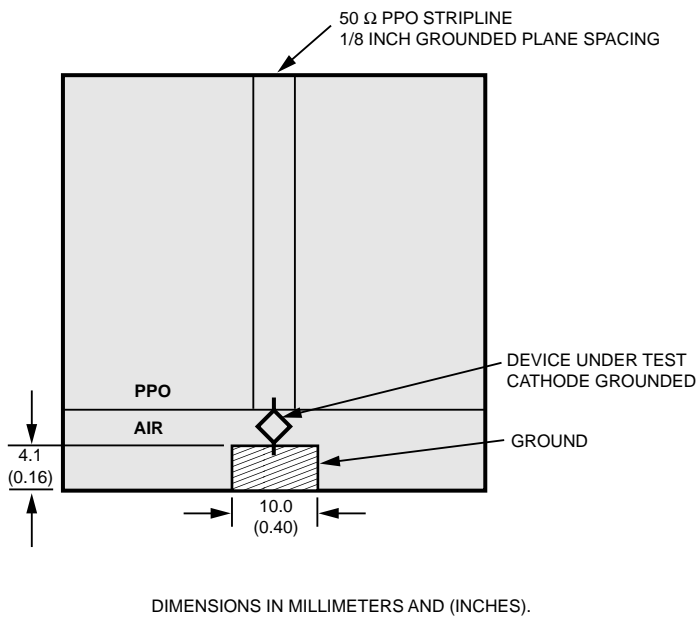


Figure 2. Test Circuit for Diode Admittance

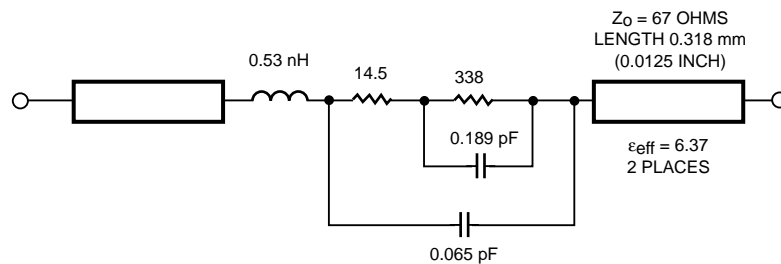


Figure 3. Diode Model

Matching Procedure

Figure 4 shows the diode admittance. There are three steps in the matching procedure. First, a high impedance line transforms the admittance so that the conductance at 8 GHz equals the conductance at 12 GHz. This is shown in Figure 5. Then a shunt susceptance is added to resonate at the band edges.

For a shorted line, the correct values of characteristic impedance and length can be found by solving the equations for required susceptance at the two frequencies. The solution is 13 ohms and 91.6° at 10 GHz.

Low impedance lines are difficult to realize. The width is a significant fraction of a wavelength, so the location of the line is not well defined. By using two shunt lines, the circuit can be realized with 26 ohm lines, but this is still a very low impedance.

The use of radial lines solves this problem. Before explaining the radial line design, the rest of the matching procedure will be shown. Figure 6 shows the admittance after the shunt susceptance is added.

The final matching element is a quarter wave transformer which centers the circle on the Smith Chart. The characteristic impedance is determined by assuming that the transformer inverts the circle without changing the diameter so that the normalized admittance at 10 GHz will be changed by the transformer from 2.8 to 0.64. The required transformer impedance is $50 / \sqrt{0.64 \times 2.8} = 37$ ohms. Figure 7 shows the admittance of the final circuit.

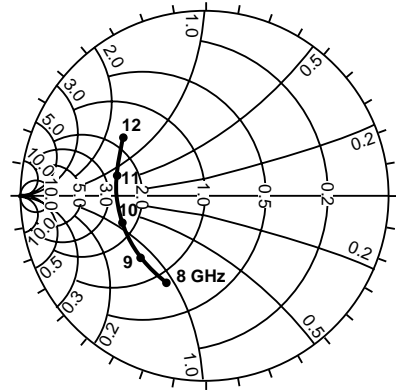
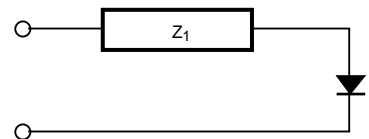
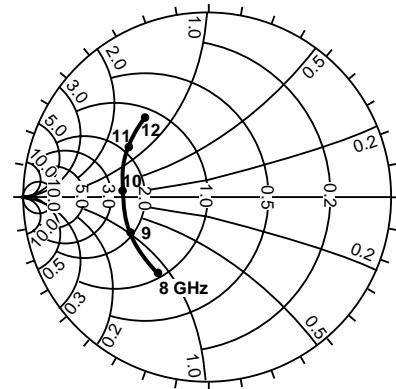
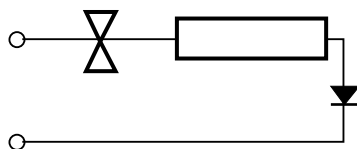
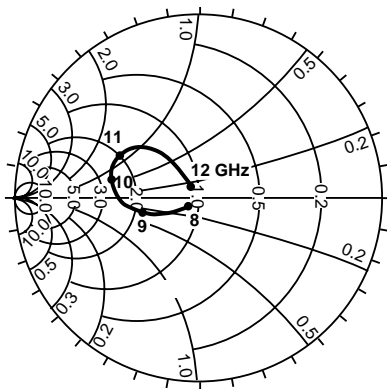


Figure 4. Diode Admittance



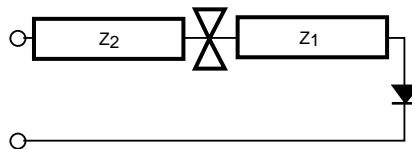
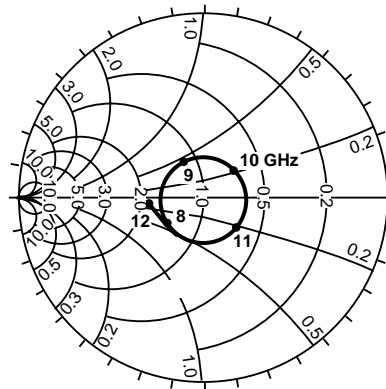
$Z_1 = 100 \Omega$
 $l = 0.25$ mm (0.010 INCH)
 $\epsilon_r = 2.2$

Figure 5. Admittance of Diode with High Impedance Line



$R_i = 0.51$ mm (0.020 INCH)
 $R_L = 11.68$ mm (0.460 INCH)
 $\alpha = 103^\circ$

Figure 6. Admittance of Resonated Mixer Circuit



$Z_2 = 36$ OHMS
 $l = 4.3$ mm (0.170 INCH)

Figure 7. Computed Mixer Admittance

Radial Line Stubs

Problems of location and parasitics of low impedance shunt stubs were solved by using fan-shaped open stubs with the narrow end connected to the main transmission line. Figure 8 shows the pertinent dimensions.

A fan-shaped stub can be considered as a portion of a radial transmission line.^[2] Vinding assumes that the reactance varies inversely as the angle so that

$$X = \frac{dZ_0}{2\pi R_i} \frac{\cos(\theta_i - \psi_L)}{\sin(\psi_i - \psi_L)} \frac{360}{\alpha}$$

where d is dielectric thickness and

$$Z_0 = \frac{120\pi}{\sqrt{\epsilon_r}} \sqrt{\frac{J_0^2(kR_i) + N_0^2(kR_i)}{J_1^2(kR_i) + N_1^2(kR_i)}}$$

$$k = \frac{2\pi\sqrt{\epsilon_r}}{\lambda_0}$$

$$\theta = \tan^{-1} \left[\frac{N_0(kR_i)}{J_0(kR_i)} \right]$$

$$\psi_{i,L} = \tan^{-1} \left[\frac{J_1(kR_{i,L})}{-N_1(kR_{i,L})} \right]$$

There is a question about the use of ϵ_r , dielectric constant of the medium, in these equations. When α is close to 360° , it appears logical to use ϵ_r because the circuit is close to a radial line where ϵ_r is correct. However, when the angle is small, the stub is very close to a microstrip stub, so it seems logical to use the microstrip expression^[3]

$$\epsilon_{\text{eff}} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} (1 + 10h/w)^{-1/2}$$

where h is the dielectric thickness and w is the line width. In this analysis, the width corresponding to splitting the stub area in half is used for W .^[4]

When a stub with parallel edges is used for the shunt elements, the solution for characteristic impedance and length requires the solution of two simple equations for the required reactances at band edge frequencies. However, the radial stub equations are not simple and there are three unknowns: angle and inner and outer radii. A third equation requiring zero reactance at center frequency could be introduced, but the solution of three simultaneous equations involving four types of Bessel functions would require considerable computer capability.

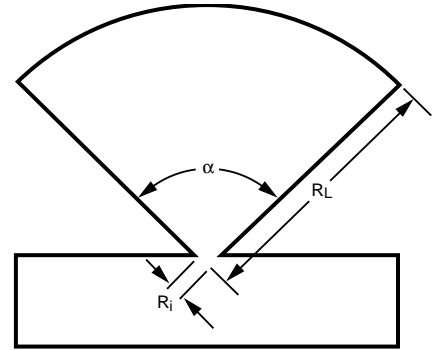


Figure 8. Radial Stub

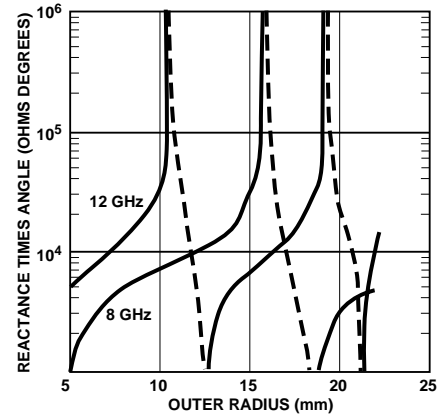
The problem is simplified by assuming a reasonably small value for the inner radius such as 0.51 mm (0.020 inch) and solving for R_L from the equation for the ratio of required reactances at the band edge frequencies. From Figure 5, the ratio is $(1.16 / -1.40)^{-1} = -1.21$.

Since the equation must be solved by substitution, it is convenient to plot $X\alpha$ at 8 GHz and 12 GHz as functions of R_L . This is shown in Figure 9 where it is seen that the desired ratio occurs near $R_L = 12$ mm.

Figure 10 expands the region near this value of R_L and shows a solution at $R_L = 11.68$ mm. Dividing $X\alpha$ at either 8 GHz or 12 GHz by the known value of X gives $\alpha = 206^\circ$. It is not possible to have an angle greater than 180° , but this problem is solved by using two shunt stubs. This requires double the reactance for each stub, so $\alpha = 103^\circ$.

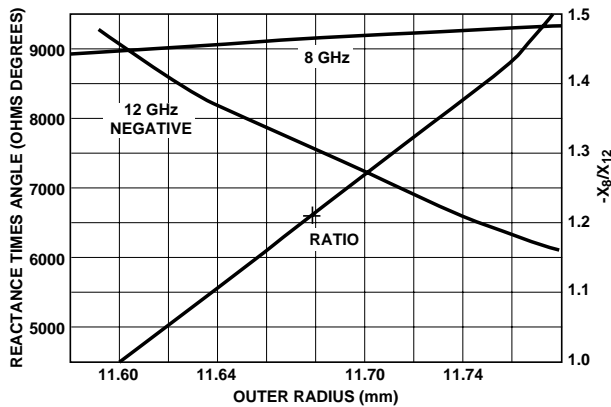
Note that the slope of reactance at 12 GHz, with respect to R_L , is steep, while the slope at 8 GHz is shallow. This behavior is confirmed in the experimental mixer. Changes in R_L have little effect on the impedance at 8 GHz, while the impedance at 12 GHz is quite sensitive.

The substrate material is RT/duroid 5880[5] with a dielectric constant of 2.2. The effective dielectric constant, ϵ_{eff} , for the half area width is 2.10.



INNER RADIUS 0.51 mm (0.020 INCH)
EFFECTIVE DIELECTRIC CONSTANT 2.10
DASHED LINES INDICATE NEGATIVE REACTANCE

Figure 9. Radial Stub



$\epsilon_{EFF} = 2.10$
INNER RADIUS = 0.51 mm (0.020 INCH)
SOLUTION FOR $\frac{X_8}{X_{12}} = \frac{86.2}{-71.6} = -1.21$

Figure 10. Radial Line Analysis

Experimental Circuit

Figure 11 shows the circuit built to demonstrate this design procedure. Noise figure at 9.375 GHz is 6.7 dB compared to 6.0 dB for the diode in the narrow band production test fixture. Measured admittance for one milliwatt local oscillator power using the calculated dimensions is shown in Figure 12. The circuit was first built with the stub length longer than calculated. As predicted, trimming the stub length improved the high frequency performance with little effect at the lower frequencies. The maximum measured SWR is 2.1 compared to 1.8 for the computed mixer admittance shown in Figure 7.

Increasing the transformer length from 4.32 mm to 6.35 mm improved the midband response with no decrease in the maximum SWR at 12 GHz. The measured admittance is shown in Figure 13.

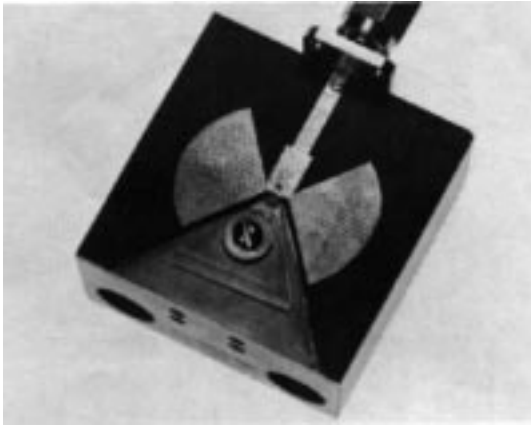


Figure 11. Photograph of the Butterfly Mixer

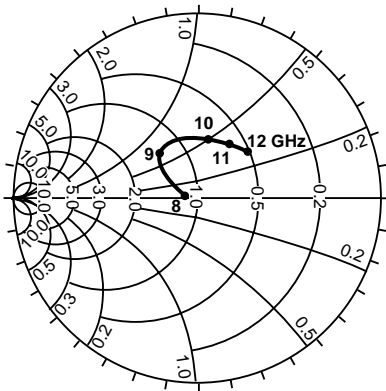


Figure 12. Measured Mixer Admittance

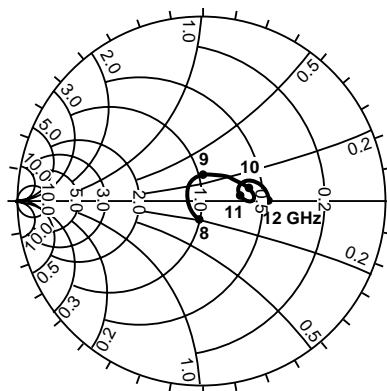


Figure 13. Measured Admittance with Longer Transformer

Conclusion

Schottky diode matching circuits at X-band usually require low impedance shunt transmission lines. Problems in realizing these lines in microstrip circuits may be avoided by using radial stubs. An X-band mixer using the 5082-2207 Schottky diode illustrates the use of this matching procedure.

References

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2. J.R Vinding, "Radial Line Stubs as Elements in Strip Line Circuits", Nerem Record, pp. 108-109, 1967.
3. M.V. Schneider, "Microstrip Lines for Microwave Integrated Circuits", Bell System Technical Journal, Vol. 48, No. 5, May-June 1969.
4. Suggested by Michael Hillbun, Compact Engineering, Inc.
5. Rogers Corporation, Chandler, AZ 85224.



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