Harmonic Mixing with the HSCH-5500 Series Dual Diode

Application Note 991

Introduction
The difficulty of generating local oscillator power at higher frequencies has stimulated interest in conversion with subharmonic local oscillators for nearly forty years [1]. Earlier designs were inefficient because so much of the signal power was used to generate the unwanted fundamental mixing product. Harmonic mixing conversion loss was 3 to 5 dB worse than fundamental mixing conversion loss.

The Antiparallel Pair
Within the past decade this problem was solved with an improved circuit which does not allow fundamental mixing, the antiparallel pair [2, 3]. This circuit has the additional advantage of suppressing local oscillator noise and all even order mixing products. However, the degree of suppression of these unwanted products is related to the matching of the diode pair.

The Monolithic Antiparallel Pair
Adjacent diodes on a wafer are nearly identical electrically. However, it is difficult to separate diodes while maintaining knowledge of each diode's position on the wafer. This problem is solved by making the diodes as monolithic pairs with a cathode-anode connection that remains when the wafer is separated. Figure 1 shows a Schottky pair with the capacitance of each diode less than 0.10 pF. Capacitance difference is less than 0.02 pF. Figure 2 shows the diode dimensions. This

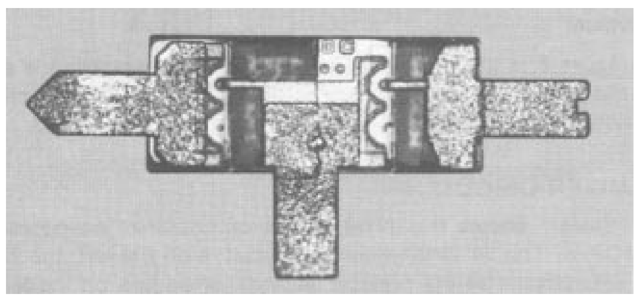

Figure 1.

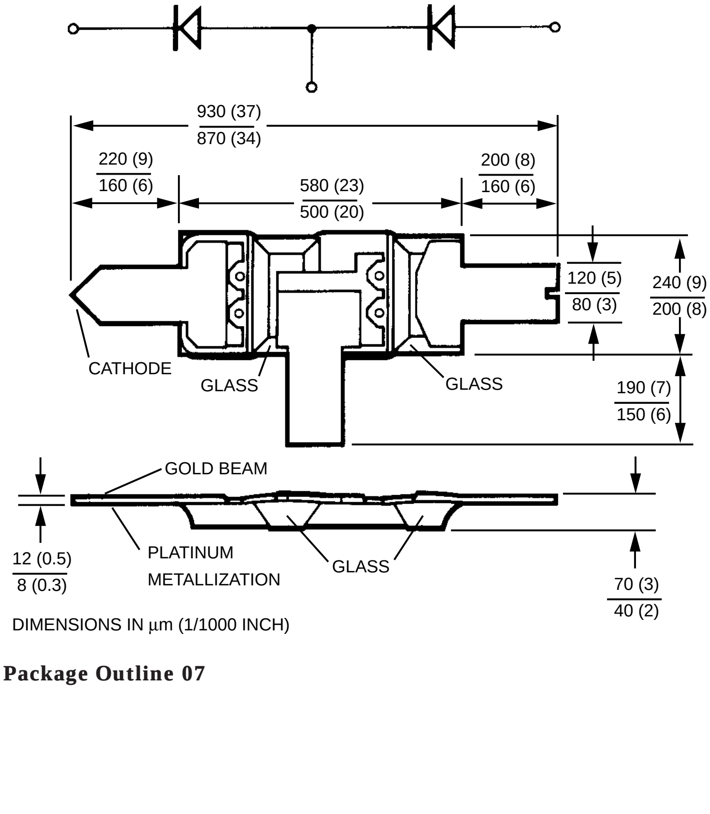

Figure 2. Package Outline 07

monolithic pair is available in the medium barrier version as HSCH-5510 as well as the low barrier HSCH-5531.

Coplanar Waveguide

The linear arrangement of the dual diode requires a transmission line with symmetrical ground planes on either side of the main line. The coplanar waveguide transmission line satisfies this requirement. Figure 3 shows the coplanar waveguide structure. The characteristic impedance is determined by the dielectric constant of the substrate and the ratio of b to a. Figure 4 shows how the dimensions can be chosen to fit the dimensions of the dual diode.

Diode Equivalent Circuit

Figure 5 shows the diode equivalent circuit. The element values are chosen to match the measured impedance with one milliampere rectified current in each diode. This corresponds to approximately one milliwatt of local oscillator power. Best conversion loss was seen at higher power. This caused a slight shift in frequency from the design value.

Figure 6 is the computer analysis of diode impedance at the design signal frequency of 34 GHz and the local oscillator frequency of 17 GHz.

Mixer Circuit

Figure 7 shows the mixer circuit on coplanar waveguide (CPW). The 34 GHz matching circuit is on the left, the 17 GHz circuit on the right. A series shorted line on the left side of the diodes is a quarter wave long at the local oscillator frequency. This decouples the signal tuning circuit from the local oscillator circuit. Similarly, a

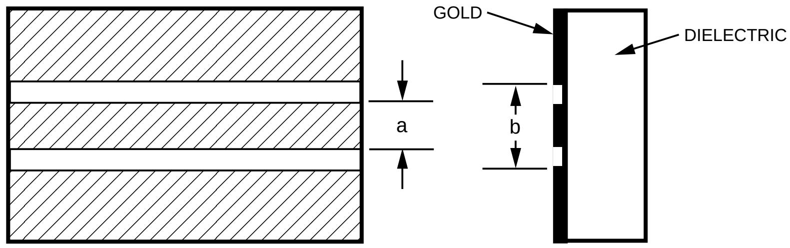

Figure 3. Coplanar Waveguide

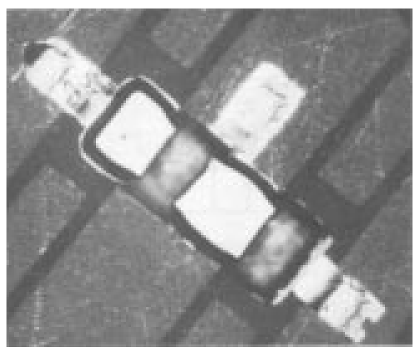

Figure 4. Monolithic Pair on Coplanar Waveguide

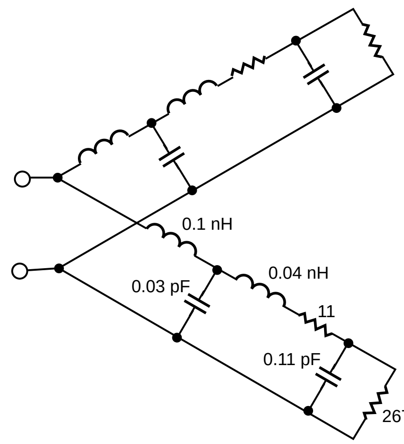

Figure 5. Diode Equivalent Circuit

```
IND   FF   SE   0.1
CAP   GG   PA   0.03
IND   HH   SE   0.04
RES   II   SE   11
CAP   JJ   PA   0.11
CAX   FF   JJ
PGR   FF   FF   267
CAS   FF   FF
RES   DG   SE   1E9
CAS   FF   GG
PRI   FF   S1   50
END
17000
34000
END
```

Frequency	S_{11} (Magn. <Angl.)	S_{21} (Magn. <Angl.)	S_{12} (Magn. <Angl.)	S_{22} (Magn. <Angl.)
17000.00	0.69 < -124	0.00 < -43.0	0.000 < -43.0	1.00 < 0
34000.00	0.79 < -172	0.00 < -28.7	0.000 < 0.0	1.00 < 0

Figure 6. Diode S-Parameters

series shorted line a quarter wave long at the signal frequency decouples the local oscillator tuning circuit from the signal circuit.

Although shunt elements can be used in CPW they require bond wires to maintain equal potential across breaks in the ground plane [4]. A simpler matching circuit uses two series transmission lines [5]. Figure 8 shows the transmission line impedance values from reference 5.

Signal Frequency Tuning

The diode is matched with a 33 ohm line which resonates the diode impedance and a quarter wave 96 ohm transformer to complete the match. Figure 9 shows the path on the Smith Chart.

It is theoretically possible to match the diode with a single transmission line [6], but the characteristic impedance is 17 ohms. The lowest reasonable impedance is about 30 ohms. Lower values require line spacings less than 0.001 inch.

Local Oscillator Frequency Tuning

Figure 10 shows the tuning on the local oscillator side of the diodes. The series stub adds 38.5 ohms of inductance to the impedance of the diodes. A 33 ohm line then resonates the circuit. A quarter wave 74.5 ohm line completes the matching. The single line replacing these two lines would require a 19 ohm characteristic impedance.

Computer Analysis

Figure 11 shows the computer analysis of the complete circuit [7]. The quarter wave series lines produce unity S_{11} at 17 GHz and

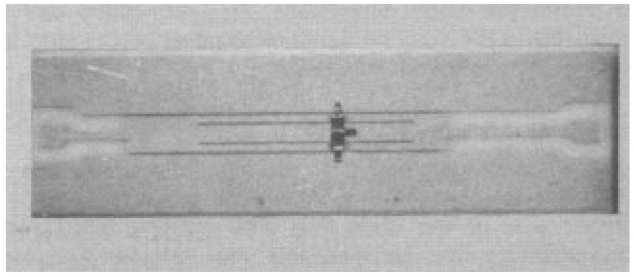

Figure 7. Harmonic Mixer Substrate

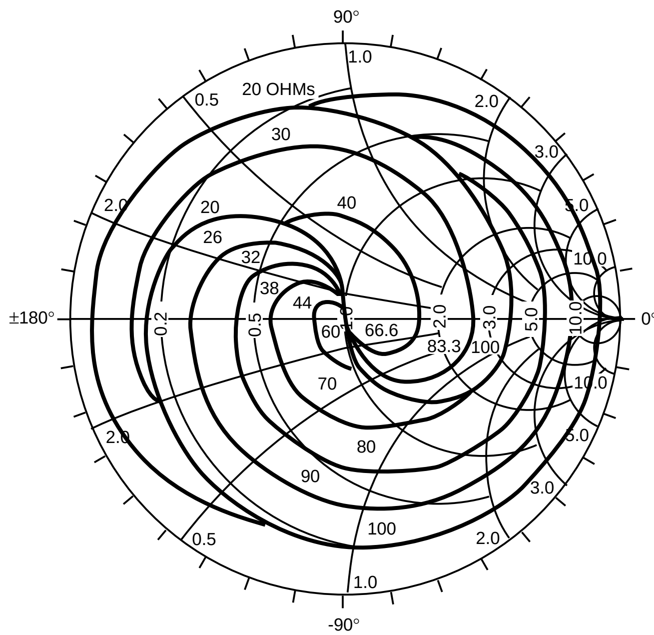

Figure 8. Transformer Impedance Values

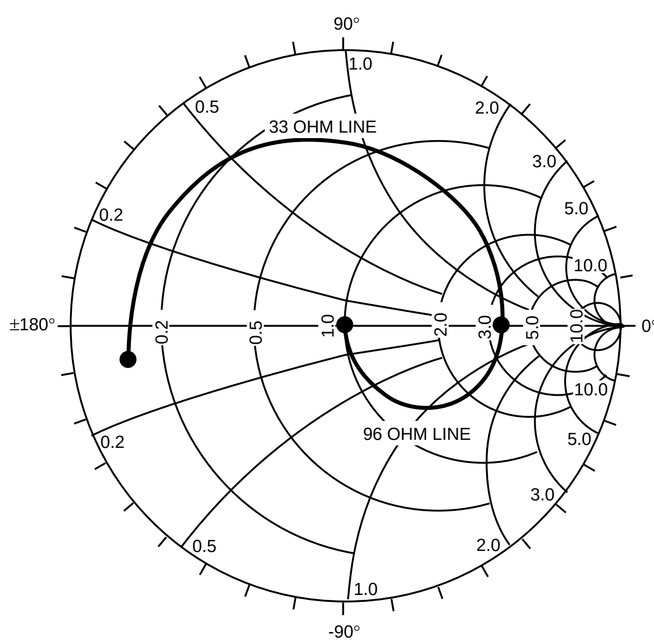

Figure 9. Matching Diodes at 34 GHz

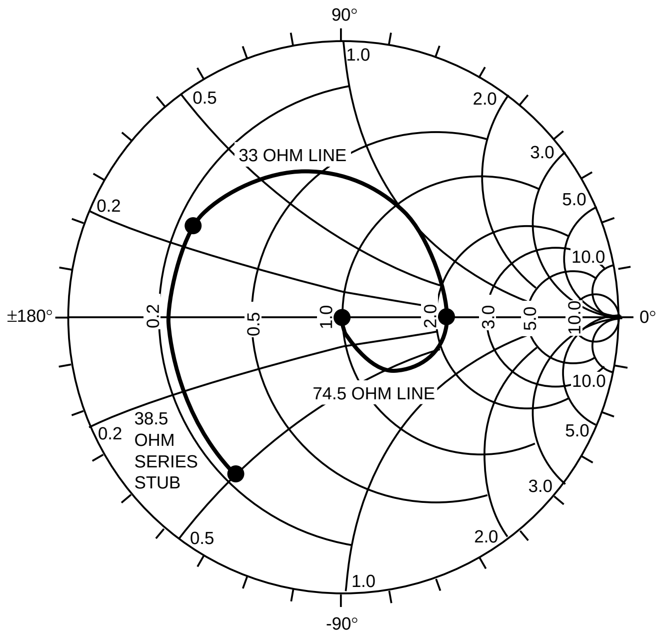

Figure 10. Matching Diodes at 17 GHz

TRL	CC	SE	96.0	90	34000
TRL	DD	SE	33	276.2	34000
SST	EE	SE	38.5	90	17000
IND	FF	SE	0.1		
CAP	GG	PA	0.03		
IND	HH	SE	0.04		
RES	II	SE	11		
CAP	JJ	PA	0.11		
CAX	FF	JJ			
PBR	FF	FF	267		
CAS	FF	FF			
SST	GG	SE	38.5	90	34000
TRL	HH	SE	33	66	17000
TRL	II	SE	74.5	90	17000
CAX	CC	II			
PRI	CC	S1	50		
END					
16250	17750	250			
32500	35500	500			
END					

Frequency	S_{11} (Magn. <Angl.)	S_{21} (Magn. <Angl.)	S_{12} (Magn. <Angl.)	S_{22} (Magn. <Angl.)
16250.00	1.00 < 36	0.05 < -108.7	0.049 < -108.7	0.28 < -42
16500.00	1.00 < 33	0.03 < -116.9	0.034 < -116.9	0.20 < -49
16750.00	1.00 < 29	0.02 < -125.6	0.017 < -125.6	0.10 < -57
17000.00	1.00 < 26	0.00 < 45.2	0.024 < -148.9	0.00 < 45
17250.00	1.00 < 23	0.02 < 35.6	0.018 < 35.6	0.11 < 103
17500.00	1.00 < 19	0.04 < 25.7	0.036 < 25.7	0.23 < 94
17750.00	1.00 < 15	0.05 < 15.8	0.055 < 15.8	0.34 < 85
32500.00	0.75 < -34	0.02 < 2.8	0.020 < 2.8	1.00 < 156
33000.00	0.61 < -48	0.02 < -14.0	0.015 < -14.0	1.00 < 144
33500.00	0.36 < -67	0.01 < -35.7	0.009 < -35.7	1.00 < 131
34000.00	0.00 < -162	0.00 < 117.9	0.054 < -35.5	1.00 < 119
34500.00	0.36 < 66	0.01 < 91.9	0.008 < 91.9	1.00 < 107
35000.00	0.62 < 47	0.01 < 71.0	0.014 < 71.0	1.00 < 95
35500.00	0.76 < 33	0.02 < 55.9	0.016 < 55.9	1.00 < 84

Figure 11. Computer Analysis

unity S_{22} at 34 GHz.

The indicated reflection coefficients correspond to 2 dB reflection loss at 33 and 35 GHz.

Measured Performance

Mixer conversion loss was measured in the circuit shown in Figure 12. Output frequency was 13 MHz. Frequency and L.O. power were varied to find the optimum operating point of 33.8 GHz. Optimum L.O. power was +3 dBm for the low barrier HSCH-5530 and +6 dBm for the medium barrier HSCH-5510. Figure 13 shows how conversion loss varies with local oscillator power. The medium barrier diode is slightly more sensitive at optimum power level but the low barrier diode is more tolerant of variations in local oscillator power level. At one milliwatt the low barrier diode is degraded about 1 dB while the medium barrier diode is degraded more than 10 dB.

Figure 14 shows the frequency performance of the medium barrier mixer. The curve for the low barrier version is similar. The dashed line is the computed mismatch loss normalized to the optimum conversion loss. The area near the design frequency correlates quite well, but the measured nulls and peaks do not appear in the computed data. These may be related to parasitic elements not considered in the analysis.

Compression characteristics for the low barrier diode are shown in Figure 15. When the optimum L.O. power for low level is used the 1 dB compression is seen at -5 dBm input and the output peaks at -13 dBm with +1 dBm input. With local oscillator power increased to

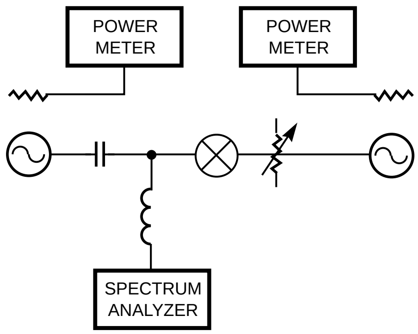

Figure 12. Test Circuit

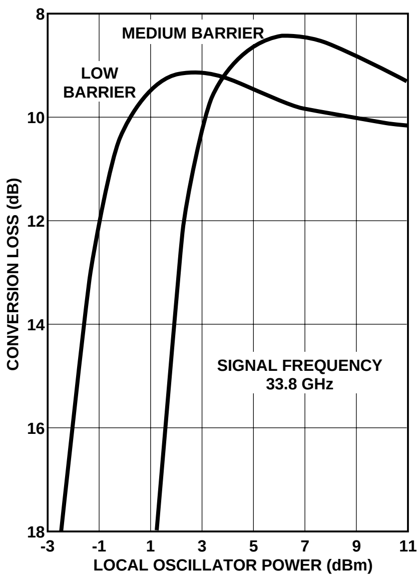

Figure 13. Effect of L.O. Power Level

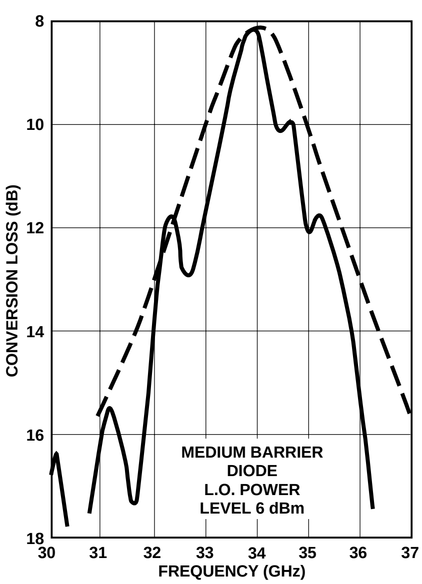

Figure 14. Mixer Bandwidth

13 dBm compression is seen at +2 dBm input and the output peaks at -7.5 dBm with +7 dBm input.

Similar data for the medium barrier mixer in Figure 16 shows a 2 or 3 dB higher level of compression and saturation with optimum L.O. power. At the higher L.O. power level there is little difference between the two diodes.

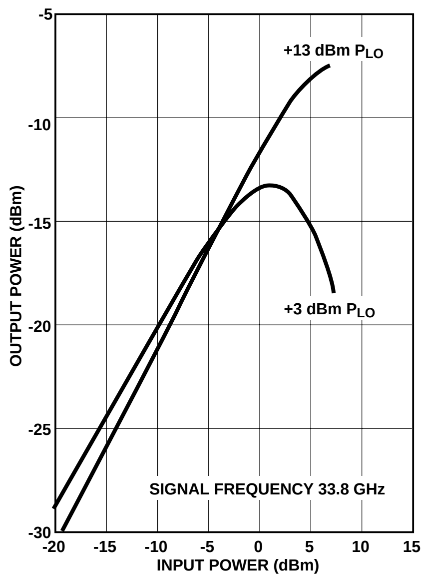

Figure 15. Mixer Saturation, Low Barrier Diode

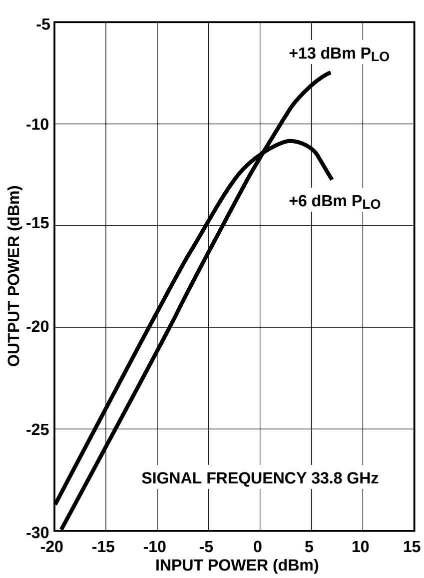

Figure 16. Mixer Saturation, Medium Barrier Diode

The 4 x 2 and 6 x 3 mixing products were seen with conversion loss exceeding 55 dB and 60 dB respectively.

Summary

A monolithic Schottky diode pair on coplanar waveguide is well suited to the design of an antiparallel pair harmonic mixer. Measured conversion loss is 8 dB at a signal frequency of 33.8 GHz. This is comparable to the loss for fundamental mixing.

Notes:

1. C.T. Torrey and C.A. Whitmer, Crystal Rectifiers, MIT Radiation Laboratory Series, 15, New York: McGraw-Hill 1948
2. M.V. Schneider and W.W. Snell, Jr., *Stripline Downconverter with Subharmonic Pump*, B.S.T.J., Vol. 53, No. 6, pp. 1179-1183, July, August, 1974.
3. Marvin Cohn, James E. Degenford, and Burton A. Newman, *Harmonic Mixing with an Antiparallel Diode Pair*, IEEE Transactions on Microwave Theory and Techniques, Vol. 23, No. 8, pp. 667-673, August, 1975.
4. R.E. Stegens, *Coplanar Waveguide FET Amplifiers for Satellite Communications Systems*, Comsat Technical Review, Vol. 9, No. 1 pp. 255-267, Spring 1979.
5. Jack H. Lepoff, *Matching: When Are Two Lines Better Than One?*, Microwaves, Vol. 20, No. 3, pp. 74-78, March, 1981.
6. Kurt B. Schwan, *Matching: When is a Single Line Sufficient?*, Microwaves, Vol. 14, No. 12, pp. 58-63, December, 1975.
7. Compact Software, Inc. Palo Alto, CA

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