Hindawi Publishing Corporation
Active and Passive Electronic Components
Volume 2007, Article ID 69515, 4 pages
doi:10.1155/2007/69515

Research Article

Integrated Balanced BPSK Modulator for Millimeter Wave Systems

Ashok Mittal[1, 2] and Asok De[1]

[1] *Delhi College of Engineering, University of Delhi, Delhi 110 042, India*
[2] *Central Research Laboratory, Bharat Electronics Ltd, Ghaziabad 201 010, India*

Received 28 April 2007; Accepted 14 September 2007

Recommended by Spartak Gevorgian

This paper details the design of integrated balanced PSK modulator using finline coplanar line hybrid junction. The PSK signal output is in suspended stripline with incident wave carrier in finline. Schottky barrier Diode MA4E2037 has been used for modulation. The balanced configuration offers high isolation between the carrier input port and the modulated carrier output port and thus the pulse width variations and amplitude deviations are suppressed. An insertion loss imbalance of ±1.5 dB with an average loss of 2 dB in the two switching states has been achieved over 38.9 to 40 GHz. The phase imbalance is ±10 degrees with phase switching from 180 to 199 degrees As the PSK output signal is in suspended stripline, two BPSK modulators can be easily combined together to work as QPSK modulator.

1. INTRODUCTION

Phase-shift-keying (PSK) modulators are been widely used in digital communications. PSK modulators are mainly divided into two different types: a balanced or a double-balanced type and a path-length modulator (unbalanced) type [1].

Path length modulators are realized as reflection or transmission-type modulators. The reflection-type modulators are constructed by using either a waveguide circulator or using an MIC 3 dB branch-line hybrid coupler. The transmission-type modulators are realized using two microstrip lines with different line lengths and two switching diodes. In the path-length modulator, amplitude variations and jitter occur in PSK waveforms due to the path-length difference.

On the other hand, the balanced modulator using equal path lengths realizes PSK waveforms without jitter and achieves good isolation between the carrier input port and the modulated carrier output port, and a good PSK waveform in a wide frequency band. Furthermore, the balanced modulator can be easily fabricated by the printed circuit MIC techniques, thus giving high yield and repeatability.

The modulators developed have high isolation between the carrier input port and the modulated carrier output port. The pulse width variations and amplitude deviations are suppressed due to the balanced configuration used.

Phase-shift keying (PSK) describes the modulation technique that alters the phase of the carrier. Mathematically,

$$s(t) = \sin(2\pi f_c t + \phi(t)). \tag{1}$$

Binary phase-shift keying (BPSK) has only two phases: 0 and π. It is, therefore, a type of ASK with $f(t)$ taking the values -1 or 1 (Figure 1), and its bandwidth is the same as that of ASK. Phase-shift keying offers a simple way of increasing the number of levels in the transmission without increasing the bandwidth by introducing smaller phase shifts.

2. TRANSMISSION LOSS CALCULATIONS

The basic planar finline circuit of BPSK modulator or 180 degrees digital phase shifter is similar to that of millimeter-wave balanced finline mixers. Figure 2 shows the equivalent circuit of the hybrid junction with Schottky Barrier Diodes MA4E2037 mounted across the finline coplanar line hybrid junction. The PSK signal output is in suspended stripline using a coaxial K connector. If we take $[T_1]$ and $[T_2]$ as the transfer matrix of the two switching states with distributed

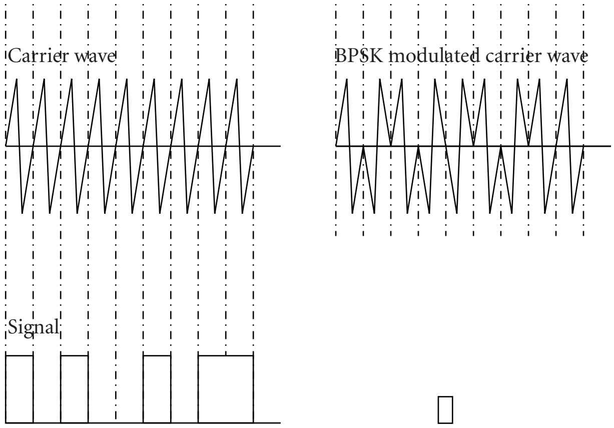

Figure 1: Binary phase-shift keying (BPSK modulation technique).

constant line and the parallel connected diodes, the expressions for $[T_1]$ and $[T_2]$ can be written as

$$[T_1] = \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} = \begin{bmatrix} \cos\theta & jZ_0 \sin\theta \\ Y_1 \cos\theta + j\dfrac{1}{Z_0}\sin\theta & jY_1 Z_0 \sin\theta + \cos\theta \end{bmatrix},$$
$$[T_2] = \begin{bmatrix} A_2 & B_2 \\ C_2 & D_2 \end{bmatrix} = \begin{bmatrix} -\cos\theta & -jZ_0 \sin\theta \\ -Y_2 \cos\theta - j\dfrac{1}{Z_0}\sin\theta & -jY_2 Z_0 \sin\theta - \cos\theta \end{bmatrix}, \quad (2)$$

assuming that the transmission line is lossless. The over all transfer matrix can be computed as

$$[T] = \begin{bmatrix} A & B \\ C & D \end{bmatrix} = \frac{1}{D_1 + D_2} \times \begin{bmatrix} 2+(A_1D_2+A_2D_1+B_1C_2+B_2C_1) & B_1D_2+B_2D_1 \\ C_1D_2+C_2D_1 & D_1D_2 \end{bmatrix}, \quad (3)$$

where $Y_1 = 1/Z_1$, the forward-biased diode admittance and $Y_2 = 1/Z_2$, the reverse-biased diode admittance and characteristic impedance of the line as $Z_0 = \sqrt{Z_{in}Z_{out}}$, and θ is the electrical length.

The transmission coefficient can be computed as

$$[T] = \frac{2\sqrt{Z_{in}Z_{out}}}{Z_{out}A + B + Z_{in}Z_{out}C + Z_{in}D}, \quad (4)$$

with Z_{in} and Z_{out} as input and output impedances.

The diodes are connected in series to the carrier input port and in parallel to the PSK signal output port.

Hence $Z_{in} = 2Z_{out}$, with

(i) $Y_1 = 1/Z_1 = 1/R_s$,
(ii) $Y_2 = 1/Z_2 = j\omega C_j$,
(iii) R_s—the Series resistance of the diode,
(iv) C_j—the Junction capacitance of the diode.

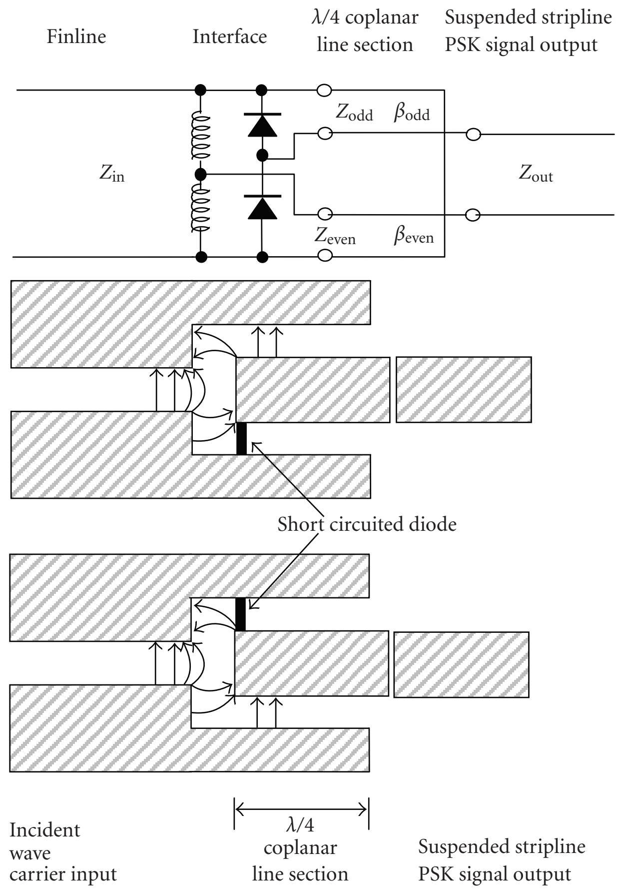

Figure 2: Equivalent circuit of the balanced BPSK modulator.

The computed insertion loss is 1.2 dB for the MA4E2037 with the junction capacitance of the diode $C_j = 0.02$ pF, the series resistance of the diode $R_s = 4$ ohms at 0 V at 1 MHz. The maximum computed insertion loss is 1.6 dB with the total capacitance of the diode $C_t = 0.05$ pF and maximum series resistance of the diode $R_s = 7$ ohms at 0 V at 1 MHz. The typical transition loss of unilateral symmetric finline for exponential taper with a length of $1.1\,\lambda$ is 0.4 dB. The total computed loss is around 1.6 dB to 2.0 dB.

3. CIRCUIT DETAILS

The layout and circuit details of the balanced PSK modulator are given in Figure 3. The circuit has been fabricated on a 10 mil RT Duroid 5880 with dielectric constant $\varepsilon_r = 2.22$. The input impedance of the unilateral finline has been taken as $Z_{in} = 172$ ohms. The output port impedance $Z_{out} = 50$ ohms with coplanar line impedance as $Z_0 = 93$ ohms and $\theta = \pi/2$. Broadband tapered transition from rectangular waveguide to symmetric unilateral finline with slot width of 0.2 mm and corresponding characteristic impedance of 172 Ω has been realized by gradually increasing the slot width using an exponential profile [2].

The input signal sees the two diodes in series and looks twice the impedance of a diode in an unbiased condition. The input port has been designed, approximating exponential

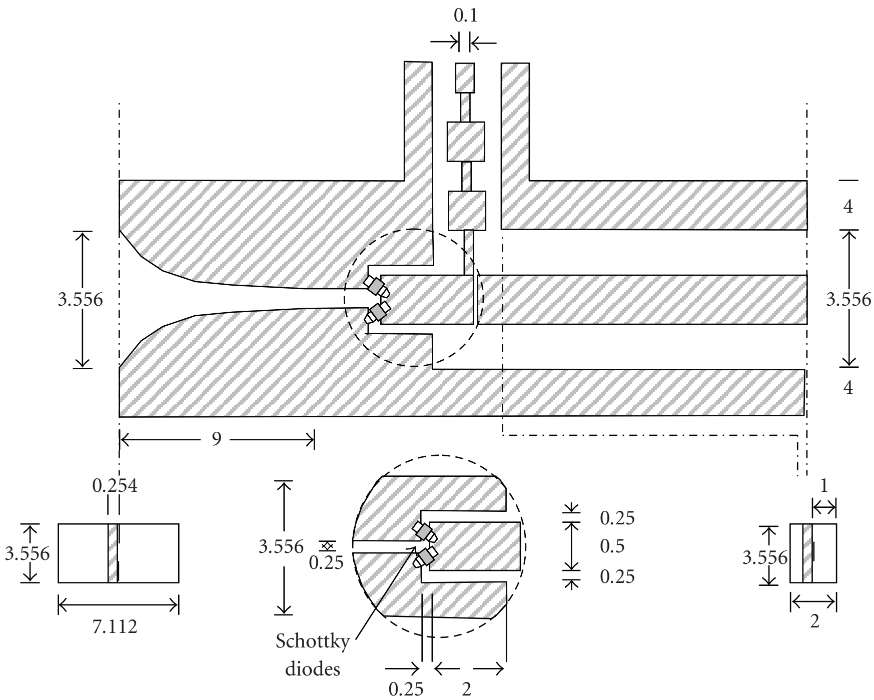

FIGURE 3: Layout and circuit details of the balanced BPSK modulator.

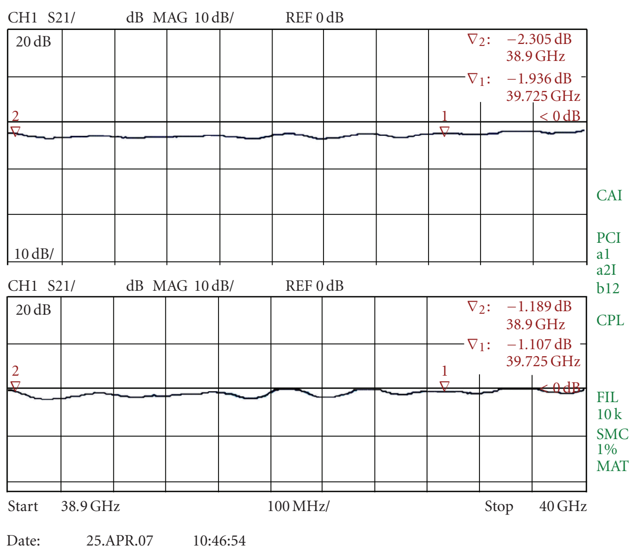

FIGURE 4: Insertion loss imbalance of the balanced BPSK modulator.

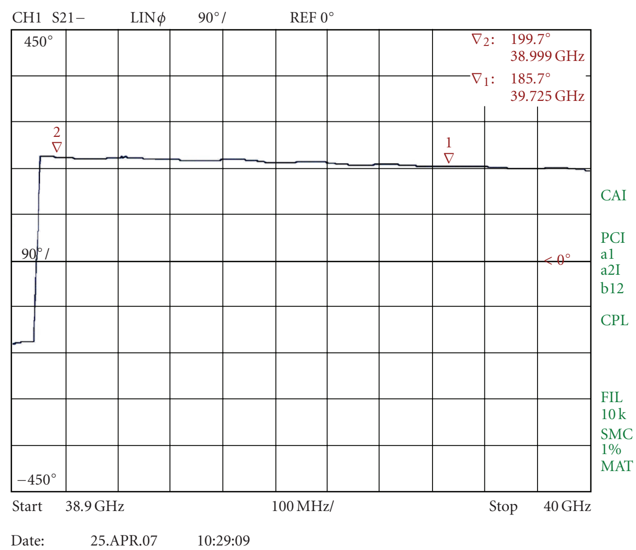

FIGURE 5: Phase shift between the two switching states of the balanced BPSK modulator.

dependence of taper to symmetrical unilateral finline to match the RF impedance of the diodes at the junction. Balanced action is achieved by a 180 degree hybrid formed at the junction of the finline, coplanar line, and suspended substrate transmission line due to the excitation of their cross-polarized electric fields. The diodes are switched to achieve the 180 degree phase-shift keying according to the input modulating wave through a low-pass filter. The balun is the actual phase-shifter circuit with switching between the two states. The transitions connect the phase shifter with the waveguide system, while the low-pass filter links the diodes to the control signal.

The balun is formed by a $\lambda/4$ coplanar line with standard rectangular waveguide cross section. One end is connected to the finline, while the other is connected to the suspended stripline which has a reduced cross section to suppress higher-order mode propagation. The Schottky barrier diodes MA4E2037 are mounted across the coplanar line at the interface with the finline, antiparallel to the center conductor, as shown in Figure 2. The coplanar line with standard waveguide cross section sustains two propagating modes: the even mode, a quasi-TEM mode resembling the dominant mode in suspended stripline, and the odd mode, a waveguide mode similar to the dominant finline mode. The even mode links the coplanar line with the suspended stripline, while the odd mode links it with the finline. To activate the balun function, a control signal is applied. As the two diodes are connected in antiparallel, one of them is forward biased, whereas the other is reverse biased. The short-circuited diode connects the center conductor of the coplanar line to one of the outer conductors. Hence an incoming wave is split into an even and an odd mode with equal amplitude. As a result, mode conversion takes place, and the finline input is coupled to the suspended stripline output.

A wave incident on the finline is phase shifted by 180 degrees, that is, the orientation of the electric field in the coplanar line is switched when the position of the short is exchanged as shown in Figure 2. The 180 degree phase shift is independent of frequency in spite of changes in characteristics due to frequency-dependent elements of the actual circuit like length of the coplanar line section which adds to the mismatch.

4. RESULTS

Figures 4 and 5 show the measured results of the balanced phase modulator. Figure 4 shows the amplitude in the two states. Figure 5 gives the phase difference between the two states. An insertion loss imbalance of ± 1.0 dB with an average loss of 1.5 dB in the two switching states has been achieved over 38.9 to 40 GHz. The phase imbalance is ± 10 degrees with phase switching from 180 to 199 degrees

5. CONCLUSION

The designed BPSK modulators have high isolation between the carrier input port and the modulated carrier output port. The pulse width variations and amplitude deviations are suppressed due to the balanced configuration used. As the PSK output signal is in suspended stripline, two BPSK modulators can be easily combined together to work as QPSK modulator for point to point millimeter-wave radio links [3]. These modulators will enable compact, low-cost, and high-efficiency transmitters.

REFERENCES

[1] H. Callsen, H. H. Meinel, and W. J. R. Hoefer, "p-i-n diode control devices in E-plane technique," *IEEE Transactions on Microwave Theory and Techniques*, vol. 37, no. 2, pp. 307–316, 1989.

[2] B. Bhat and S. K. Koul, *Analysis, Design and Applications of Fin Lines*, Artech House, Boston, Mass, USA, 1987.

[3] B. Jokanovic, S. Stojanovic, and M. Peric, "Direct QPSK modulator for point-to-point radio link at 23 GHz," in *Proceedings of the 5th International Conference on Telecommunications in Modern Satellite, Cable and Broadcasting Service (TELSIKS '01)*, vol. 1, pp. 217–220, Nis, Yugoslavia, September 2001.