A New Constant-Resistance ASK Modulator Using Double-Sided MIC

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Abstract **—A new constant-resistance ASK modulator using double-sided MIC techniques is proposed. (The term "double-sided MIC" refers to a circuit that utilizes both substrate surfaces.) The circuit consists of two quarter-wavelength slotlines, two variable-resistance elements, and a slot-to-microstrip transition. A balanced circuit configuration is used to obtain a high ON/OFF ratio at high frequencies. The modulator does not require circulators or hybrid couplers for perfect matching. The conditions required for impedance matching are also calculated. The experimental results are obtained in the frequency range from 25.0 to 29.5 GHz. The minimum insertion loss obtained is 2.8 dB, and the ON/OFF ratio is greater than 40 dB. The return loss is kept above 12 dB in the frequency range. This new modulator should prove useful for various applications such as variable equalizers and variable attenuators.**

I. Introduction

AMPLITUDE SHIFT KEYING (ASK) modulators have been applied to microwave and millimeter-wave transmitters/receivers [1], [2]. The ASK modulator plays an especially important role in subscriber radio systems employing time division multiple access (TDMA) technology in the 26-GHz band [3]. ASK modulators are divided into two types. One is a reflection-type modulator [4], [5], the other a low-pass filter (LPF) type modulator [6]. Reflection-type modulators need circulators or hybrid couplers in order to maintain perfect matching. The ON/OFF ratio, which is defined as the difference between the insertion losses of the circuit in the ON and OFF states, depends on the Q of the diodes [7]. It is difficult for the reflection-type modulator to realize a high ON/OFF ratio at high frequencies, because the Q of the diodes is inversely proportional to the frequency. On the other hand, the high ON/OFF ratio can be improved by increasing the number of diodes in the LPF-type modulator [1]. However, circulators or hybrid couplers are still necessary.

In this paper, a new constant-resistance ASK modulator, which does not require circulator or hybrid couplers for perfect matching, is proposed. The circuit utilizes a combination of microstrip lines and slotlines (double-sided MIC's) [8]. It consists of two quarter-wavelength slotlines, a slot-to-microstrip transition, and two variable-resistance elements. The ASK modulator proposed here has the following advantages.

(1) The size of the circuit is smaller than that of the reflection- and the LPF-type ASK modulators, because no circulators or hybrid couplers are required.
(2) The ON/OFF ratio does not depend on the diodes' Q because of the balanced circuit configuration.
(3) The circuit can be expected to operate in the millimeter-wave band because of the simplified circuit configuration.

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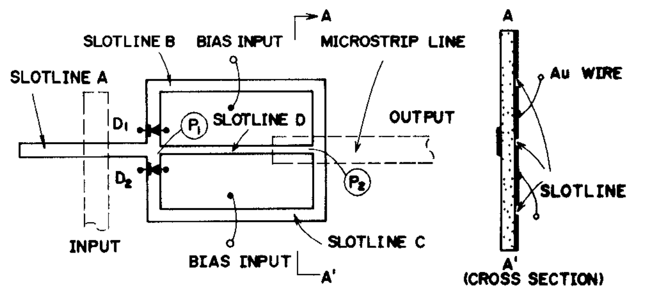


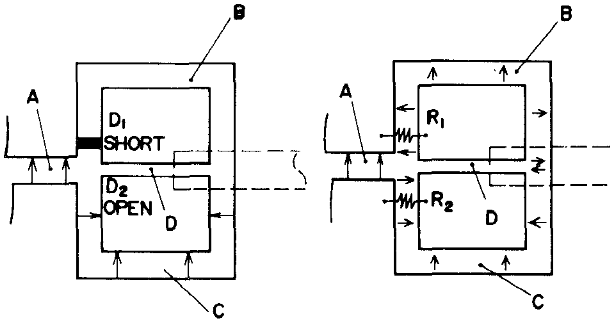
Fig. 1. Circuit configuration of the constant-resistance ASK modulator. Solid lines represent slotlines on the substrate, while dotted lines represent microstrip lines on the reverse side of the substrate.

II. Circuit Configuration

The circuit configuration of the constant-resistance ASK modulator is shown in Fig. 1. The circuit is composed of microstrip lines, slotlines, and two variable-resistance elements p-i-n diodes). The solid lines show slotlines on the substrate, while the dotted lines show microstrip lines on the reverse side of the substrate. The balance–unbalance transition circuits, which are necessary in this modulator, are made by the combination of the slotlines and the microstrip line. The significance of the double-sided MIC configuration is that it allows construction of the constant-resistance circuit.

The lengths of slotlines B and C are equal to one quarter or three quarters of a wavelength. Point P_2 of slotline D is short-circuited by a quarter-wavelength microstrip line. If the length of slotline D is equal to a half-wavelength, point P_1 is also short-circuited. Therefore, the modulated carrier does not propagate along slotline D, and two bias voltages can be separately supplied to two diodes.

Fig. 2 shows the fundamental behavior of the ASK modulator. Arrows indicate the direction of the electric field along slotlines. Fig. 2(a) shows the ON state of the ASK modulator, where diode D_1 is forward biased (short) and diode D_2 is reversed biased (open). The carrier fed into slotline A propagates on slotline C, and it is converted



(a) (b)

Fig. 2. Fundamental operation of the constant-resistance ASK modulator. Arrows indicate the direction of the electric field along slotlines. (a) ON state. (b) OFF state.

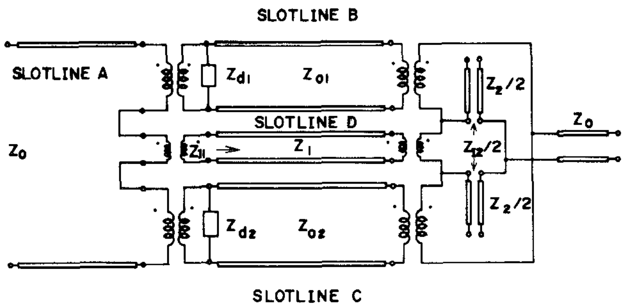


Fig. 3. Equivalent circuit of the constant-resistance ASK modulator. Input microstrip lines are eliminated in this figure.

to the microstrip line through the slot-to-microstrip transition. On the other hand, when resistance R_1 of diode D_1 is equal to resistance R_2 of diode D_2, the carrier fed into slotline A is divided into slotlines B and C with the same amplitude, and out of phase. In this state, slotlines B and C behave as short-circuited stubs, as shown in Fig. 2(b). If the sum of R_1 and R_2 is equal to the line impedance Z_0 of slotline A, the input carrier is not reflected; i.e., perfect matching can be attained in the OFF state. Thus, the input impedance of the ASK modulator is constant in both ON and OFF states.

III. Circuit Analysis

The equivalent circuit of the ASK modulator is shown in Fig. 3. In this analysis, the following two assumptions are made: (1) the mode conversion from the slotline to the microstrip line is ideal; and (2) the frequency dependence of the slotline impedance is negligible. The impedances Z_{d1} and Z_{d2} refer to those of diodes D_1 and D_2, and Z_0, Z_{01}, and Z_{02} refer to the characteristic impedances of slotlines A, B, and C, respectively.

The input impedance Z_{I2} of the quarter-wavelength microstrip line is very small in the vicinity of the center frequency. The input impedance Z_{I1} of slotline D is related to Z_{I2} and is independent of the input impedance of slotlines B and C. Therefore the equivalent circuit shown in Fig. 3 can be simplified to the series–parallel connected circuit shown in Fig. 4. Transmission matrices $[F_1]$ and $[F_2]$ for slotlines B and C, respectively, including diodes,

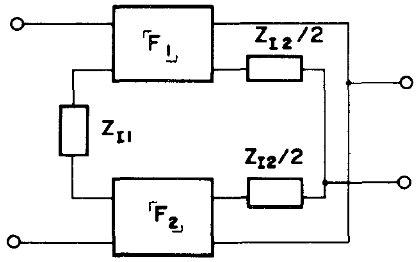


Fig. 4. Schematic diagram of the series–parallel circuit connection including Z_{I1} and Z_{I2}.

are expressed as follows:

$$[F_1]=\begin{bmatrix}\cos\theta & jZ_{01}\sin\theta\\ \dfrac{1}{Z_{d1}}\cos\theta+j\dfrac{1}{Z_{01}}\sin\theta & j\dfrac{Z_{01}}{Z_{d1}}\sin\theta+\cos\theta\end{bmatrix} \quad (1)$$

$$[F_2]=\begin{bmatrix}\cos\theta & jZ_{02}\sin\theta\\ \dfrac{1}{Z_{d2}}\cos\theta+j\dfrac{1}{Z_{02}}\sin\theta & j\dfrac{Z_{02}}{Z_{d2}}\sin\theta+\cos\theta\end{bmatrix} \quad (2)$$

where θ is the electrical length of slotlines B and C. Since Z_{I1} and Z_{I2} are 0 Ω at the center frequency, the overall transfer matrix $[F_t]$ is given by

$$[F_t]=\frac{1}{j\left(\dfrac{Z_{01}}{Z_{d1}}-\dfrac{Z_{02}}{Z_{d2}}\right)}\cdot\begin{bmatrix}2+\dfrac{Z_{01}}{Z_{02}}+\dfrac{Z_{02}}{Z_{01}} & \dfrac{Z_{01}Z_{02}}{Z_{d1}}+\dfrac{Z_{01}Z_{02}}{Z_{d2}}\\ \dfrac{Z_{01}}{Z_{02}Z_{d1}}+\dfrac{Z_{02}}{Z_{01}Z_{d2}} & \dfrac{Z_{01}Z_{02}}{Z_{d1}Z_{d2}}\end{bmatrix}. \quad (3)$$

From (3), input impedance Z_{in} of the circuit is written as

$$Z_{in}=\frac{\left(2+\dfrac{Z_{01}}{Z_{02}}+\dfrac{Z_{02}}{Z_{01}}\right)Z_0+\dfrac{Z_{01}Z_{02}}{Z_{d1}}+\dfrac{Z_{01}Z_{02}}{Z_{d2}}}{\left(\dfrac{Z_{01}}{Z_{02}Z_{d1}}+\dfrac{Z_{02}}{Z_{01}Z_{d2}}\right)Z_0+\dfrac{Z_{01}Z_{02}}{Z_{d1}Z_{d2}}}. \quad (4)$$

If $Z_{01}=Z_{02}=Z_0$, the impedance-matched condition is expressed as follows:

$$4Z_{d1}Z_{d2}=Z_0^2. \quad (5)$$

When $Z_{d1}=0$ and $Z_{d2}=\infty$ (ON state), the insertion loss becomes zero. When $Z_{d1}=Z_{d2}^*=Z_0/2$ (OFF state), the insertion loss is ideally infinite. The calculated insertion loss and return loss as a function of the normalized frequency are shown in Fig. 5. In the calculation, the imaginary parts of Z_{d1} and Z_{d2} are equal to zero and the length of slotline B and C is set to a quarter-wavelength of the center frequency. Thus, the constant-resistance characteristics at the center frequency are predicted. The relative bandwidth of a return loss (> 20 db) greater than 40 percent can be achieved by choosing adequate diode im-

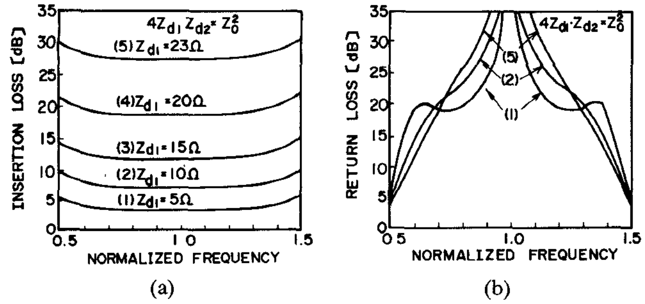


Fig. 5. Insertion loss and return loss variations calculated as a function of normalized frequency for various diode impedances Z_{d1} and Z_{d2}. (a) Insertion loss. (b) Return loss.

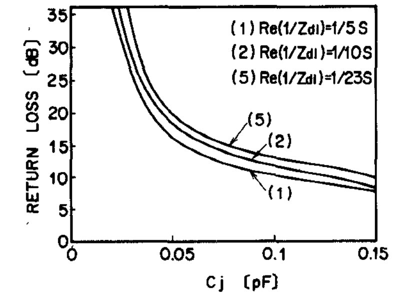


Fig. 6. Return loss degradation calculated as a function of the diode junction capacitance C_j.

pedances. These diode impedances are properly controlled by the applied bias voltage.

In the actual circuit, diodes have such parasitics as the series resistance R_s and junction capacitance C_j. The impedance-matched condition of (5) cannot be satisfied because of capacitance C_j. The return loss degradation caused by the existence of C_j at the center frequency is shown in Fig. 6. A return loss greater than 30 dB can be achieved, when C_j is less than 0.025 pF. On the other hand, the ON/OFF ratio is not degraded by the capacitance, because the infinite insertion loss can be realized by the balanced circuit configuration as long as Z_{d1} is equal to Z_{d2}.

IV. Experimental Results

The constant-resistance ASK modulator has been designed with an input impedance of 50 Ω and a center frequency of 26 GHz. The lengths and line widths of slotlines B and C were a quarter-wavelength (1.4 mm) of 26 GHz and 80 μm, respectively. The circuit was fabricated on an alumina (Al_2O_3) substrate with a thickness of 0.3 mm and a relative dielectric constant of 9.6. Slotlines and microstrip lines were fabricated by conventional photolithographic techniques. Beam-lead Si p-i-n diodes (ALPHA 4380E) were bonded on the slotlines.

The measured insertion loss and return loss are shown in Fig. 7. The bias currents of the two diodes were adjusted to satisfy the conditions of (5). The measured minimum insertion loss was 2.8 dB under the conditions of diode bias current $I_{d1}=0$ and $I_{d2}=100$ mA in the frequency range from 25.0 to 29.5 GHz. The return loss was kept

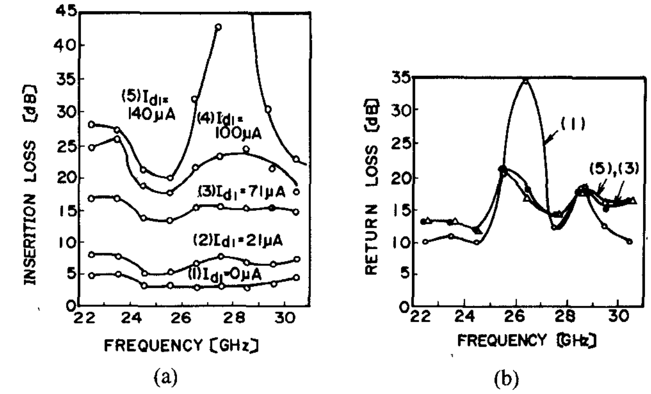


Fig. 7. Insertion loss and return loss variations measured as a function of frequency for various p-i-n diode bias currents. (a) Insertion loss. (b) Return loss.

above 12 dB while the insertion loss was changed from 2.8 to 40 dB.

The diodes used in the experiment had series resistance $R_s=2.5$ Ω and junction capacitance $C_j=0.025$ pF. The minimum insertion loss is estimated to be 1 dB. The remaining loss of 1.8 dB was attributed to the insertion loss of the slot-to-microstrip transition and the conductor loss of the microstrip lines and slotlines. The bandwidth of the insertion loss was narrower than that of the calculated results because of the junction capacitance of diodes and the unbalance of two diode impedances. It is important in designing the constant-resistance ASK modulator to use a pair of diodes which have the same characteristics and very small junction capacitances. However, in spite of the low Q of the diodes (≈ 98), a large ON/OFF ratio was obtained in the narrow bandwidth.

The return loss was less than the calculated value. This is attributed to the junction capacitance and the impedance mismatching of the slot-to-microstrip transition. Since the ASK modulator described here effectively utilizes the balanced circuit configuration, the characteristics of the circuit are strongly affected by the unbalance of the two diodes. The bias voltage must be supplied to equalize the diode impedances.

As the carrier input power increases, the impedance of the reverse-biased diode is changed by the RF voltage swing. However, in the ON state (Fig. 2(a)), the backward bias voltage of diode D_2 can be larger than the RF voltage amplitude. This does not degrade the modulation characteristics. In the OFF state (Fig. 2(b)), both diodes D_1 and D_2 are equally forward biased. Even if the carrier input power increases and the RF voltage amplitude becomes larger than the applied bias voltage, both diodes are still equally self-biased and have the same impedance. This also maintains the constant-resistance condition and the high return loss.

The dynamic performance of the modulation (ASK signal envelope) is shown in Fig. 8. The carrier frequency is 27 GHz and the modulating-signal frequency is 30 MHz. The rise time and the fall time of the envelope are less than 2 ns. The ASK modulator proposed here has high speed

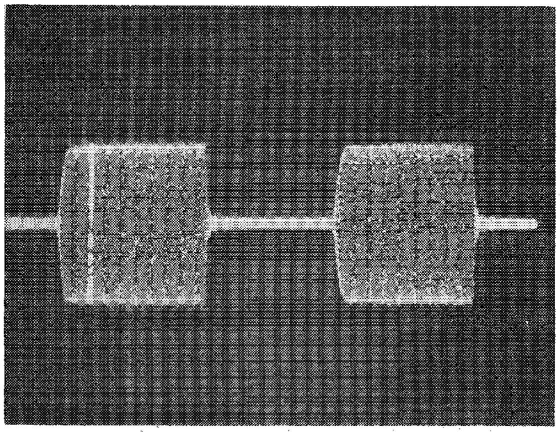


Fig. 8. Dynamic characteristics (ASK signal envelope) of ASK modulator. The carrier frequency is 27 GHz and the modulating pulse signal frequency is 30 MHz. The carrier input power is 10 dBm.

switching performance as well as high return loss characteristics.

V. Conclusions

A new constant-resistance ASK modulator has been proposed using double-sided MIC techniques. The circuit consists of two quarter-wavelength slotlines, two p-i-n diodes, and a slot-to-microstrip transition. The circuit was analyzed and the required matching conditions were calculated. The 26-GHz band ASK modulator was designed and fabricated using photolithographic techniques. With the experimental modulator, a minimum insertion loss of 2.8 dB was obtained, and the ON/OFF ratio was greater than 40 dB. The return loss was kept above 12 dB in the frequency range from 25.0 to 29.5 GHz. The last two results, although comparable to the conventional ASK modulator, were realized without additional circuits. The proposed ASK modulator will be very practical for use in equalizers and variable attenuators, where constant resistance characteristics are desirable.

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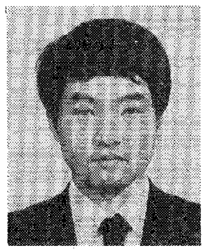

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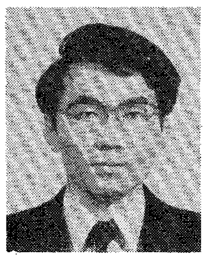

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