

# 8Gbps CMOS ASK Modulator for 60GHz Wireless Communication

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**Abstract** — In this paper we present a millimeter-wave CMOS amplitude-shift-keying (ASK) modulator for 60GHz wireless communication at greater than 1Gbps. It is designed using shunt NMOSFET switches between the signal and the ground line of a transmission line. A reduced-switch architecture is used to achieve high speed. The transmission line length between switches is adjusted to achieve high isolation with a reduced number of switches. A 60GHz millimeter-wave ASK modulator is successfully realized by using a 6-metal 1-poly 90nm CMOS process. The size of the chip is 0.8mm × 0.48mm including the pads. The core size is 0.61mm × 0.3mm. The isolation and maximum data rate of the modulator at 60GHz are measured to be 26.6dB and 8Gbps, respectively. The product of the maximum data rate and the isolation of this modulator is 170GHz, which is the highest value among over-Gbps ASK modulators.

## I. INTRODUCTION

Scaling in CMOS technology has led to the realization of new electronic appliances with a processing power of over 1Gbps and a memory of tens of gigabits. Demand for over-gigabit-per-second (over-Gbps) wireless multimedia communication is increasing. With license-free bandwidths of 9GHz in Europe and 7GHz in Japan, USA, Canada and Korea, the 60GHz millimeter-wave band is promising for realizing short-range over-Gbps wireless communication applications worldwide, where low-cost and low-power wireless multimedia communication is required. Recently, millimeter-wave transceiver building blocks in CMOS have been reported [1,2]. In particular, a millimeter-wave CMOS impulse radio, as shown in Fig. 1, is promising for low-cost and low-power wireless communication, in which a digital switch controls a millimeter-wave CMOS amplitude-shift-keying (ASK) modulator in the transmitter. The receiver receives 60GHz pulses and converts them to a digital signal [3]. In this paper, we report for the first time a design of an 8Gbps CMOS ASK modulator for a 60GHz millimeter-wave impulse radio.

Figure 2(a) shows a conventional millimeter-wave ASK modulator in CMOS [4]. It consists of an oscillator and a buffer. Millimeter-wave pulses are obtained by turning the biasing on and off. Although this architecture has high isolation when the biasing is turned off, the switching speed is limited by the stored energy in the oscillator tank. High-speed conventional distributed traveling-wave millimeter-wave ASK modulators in compound semiconductors have been reported [5-10]. They

were realized using distributed shunt switches between the signal and the ground line of a transmission line as shown in Fig. 2(b). In this architecture, when the switches are off the input signal is transferred to the output and the ASK modulator is in the ON state. On the other hand, when the switches are turned on, no input signal is transferred to the output and the ASK modulator is in OFF state. The distributed structure requires a large number of switches since the resistances of the switches in the OFF state should be small to realize a lossy transmission line.

A possible distributed CMOS modulator is shown in Fig. 3(a). However, low-quality parasitic capacitances in the switches, which are located on a silicon substrate, are expected to degrade the transmission line characteristics. In this study, a reduced-switch architecture is used for a high-speed millimeter-wave CMOS ASK modulator as shown in Fig. 3(b). Note that the isolation characteristics become degraded upon reducing the number of switches since each switch has a leakage to the output. To achieve high isolation with a reduced number of switches, the transmission line length between switches is adjusted. When the millimeter-wave signal travels from the source to the load, the switches do not only dissipate the incident signal, but they also reflect and leak it as shown in Fig. 4. Note that, in a transmission line, impedance transformation between the two terminals occurs as shown in Fig. 5(a). In Fig. 5(b), the calculated leaked, reflected and dissipated powers are shown as a function of the distance between switches. Since the dissipated power in the switches is insensitive to the transmission line length, reflection should be maximized to minimize the leakage. To obtain maximum reflected power and minimum leaked power, the switches are separated by a quarter-wavelength distance. In this case, the isolation is maximized with a lower number of switches.

## II. 60GHZ ASK MODULATOR DESIGN IN CMOS

A 60GHz CMOS ASK modulator is designed with three NMOSFET switches and two quarter-wavelength transmission lines as shown in Fig. 6. When the digital input is 0V, the NMOSFET switches are turned off. Since the parasitic capacitance of each switch in the OFF state is negligible, the input impedance of each transmission line is equal to the load impedance and the input power is transferred to the output. When the digital input is 1V, the switches are turned on. The

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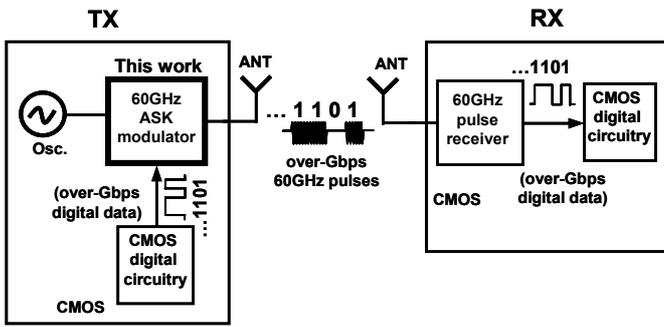
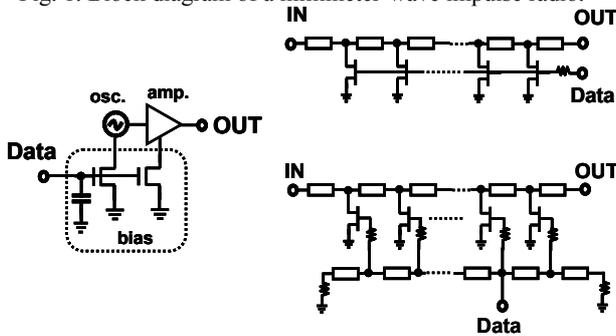


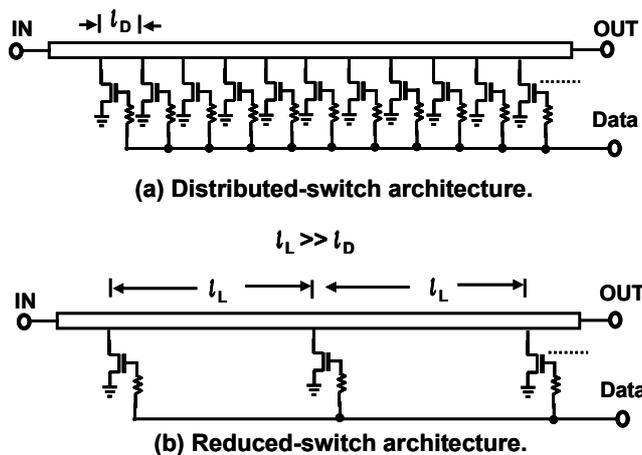
Fig. 1. Block diagram of a millimeter-wave impulse radio.



(a) High isolation ASK modulator.

(b) High speed ASK modulator.

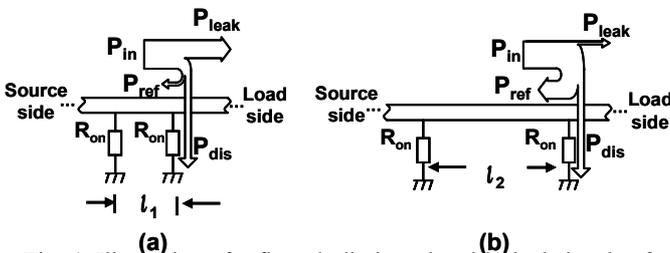
Fig. 2. Architectures of conventional (a) high-isolation and (b) high-speed millimeter-wave ASK modulators.



(a) Distributed-switch architecture.

(b) Reduced-switch architecture.

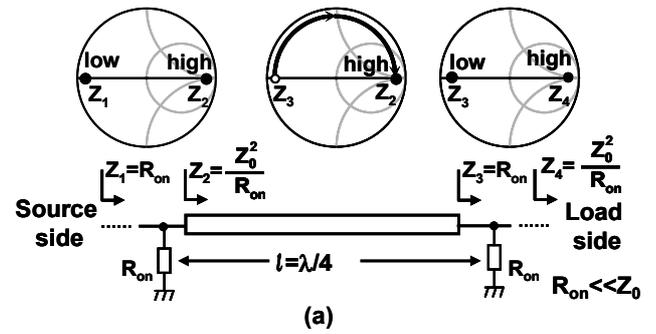
Fig. 3. Architectures of (a) distributive and (b) reduced-switch ASK modulators in CMOS process.



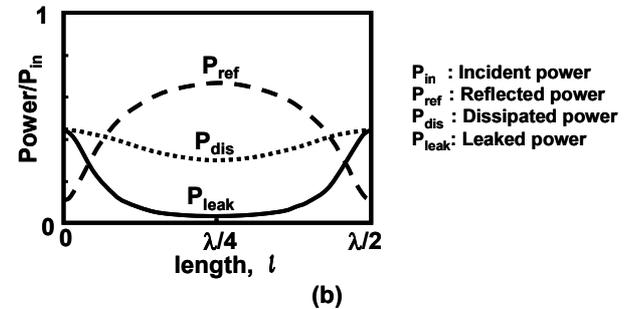
(a)

(b)

Fig. 4. Illustration of reflected, dissipated and leaked signals of a switch in the OFF state of the modulator for two different transmission line lengths (a) and (b) when the millimeter-wave signal travels from source to load.



(a)



(b)

Fig. 5. (a) Impedance transformation along the modulator and (b) calculated reflected, dissipated and leaked powers as a function of the transmission line distance between switches.

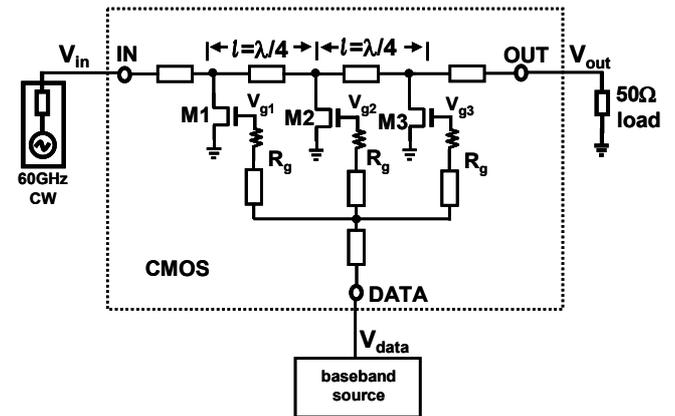


Fig. 6. Circuit schematic of the CMOS ASK modulator for 60GHz wireless communication.

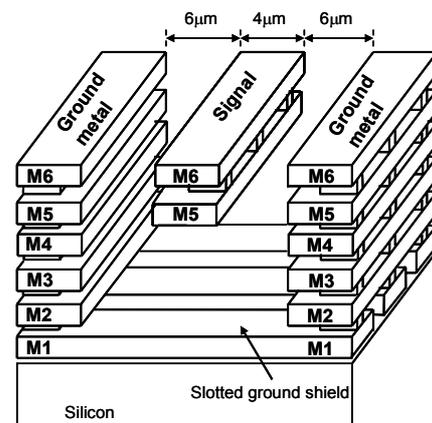


Fig. 7. Structure of the slow-wave transmission line used in the circuit.

transmission line with a quarter wavelength transforms the low impedance of the switch to a high impedance and reflection is maximized. In this case, the leaked power to the output is minimized and high isolation is achieved.

Millimeter-wave NMOSFET models are established by extracting the parasitic components based on on-wafer measurements. The slow-wave transmission line (SWTL) [11] shown in Fig. 7 is used for implementing the quarter-wavelength transmission lines and the networks between the circuit and the pads to reduce the size of the modulator. In the SWTL, a slotted ground shield under the signal line is laid orthogonal to the direction of the signal current flow. This structure results in the propagating waves having lower phase velocity; thus, the corresponding wavelength at a given frequency is reduced. A quarter wavelength is obtained using a 450- $\mu\text{m}$ -long SWTL. Note that the quarter wavelength would be 850 $\mu\text{m}$  if a microstrip line (MSL) was used.

200 $\Omega$  gate resistors are inserted to ensure operation with sufficient stability at high speed. Transient internal waveforms are simulated as shown in Fig. 8. A 200ps pulse is applied from the data port to analyze the response of the circuit. The total time of the rising and falling gate voltages is estimated as 125ps, which corresponds to the maximum data rate of 8Gbps. The 60GHz millimeter-wave ASK modulator is fabricated by a 6-metal 1-poly 90nm CMOS process. The cutoff frequency  $f_T$  and the maximum operation frequency of the nMOSFET are 130GHz and 150GHz, respectively. Figure 9 shows a micrograph of the fabricated ASK modulator. The size of the chip is 0.8mm  $\times$  0.48mm including the pads. The core size is 0.61mm  $\times$  0.3mm.

### III. EXPERIMENTAL RESULTS AND DISCUSSION

On-wafer two-port measurements were performed up to 110-GHz with Anritsu ME7808 network analyzer with transmission reflection modules for the ON and OFF states by applying 0V and 1V DC voltages to the gate terminal, respectively. The measured and simulated insertion losses of the modulator for the two states are shown in Fig. 10 for comparison. The insertion losses in the ON and OFF states are 6.6dB and 33.2dB, respectively, at 60GHz. Isolation is defined as the insertion loss difference between the ON and OFF states, which is 26.6dB. The isolation is nearly flat from 20 to 80GHz, although the maximum isolation is measured at 60GHz. As a result, shorter transmission lines may be adopted to reduce the insertion loss caused by the SWTL in the ON state of the modulator. The simulated isolation is shown at frequencies up to 350GHz in Fig. 11 to demonstrate the frequency behavior of the modulator. The minimum isolation appears at 60GHz when the electrical length of the transmission lines is  $\lambda/4$ , where  $\lambda$  is the wavelength. Local maxima in the OFF-state insertion loss occur at 180GHz and 300GHz, which correspond to  $3\lambda/4$  and  $5\lambda/4$ , respectively.

The time-domain response is measured using a 70GHz sampling oscilloscope, a 60GHz millimeter-wave source module and a pattern generator. No external filters are applied

in the measurement. A 60GHz continuous wave is applied to the RF input and the modulator is controlled by the pattern generator. The rising and falling times of the applied baseband signal are 6ps and 8ps, respectively. The output response for the maximum data rate is shown in Fig. 12(a). In Fig. 12(b), the output response is shown for a 125ps single-baseband pulse by reducing the scale to 20ps.

The maximum data rates as a function of the isolation of the millimeter-wave ASK modulators are shown in Fig.13. It can be seen that the isolation and the maximum data rate have a tradeoff relationship. The product of the maximum data rate and the isolation of this modulator is 170GHz, which is the highest value among over-Gbps ASK modulators.

### IV. CONCLUSION

A 60GHz millimeter-wave band ASK modulator was successfully fabricated by a 6-metal 1-poly 90nm CMOS process. The maximum isolation at 60GHz was obtained by adjusting the transmission line length. The isolation and maximum data rate of the switch were measured to be 26.6dB and 8Gbps, respectively. The ASK modulator does not consume DC operating power. Results indicate that a very high data rate can be obtained at a 60GHz millimeter-wave band using a standard CMOS process.

### ACKNOWLEDGEMENT

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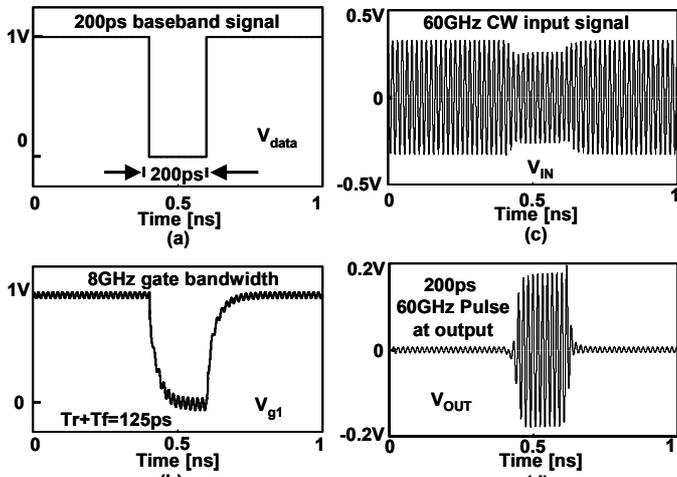


Fig. 8. Transient simulation; (a) 200ps applied data pulse, and responses of (b) the gate voltage of the NMOSFET switch, and (c) input and (d) output signals.

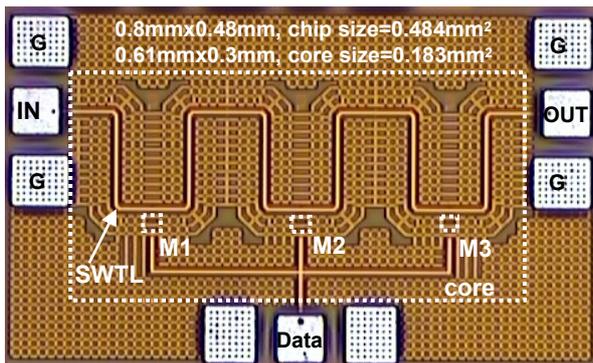


Fig. 9. Micrograph of the fabricated chip.

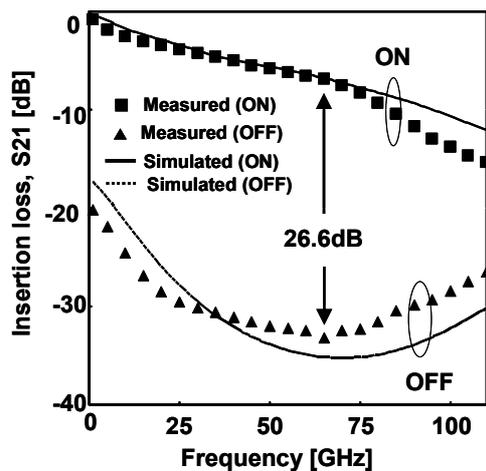


Fig. 10. Measured and simulated insertion loss (S21) of the ASK modulator for ON and OFF states.

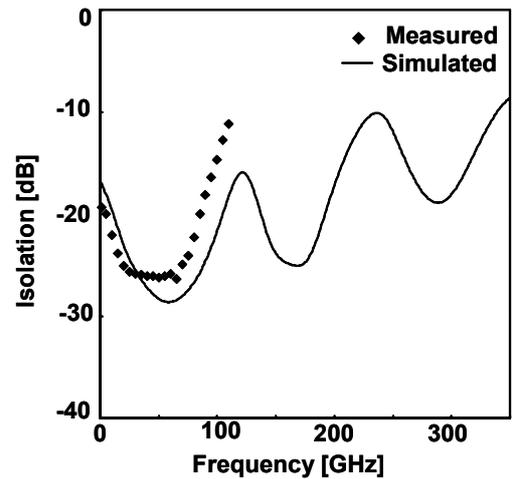
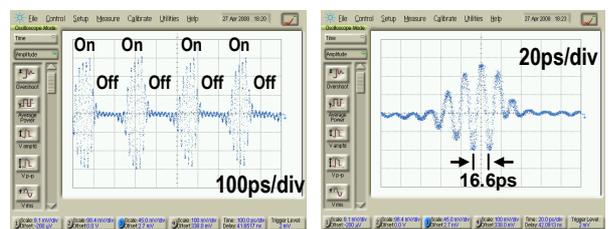


Fig. 11. Measured and simulated isolation of the ASK modulator.



(a) (b)

Fig. 12. Measured output response of the modulator for (a) an 8Gbps data train and (b) a single 125ps data pulse.

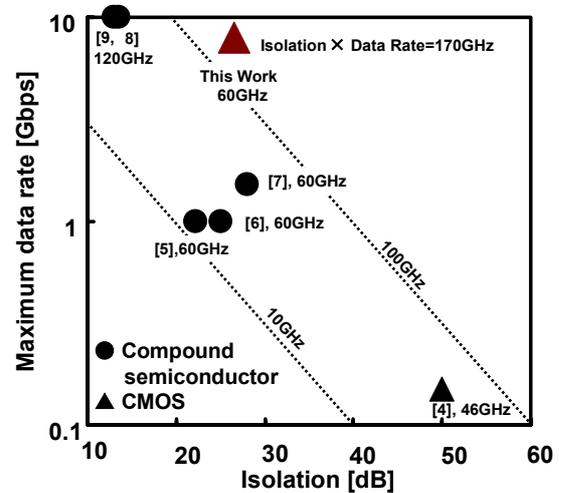


Fig. 13. Maximum data rates as a function of isolation of the ASK modulators.