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A BPSK Modulator Using A Ring-Hybrid And HFET Switches

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Abstract — **A binary phase-shift keying(BPSK) modulator using a microstrip ring-hybrid and HFET switches is proposed here. The fabricated BPSK modulator works from 3.2GHz to 3.5GHz with output amplitude balance less than 1dB and phase balance within 2° of ideal 180°. Its conversion loss is around 6.7dB and relative flat across this frequency range. Around its center frequency, the amplitude balance is less than 0.1dB and the phase balance is almost ideal 180°. This results in a perfect square-wave modulation spectrum with carrier suppression over 40dB and spurious suppression over 33dB. The fabricated modulator has better power performance than the previously-published modulators.**

Index Terms — **BPSK modulator, HFET, hybrid, microstrip, switch.**

I. INTRODUCTION

Direct-digital modulation can dramatically reduce size, weight and power consumption of a transmitter system by eliminating the IF circuit and the upconverter circuit used in heterodyne systems, and thus are very suitable for onboard or portable wireless systems, such as satellite communication system and wireless personal area network (WPAN).

There are some common techniques developed to achieve direct BPSK modulation. Mixer-type techniques using Gilbert-cell mixer[1][2][3], ring-mixer[4] or sub-harmonic mixer[5] usually have high LO-to-RF isolation due to their balanced topologies (Gilbert-cell mixer and ring-mixer) or different LO and RF frequencies (sub-harmonic mixer). These modulators have been demonstrated to have good performance below 10GHz. Over 10GHz, their performance degrades due to the frequency limit presenting on their devices. Switch techniques engaging transmission-line circuits and switches do not have this frequency limit, however, and can work from low microwave frequency up to millimeter-wave frequency. Reflection-type modulators [6]-[9] are popular among these switch techniques. Although they can be designed to also work at low microwave frequency, most of them are designed for operation at millimeter-wave frequency to reduce their sizes, because of the four couplers/hybrids they use, which are proportional to their carrier wavelength. The other switch techniques utilizing a single-pole-double-throw (SPDT) switch with an active 180° balun [10][11] can be alternatives to the reflection-type topologies. MEMS switches [12][13] have also been tested for this purpose.

A BPSK modulator using a microstrip ring-hybrid and two GaAs HFET switches is proposed and demonstrated here. It is specifically suited for BPSK modulation because the ring-hybrid generates almost ideal 180° phase difference between two carrier paths controlled by the two GaAs HFET switches, resulting in high carrier suppression and high spurious suppression. The two HFET switches are in a common-gate configuration, which has been used in other mixer-type circuits such as [14][15]. The modulator presented in this paper has better power performance than the previous switch techniques due to its passive and distributed topology. The rest of this paper is organized as follows. The proposed BPSK modulator circuit is described in Section II and the experimental results from the fabricated modulator are presented in Section III. Section IV gives a conclusion of this paper.

II. CIRCUIT DESCRIPTION

A circuit diagram of the BPSK modulator is shown in Fig. 1, where the carrier signal from a local oscillator (LO) is divided into two in-phase carrier signals by a Wilkinson power divider. These two signals are then fed to two common-gate HFET transistors, whose gates are controlled by two complementary voltages V_{Data} and $\overline{V_{Data}}$ from the modulation data. They work as two RF switches for the two carrier signals and switch on and off alternatively according to the modulation data. Only one carrier signal is allowed to pass them at all time. The other carrier signal is mostly reflected back from the off transistor and dissipated in the Wilkinson power divider. It will be demonstrated in Section III that there is very small portion of the reflected signal presenting at the input port of the power divider. The resistors R_1 and R_2 at the gates of the two HFETs provide

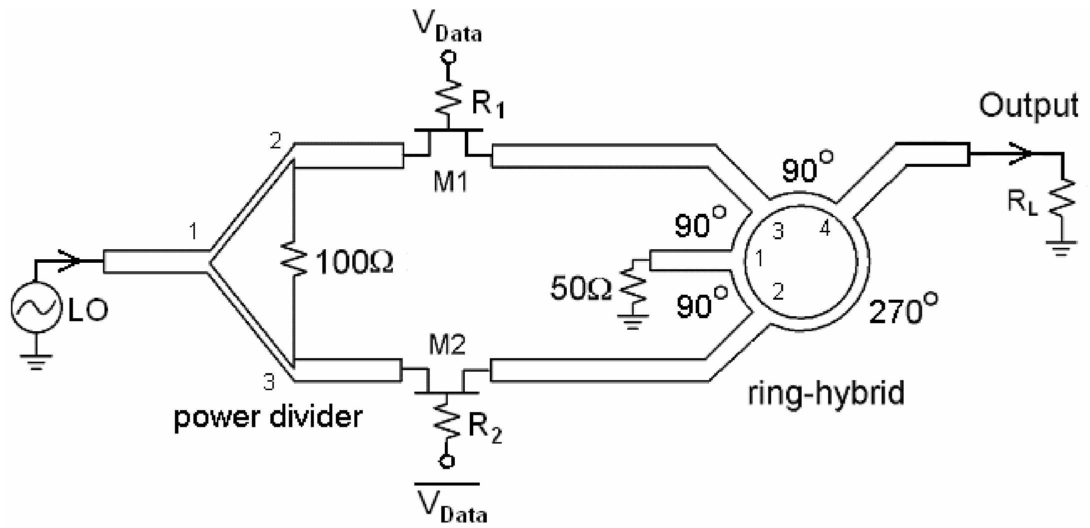

Fig. 1. Circuit diagram of the BPSK modulator.

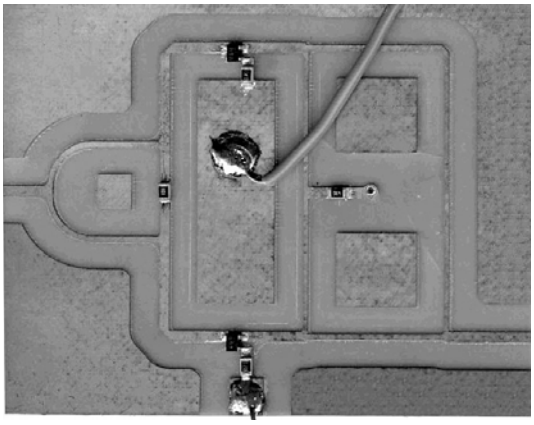

Fig. 2. A photograph of the fabricated BPSK modulator.

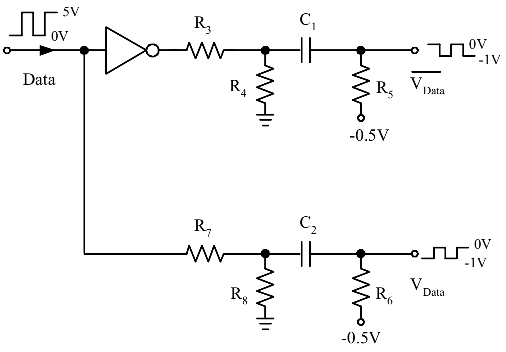

Fig. 3. The external modulation drive circuit.

the isolation and prevent the high-frequency LO carrier from being coupled to the external modulation drive circuit. After the switches, the carrier signal, either the top one or the bottom one, enters an 180º ring-hybrid at its port 3 or port 2. The modulator output is picked up at its port 4, i.e. the difference port of the ring-hybrid. As illustrated in Fig. 1, there is a 90º phase delay from the port 3 to the port 4 (the top path), while there is a 270º phase delay from the port 2 to the port 4 (the bottom path). This indicates an 180º phase difference between the two carrier paths. As a result, the alternative switching of the top carrier and the bottom carrier according to the modulation data will produce an 180º phase switching at the modulator output, as expected for a BPSK modulator.

III. EXPERIMENTAL RESULTS

The proposed BPSK modulator was fabricated using a microstrip substrate with a relative dielectric constant of 3.2 and a thickness of 0.02 inches. A photograph of the microstrip circuit is illustrated in Fig. 2. The Wilkinson power divider and the ring–hybrid were designed for a center frequency of 3.3GHz and the ring-hybrid has a rectangular geometry to ease the milling machining. The used GaAs HFET transistors were packaged devices (NE34018CT) from NEC. According to their property, the required gate-source voltages to turn on and off these devices are 0V and -1V respectively. Thus an external modulation drive circuit was required to convert the modulation data from their standard 5V level to the proper level to drive the two HFETs. This was done by passing the standard data and their inverted data through two voltage dividers, comprising R_3/R_4 and $R_7/R8$ respectively, as shown in Fig. 3. Thereafter two DC biases (-0.5V) were introduced into these data by the capacitors C_1 and C_2 and the resistors R_5 and R_6. It finally resulted in the required two complementary control voltages, V_{Data} and $\overline{V_{Data}}$, switching between 0V and –1V in accordance with the input modulation data.

Fig.4 shows the measured conversion loss (S21) and input reflection coefficient (S11) of the fabricated BPSK modulator in the two different output phase states in accordance with the modulation date of bit “1”(State 1) and bit “0”(State 2) respectively. The conversion loss for both states was around 6.7dB at the center frequency of 3.3GHz and relatively flat across a frequency range from 3.2GHz to 3.5GHz. This loss was a sum of 3dB loss from the Wilkinson power divider and the other 3dB loss from the ring-hybrid, plus a small loss from the transmission-lines and the input/output inter-connectors. The input reflection coefficient for both states was lower than –22dB across the frequency range from 3.2GHz and 3.5GHz, an excellent input matching for this BPSK modulator.

It is shown in Fig. 4 that there is not much conversion loss difference between the two output phase states. This is illustrated more clearly in Fig. 5, with the measured output amplitude balance and phase balance for the two states. It can be noted that from 3.2GHz to 3.5GHz, the amplitude difference was less than 1dB and the phase difference was from 178° to 181°, within 2° of the idea 180°. Especially at the vicinity of 3.3GHz, the amplitude difference was 0.1dB and the phase difference was exactly at 180°, indicating the best operation frequency point of this BPSK modulator.

A modulation experiment was then carried out at the carrier frequency of 3.3GHz. The complementary control voltages of the two HFETs came from the external modulation drive circuit shown in Fig. 3. A square-wave data with data rate of 4Mb/s was tested in this modulation, with input carrier power of –1dBm. Fig. 6 presents the measured output frequency spectrum from an Agilent E4446A spectrum analyzer. Extremely high carrier suppression over 40dB was achieved in this measurement. Moreover, the suppressions of all spurious spectra were over 33dB. It was very close to an ideal BPSK modulation spectrum.

Furthermore, to examine the power performance of the fabricated BPSK modulator, the fundamental and second-harmonic output powers versus the input power in the output phase state corresponding to the data bit “1” was measured and shown in Fig. 7. The other state (for the data bit “0”) has similar power performance due to the nearly equal conversion loss for the two states. The input 1-dB compression point (P1dB) was measured to be 1dBm. Note that the suppression of the second-harmonic output compared to the fundamental output is 21dB at this P1dB point. The maximum output power is –3dBm and the input second-order intercept point (IIP2) is 8.2dBm according to Fig. 7.

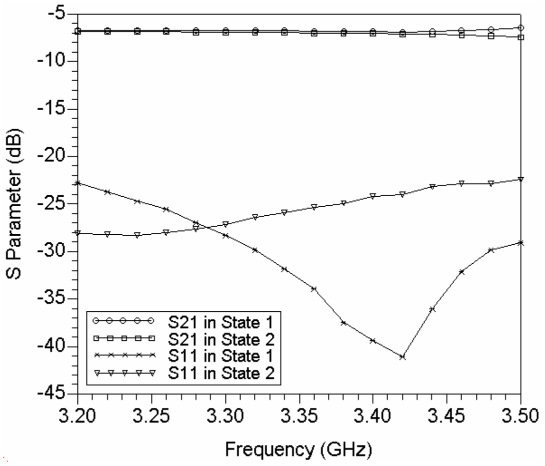

Fig. 4. The conversion loss (S21) and the input reflection (S11) in the two states of the HFET switches (State 1: M1 on and M2 off, 90° phase output; State 2: M1 off and M2 on, 270° phase output).

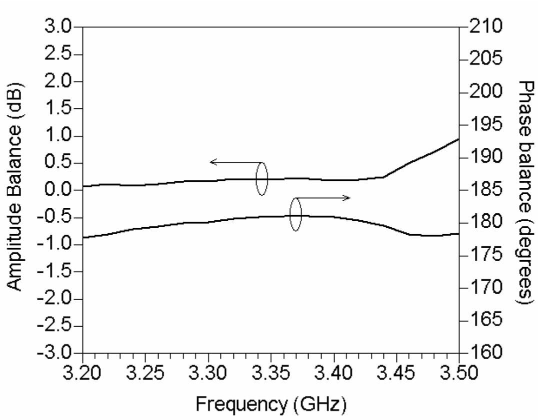

Fig. 5. The output amplitude balance and phase balance in the two states.

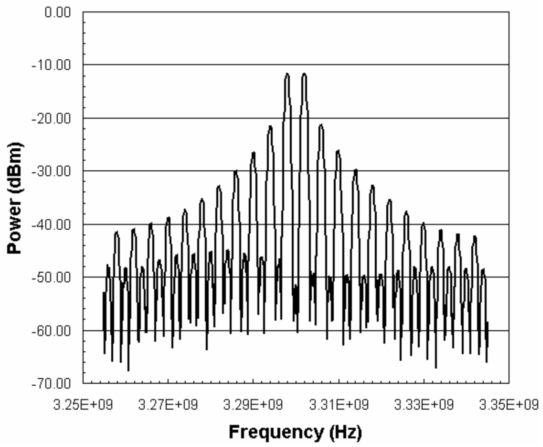

Fig. 6. The measured output frequency spectrum with a modulation data rate of 4Mb/s (Input LO power: -1dBm).

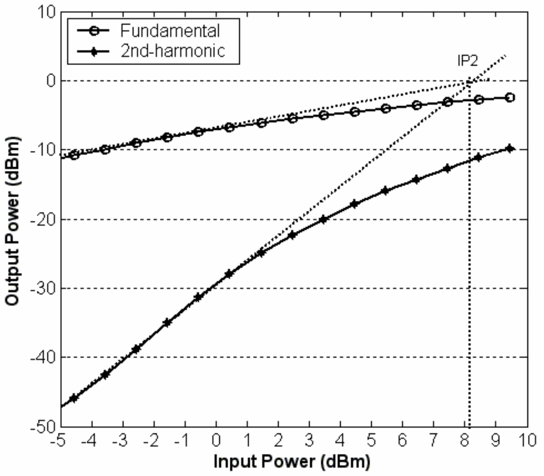

Fig. 7. The measured fundamental and second-harmonic output powers versus the input power in the state corresponding to data bit "1".

IV. CONCLUSION

A BPSK modulator using a microstrip ring-hybrid and HFETs switches is proposed and demonstrated here. It can achieve very precise output phases for the two output phase states, resulting in a perfect output spectrum with over 40dB carrier suppression and over 33dB spurious suppression. The fabricated BPSK modulator has good matching and consumes nearly zero DC power. Due to its passive and distributed topology, the modulator can transmit higher RF power than the previously-published BPSK modulators, thus it is suitable for it to be directly integrated with an antenna to transmit digital data. Higher modulation data rate for this modulator will be possible if the external modulation drive circuit is also integrated.

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