2.4 GHz direct-digital binary phase shift keying modulator using MEMS switch

B.R. Jackson and C.E. Saavedra

A novel MEMS-based binary phase shift keying direct-digital modulator operating at a carrier frequency of 2.4 GHz is presented. The circuit is composed of a rat-race coupler and a single-pole double-throw MEMS switch controlled by a digital baseband signal. The coupler divides the input waveform into two signals that are 180° out of phase and the MEMS switch is used to select between these two signals. This circuit has been experimentally verified and results are reported.

Introduction: In binary phase shift keying modulation (BPSK), the phase of the carrier signal varies in discrete steps of 180° when there is a bit transition in the baseband digital data signal. Several circuits have been proposed to achieve BPSK modulation at microwave carrier frequencies [1, 2]. BPSK modulators can be implemented using a switching-type mixer with either transistors or diodes. Such modulators can have significant insertion loss. Microelectromechanical (MEMS) switches have several advantages over solid-state switches including higher isolation, lower insertion loss, and extremely wide bandwidths [3–5].

In this Letter, a novel MEMS-based direct digital BPSK modulator using a 180° ring hybrid and a MEMS switch is proposed and demonstrated. Direct modulation has the significant advantage of eliminating the need for IF modulation and upconversion stages by modulating the RF carrier directly with a digital bit stream, consequently reducing the size and complexity of the circuit. To the best of the authors' knowledge, only one other MEMS-based modulator has been proposed to date, yet it employs a significantly different approach by using a distributed MEMS transmission line [6].

Circuit description: A diagram of the BPSK circuit is shown in Fig. 1. A ring hybrid, or rat-race coupler, is used to equally split the input carrier waveform into two signals with a 180° phase difference at the output ports of the coupler. A single-pole double-throw (SPDT) MEMS switch, controlled by the baseband digital bit stream, is used to connect either one of the two signals from the rat-race coupler to the output of the circuit, thus achieving BPSK modulation.

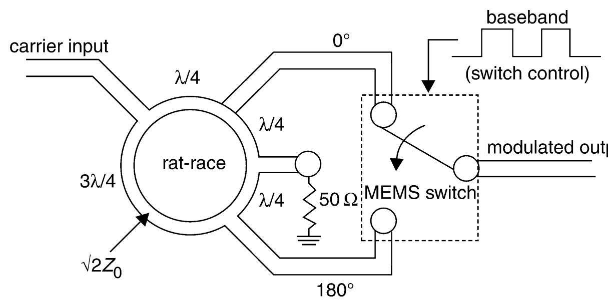

Fig. 1 *Diagram of proposed BPSK modulator*

The MEMS switch used in this work is a packaged, commercially available, magnetically actuated device [7]. It is designed for signals from DC to 6 GHz and has an insertion loss of <0.5 dB and isolation >45 dB throughout this band. The operational principle of this class of MEMS devices [8] is based on the preferential magnetisation of a cantilever. The cantilever can have either a clockwise or a counter-clockwise torque in a constant, perpendicular magnetic field, depending on the angle between the cantilever and the field. A current pulse through a coil can change the magnetisation alignment of the cantilever, thus changing the direction of the magnetic torque causing the cantilever to change states. The switch maintains its state until the next switching signal realigns the cantilever magnetisation. The switch consumes no power while in the latched state, but does consume power when a control current pulse is applied. A significant advantage to using this switch is the relatively low actuation voltage required (approximately ±5 V). Electrostatically actuated MEMS switches typically require 30–80 V to change the state of the switch [9], making integration with CMOS or bipolar electronics challenging.

Currently, one of the few challenges with RF MEMS switches, in general, is their relatively slow switching speed compared to FET transistors and PIN diodes. The switch used in this work takes approximately 200 μs to change states. Clearly the data rate of the modulating signal cannot exceed the maximum switching rate if the modulator is to maintain correct operation. Therefore, the data rate limit imposed by this MEMS switch is approximately 5 kbit/s, with much better performance expected at lower data rates. As MEMS technology continues to develop, the switching speed will be reduced, thus increasing the maximum data rate of the proposed modulator topology.

Experimental results: To experimentally verify the proposed BPSK modulator, the rat-race coupler and passive circuitry were designed on a microwave substrate with a relative dielectric constant of 3.2 and thickness of 0.5 mm. The centre frequency of the rat-race coupler was 2.4 GHz, corresponding to the carrier frequency. Three measurements were performed on the modulator: (*a*) phase balance between the two output signals of the coupler after the MEMS switch and (*b*) the insertion loss of the modulator, and (*c*) the output spectrum of the BPSK signal. Fig. 2 shows the simulated and measured phase difference between the two output signals of the rat-race coupler. To perform this measurement, the switch was held constant in one position and the phase of the signals was recorded using a network analyser. The switch was then held stationary in the other position while the same measurement was taken. In simulations, an ideal switch was assumed. There is less than a 2° difference from the ideal 180° phase difference at 2.4 GHz.

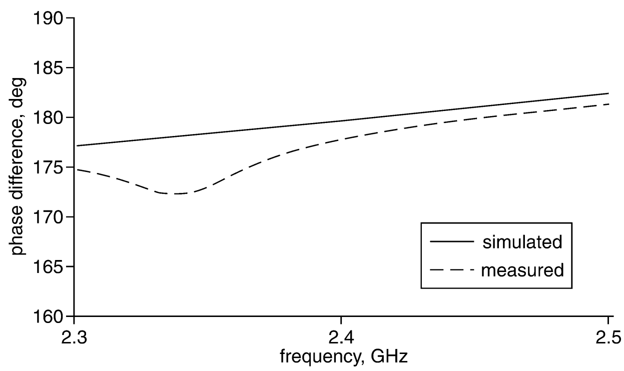

Fig. 2 *Simulated and measured BPSK carrier output phase difference*

The insertion loss for the modulator was simulated to be approximately 3.3 dB assuming an ideal switch. The measured values showed a loss of 3.8 and 3.9 dB in each of the two switch states with the slightly larger loss being caused by the longer transmission line in the rat-race. The MEMS switch therefore contributes approximately 0.5 dB of loss to the system. The spectrum of the BPSK modulator is shown in Fig. 3. The digital control signal is a ±4.5 V square-wave with a frequency of 1 kHz corresponding to a 2 kbit/s data rate. The carrier suppression was measured to be approximately 9 dB.

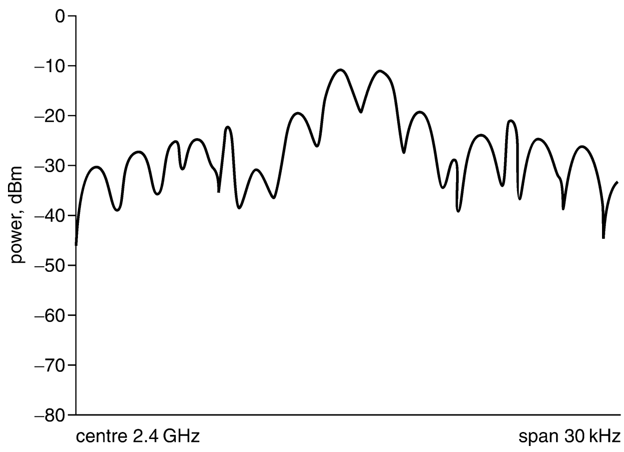

Fig. 3 *Spectrum of BPSK modulator with carrier frequency of 2.4 GHz and 1 kHz square-wave modulating signal*

Since current control pulses are continuously being sent through a coil to change the state of the switch, the power consumption for this magnetically actuated device is somewhat high at approximately 0.4 W. If an electrostatically actuated switch was employed, the power consumption would be much lower, but the actuation voltage would likely be significantly higher.

Conclusions: A novel direct-digital BPSK modulator has been proposed and experimentally demonstrated. The MEMS switch utilised requires a relatively low actuation voltage, which makes the integration of this circuit with CMOS or bipolar electronics a realistic possibility. Another important advantage of this approach is the low insertion loss of the modulator. The topology proposed here becomes even more attractive at millimetre-wave frequencies as the dimensions of the passive components are reduced.

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