DRIVERLESS PHASE SHIFTERS

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Abstract

Characteristics of two novel microwave semiconductor switching devices which do not require forward current for switching are described. These devices effectively eliminate the need for drivers in phased array antennas; hence, greatly reducing the cost of phased array radars.

Introduction

Semiconductor diode switches and phase shifters reported in the past have used either a PIN or varactor diode as the control element. The varactor has primarily been used for analog phase shifter applications and its use has been limited to low power levels due to the modulation of the non-linear capacitive-voltage characteristics with high power. The PIN diode has extended the power handling capabilities of diode phase shifters up into the kilowatt region. The major drawback to PIN diode switches is that they require two bias levels of opposite polarities with 50 to 100 mA of drive current required in one state. The net result is that in a large phased array, the cost of the drivers is very expensive, typically the same order as the phase shifters.

Two new RF switching devices, the "field effect diode" and the "resistive gate switch" do not require current to switch. These devices switch with only a voltage change. In addition, they can operate directly from computer logic levels, thus eliminating the requirement for an expensive driver, and they require holding power on the order of microwatts compared to 0.1 watts for a conventional PIN diode switch. This reduction in control power is important since the prime control power requirements for a phased array with several thousand elements is very large, typically on the order of several kilowatts. This problem is particularly severe in airborne or space applications. Phased array control power can be reduced to a level of several watts by using devices which do not require current to switch.

Work on semiconductor driverless phase shifters began at Hughes Ground Systems in 1969. Work initially began on phase shifters using a field effect diode which operates as an RF switch with a small voltage change. Recently, Hughes has developed the resistive gate switch[1] which also operates with only a voltage change, and in addition, it offers the promise of much higher RF power operation than the field effect diode. Work on components using this new device is currently under way.

Comparison of RF Switching Devices

The field effect diode and the resistive gate switch are compared with other microwave semiconductor switching devices in Figure 1. The PIN diode has a constant capacitive-voltage characteristic and is useful for power levels into the kilowatt range. The PIN diode switch requires two bias levels of opposite polarity. In one bias state, the PIN diode draws about 50 mA at one volt and in the opposite state one microamp at -100 volts. In a large phased array with thousands of elements, the driver power requirement including the driver may be in the range of 2 to 5 kilowatts. The varactor does not require forward bias, but has a non-linear capacitance-voltage characteristic with high RF power. The field effect diode has two regions where the capacitance is independent of the voltage and, therefore, is capable of much higher power than the varactor diode. The major drawback to the field effect diode is that it has a very fast response time and essentially follows the RF voltage swing. RF peak power capacity is, therefore, limited by the allowable RF swing in the two flat capacitance regions. The resistive gate switch has two regions where the resistance is independent of voltage. The resistance of these two regions is different by a factor of typically 500 to 1000. Because of its unique construction there is a capacitance associated with each constant resistance region, hence, each has a time constant. During the fabrication process, these time constants can be adjusted so that the device will change state within the required switching time interval, and at the same time be much slower than the period required for an RF cycle. This means that the resistive gate switch is slower compared with the varactor or field effect diode, but it can handle much higher peak powers because the RF voltage can overswing the "static" voltage regions of the device with no effect. Since the bias voltage controls the resistance of the device, large variations of bias voltages on the order of ±10 percent can be tolerated with no change in phase shift. The switching time of this device is still in the order of 10 microseconds.

Components Developed Using Field Effect Devices

The field effect diode was developed for the specific purpose of obtaining phase shift at microwave frequencies without the use of forward bias. A measured capacitance and series resistance characteristic for the device is shown in Figure 2. At zero bias, the capacitance is about 10 picofarads with a series resistance of about 3 ohms. At a voltage of about 3 volts both the capacitance and resistance start to decrease reaching a minimum value at a bias of about 8 volts. Both the resistance and capacitance are independent of voltage out to the breakdown voltage which is typically 15 to 25 volts.

Several circuits incorporating field effect devices have been developed and fabricated by Hughes Ground Systems. Figure 3 shows a photo of an L-Band SP2T FED switch etched on a 1" x 1" alumina microstrip substrate. This switch uses two shunt mounted FED switches spaced a quarter wavelength distance from a common junction. When one switch is biased "OFF" to a short circuit condition, the other is biased "ON" to a pass condition.

Figure 4 shows the measured performance of the switch. The isolation of the "OFF" arm is greater than 20 dB over a 15 percent bandwidth. Insertion loss from the input to the pass arm is less than 0.5 dB and input VSWR is less than 1.5 over the same bandwidth.

Figure 5 shows a photo of an L-band, 3-bit FED phase shifter etched on an 8" x 9" teflon fiberglass microstrip circuit board. The phase shifter uses a hybrid coupled ring for the 180° bit. The 90° and 45° bits are combined into a "spoke" design on a second ring hybrid. Figures 6 and 7 show the measured performance of the phase shifter. Average loss is about 1.8 dB, and the average VSWR is less than 1.5 over a 15 percent bandwidth. Phase shift is within $\pm 3^{\circ}$ for any step at midband.

References

1. MOS-Type Switch Boon to Radar, Electronics, July 3, 1972, pp. 30-31.

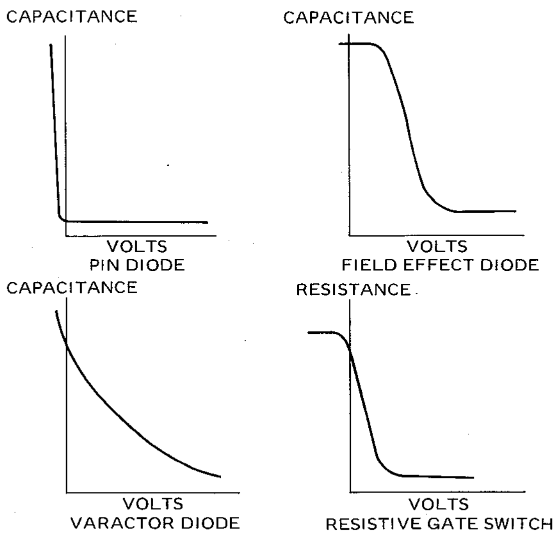

Figure 1. Comparison of PIN, Varactor, Field Effect Diode and Resistive Gate Switch

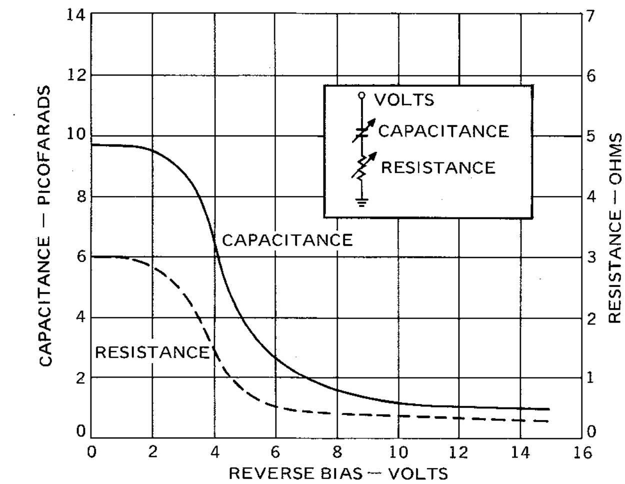

Figure 2. Measured Resistance and Capacitance of Field Effect Diode

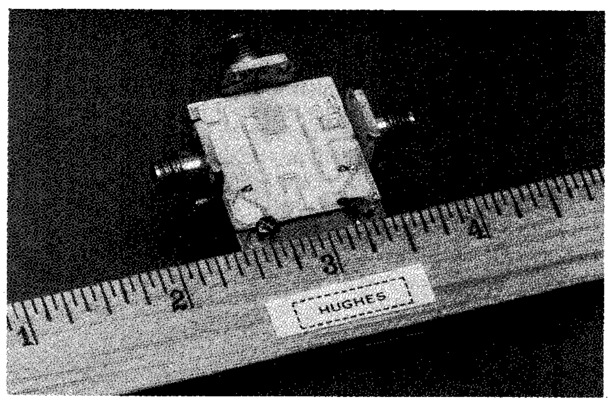

Figure 3. Micromin L-Band SP2T Field Effect Diode Switch

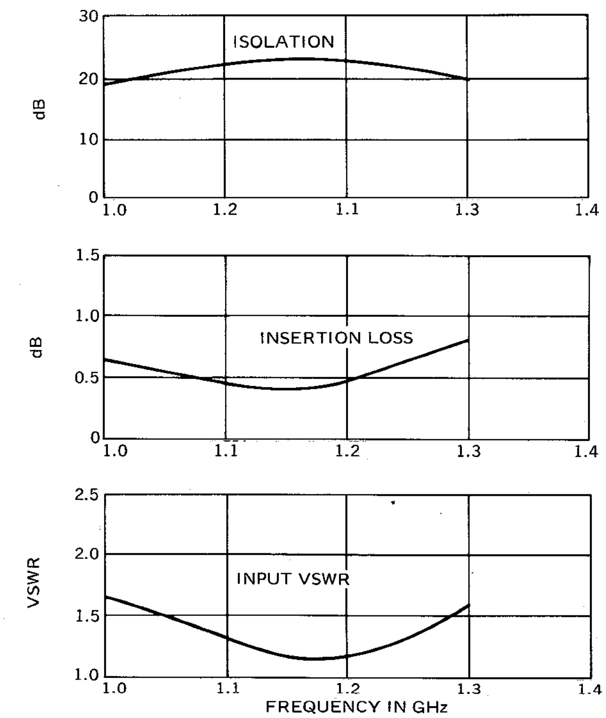

Figure 4. Performance of SP2T FED Switch

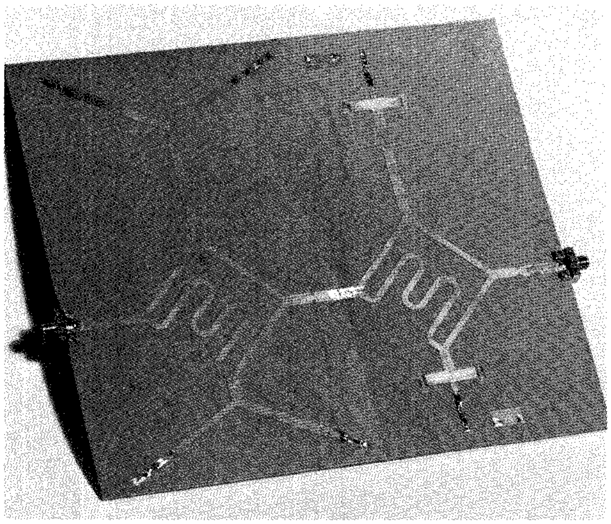

Figure 5. L-Band 3-Bit Field Effect Diode Phase Shifter

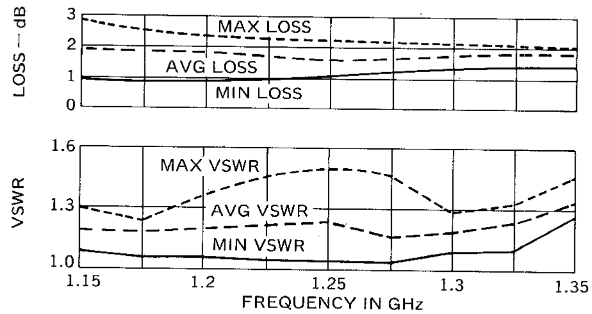

Figure 6. VSWR and Loss for 3-Bit FED Phase Shifter

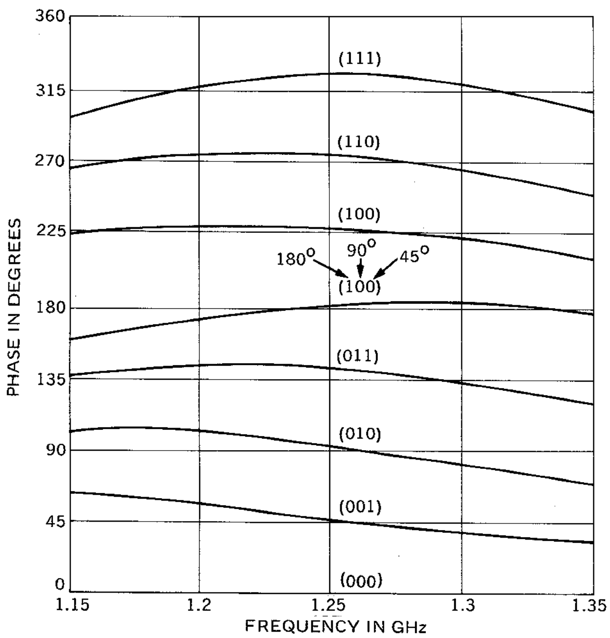

Figure 7. Phase Shift for 3-Bit FED Phase Shifter

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