GaAs MMIC Based Control Components with Integral Drivers

Rev. V5

Introduction

This application note describes the fundamental operation and features of a new series of control components. These switches comprise a family of devices that use GaAs FET MMIC technology for the RF circuitry and incorporate application specific integrated circuit (ASIC) technology to realize an integral TTL or CMOS compatible driver. The circuitry is housed in ceramic surface mount packages that give repeatable and predictable performance from DC to 3 GHz.

GaAs MMIC Switch Technology

This family of switches is based on metal semiconductor field effect transistor (MESFET) technology. The MESFETs are N-Channel depletion mode devices with 1 µm Schottky gates. Depletion mode devices are low resistance at 0 bias. When a negative voltage is applied to the gate, the electric field begins to narrow the channel, increasing the resistance. The voltage that closes off the channel and creates the highest resistance of the MESFET device is known as the "pinch-off" voltage. Pinch-off voltages for M/A-COM MESFETs are typically –2.5 volts.

By varying the gate voltage between 0 volts and some value greater than pinch-off (typically –5 to –8 volts), the MESFET acts as a variable resistor. MESFETs can be arranged into series and/or shunt configurations and biased to provide *on* and *off* switching characteristics. A representative schematic for a GaAs MMIC switch chip is shown in Figure 1.
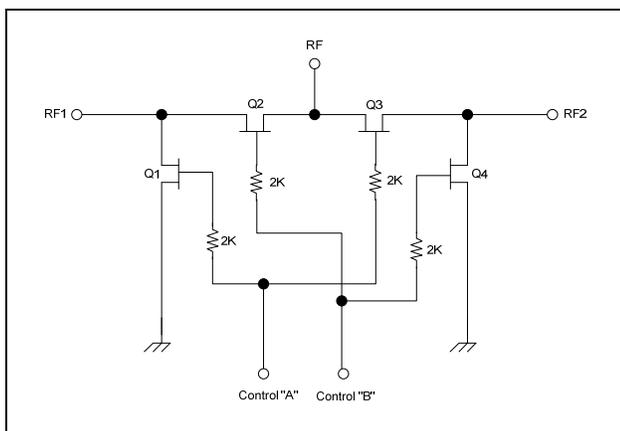

Figure 1. Schematic for MASW6010

The voltages at control inputs A and B are complementary. From the preceding discussion, when control input A is low (0 to –0.2 volts), the MESFETs controlled by input A will be low resistance. Since the inputs are complementary, control input B will be high (-5 to -8 volts). The MESFETs controlled by this input will be in the high resistance state. Under this set of logic conditions, the incident RF signal will be switched to port RF2 as shown in Figure 1.

Definition of Terms

The final design of a switch represents a trade-off among several performance parameters. Many of these parameters are interrelated; so improved performance in one area comes at the expense of degraded performance in another. This section will define commonly used terms and provide insight into design trade-offs.

Insertion Loss

Insertion Loss, represented in Figure 2, is a measure of the difference between the input and output power of the *on* path of a device. This loss, expressed in decibels (dB), is composed of power dissipated in components, reflected from mismatches and radiated into free space. Insertion loss arises from the fact that components used in the design of the switch are not ideal.
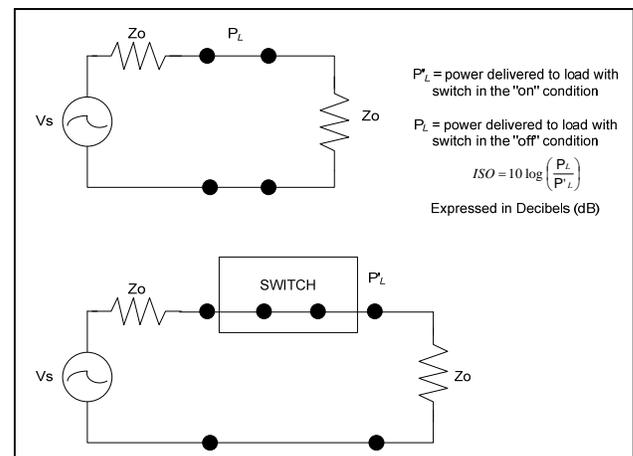

P'_L = power delivered to load with switch in the "on" condition

P_L = power delivered to load with switch in the "off" condition

$$ISO = 10 \log \left(\frac{P_L}{P'_L} \right)$$

Expressed in Decibels (dB)

Figure 2. Insertion Loss

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Isolation

Isolation, shown in Figure 3, is a measure of the difference between the input and output power of the *off* path of a device. To increase isolation, additional components can be added to a design, or the existing components can be optimized for isolation performance. In either case, the result will be increased insertion loss. Typically, a path in isolation presents a reflective termination.
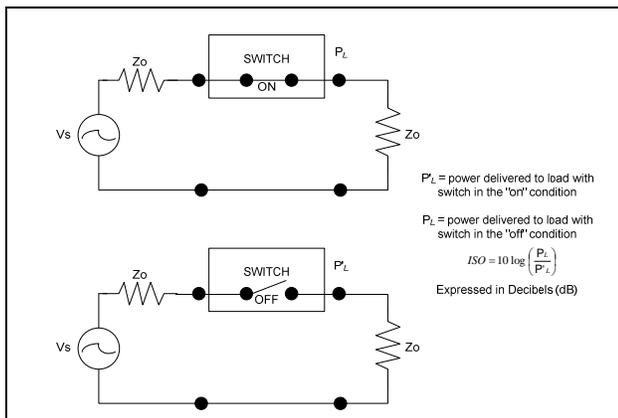

P'_L = power delivered to load with switch in the "on" condition

P_L = power delivered to load with switch in the "off" condition

$$ISO = 10 \log \left(\frac{P_L}{P'_L} \right)$$

Expressed in Decibels (dB)

Figure 3. Isolation

VSWR

VSWR (Voltage Standing Wave Ratio) is a measure of how well the device matches the characteristic impedance of the system. VSWR is a number derived from a return loss measurement. Return loss compares the input power to a device with the power level that is reflected from that device. Knowing these two powers, a reflection coefficient can be derived which translates to a VSWR number as follows in Figure 4.

As mentioned, typical designs result in the isolation path appearing as a short circuit that will reflect a significant portion of the input power. This results in a low return loss and a correspondingly high VSWR. If this presents a problem, a switch can be designed so that when the path is in isolation, incident signals are terminated in a resistive load. This technique allows the VSWR of the isolation path to be comparable to that of the insertion loss path. These devices are called absorptive or non-reflective switches.
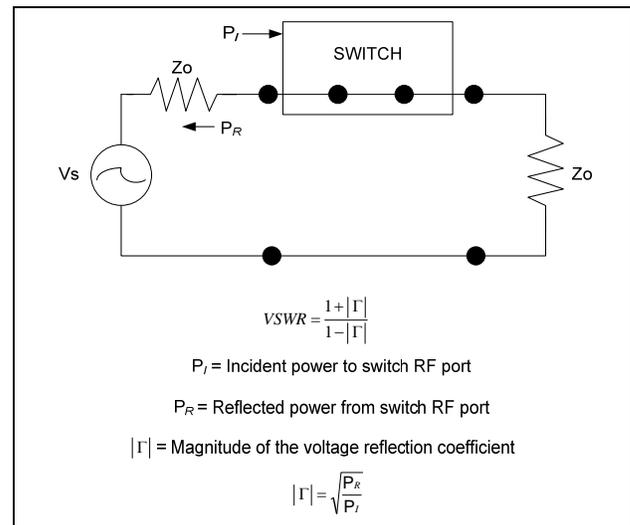

$$VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

P_I = Incident power to switch RF port

P_R = Reflected power from switch RF port

$|\Gamma|$ = Magnitude of the voltage reflection coefficient

$$|\Gamma| = \sqrt{\frac{P_R}{P_I}}$$

**Figure 4. VSWR**

Switching Speed

As discussed previously, the MESFET is essentially a voltage variable resistor. With MESFETs configured as a switch, switching speed is a measure of time required to change from insertion loss (*on*) to isolation (*off*) or vice versa. To completely specify switching speed, four terms must be known. A pictorial representation and definition appear in Figure 5.

Rise and fall times relate primarily to the device and reflect how quickly a change of state can occur.

On and *off* times include a component of delay, which is dependent on how the devices are being driven. This family of switches with integral drivers includes this delay in their *on* and *off* times. These quantities are a measure of the time elapsed between the command pulse reaching a specified level and the detected RF response changing state to within a certain level (typically, to within 10% of its final state). When a device contains no driver, *on* and *off* times are not specified, because the times will be dependent on how the device is driven.

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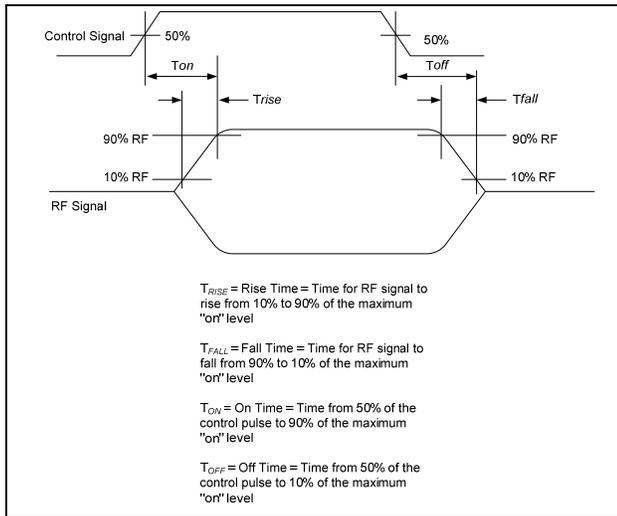
Figure 5. Switching Parameters

Switching Transients

When a device is pulsed, the leading and falling edge of the pulse contains many higher frequency components. The number of components and their contribution is determined by the sharpness of the pulse edges. In addition, the MESFETs are non-linear devices that generate harmonics of the incident signals. The fundamental switching structure filters out some of these frequency components; however, some component of these switching signals will be present in the switch output. These signals can be specified as a maximum voltage amplitude, or in terms of spectral content with a maximum power level.

Power Handling

Any RF signal has an associated RF voltage. This RF voltage is sinusoidal with a period related to the frequency. As we have discussed, the MESFET can be thought of as a voltage variable resistor. As the RF voltage swing gets high enough, it can counteract the DC bias level. If this happens, the resistance of the MESFET will change. If the MESFET is in its low resistance state, the increase in resistance appears as increased loss.

Power handling is measured in many ways. One convenient benchmark is to specify the power level at which the device has an additional 1dB of insertion loss. This quantity, known as the 1dB compression point, is not a maximum power level. It is a standard measurement point that provides information about the range of usable input power levels.

The 1dB compression point is frequency dependent, reflecting the increasing period of the RF voltage with decreasing frequency. At very low frequencies, the RF voltage is closely approximated as a DC signal that more efficiently increases the resistance than a high frequency, time-varying signal. The 1dB compression point can be increased by increasing the negative bias to the MMIC chip from –5 volts to –8 volts. This increases the DC bias level that the RF voltage swing must counteract, increasing the power level required to get the same amount of compression.

Another measure of power handling is the maximum power, which is the highest input power that is guaranteed without damage. Implicit in this specification is that the device is "cold switched". Cold switching means the device is switched in the absence of power. This is an important consideration. If the device changes state in the presence of power ("hot switching"), the MESFETs will transition through a resistance region where a significant portion of the incident power will be dissipated. This can easily lead to damage.

Intermodulation Intercept Points

Intermodulation intercept points are measured with two equal amplitude input signals spaced closely together in frequency. Since MESFETs are non-linear devices, they exhibit "mixing" or frequency-generation characteristics. In any kind of receiving system, signals that are generated internal to the device can degrade overall system performance. This measurement is used to determine the intercept points (typically second and third order) of a device. The intercept points are calculated values and are defined as the power at which the intermodulation product amplitude is equal to the input. This quantity plays a major role in system dynamic range and sensitivity performance. The intercept points are calculated as follows:

$$IP_n = [IMD_n/(n-1)] + P_{in}$$

Where: IP_n = n^{th} order intercept point (dBm)

IMD_n = n^{th} order intermodulation distortion product (dBc)

n = order

P_{in} = input power (dBm)

Distortion is a measure of the non-linearity of a device. GaAs FET based switches offer significant advantages in performance over PIN diode based switches. Distortion arises when non-linearities in device operation are introduced. Non-linearities result from time-varying changes in resistance or capacitance of a device. Since GaAs MESFET switches are voltage controlled, they are less susceptible to modulation at normal operating power levels. This results in superior distortion performance.

Internal Driver Circuitry

To realize the performance parameters outlined in this application note, the GaAs MESFETs must be driven with complementary voltages in the range of 0 to -0.2 volts and -5 to -8 volts. M/A-COM's switch family accomplishes this with an integral ASIC driver. The integral driver is configured to be compatible with TTL or CMOS input signals. The ASIC chip driver technology results in very low power consumption (10 mW at nominal voltages) and quiescent current (1 mA max from either power supply). Despite low power consumption, the devices have typical switching speeds of 12 - 18 nSec (including driver delay).

Inclusion of a driver greatly simplifies the integration of the switches into systems. The user needs only to supply the recommended bias voltages and control signals, and the switch is operational.

For more detailed information on the M/A-COM GaAs FET ASIC driver, contact M/A-COM.

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