

This white paper is an executive summary of a webcast of the same title released on November 18, 2015, sponsored by Analog Devices.

# RF AND MW CONTROL PRODUCTS IN SILICON

## Introduction

Analog Devices' new RF and microwave (MW) switch and attenuator products implemented in advanced silicon process benefit inherent advantages of silicon technology compared to legacy counterparts using gallium-arsenide (GaAs). This paper provides highlights on features and key performance parameters of the new switch and attenuator products.

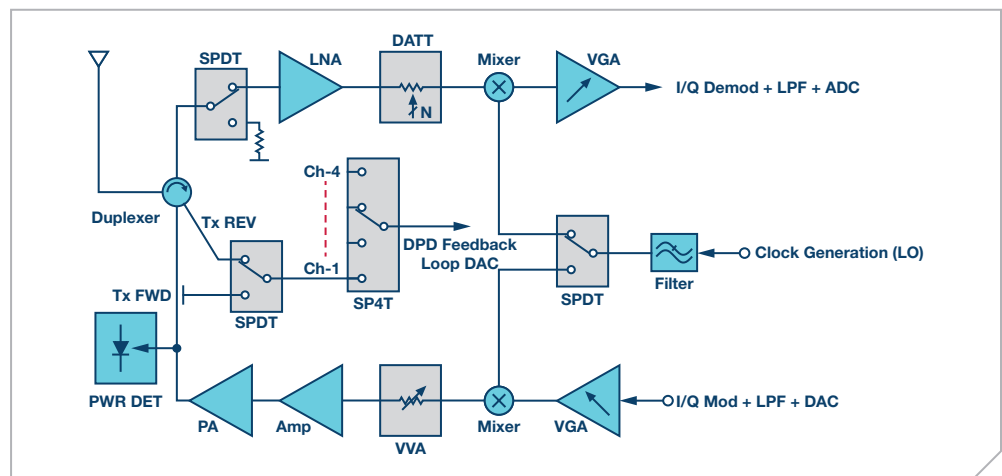


Figure 1. A generic transceiver. On the bottom is the transmit side and on the top is the receive side. In the middle is the predistortion feedback loop.

Analog Devices offers more than 1000 components covering all RF and MW signal chains and applications. RF switches and attenuators are often used in the same application and comply with similar system requirements. They are grouped under the same product category, RF and MW control products. Figure 1 shows a generic transceiver. On the bottom is the transmit side and on the top is the receive side. In the middle is the predistortion feedback loop, together with the clock generation. In the diagram, switches are used in various slices. A single-pole, double-throw (SPDT) switch is used in front of the low noise amplifier to guarantee the required level of isolation against the excessive power, which can leak through the duplexer during transmit mode. Another SPDT switch is used in the digital predistortion feedback loop to select between the transmit or reflected signal. A single-pole four-throw (SP4T) is then used to select between multiple transceivers in case one detector is used for all.

Another SPDT switch is used to route the clock signal from the local oscillator between the receive and transmit sides. Digital attenuators (DATT) and continuously adjustable voltage variable attenuators (VVA) are used in the signal chain where gain adjustment is needed.

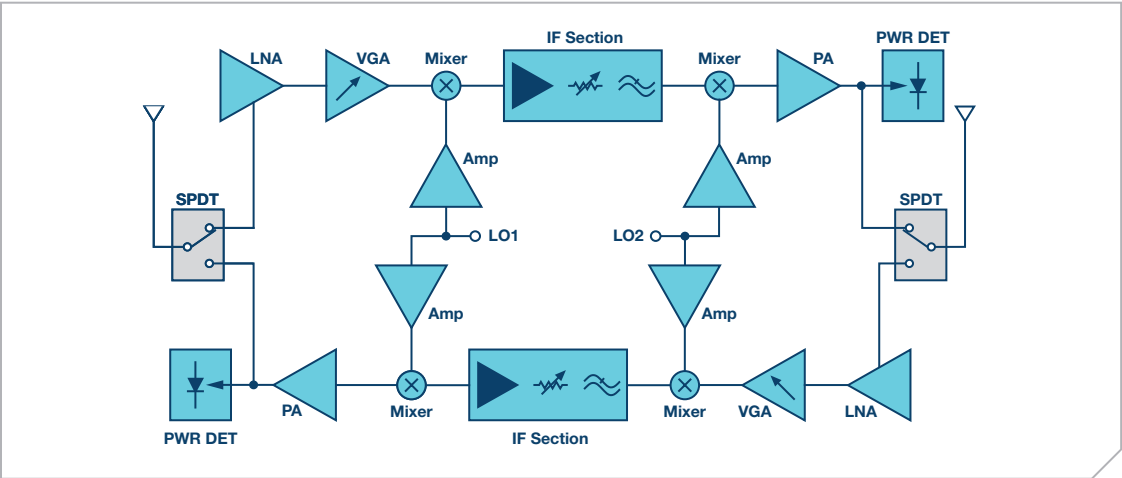


Figure 2. High power, reflective transmit/receive SPDTs are used at the antenna interface.

Another application is the cellular repeater. In Figure 2, SPDT switches are used at the antenna interface. These are high power transmit and receive switches designed especially for this purpose.

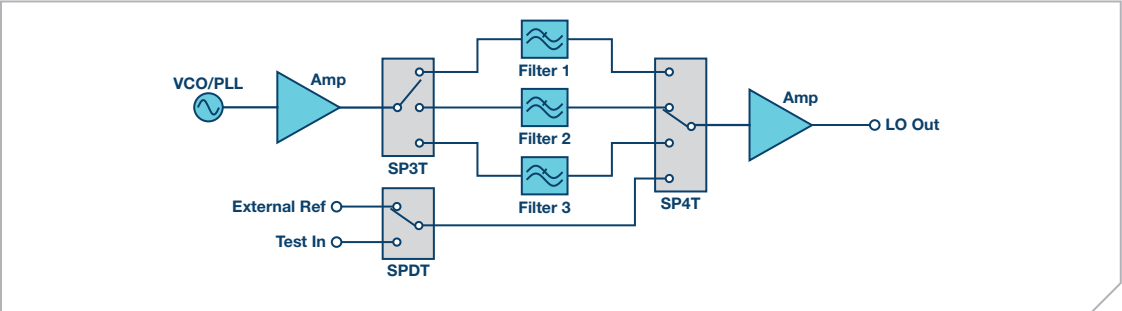


Figure 3. Use of the control product for clock, or local oscillator (LO) generation.

Figure 3 shows the use of the control product for clock, or LO generation. Here, the signal is generated through the VCO/PLL or oscillator, is amplified, and then applied to a switch. In the diagram, a single-pole, three-throw (SP3T) switch is used to switch between the filter banks. At the output side, a single pole, four-throw switch is used, and an extra path is added for calibration and external reference. Digital attenuators or voltage variable attenuators can be included in the signal path, where gain adjustment is required.

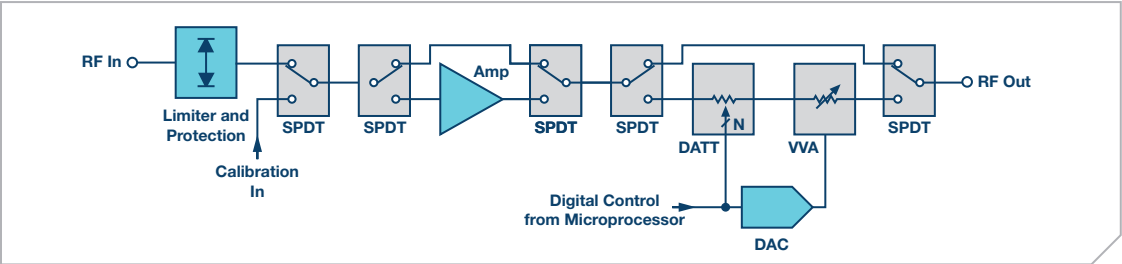


Figure 4. In the test equipment input stage, the signal is applied to the equipment, and the n passes through the amplification path or attenuation path.

A last example is a block diagram of an RF test equipment input stage (Figure 4). In the first section, an SPDT is used to select between the incoming signal or the calibration signal. The selected signal is then fed to another SPDT to route the signal to an amplification path or bypass path. This is followed by an attenuator section incorporating a DATT and a VVA. The digital attenuator is used for the course calibration, and the voltage variable attenuator is used for the fine gain adjustment.

In these applications, high performance is required, and low insertion loss, good return loss, high linearity, and high power handling are key parameters. Flat frequency characteristics are very important for the performance of the equipment. Signal bandwidth in such applications has to be wide enough to cover the full frequency range of the operation. In such applications, 9 kHz low cutoff frequency for spectrum and network analyzers is critical.

## Silicon vs. GaAs

This comparison is made mainly on the design features. If the product requires a fast settling time and fast switching time, the silicon process offers advantages over GaAs. The silicon process offers greater integration capability, and for low frequency operations, silicon has advantages over GaAs. If power handling, insertion loss, isolation, and linearity are design parameters, both silicon and GaAs can meet the requirements. Silicon offers higher ESD robustness. For high temperature operation, GaAs is still a superior platform over silicon. In GaAs depletion mode, devices are generally used that make the implementation of functions like fail-safe operation possible.

GaAs devices suffer what is called gate-lag effect. When the transistor is switched, the residual charge in the channel takes much longer to decay compared to the switching time. It's a common practice for RF designers to foresee a 10 $\times$  margin in settling time, but this may not be enough if high accuracy is needed. The gate-lag is dependent on process variations, bias conditions, and control voltage levels.

Silicon devices exhibit reliable fast switching and settling. The device characteristics are well defined and modeled. Dependency to process variation and bias conditions is well controlled and limited.

Fast settling time is important in time division multiplexed communication systems for achieving good performance. In most test and measurement equipment, fast settling time is critical to increasing accuracy and reducing test time.

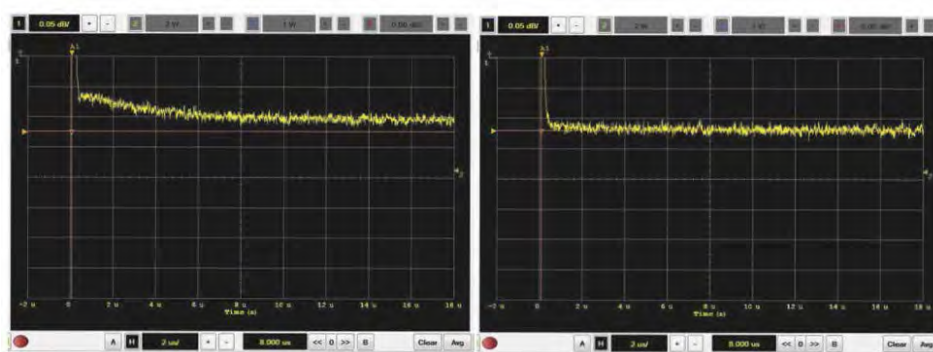


Figure 5. A comparison of the settling time measurements between GaAs (left) and silicon.

Figure 5 shows a comparison between two products: an HMC540 manufactured in GaAs, and the HMC540S, which has very similar characteristics, but is designed using the silicon process. The GaAs product, due to the gate-lag effect, takes  $\sim 8 \mu\text{s}$  to settle to final RF power level. The silicon product settles to the same RF level in less than  $\sim 1 \mu\text{s}$ .

The GaAs process has integration limitations due to the device characteristics. In GaAs, the pHEMT device threshold voltage varies between  $-1 \text{ V}$  and  $-3 \text{ V}$ . Designing complex interface circuits like low voltage CMOS interfaces is not feasible, so external circuits are needed for GaAs devices. In the silicon process, threshold voltages are much lower, and comply with standard CMOS interface voltages. It's possible to implement the same interfaces together with the control product or attenuator switch on the same die, and the device can interface with a standard CMOS device.

The high level of integration offers the designer the opportunity to simplify designs, reduce the PCB area and number of components used, and save costs. The integration in the silicon process can be extended to incorporate complex functions and feature-rich products.

As an example, GaAs digital attenuators are designed as multichip modules incorporating a CMOS driver in the same package. In silicon digital attenuators, on the other hand, the complete device is designed as a monolithic single die.

Another advantage of the silicon process is ESD robustness. In the GaAs process, there are limited components that can be used to implement the ESD structure. Diodes and layout techniques are used to get to a certain level of ESD protection. In the silicon process, it's possible to implement dedicated protection circuits like a clamp and one-shot trigger circuit.

The diagram on the left of Figure 6 shows a typical GaAs ESD cell, which is based on the diode. On the right side is a typical ESD cell in silicon. There is a dedicated ESD structure to give a higher level of protection. Robust ESD protection ensures the reliable operation of the devices under ESD sensitive environments such as automotive, military, and test and measurement applications.

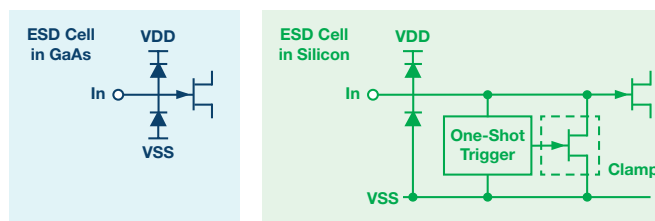


Figure 6. In the test equipment input stage, the signal is applied to the equipment, and the signal passes through the amplification path or attenuation path.

In further comparing GaAs and silicon, silicon enables integration of multiple features in the same design. For example, ADI's silicon digital attenuators feature serial interfaces that can manage state transitions. Safe-state transition ensures that overshoot on the RF signal is limited during state transitions. Glitch-free operation ensures that fluctuations on the RF signal power are limited during state transitions. Reliable state transitions simplify designs and protect other components in the signal chain from experiencing overshoot or extra power.

Another advantage of the silicon process is being able to design components for low frequency operation. The GaAs process has limitations due to gate leakage current, and it is almost impossible to use a GaAs device at low frequency. With the silicon process, there is no gate leakage because the gates are totally isolated, and high value resistors are available. The design can be optimized for the low frequency band. The low frequency end covers 9 kHz operation, making silicon ideal for test and measurement applications.

## New Switch Products in Silicon

ADI offers three new switch products in silicon:

- ▶ HMC1118, a high isolation silicon SPDT nonreflective switch that operates in 9 kHz to 13 GHz
- ▶ HM8038, a high isolation silicon SPDT nonreflective switch that operates in 0.1 GHz to 6 GHz
- ▶ HMC7992, a compact silicon SP4T nonreflective switch that operates in 0.1 GHz to 6 GHz

The HMC1118 is optimized for low frequency operation. It has a settling time of 7.5  $\mu$ s for 0.05 dB margin, excellent isolation of 56 dB at 8 GHz, and a low insertion loss of 0.6 dB at 8.0 GHz. It offers high power handling of 36 dBm through path and 27 dBm terminated path.

The HM8038 features a high isolation of 60 dB typical, a low insertion loss of 0.8 dB typical, and a fast settling time of 170 ns for 0.1 dB margin. It offers high power handling of 34 dBm through path and 29 dBm terminated path, and high linearity of 34 dBm for 0.1 dB compression point.

The HMC7992 offers a high isolation of 45 dB typical at 2 GHz, a low insertion loss of 0.6 dB at 2 GHz, and a fast settling time of 320 ns for 0.1 dB margin. It features high power handling of 33 dBm through path and 27 dBm terminated path, and high linearity of 1 dB compression point (P1 dB), with 35 dBm typical.

## New Digital Attenuator Products in Silicon

New digital attenuator products available in silicon are:

- ▶ HMC1119, a 0.25 dB, LSB, 7-bit silicon digital attenuator (0.1 GHz to 6 GHz)
- ▶ HMC1122, a 0.5 dB, LSB, 6-bit silicon digital attenuator (0.1 GHz to 6 GHz)
- ▶ HMC305S, a 0.5 dB, LSB, 5-bit silicon digital attenuator (0.4 GHz to 7.0 GHz)
- ▶ HMC540S, a 1 dB, LSB, 4-bit silicon digital attenuator (0.1 GHz to 8 GHz)

Find out more about these and all of ADI's products at [www.analog.com](http://www.analog.com).

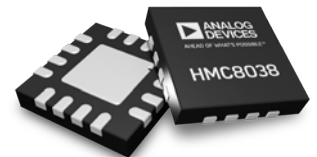
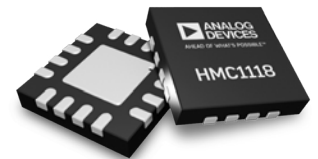
The HMC1119 and HMC1122 are designed for high accuracy and exhibit less than 0.1 dB step error. Both parts have an attenuation range of 30 dB, insertion loss of 1.3 dB, and a typical switching time of around 150 ns. They have a serial control interface with safe-state transition feature.

The HMC305S has an attenuation range of 15.5 dB with insertion loss of 1.1 dB at 2 GHz. The part has serial control interface and features glitch-free state transitions.

The HMC540S is a wideband, 1 dB step, 4-bit digital attenuator optimized for low insertion of 0.7 dB. The part has excellent linearity of 0.1 dB compression point of 31 dBm. The HMC540 comes in compact 3 mm  $\times$  3 mm package and has parallel control.

### Author/Presenter

Bilge Bayrakci is Marketing and Product Manager for RF and MW Control Products at ADI. He has B.S.E.E. and M.S.E.E. degrees from Istanbul Technical University. Starting his professional life at ST Microelectronics in 1997 as an IC design engineer, Bilge has been in the telecom and consumer semiconductor industry at various R&D management positions over the years. He has been with ADI since 2009.



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