PE613010 and PE613050 Tuning Control Switches

Application Note 47

Summary

Peregrine Semiconductor's UltraCMOS® PE613010 and PE613050 tuning control switches provide robust solutions to problems posed by today's challenging environments for flexible wireless antenna systems. The requirement for supporting complex modulation schemes such as 4G LTE and 802.11ac OFDM, which are pushing the RF front-end performance, necessitates use of an efficient active antenna tuning system. Such systems utilize dynamic impedance tuning techniques to optimize antenna performance for both frequency of operation and environmental conditions. Peregrine's PE613010 and PE613050 switches exhibit very low ON-resistance (1.2Ω and 1.6Ω, respectively) and low insertion loss—0.20 dB at 900 MHz and 0.40 dB at 1.9 GHz for the PE613010, and 0.25 dB at 900 MHz and 0.40 dB at 2.2 GHz for the PE613050. These switches implement high power handling (38 dBm at 50Ω for the PE613010 and 38.6 dBm at 900 MHz and 37.6 dBm at 2.2 GHz for the PE613050) and a wide power supply range (2.3–4.8V for the PE613010 and 2.3–5.5V for the PE613050). Numerous applications include tunable antennas, tunable matching networks, bypass switching (PE613010) and switched filter networks (PE613050). UltraCMOS antenna tuning devices feature ease of use while delivering superior RF performance. With built-in bias voltage generation and electrostatic discharge (ESD) protection, the PE613010 and PE613050 switches provide monolithically integrated tuning solutions for demanding RF applications.

Introduction

In modern wireless communication systems, such as cellular handsets, it is common to find multiple antennas. In the case of cellular antennas, these multiple antennas are necessary to support different wireless protocols such as 2G/3G/4G, near field communication (NFC), Wi-Fi®/Bluetooth®, GPS and FM radio. The situation is further complicated by 4G LTE-Advanced technology. It is expected that four antenna multiple input, multiple output (MIMO) will need to be implemented in the handset to achieve the highest data rates included in this standard. The need for multiple antennas, coupled with reducing size and volumetric constraints, creates a challenging environment for wireless antenna systems. Thus, the space available for the antenna system is shrinking at a rapid rate. As antennas are reshaped from their ideal and reused for multiple bands and protocols, they lose efficiency. Some of this lost performance may be recovered with active antenna tuning systems, in which the system uses dynamic impedance tuning techniques to optimize antenna performance for both frequency of operation and environmental conditions.

For example, LTE-Advanced networks and carrier aggregation specifications are pushing RF front-end performance demands higher. These performance demands often require adding antennas or a multi-feed antenna to the handset, which places further demands on antenna size or tuning selectivity. Tunable devices have proved highly valuable in supporting the increased bandwidth demanded by LTE handsets. Tunable devices enable smaller antennas to be efficient across the entire LTE band from 700 MHz to 3 GHz, saving battery power and facilitating slim and more ergonomic designs. Thus, a popular solution to these expanding challenges is the development of active antenna tuning systems.

The UltraCMOS Technology Advantage

Continuing with the mobile handset example, one of the most significant challenges facing mobile handset designers is poor antenna performance for multi-band, multi-mode handsets. Dynamically tuning the antenna to compensate for increasing bandwidth requirements and environmental effects will significantly improve antenna performance. Further, as the market demands new wideband services in the handset, such as video streaming, remote monitoring and control, and increasing cloud storage, the use of antenna tuning becomes a necessity. Until now, no tunable element met the needs of the mobile products industry in power handling, reliability, high volume production and integration. Peregrine Semiconductor's UltraCMOS technology is the key to unlocking the future of digitally tunable RF performance in mobile handsets.

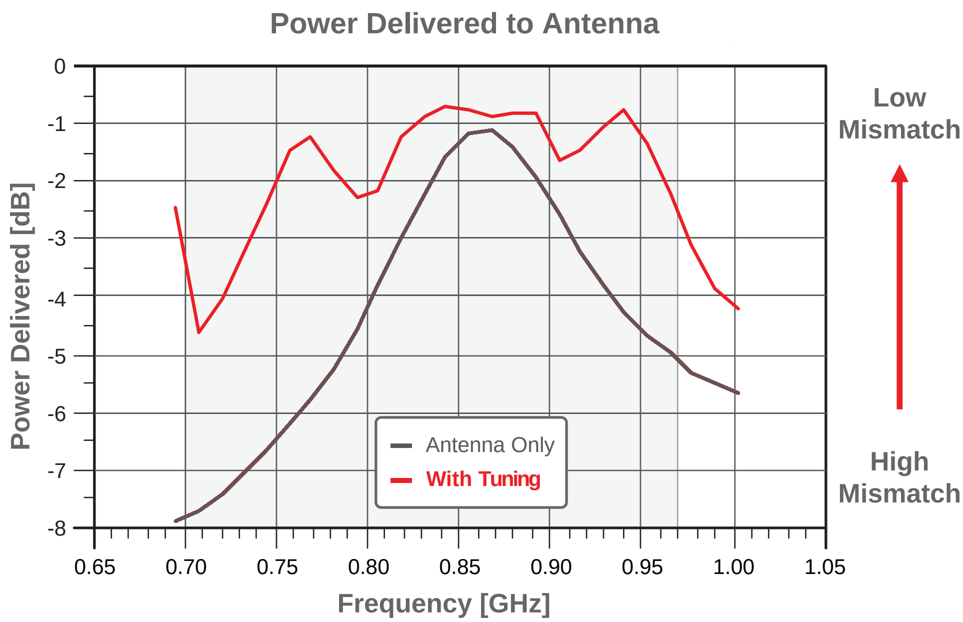
Peregrine's tuning control switches, based on UltraCMOS technology, are highly versatile switches that support a wide variety of antenna tuning circuit topologies. UltraCMOS tuning control switches enable impedance tuning and aperture tuning applications across a broad range of frequencies from 100 MHz to 3 GHz. Peregrine's tuning control switches feature high RF power handling and ruggedness, while meeting challenging harmonic and linearity requirements. With low voltage CMOS control, all decoding and biasing is integrated on-chip and no external bypassing or filtering components are required. Peregrine's tuning control switch line also feature excellent ESD tolerance and provide a monolithically integrated solution for tunable networks.

Antenna Tuning Methods

Impedance Tuning

Impedance tuning (impedance matching) may be employed for fine RF tuning over a limited tuning range as shown in **Figure 1**. Antenna impedance tuning optimizes power transfer from the transmission line into the antenna terminals by matching input impedance and output impedance. It tunes the antenna to the entire system, creating a tuned matching network that is added to the antenna input. Impedance tuning provides improvement in total radiated power (TRP) and total isotropic sensitivity (TIS) metrics. This solution is easy to implement. Tunable components are used in shunt or series configurations.

Figure 1 • ***Impedance Tuning for Improved Match Results in Increased RF Power Delivered***



Aperture Tuning

Aperture tuning is incorporated into the antenna design to enable a wider frequency range. With aperture tuning, the tunable component is added to the antenna structure itself. The electrical length of the antenna element is dynamically adjusted to shift its resonance to the desired frequency band of operation as shown in Figure 2. Band switching is able to achieve higher levels of performance compared with input tuning, as the actual radiating element is being tuned. Aperture tuning optimizes radiation efficiency from the antenna terminals into free space. Also, aperture tuning optimizes insertion loss, isolation and rejection levels. Tuning is achieved by loading with a digitally tunable capacitor (DTC) or by using a tunable control/shorting switch. In both cases, the tuning components must have low loss to avoid degrading the radiating efficiency of the antenna.

Figure 2 • *Antenna Element Length Adjusted Dynamically to Tune Resonant Frequency*

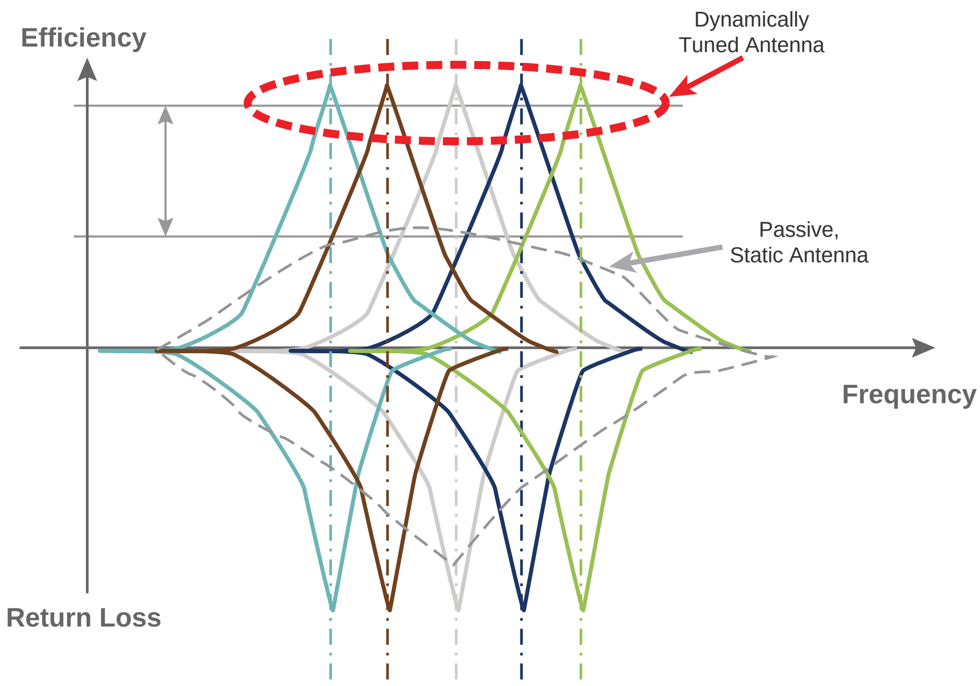
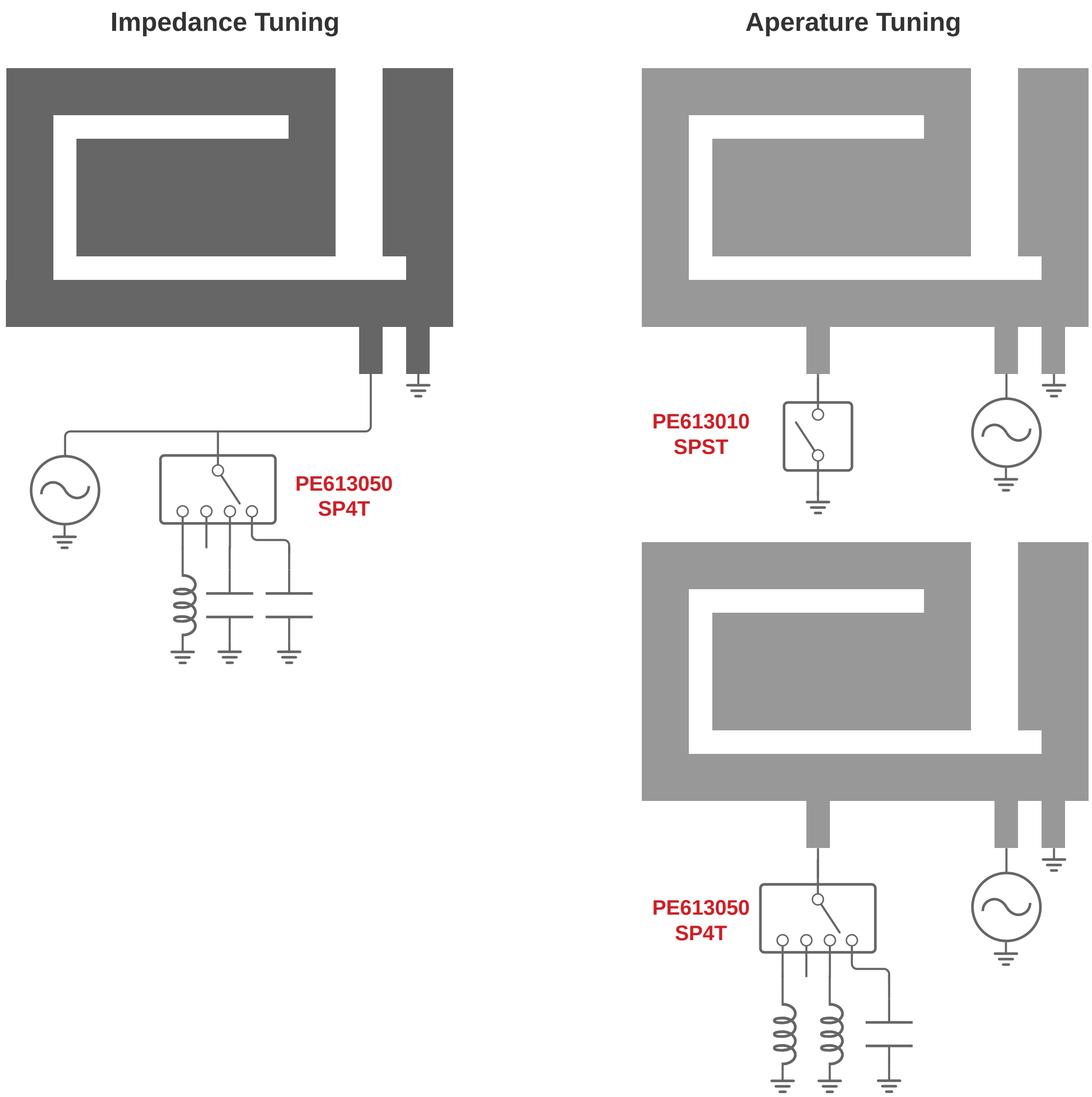


Figure 3 depicts antenna impedance tuning and antenna aperture tuning.

Figure 3 • Antenna Impedance (left) and Antenna Aperture Tuning (Right)



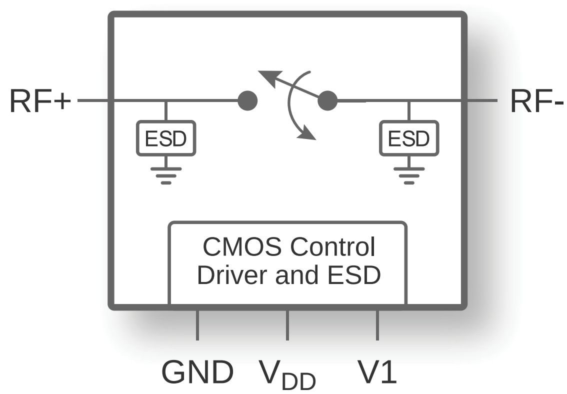
PE613010 Product Overview

The PE613010 SPST tuning control switch is based on Peregrine Semiconductor's UltraCMOS technology. This highly versatile switch supports a wide range of tuning circuit topologies with emphasis on impedance matching and aperture tuning applications. The PE613010 switch features low ON-resistance and low insertion loss across key cellular frequency bands from 100 MHz to 3 GHz.

The PE613010 switch offers high RF power handling and ruggedness, while meeting challenging harmonic and linearity requirements enabled by Peregrine's patented technology. With single pin low voltage CMOS control, all decoding and biasing is integrated on-chip, and no external bypassing or filtering components are required.

UltraCMOS antenna tuning devices feature ease of use while delivering superior RF performance. With built-in bias voltage generation and ESD protection, the PE613010 switch provides a monolithically integrated tuning solution for demanding RF applications.

Figure 4 • ***PE613010 Functional Diagram***



Features

- Frequency range targets 100 MHz to 3 GHz
- Very low ON-resistance of 1.2Ω
- Open reflective architecture
- Low insertion loss
  - 0.20 dB @ 900 MHz
  - 0.40 dB @ 1.9 GHz
- Low C_{OFF} capacitance @ 50Ω
- High power handling of 38 dBm @ 50Ω
- Wide power supply range of 2.3–4.8V
- High ESD tolerance of 2 kV HBM on all pins

Applications

- Open-loop and closed-loop tunable antennas
- Tunable matching networks
- Tunable filter networks
- Bypass switching
- RFID readers

The low loss PE613010 SPST switch enables:

- Point application, e.g., modifying antenna behavior by adding differing surface-mount device loading
- Selectability of length of line
- Microstrip disc antenna
- Flexible surface-mount technology (SMT) tuning by providing a single-bit option

Design Considerations

- Circuit-loaded Q versus impact on power/voltage handling, with implications for rejection of harmonics or other frequencies
- Minimizing R_{ON} and C_{OFF}
- Packaging and GPIO control interfaces
- ESD and peak power handling

Peregrine Semiconductor

Electrical Specifications

Table 1 provides the PE613010 key electrical specifications at 25 °C and V_{DD} = 2.75V, unless otherwise specified.

Table 1 • *PE613010 Electrical Specifications*

Parameter	Condition	Min	Typ	Max	Unit
Operational frequency		100		3000	MHz
R_{ON}	RF+ to RF–, SW_{ON}, DC measurement		1.20		Ω
C_{OFF}	RF+ to RF–, SW_{OFF}		0.40		pF
Insertion loss(1)	100–960 MHz, RF+ to RF–, SW_{ON} 960–1710 MHz, RF+ to RF–, SW_{ON} 1710–2170 MHz, RF+ to RF–, SW_{ON} 2170–2700 MHz, RF+ to RF–, SW_{ON} 2700–3000 MHz, RF+ to RF–, SW_{ON}		0.20 0.30 0.40 0.60 0.80	0.30 0.40 0.50 0.70 0.95	dB dB dB dB dB
Isolation(2)	100–960 MHz, RF+ to RF–, SW_{OFF} 960–1710 MHz, RF+ to RF–, SW_{OFF} 1710–2170 MHz, RF+ to RF–, SW_{OFF} 2170–2700 MHz, RF+ to RF–, SW_{OFF} 2700–3000 MHz, RF+ to RF–, SW_{OFF}	10 6 4 3 3	11 7 5 4 4		dB dB dB dB dB
Harmonics(3)(4)	2fo, 3fo; 698–915 MHz, P_{IN} +35 dBm (SW_{ON}), P_{IN} +31 dBm (SW_{OFF}) 2fo, 3fo; 1710–1910 MHz, P_{IN} +33 dBm (SW_{ON}), P_{IN} +29 dBm (SW_{OFF})		–60 –50	–36 –36	dBm dBm
Input IP3	100–3000 MHz		70		dBm
IMD3	Bands I, II, V, VIII, +20 dBm CW @ TX freq, –15 dBm CW @ 2TX–RX freq, 50Ω, SW_{ON}		–115	–105	dBm
Switching time	50% VCTRL to 90% RF ON or 10% RF OFF		7	12	µs

Notes:
1) Assumes optimal matching with 1.5 nH inductor in series with RF port.
2) Open reflective architecture for flexible configuration of switch in tuning application.
3) Pulsed RF input with 4620 µs period, 50% duty cycle, measured per 3GPP TS 45.005.
4) Power handing in the OFF state reduced due to highly reflective load condition.

Equivalent Circuit Model Description

The equivalent circuit model (ECM), as shown in **Figure 5**, includes all parasitic elements and is accurate in switch ON and OFF states, reflecting physical circuit behavior accurately and providing very close correlation to measured data. The ECM may be used to accurately model the impedance, insertion loss and isolation of the PE613010 SPST tuning control switch. The ECM may easily be used in circuit simulation programs. The ECM parameters are presented in **Table 2**.

In **Figure 5**, capacitor C_S represents switch core capacitance between RF+ and RF– ports in the SW_{OFF} state. The parameter R_{SW} represents the equivalent series resistance (ESR) of the switch core. Parasitic inductance owing to circuit and package is modeled as L_S. C_P represents the circuit and package parasitics from RF ports to ground.

Figure 5 • ***PE613010 Equivalent Circuit Model Schematic***

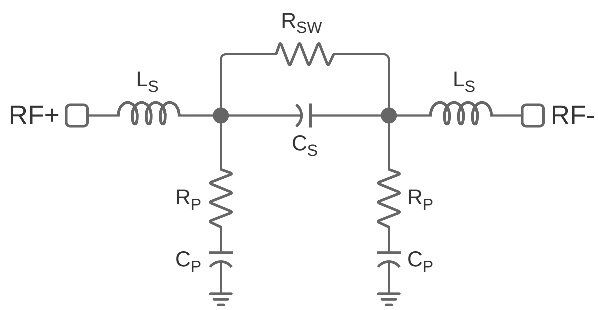


Table 2 • ***PE613010 Equivalent Circuit Model Parameters***

Parameter	Equation (SW = 0 for OFF and SW = 1 for ON)	Unit
C_S	0.40	pF
C_P	0.65	pF
R_{SW}	if SW = 1 then 1.2 else 100e3	Ω
R_P	6	Ω
L_S	0.35	nH

PE613050 Product Overview

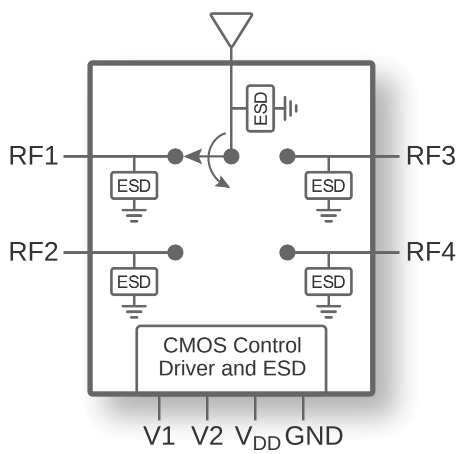
The PE613050 SP4T tuning control switch is based on Peregrine Semiconductor's UltraCMOS technology. This highly versatile switch supports a wide range of tuning circuit topologies with emphasis on impedance matching and aperture tuning applications. The PE613050 switch features low ON-resistance and low insertion loss across key cellular frequency bands from 100 MHz to 3 GHz.

The PE613050 SP4T switch may be used in multiple aperture tuning configurations. The tuning values should be optimized with the specific antenna configuration and desired frequency range. For example, it is quite common for the tuning values of a network to vary by 2–3 times just between the center frequencies of 700 MHz and 800 MHz.

The PE613050 switch offers high RF power handling and ruggedness, while meeting challenging harmonic and linearity requirements enabled by Peregrine's patented technology. With two-pin low voltage CMOS control, all decoding and biasing is integrated on-chip and no external bypassing or filtering components are required.

UltraCMOS antenna tuning devices feature ease of use while delivering superior RF performance. With built-in bias voltage generation and ESD protection, the PE613050 switch provides a monolithically integrated tuning solution for demanding RF applications.

Figure 6 • *PE613050 Functional Block Diagram*



Features

- Frequency range targets 100 MHz to 3 GHz
- Very low ON-resistance of 1.6Ω
- Open reflective architecture
- Low insertion loss
  - 0.25 dB @ 900 MHz
  - 0.40 dB @ 2.2 GHz
- Low C_{OFF} capacitance @ 50Ω
- High power handling
  - 38.6 dBm @ 900 MHz
  - 37.6 dBm @ 2.2 GHz
- Wide power supply range (2.3–5.5V)
- High ESD tolerance of 2 kV human body model (HBM) on all pins

Applications

- Open-loop and closed-loop tunable antennas
- Tunable matching networks
- Tunable filter networks
- Bypass switching
- RFID readers

Aperture tuning examples for the PE613050 switch include:

- Multiple SMT selection applied to PIFA tuning
- Selectable ground connection

Design Considerations

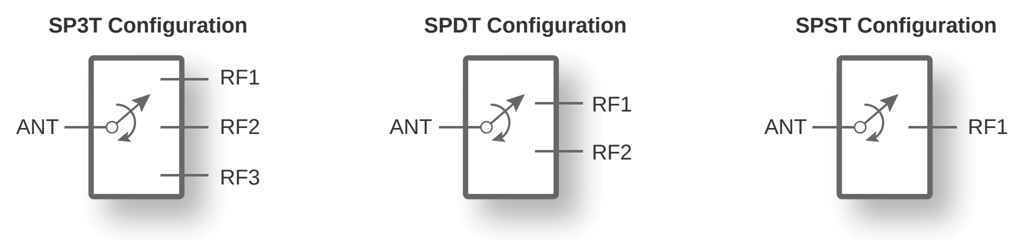
- Circuit-loaded Q versus impact on power/voltage handling, with implications for rejection of harmonics or other frequencies
- Minimizing R_{ON} and C_{OFF}
- Packaging and GPIO control interfaces
- ESD and peak power handling

Additional design considerations include peak voltage (V_{PK}) and harmonic generation. Operation must focus more on V_{PK} than the maximum operating power specified in the datasheet. As the PE613050 switch is utilized as part of an antenna, the input impedance of the switch will not be fixed at 50Ω. Thus, the harmonic inflection point could rapidly be reached or exceeded based on the antenna load impedance. Harmonic regrowth can easily cause 10–30 dB degradation in receiver sensitivity.

SPnT Configuration Flexibility

The PE613010 SPST and the PE613050 SP4T offer low-R_{ON} switch solutions optimized for antenna tuning applications. By using the open-reflective (shuntless) architecture, the family of switches offer flexibility to support various series and shunt tuning applications. For example, the SP4T can be used as a high-performance SPST, SPDT or SP3T by leaving unused ports in the high impedance open state. This will result in significant high-frequency insertion loss improvements for the lower throw count configurations. And leaving ports open also enables an all-isolated state for SPST, SPDT and SP3T configurations.

Figure 7 • *PE613050 Alternative Configurations*(*)



Note: * Unused RF ports labeled as N/C should be left open circuit at the package pin of the part.

Table 3 • *PE613050 Alternative Configurations Truth Tables*

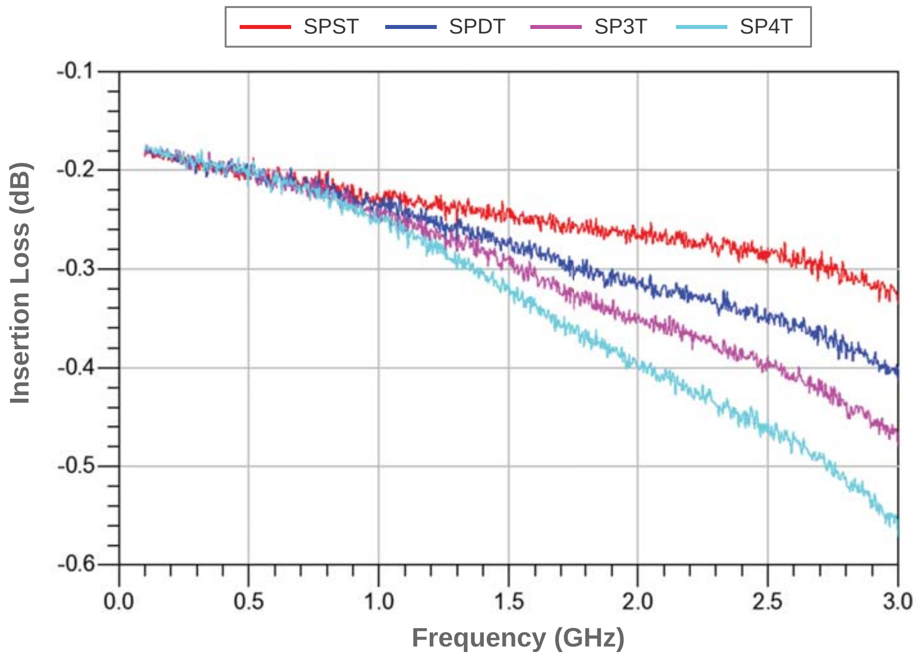
SP3T		
Path	V2	V1
ANT–RF1	0	0
ANT–RF2	1	0
ANT–RF3	0	1
ALL–ISO	1	1

SPDT		
Path	V2	V1
ANT–RF1	0(*)	0
ANT–RF3	0(*)	1
ALL–ISO	1	0
ALL–ISO	1	1

SPST		
Path	V2	V1
ANT–RF1	0(*)	0
Isolated	0(*)	1
Isolated	1	0
Isolated	1	1

Note: * If no ALL-ISO state is required. V2 can be tied to GND on SPDT.

Figure 8 • *PE613050 Measured S_{21} as SPST, SPDT or SP3T*[(1)(2)(3)]



Notes:

1) PE613050 may be used as a high-performance SPST, SPDT or SP3T.
2) Unused ports should be left open (floating) to reduce loading on the ANT port.
3) This translates to up to 0.25 dB improvement in high frequency insertion loss.

Electrical Specifications

Table 4 provides the PE613050 key electrical specifications at 25 °C and V_{DD} = 2.75V, unless otherwise specified.

Table 4 • *PE613050 Electrical Specifications at 25 °C, V_{DD} = 2.75V*

Parameter	Condition	Min	Typ	Max	Unit
Operational frequency		100		3000	MHz
R_{ON}	RF–ANT, ON state, DC measurement		1.6		Ω
C_{OFF}	RF–ANT, any OFF state		0.14		pF
Insertion loss(1)	RF–ANT 100–698 MHz RF–ANT 698–960 MHz RF–ANT 960–1710 MHz RF–ANT 1710–2170 MHz RF–ANT 2170–2500 MHz RF–ANT 2500–2690 MHz RF–ANT 2690–3000 MHz		0.20 0.25 0.35 0.40 0.45 0.50 0.55	0.30 0.35 0.45 0.50 0.55 0.60 0.70	dB dB dB dB dB dB dB
Isolation(2)	RF–ANT 100–698 MHz RF–ANT 698–960 MHz RF–ANT 960–1710 MHz RF–ANT 1710–2170 MHz RF–ANT 2170–2500 MHz RF–ANT 2500–2690 MHz RF–ANT 2690–3000 MHz	26 25 21 19 18 17 15	28 27 23 21 20 19 17		dB dB dB dB dB dB dB
Harmonics(3)	RF–ANT (2fo: 698–915 MHz; +35 dBm @ TX) RF–ANT (3fo: 698–915 MHz; +35 dBm @ TX) RF–ANT (2fo: 1710–1910 MHz; +33 dBm @ TX) RF–ANT (3fo: 1710–1910 MHz; +33 dBm @ TX) RF–ANT (2fo: 698–798 MHz; +26 dBm @ TX) RF–ANT (3fo: 698–798 MHz; +26 dBm @ TX) RF–ANT (2fo: 2500–2570 MHz; +26 dBm @ TX) RF–ANT (3fo: 2500–2570 MHz; +26 dBm @ TX)		–62 –55 –58 –55 –80 –82 –70 –70	–36 –36 –36 –36 –36 –36 –36 –36	dBm dBm dBm dBm dBm dBm dBm dBm
Input IP3	100–3000 MHz		72		dBm
IMD3	Bands I, II, V and VIII, +20 dBm CW @ TX freq, –15 dBm CW @ 2TX–RX freq, 50Ω, SW_{ON}		–120	–105	dBm
Switching time	50% V_{CTRL} to 90% RF ON or 10% RF OFF		2	5	µs
Startup time(3)	Time from V_{DD} within specification to all performances within specification			70	µs

Notes:
1) Tapered transmission lines on the evaluation board provide optimal matching. No additional components on the evaluation board are required to meet the specified performance.
2) Open reflective architecture for flexible configuration of the switch in tuning application.
3) Pulsed RF input with 4620 µs period and 50% duty cycle, measured per 3GPP TS 45.005.

Equivalent Circuit Model Description

The ECM, as shown in **Figure 9**, includes all parasitic elements and is accurate in switch ON and OFF states, reflecting physical circuit behavior accurately and providing very close correlation to measured data. The ECM may be used to accurately model the impedance, insertion loss and isolation of the PE613050 SP4T switch. The ECM may easily be used in circuit simulation programs.

Table 5 provides the mapping between the desired switch RF state (RF1 through RF4) and the state variables (SW1 through SW4).

The equivalent circuit model parameter values may be calculated using equations shown in **Table 6**.

Figure 9 • ***PE613050 Equivalent Circuit Model Schematic***

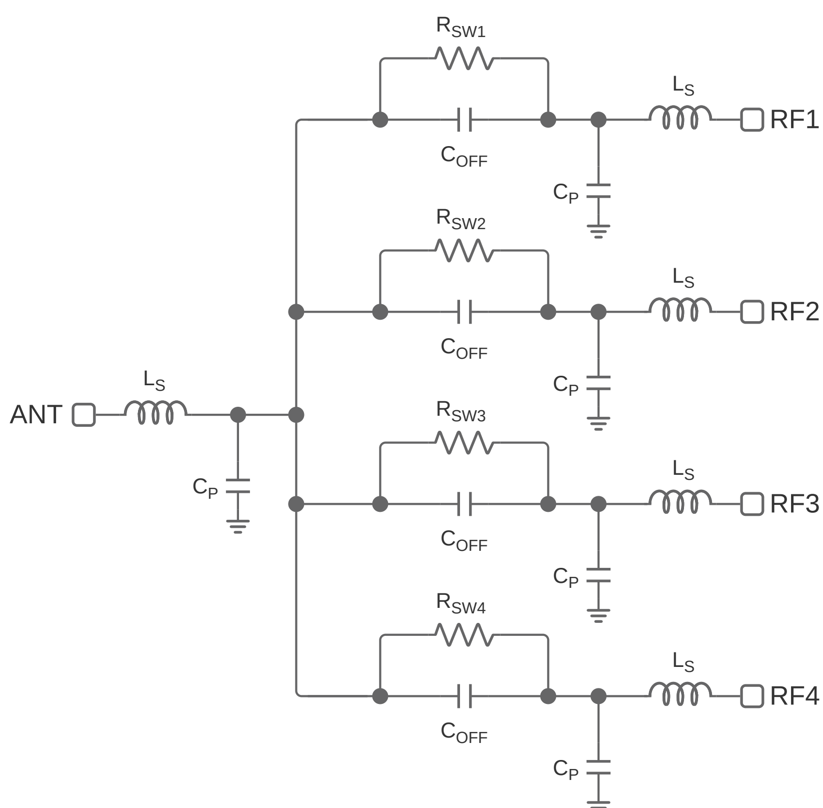


Table 5 • *PE613050 Equivalent Circuit Model Variables*

RF State			Variable			
Path	V2	V1	SW1	SW2	SW3	SW4
RF1–ANT	0	0	1	0	0	0
RF2–ANT	1	0	0	1	0	0
RF3–ANT	0	1	0	0	1	0
RF4–ANT	1	1	0	0	0	1

Table 6 • *PE613050 Equivalent Circuit Model Parameters*

Parameter	Equation (SW = 0 or OFF and SW = 1 or ON)	Unit
C_P	0.25	pF
C_{OFF}	0.14	pF
R_{SW1}	if SW1 = 1 then 1.6 else 400e3	Ω
R_{SW2}	if SW2 = 1 then 1.6 else 400e3	Ω
R_{SW3}	if SW3 = 1 then 1.6 else 400e3	Ω
R_{SW4}	if SW4 = 1 then 1.6 else 400e3	Ω
L_S	0.4	nH

Conclusion

The use of the PE613010 and PE613050 tuning switches in antenna impedance and aperture tuning networks will result in more optimized RF performance while meeting the increasing demand for the antenna system to have greater bandwidth coverage, and all in a smaller space. Eliminating the need for any external components, the lower voltage CMOS control, and the exceptionally low ON-resistance levels make these parts ideally suited for RF front end and antenna applications.

Sales Contact

For additional information, contact Sales at sales@psemi.com.

Disclaimers

Patent Statement

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