PE613050
Tuning Control Switch

Application Note 47

Summary

The pSemi UltraCMOS® PE613050 tuning control switch provides robust solutions to problems posed by today's challenging environments for flexible wireless antenna systems. The requirement for supporting complex modulation scheme such as 4G LTE and 802.11ac OFDM—which are pushing the RF front-end performance—requires the use of an efficient active antenna tuning system. Such systems use dynamic impedance tuning techniques to optimize antenna performance for both the frequency of operation and the environmental conditions. The pSemi PE613050 switch exhibits very low ON-resistance (1.6Ω) and low insertion loss—0.25 dB at 900 MHz and 0.40 dB at 2.2 GHz. The switch implements high power handling—38.6 dBm at 900 MHz and 37.6 dBm at 2.2 GHz—and a wide power supply range (2.3–5.5V). Numerous PE613050 applications include tunable antennas, tunable matching networks, and switched filter networks. This UltraCMOS antenna tuning device feature ease of use while delivering superior RF performance. With built-in bias voltage generation and electrostatic discharge (ESD) protection, the PE613050 switch provides 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 needed 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. Four antenna multiple input, multiple output (MIMO) must 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 can 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 the 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 significantly improves 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. pSemi's UltraCMOS technology is the key to unlocking the future of digitally tunable RF performance in mobile handsets.

The pSemi PE613050 tuning control switch, based on UltraCMOS technology, is a highly versatile switch that supports a wide variety of antenna tuning circuit topologies. It enables impedance tuning and aperture tuning applications across a broad range of frequencies from 100 MHz to 3 GHz. The PE613050 features 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. The PE613050 also features excellent ESD tolerance and provides a monolithically integrated solution for tunable networks.

Antenna tuning methods

Impedance tuning

Impedance tuning (impedance matching) can 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 the input and output impedance. It tunes the antenna to the entire system, creating a tuned matching network 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.

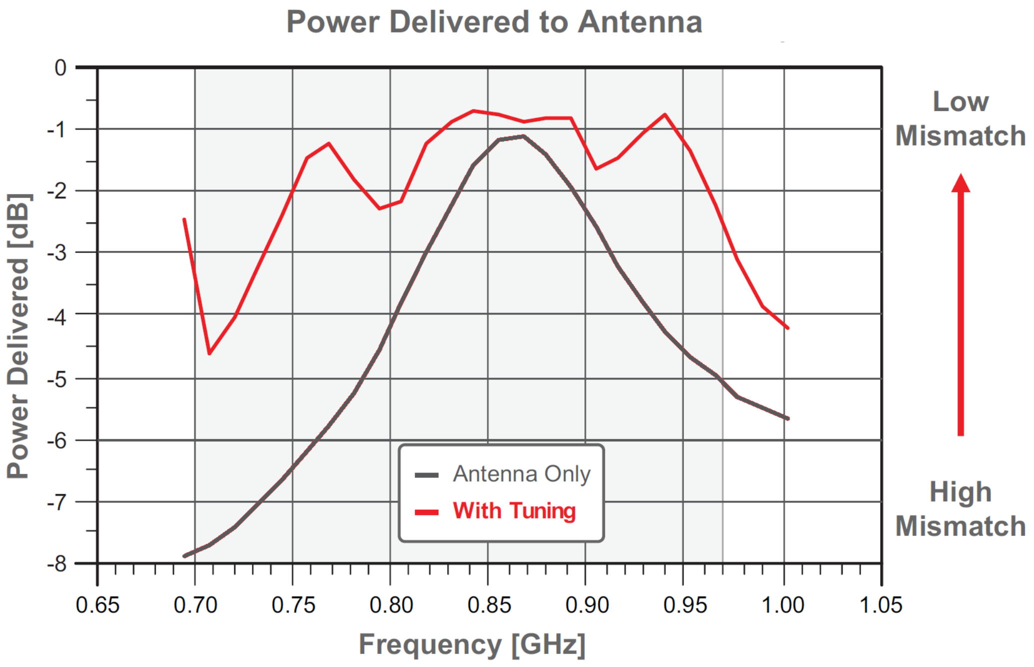

Figure 1. Impedance tuning for improved match results in increased RF power delivered

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 preferred frequency band of operation, as shown in Figure 2. Band switching can achieve higher levels of performance compared with input tuning, because 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.

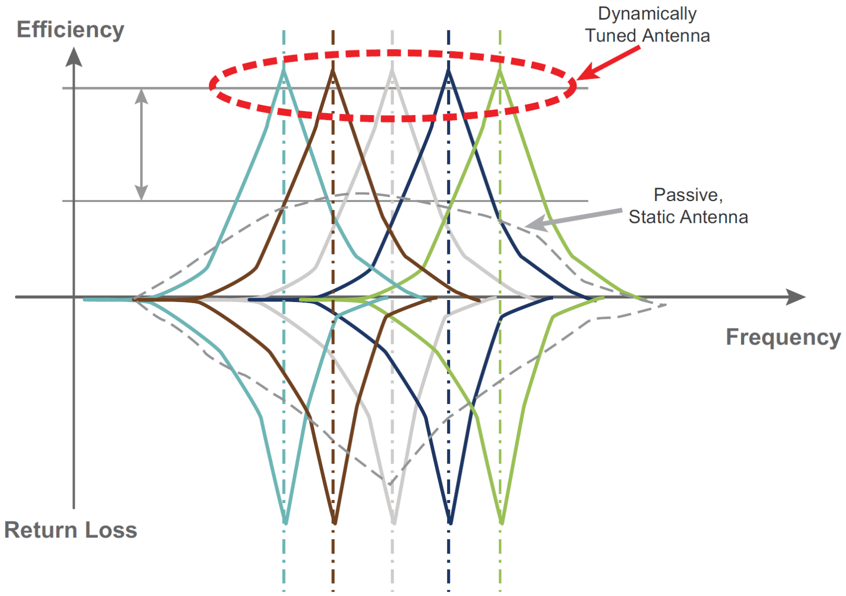

Figure 2. Antenna element length adjusted dynamically to tune resonant frequency

For comparison, Figure 3 shows antenna impedance tuning and Figure 4 shows antenna aperture tuning.

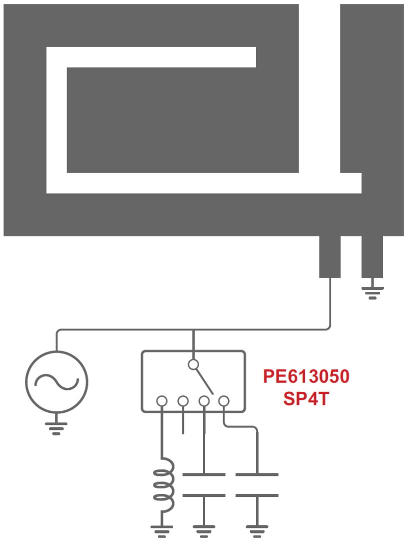

Figure 3. Impedance tuning

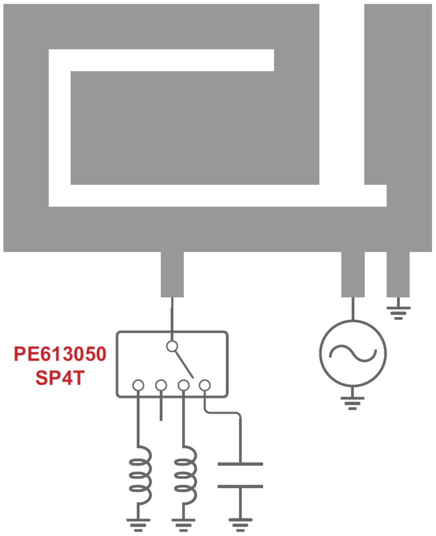

Figure 4. Aperture tuning

PE613050 product overview

The PE613050 SP4T tuning control switch is based on pSemi'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 can be used in multiple aperture tuning configurations by optimizing the tuning values with the specific antenna configuration and preferred 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 pSemi'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.

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

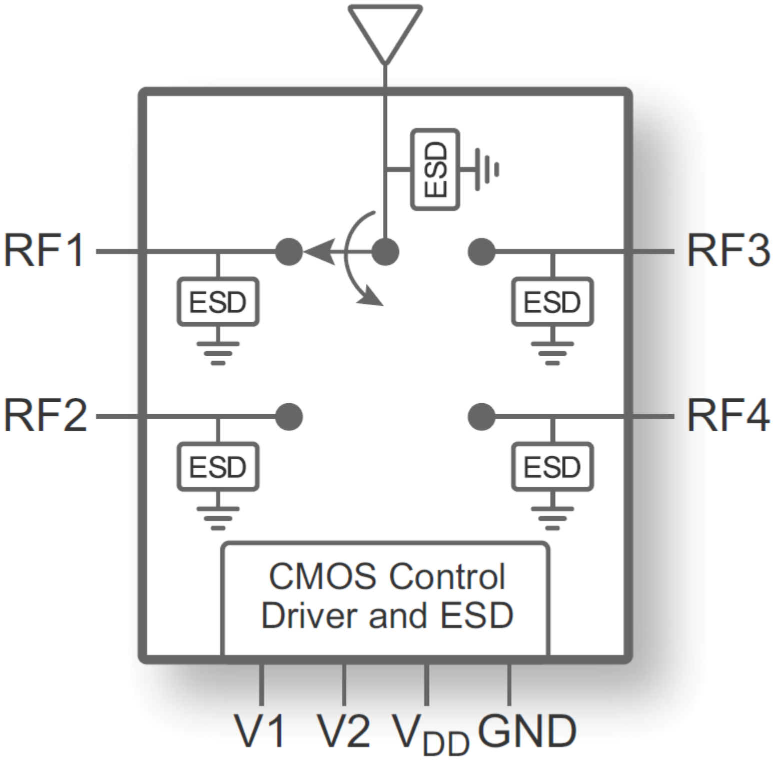

Figure 5. PE613050 functional diagram

Features

- Frequency range targets: 100 MHz to 3 GHz
- Very low ON-resistance: 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: 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 the following:

- 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 data sheet. As the PE613050 switch is used as part of an antenna, the input impedance of the switch is not 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 PE613050 SP4T switch offers a low-R_{ON} switch solution optimized for antenna tuning applications. By using the open-reflective (shuntless) architecture, the switch offers the 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 any unused ports in the high-impedance open state. This results in significant high-frequency insertion loss improvements for the lower throw count configurations. Leaving ports open also enables an all-isolated state for the SPST, SPDT, and SP3T configurations.

Figure 6 through Figure 8 show the PE613050 alternate configurations.(*)

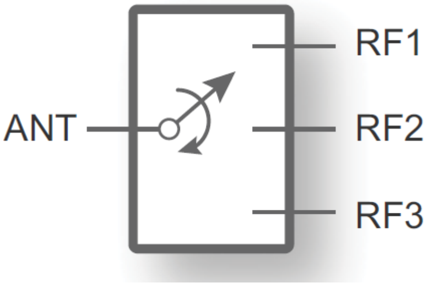

Figure 6. SP3T configuration

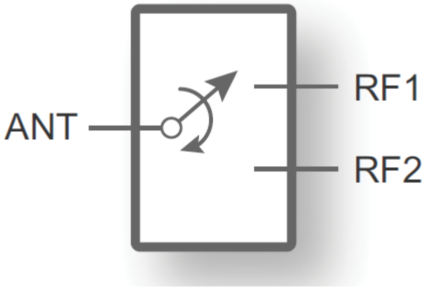

Figure 7. SPDT configuration

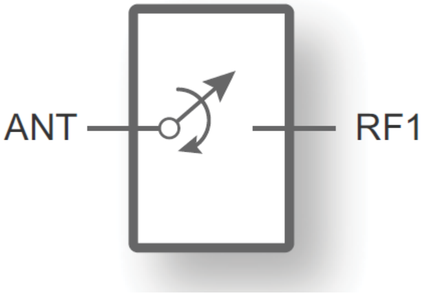

Figure 8. SPST configuration

* Leave any unused RF ports labeled as N/C open circuit at the package pin of the part.

Table 1. PE613050 alternate configurations truth table

SP3T configuration			**SPDT configuration**			**SPST configuration**		
Path	**V2**	**V1**	**Path**	**V2**	**V1**	**Path**	**V2**	**V1**
ANT–RF1	0	0	ANT–RF1	0(*)	0	ANT–RF1	0(*)	0
ANT–RF2	1	0	ANT–RF3	0(*)	1	Isolated	0(*)	1
ANT–RF3	0	1	ALL–ISO	1	0	Isolated	1	0
ALL–ISO	1	1	ALL–ISO	1	1	Isolated	1	1

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

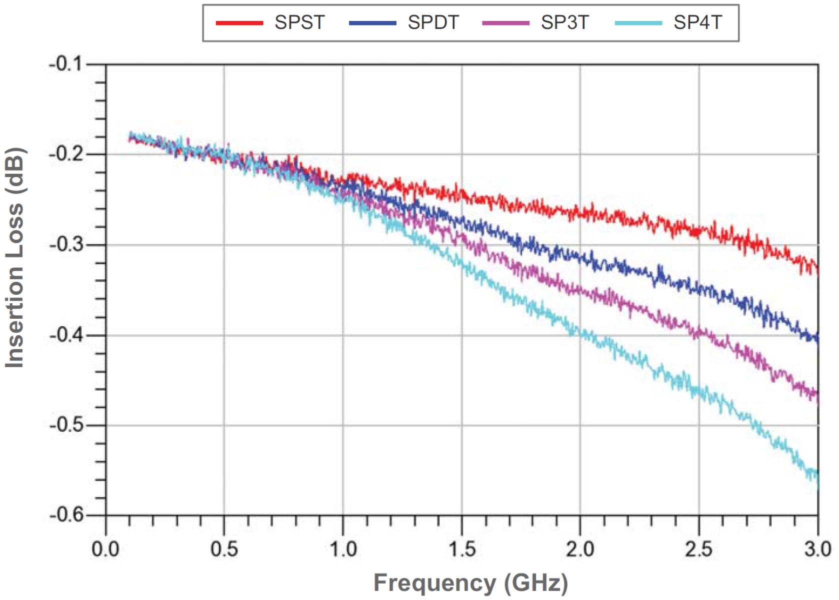

Figure 9 PE613050 measured S21 as SPST, SPDT, or SP3T(1)(2)(3)

1. You can use the PE613050 as a high-performance SPST, SPDT, or SP3T switch.
2. To reduce loading on the ANT port, leave unused ports open (floating).
3. This translates to up to 0.25-dB improvement in high-frequency insertion loss.

Electrical specifications

Table 2 lists the PE613050 key electrical specifications at 25 °C and V_{DD} = 2.75V, unless otherwise specified.

Table 2. PE613050 electrical specifications

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	–	0.20	0.30	dB
	RF–ANT 698–960 MHz	–	0.25	0.35	dB
	RF–ANT 960–1710 MHz	–	0.35	0.45	dB
	RF–ANT 1710–2170 MHz	–	0.40	0.50	dB
	RF–ANT 2170–2500 MHz	–	0.45	0.55	dB
	RF–ANT 2500–2690 MHz	–	0.50	0.60	dB
	RF–ANT 2690–3000 MHz	–	0.55	0.70	dB
Isolation(2)	RF–ANT 100–698 MHz	26	28	–	dB
	RF–ANT 698–960 MHz	25	27	–	dB
	RF–ANT 960–1710 MHz	21	23	–	dB
	RF–ANT 1710–2170 MHz	19	21	–	dB
	RF–ANT 2170–2500 MHz	18	20	–	dB
	RF–ANT 2500–2690 MHz	17	19	–	dB
	RF–ANT 2690–3000 MHz	15	17	–	dB
Harmonics(3)	RF–ANT (2fo: 698–915 MHz; +35 dBm @ TX)	–	–62	–36	dBm
	RF–ANT (3fo: 698–915 MHz; +35 dBm @ TX)	–	–55	–36	dBm
	RF–ANT (2fo: 1710–1910 MHz; +33 dBm @ TX)	–	–58	–36	dBm
	RF–ANT (3fo: 1710–1910 MHz; +33 dBm @ TX) RF–ANT (2fo: 698–798 MHz; +26 dBm @ TX)	–	–55 –80	–36 –36	dBm dBm
	RF–ANT (3fo: 698–798 MHz; +26 dBm @ TX)	–	–82	–36	dBm
	RF–ANT (2fo: 2500–2570 MHz; +26 dBm @ TX)	–	–70	–36	dBm
	RF–ANT (3fo: 2500–2570 MHz; +26 dBm @ TX)	–	–70	–36	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% VCTRL to 90% RF ON or 10% RF OFF	–	2	5	µs

Parameter	Condition	Min	Typ	Max	Unit
Startup time(3)	Time from V_{DD} within specification to all performances within specification	–	–	70	µs

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

The equivalent circuit model (ECM) shown in Figure 10 includes all parasitic elements and is accurate in switch ON and OFF states, reflecting the physical circuit behavior accurately and providing a very close correlation to measured data. You can use the ECM to accurately model the impedance, insertion loss, and isolation of the PE613050 SP4T switch. You can also easily use the ECM in circuit simulation programs.

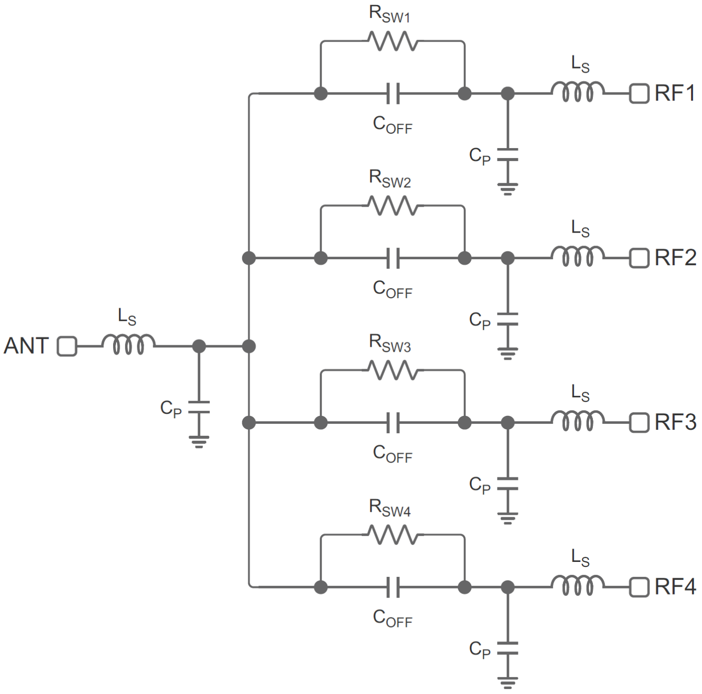

Figure 10. PE613050 equivalent circuit model schematic

Table 3 lists the mapping between the preferred switch RF state (RF1 through RF4) and the state variables (SW1 through SW4).

Table 3. 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

You can calculate the equivalent circuit model parameter values using the equations in Table 4.

Table 4. 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

Using the PE613050 tuning switch in antenna impedance and aperture tuning networks results 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 this device 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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