

Introduction and Operation of the PE42020 True DC RF Switch



Application Note 44

Summary

Peregrine Semiconductor's PE42020 True DC RF switch combines 8 GHz RF performance with power handling to DC (0 Hz). This switch features full $\pm 10\text{V}$ DC voltage handling from RFC to either RF1 or RF2 switched port and up to $\pm 80\text{ mA}$ current handling. The PE42020 switch exhibits high power handling of 30 dBm at 0 Hz and 36 dBm at 8 GHz and high linearity with greater than 60 dBm input IP3 and less than -84 dBc total harmonic distortion (THD). Additionally, the PE42020 switch features a 30,000:1 OFF-to-ON resistance ratio. Intelligent integration of the monolithic die enables the PE42020 switch to pass DC, RF, analog and digital signals without degrading signal performance. Peregrine's PE42020 True DC RF switch supports combining DC with RF signal path switching. This switch is ideal for test and measurement (T&M) applications such as communication testers, spectrum analyzers and network analyzers and automated test equipment (ATE) incorporating complex combinations of signals.

Figure 1 • PE42020 Functional Diagram

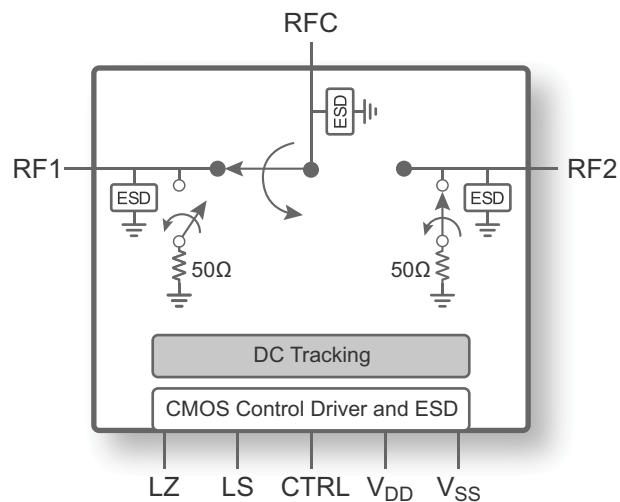
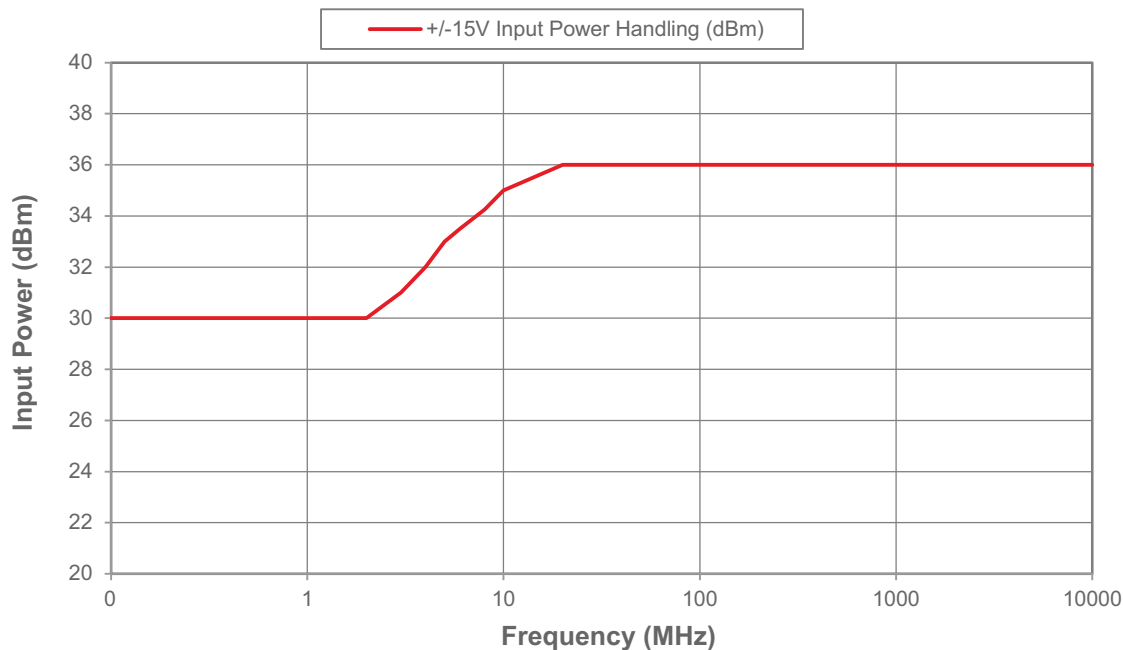


Figure 2 • Power Handling Curve



Introduction

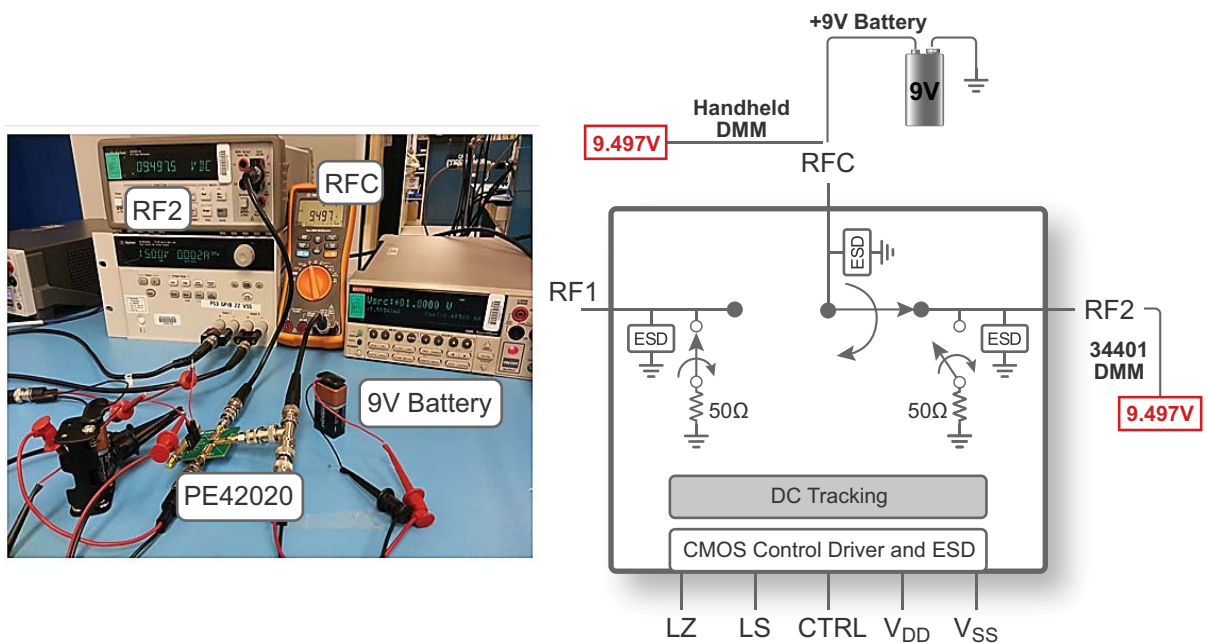
Peregrine Semiconductor’s PE42020 True DC RF switch, based on UltraCMOS® technology, is the world’s first RF-integrated switch that operates at true DC (0 Hz). The PE42020 switch maintains high frequency signal fidelity from 8 GHz all the way down to 0 Hz, while handling DC signal voltages in the range of +10V to –10V. The PE42020 single pole double throw (SPDT) switch features intelligent integration, high power handling, exceptional linearity, excellent THD, low insertion loss and fast switching time. The PE42020 switch integrates analog DC tracking, digital logic control, impedance control and high-performance RF switching onto a single chip, optimizing considerations of die size, high-frequency performance and cost. The PE42020 switch is the optimal solution for applications that rely on accuracy and precision such as T&M and ATE. The ability of the PE42020 switch to handle any signal composition enables innovative and robust solutions that address complex signaling functions. By truly covering the signal over the entire frequency spectrum, Peregrine’s PE42020 True DC RF switch solves the reliability issues and lack of integration of mechanical relay systems and analog functions on a monolithic die and provides superior reliability, markedly improved flexibility, enhanced performance and greater system capability.

DC Voltage and Current Handling

DC Pass-through

The PE42020 switch supports DC pass-through while preserving signal integrity. The PE42020 can switch DC or AC peak voltages in the range of +10V to -10V on the RF ports and can handle continuous DC current through its RF ports of up to 80 mA. These performance specifications are first-in-class for this type of switch. **Figure 3** demonstrates the fundamental capability of DC pass-through using a 9V battery. The 9V battery is attached to the RFC port. Its voltage is monitored directly on the handheld digital multimeter (DMM). The RF2 port, in its through state, is connected to the 34401 DMM on the left. Both meters register 9.497V.

Figure 3 • DC Pass-through with the PE42020 True DC RF Switch



Safe DC Operating Range

The PE42020 switch must not be operated outside the recommended operating conditions.

As the switch is designed to handle a broad range of DC voltage and current, the definition of safe operating range includes DC parameter limitations on the RF ports. Instead of the typical RF switch specification requiring either DC blocking capacitors or no DC present on the RF ports, the PE42020 switch expects to handle a variety of DC levels on its RF ports.

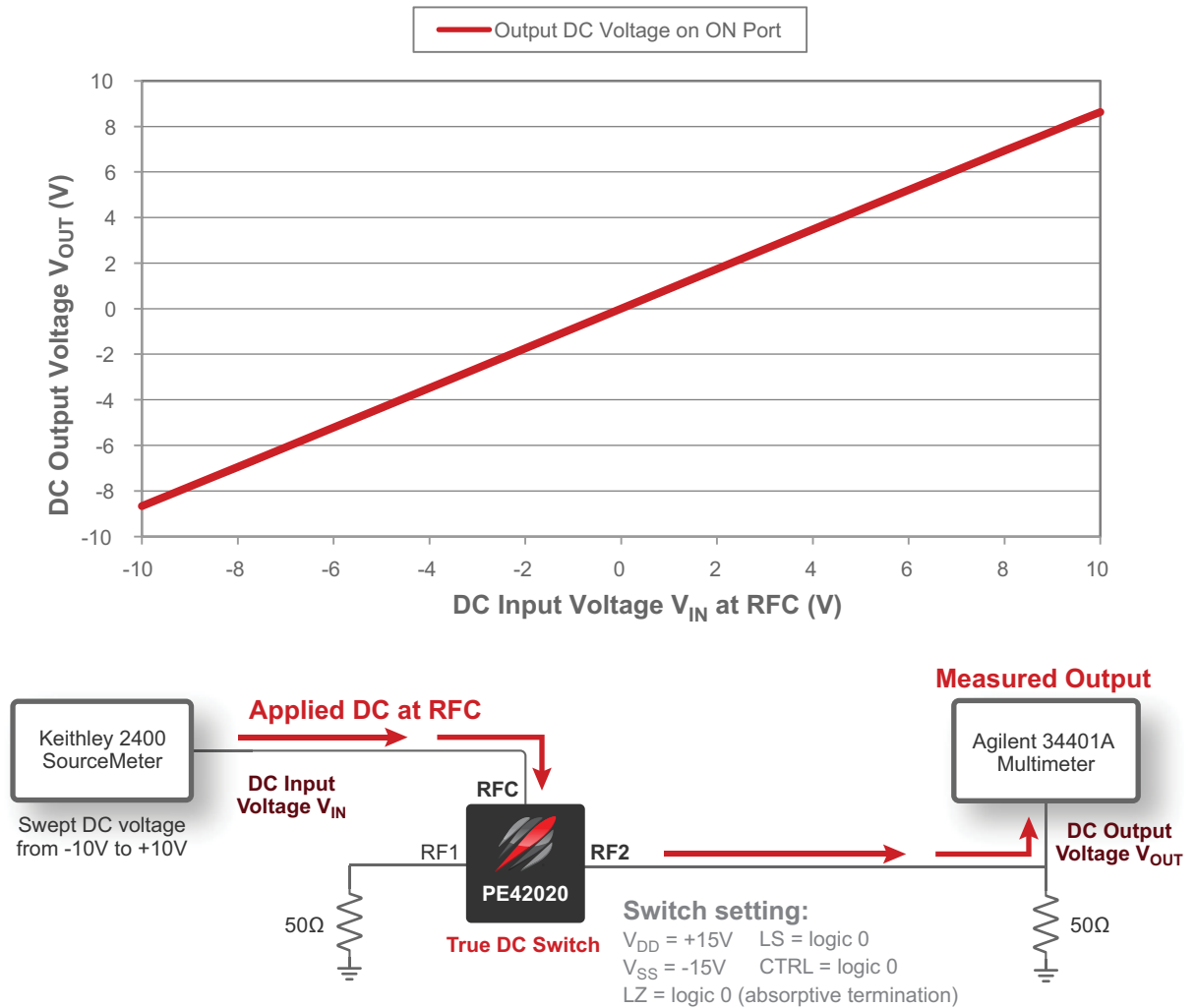
The PE42020 switch requires both positive and negative supply voltages in order to operate correctly. The two supply voltages are not required to be of identical absolute magnitudes, but optimal linearity and distortion behavior is obtained when these voltages are held to within 8% of each other.

The PE42020 switch is characterized at supply voltages from $\pm 11V$ to $\pm 15V$. These voltages permit a broad range of useful DC levels to be passed through the RF ports. A 4–5V offset exists between the supply rail voltages and the maximum DC voltage that may be passed through the device. **Table 1** defines the safe DC operating voltage range for the RF ports for specific supply voltages V_{DD} and V_{SS} . **Figure 4** demonstrates output DC voltage (50 Ω load) at the ON port versus input DC voltage at the RFC port. The ON path DC resistance is typically in the range of 7–8 Ω .

Table 1 • Safe DC Operating Range

	RLoad = 300 Ω					RLoad = 50 Ω					RLoad = 1 k Ω				
Measured total harmonic distortion with 1 kHz, 2.5 V_{pp} sinusoidal input under various load conditions (dBc) (1st five harmonics: $V_{DD}/V_{SS} = \pm 15V$)															
Serial #	CTRL=0 LZ=0	CTRL=0 LZ=1	CTRL=1 LZ=0	CTRL=1 LZ=1	System	CTRL=0 LZ=0	CTRL=0 LZ=1	CTRL=1 LZ=0	CTRL=1 LZ=1	System	CTRL=0 LZ=0	CTRL=0 LZ=1	CTRL=1 LZ=0	CTRL=1 LZ=1	System
57	-84.12	-84.10	-83.87	-83.87	-84.40	-83.31	-83.24	-82.72	-82.68	-84.38	-84.14	-84.19	-84.18	-84.10	-84.31
64	-84.59	-84.56	-84.12	-84.03	-84.40	-83.27	-83.19	-82.51	-82.43	-84.38	-84.26	-84.24	-84.21	-84.12	-84.31
65	-84.09	-83.99	-84.18	-84.12	-84.40	-83.05	-82.97	-83.46	-83.38	-84.38	-84.18	-84.17	-84.23	-84.21	-84.31
69	-84.01	83.94	-83.80	-83.77	-84.40	-83.02	-82.94	-82.51	-82.47	-84.38	-84.16	-84.15	-84.09	-84.04	-84.31
61	-84.14	-84.00	-84.02	-84.02	-84.40	-82.90	-82.78	-82.97	-82.87	-84.38	-84.18	-84.11	-84.18	-84.31	-84.31
Measured total harmonic distortion with 1 kHz, 2.5 V_{pp} sinusoidal input under various load conditions (dBc) (1st five harmonics: $V_{DD}/V_{SS} = \pm 11V$)															
Serial #	CTRL=0 LZ=0	CTRL=0 LZ=1	CTRL=1 LZ=0	CTRL=1 LZ=1	System	CTRL=0 LZ=0	CTRL=0 LZ=1	CTRL=1 LZ=0	CTRL=1 LZ=1	System	CTRL=0 LZ=0	CTRL=0 LZ=1	CTRL=1 LZ=0	CTRL=1 LZ=1	System
57	-84.59	-84.56	-84.12	-84.03	-84.40	-84.22	-84.13	-83.18	-83.10	-84.38	-84.34	-84.37	-84.24	-84.17	-84.31
64	-84.77	-84.64	-84.73	-83.97	-84.40	-84.44	-84.40	-82.54	-82.47	-84.38	-84.44	-84.38	-84.46	-84.14	-84.31
65	-84.38	-84.32	-84.61	-84.58	-84.40	-83.83	-83.74	-84.31	-84.23	-84.38	-84.30	-84.28	-84.39	-84.37	-84.31
69	-84.19	-84.11	-83.76	-83.82	-84.40	-83.40	-83.31	-82.37	-82.29	-84.38	-84.25	-84.22	-84.10	-84.05	-84.31
61	-84.34	-84.38	-84.33	-84.29	-84.40	-83.45	-83.35	-83.61	-83.48	-84.38	-84.29	-84.24	-84.25	-84.22	-84.31

Figure 4 • ON Port DC Performance Measurement (DC Voltage Range)



Power-up/Power-down Sequence

The following power-up/power-down sequence must be followed. Failure to follow this sequence will cause permanent damage to the device.

- During the power-up sequence, V_{SS} must be turned on before V_{DD} .
- During the power-down sequence, V_{DD} must be turned off before V_{SS} .

It is recommended to turn on V_{DD} within 1 second of turning on V_{SS} during the power-up sequence and turn off V_{SS} within 1 second of turning off V_{DD} during the power-down sequence. The device is not sensitive to the timing and level of the control voltages.

Current Handling

In addition, the PE42020 switch handles up to 80 mA of continuous DC current draw. Users must understand the implications of this current level on their circuit definition and DC power draw. Circuits requiring high voltages on low load impedances will need to carefully check the maximum current draw expected through the PE42020. Exceeding the 80 mA will not cause catastrophic failure, but will reduce the long-term reliability of the switch. **Figure 5** demonstrates DC current flow in a 50Ω load. **Figure 6** demonstrates DC current flow in a 300Ω load. If the current is sinusoidal rather than DC, the operating lifetime of the switch is greatly increased. For example, the lifetime is greater than 10 years for a 1 GHz, 30 dBm RF signal delivered to a 50Ω load impedance. The associated peak current level passing through the PE42020 switch in this case is 200 mA.

Figure 5 • ON Port DC Performance Measurement (DC Current Flow in a 50Ω Environment)

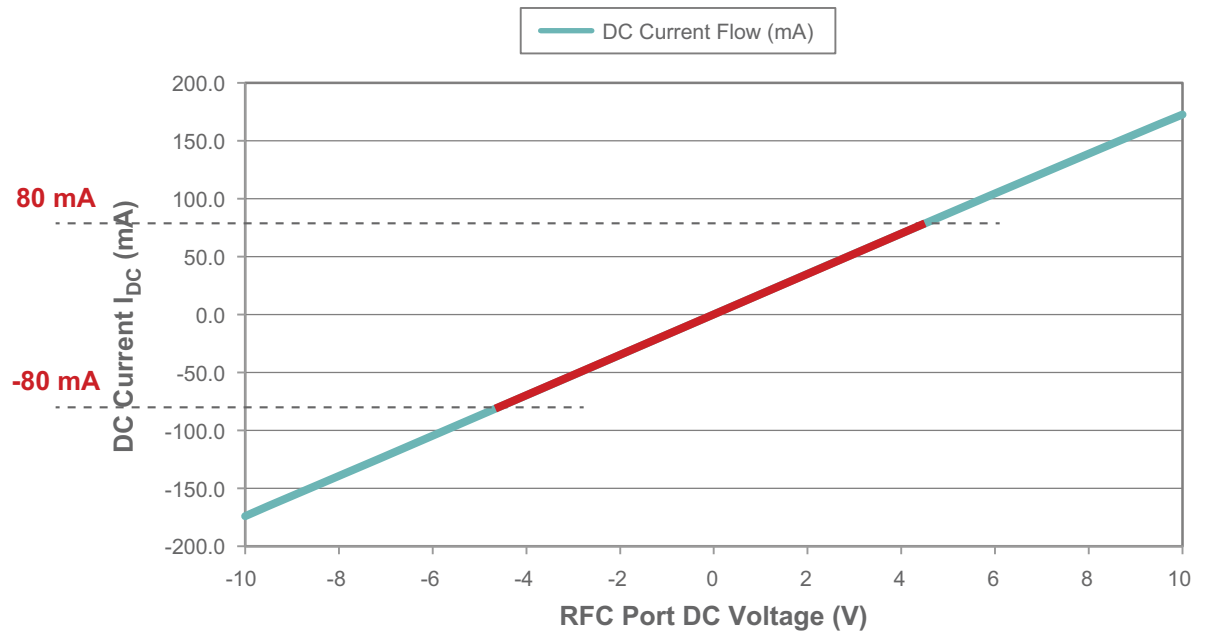
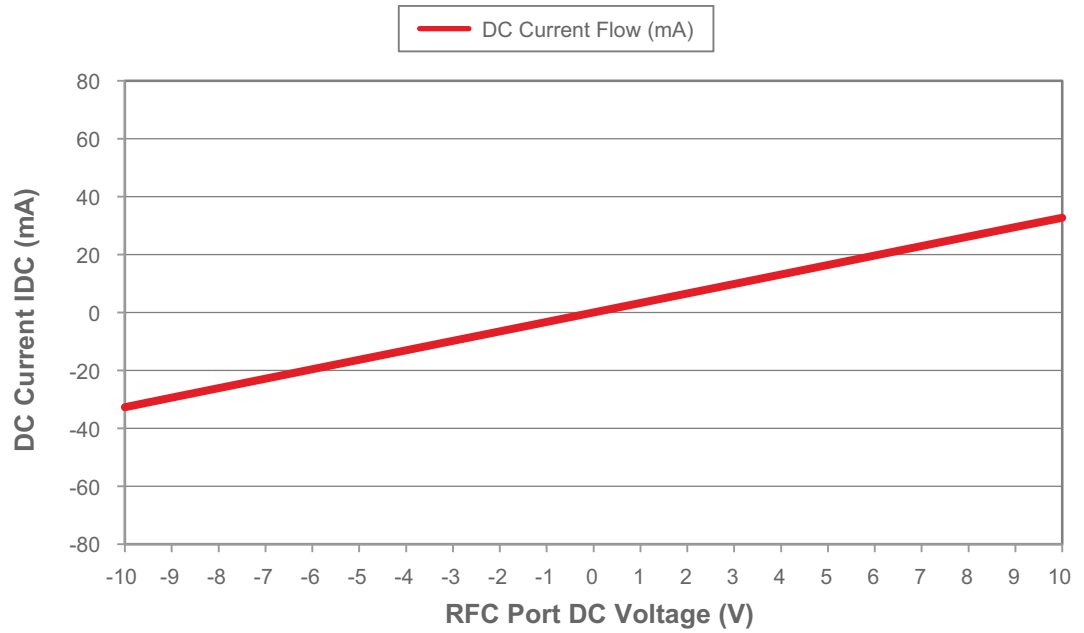


Figure 6 • DC Current Flow in a 300Ω Environment^(*)

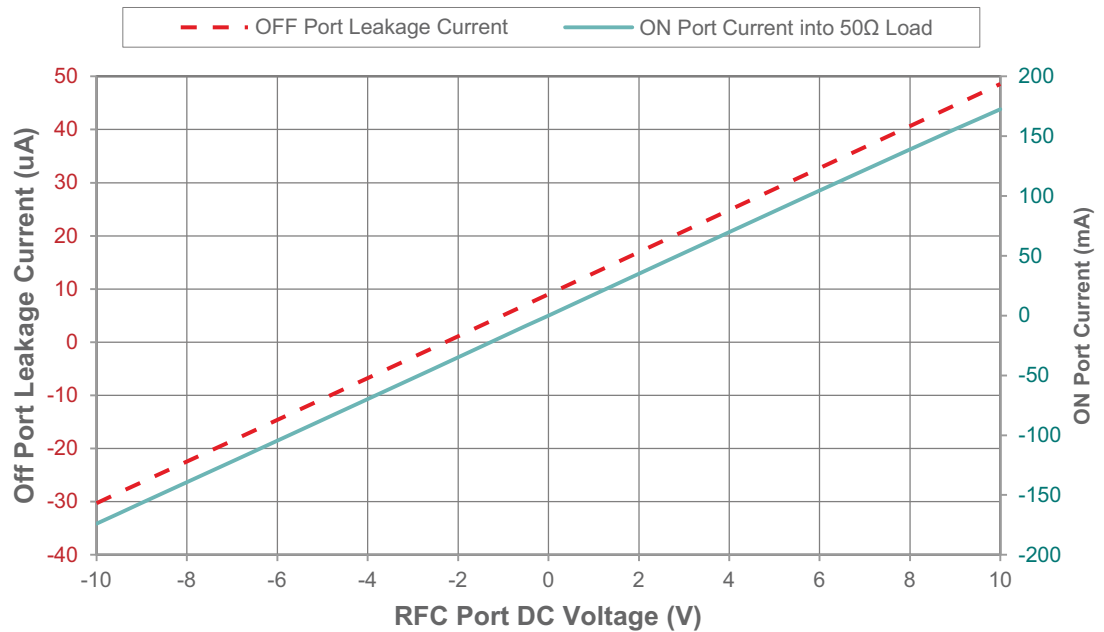


Note: * Higher load impedances permit using the full DC voltage range of $\pm 10\text{V}$ while remaining within the specified current range for long-term reliability.

ON vs OFF Current Levels

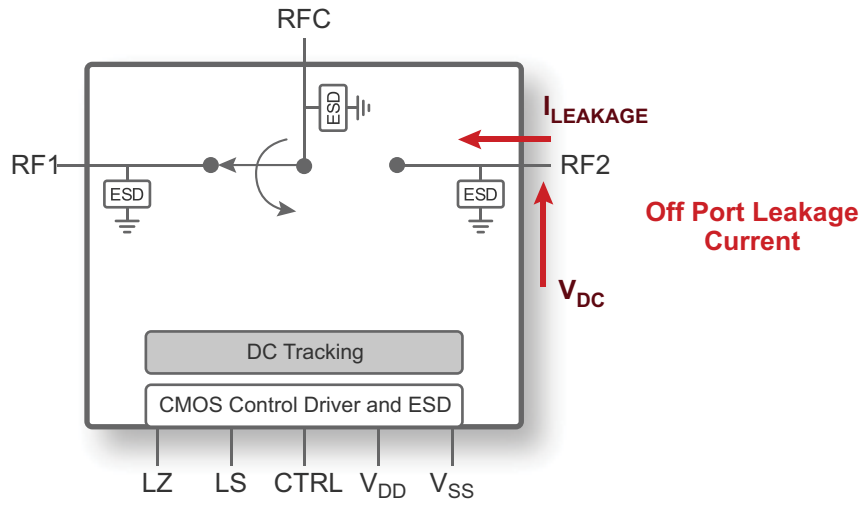
In addition to passing voltage from port to port, current flow is critically essential for DC operation. **Figure 7** demonstrates port-to-port current flow for the PE42020's ON path, for which the switched port is terminated externally into 50Ω. The DC voltage at the common port is swept while the current through the switch is monitored. The ON resistance typical range is between 7–8Ω over the input port DC voltage range of ±10V. The leakage current of the OFF path for the same DC voltage sweep is also shown in **Figure 7**. The 48 μA leakage represents a more than 30,000:1 ratio between the OFF and ON DC resistance levels of the PE42020.

Figure 7 • ON vs OFF Current Levels^(*)



Note: * ON Port Current level shown is well above the long-term reliability level of ±80 mA. This demonstrates the ability of the PE42020 to handle full voltage swings with 50Ω loading over limited durations.

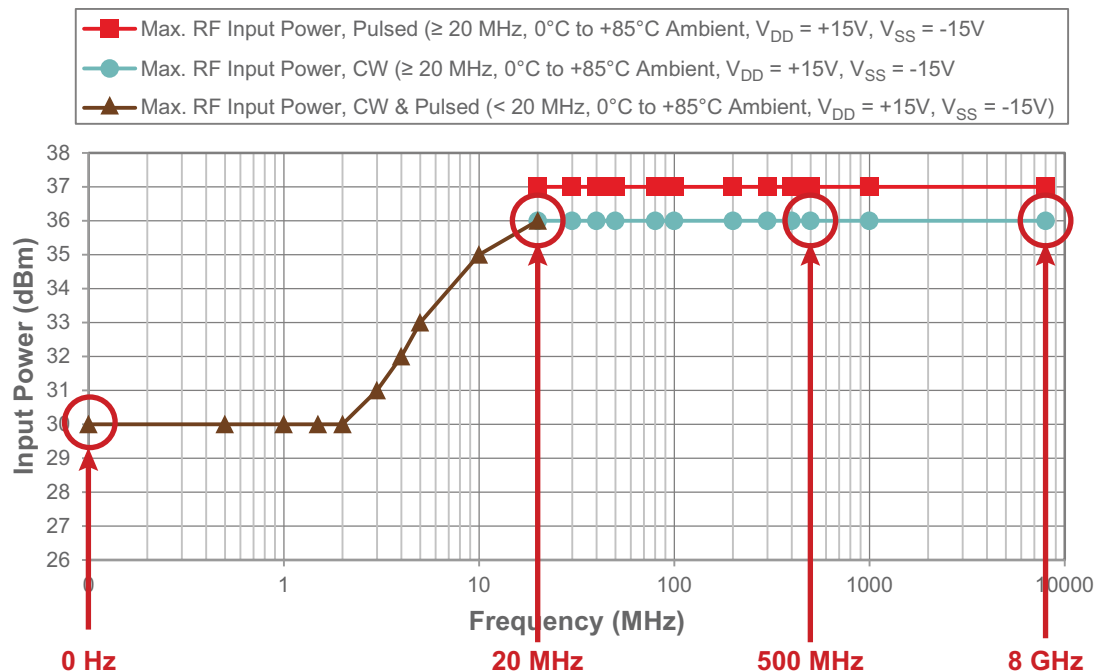
Figure 8 • OFF Port Leakage Current



Power Handling

The PE42020 switch is the first RF switch that can maintain power handling across the entire frequency spectrum. The PE42020 switch features high power handling of 30 dBm at 0 Hz and 36 dBm at 8 GHz (Figure 9). This switch passes any combination of RF, analog, digital and DC content, allowing RF engineers to utilize the PE42020 in complex applications requiring multiplexed arrangements of information and control signals.

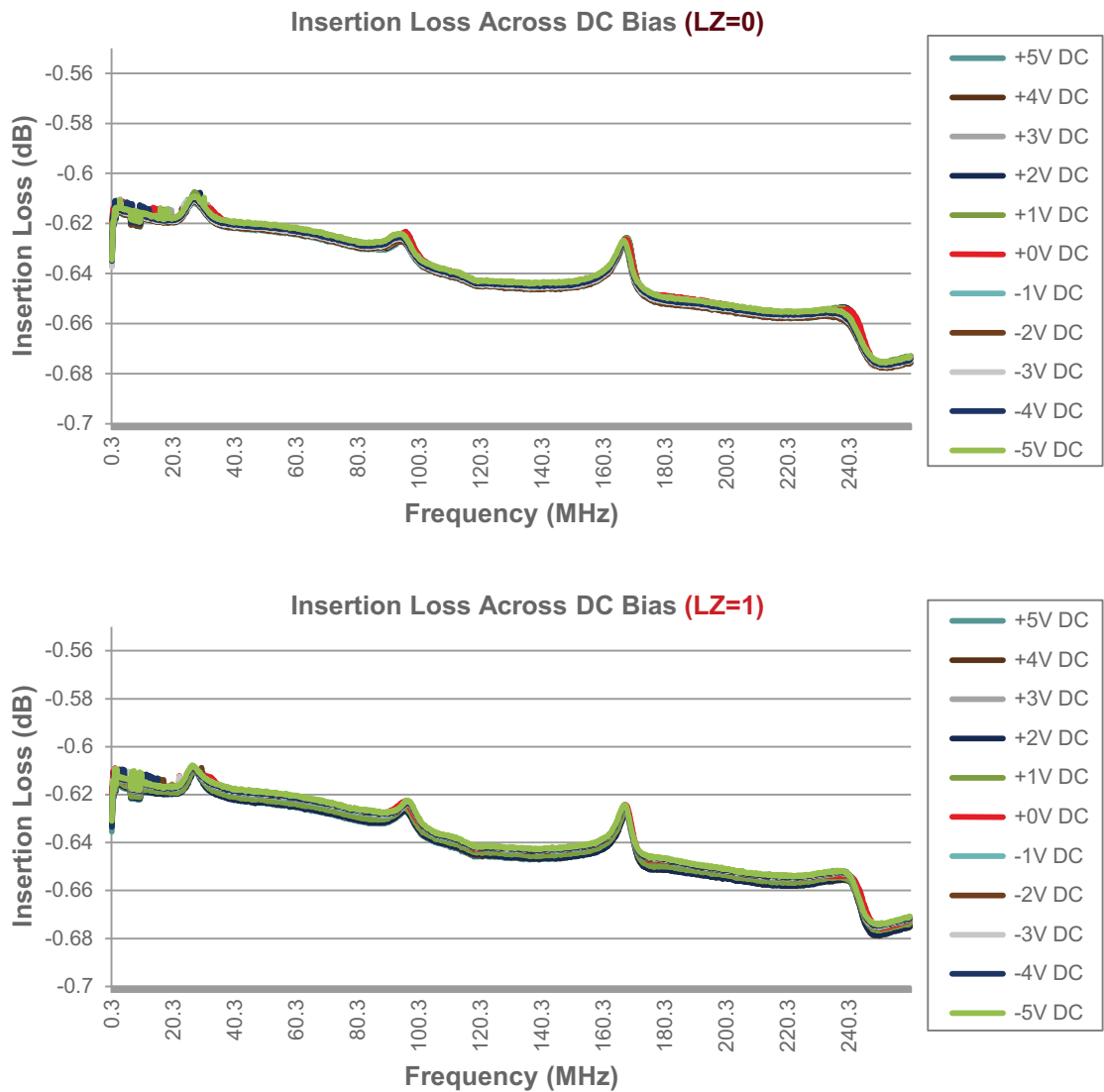
Figure 9 • Power Handling Across Frequency



Low Frequency AC Behavior with DC Present

The PE42020 switch is designed and optimized for low frequency down to 0 Hz (true DC). S-parameter measurements with DC bias present at the RFC port demonstrates the capability of AC signal mixing with DC voltage. The applied DC bias ranges from -5V to $+5\text{V}$. **Figure 10** shows there is no performance degradation.

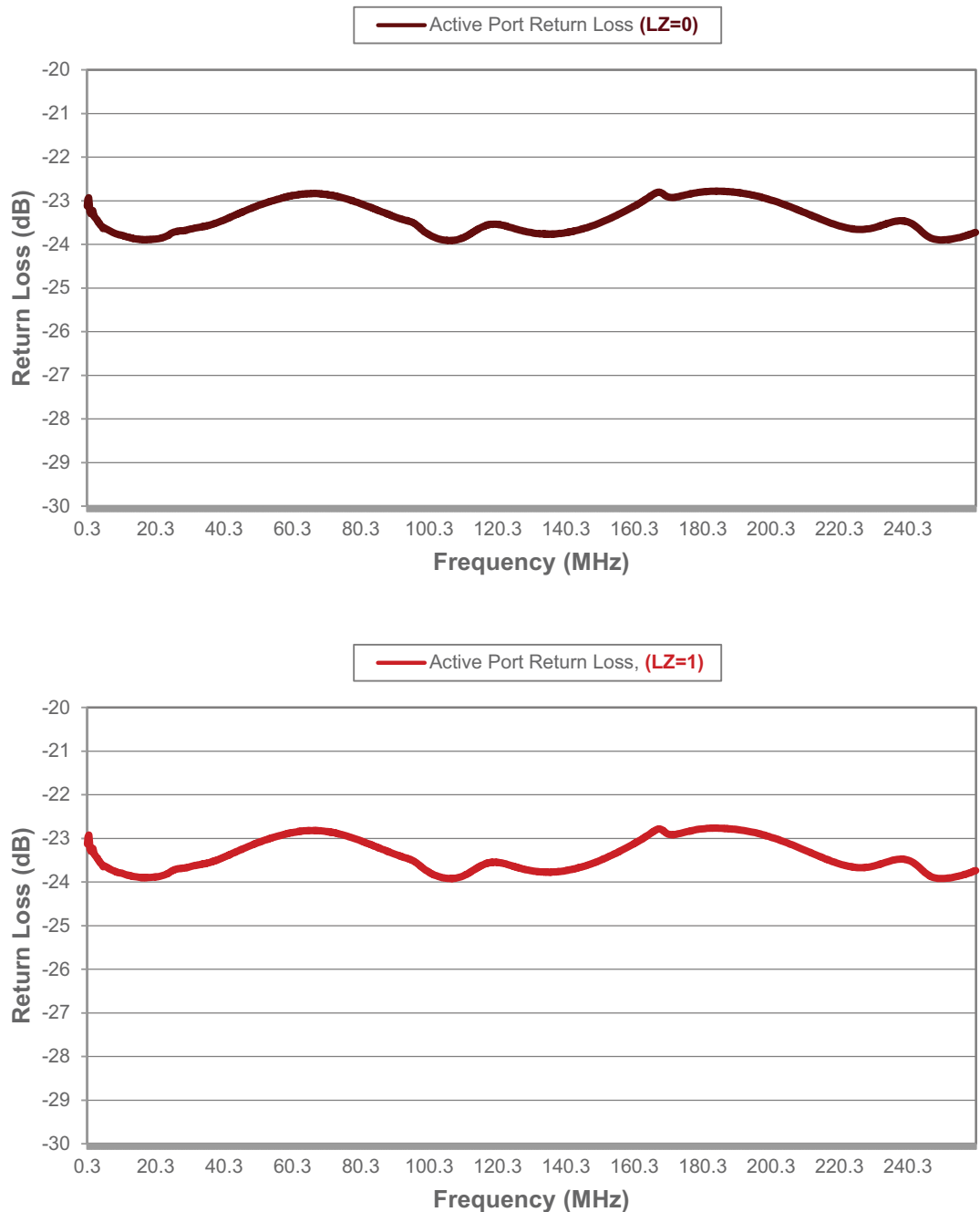
Figure 10 • Low Frequency Insertion Loss Across DC Bias at RFC



Low Frequency ON Port Return Loss

There is an ON port 23.5 dB average return loss at low frequency (Figure 11).

Figure 11 • *Low Frequency Active Port Return Loss*^(*)



Note: * 23.5 dB average return loss at low frequency.

RF Large Signal Performance with DC Present

The PE42020 switch is designed to handle an RF signal with co-existent DC voltage. RF large signal parameters such as P0.1dB, IIP2 and IIP3 are measured with DC voltage present at the RF port and varied up to $\pm 10\text{V}$. **Figure 12** shows RF large signal performance is kept fairly consistent with DC present and only a slight variation with P0.1dB performance.

Figure 12 • P0.1dB Compression vs DC Voltage

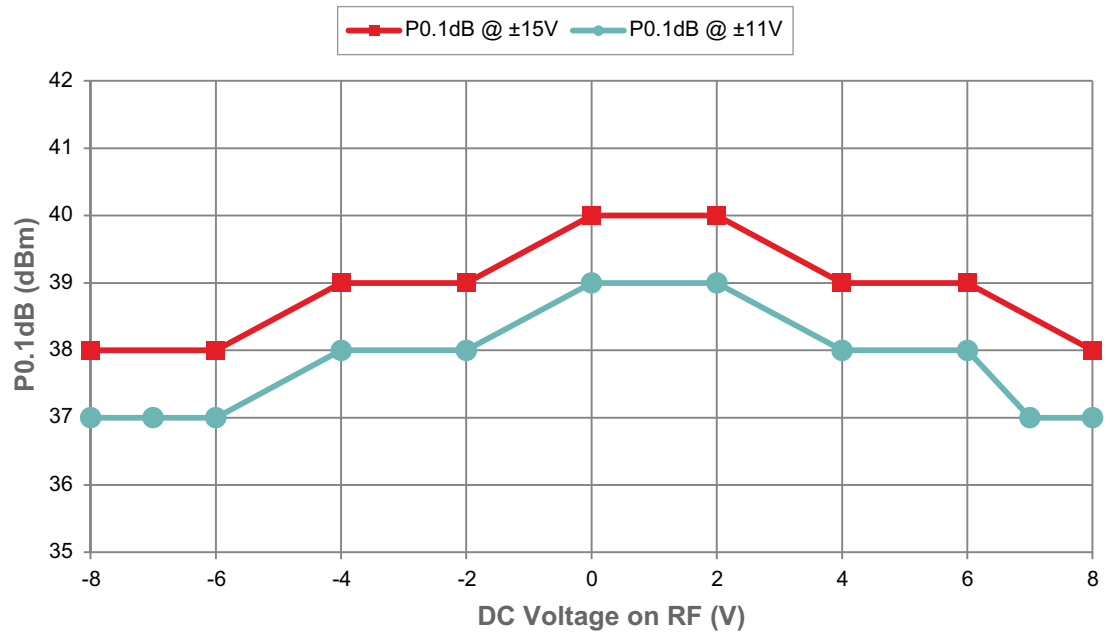


Figure 13 • IIP2 vs DC Voltage

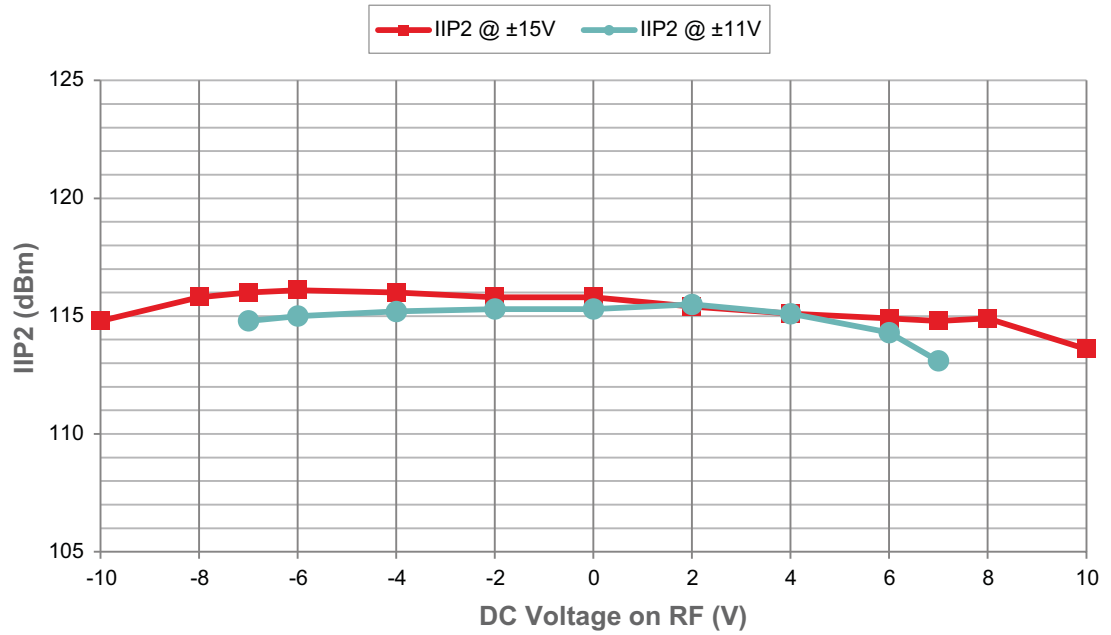
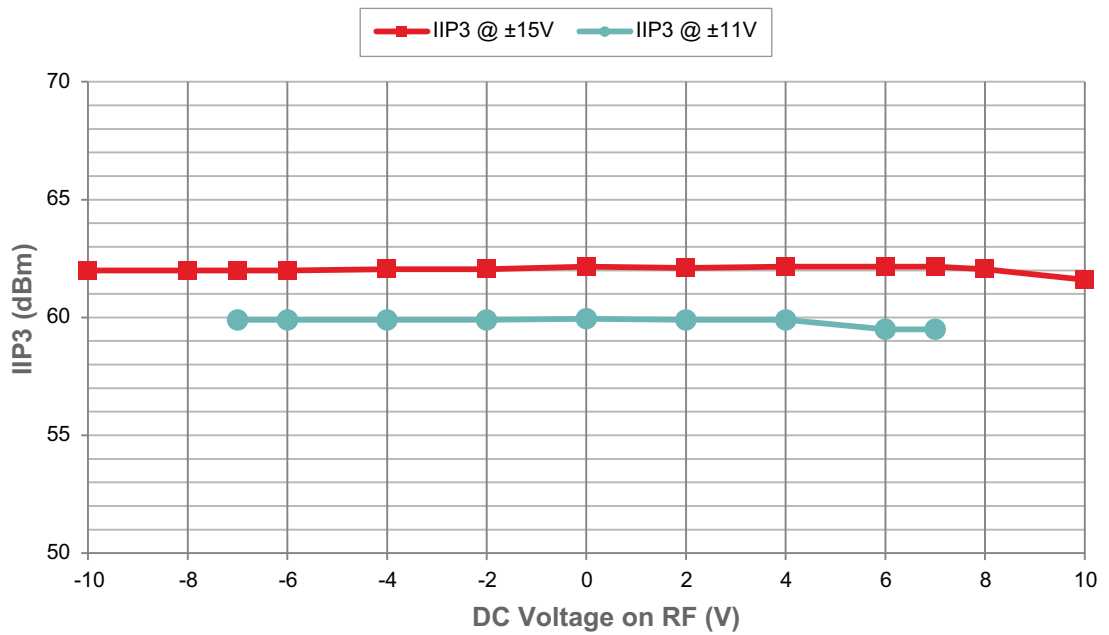


Figure 14 • IIP3 vs DC Voltage



LZ Operation

The PE42020 True DC RF switch implements two options for OFF port configuration. The control logic truth table is shown in **Table 2**.

Table 2 • PE42020 True DC Control Logic Truth Table

LS	CTRL	LZ(*)	RFC–RF1	RFC–RF2	OFF Port Terminated
0	0	0	OFF	ON	Yes
0	0	1	OFF	ON	No (High–Z)
0	1	0	ON	OFF	Yes
0	1	1	ON	OFF	No (High–Z)
1	0	0	ON	OFF	Yes
1	0	1	ON	OFF	No (High–Z)
1	1	0	OFF	ON	Yes
1	1	1	OFF	ON	No (High–Z)

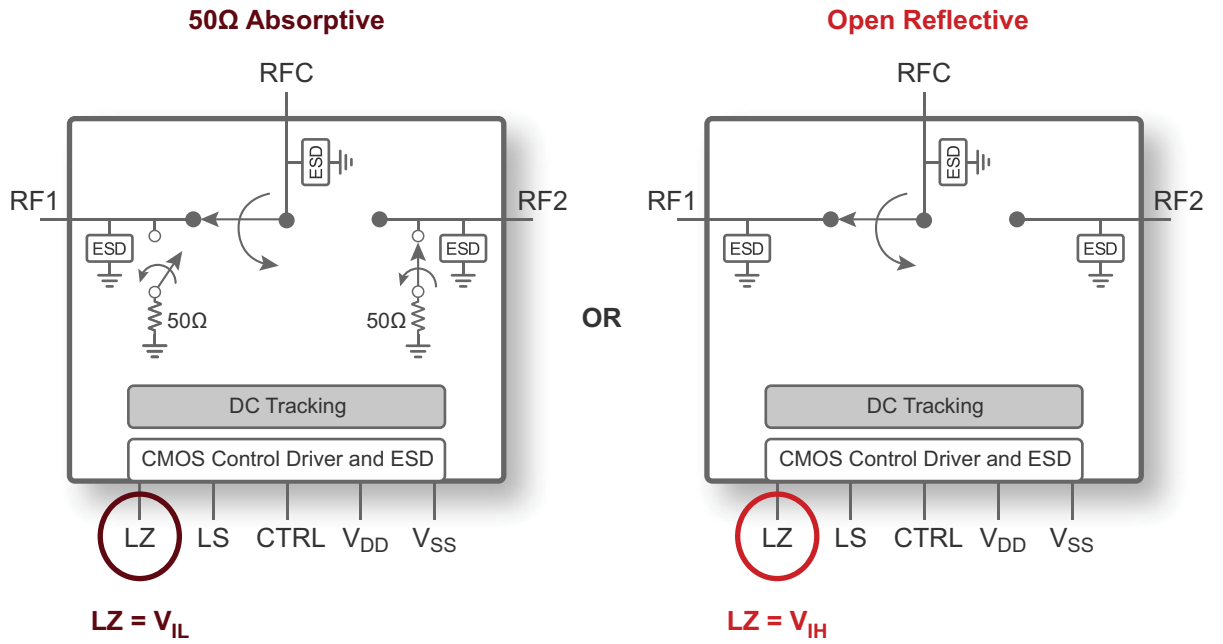
Note: * The part is configured as an open reflective switch if LZ pulls high.

When the LZ pin is set to logic LOW (0), the switch configures the OFF port to 50Ω absorptive (**Figure 15**). In the absorptive mode, shunt 50Ω termination resistors are switched in to provide stable reference impedance for the isolated path. Any DC voltage applied to the OFF port, when the switch is configured for the absorptive mode, would need to stay within the 20 dBm dissipated DC power rating of the OFF port.

When the LZ pin is set to logic HIGH (1), the switch configures the OFF port to be open reflective, disconnecting the internal 50Ω termination to ground (**Figure 15**). Thus, in open reflective mode, no shunt element is placed on the isolated port and its impedance appears as high impedance to external circuitry.

Tying the LS pin either HIGH or LOW will fix the CTRL pin's truth table to the desired behavior.

Figure 15 • Flexible OFF Port Configuration



Technology Performance Comparisons: Reliability and Switching Speed

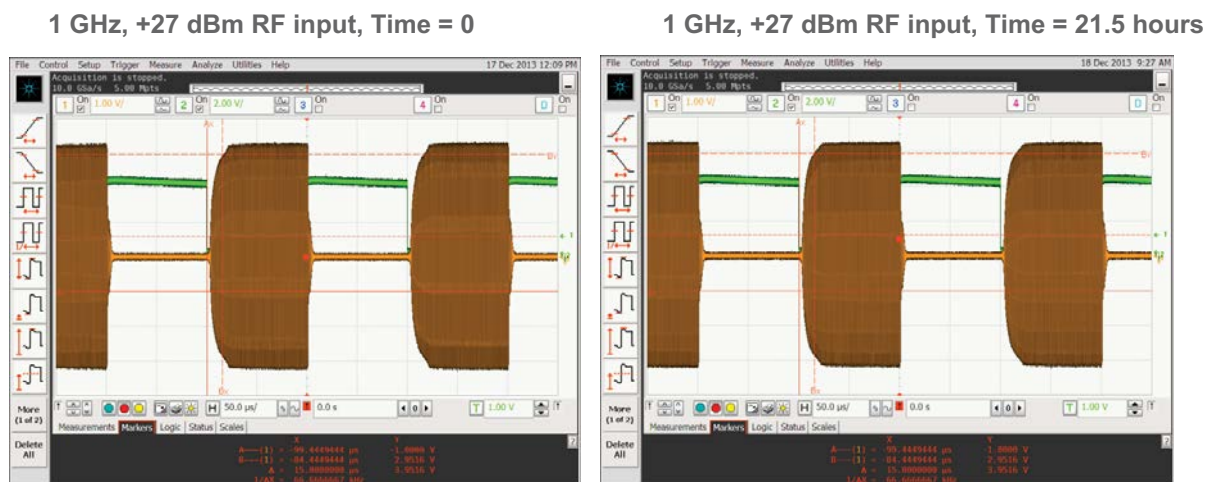
The PE42020 True DC RF switch is far more reliable than mechanical relay systems and MEMS technology for use in T&M devices and ATE systems. For example, mechanical relays often fail after just tens of millions of cycles. In marked contrast, the PE42020 switch can handle an unlimited number of cycles, eliminating the need for maintenance, downtime and backup equipment. Additionally, the PE42020 fast switching time of 10 μs and impressive 35 μs settling time speed ATE production test cycle times. These performance specifications are greater than 150 times faster than most mechanical relay systems and MEMS. The PE42020 switch can route to any test device with any test signal definition, giving T&M equipment designers the broadest flexibility provided by any switch on the market. The test signal can comprise any DC, RF, analog or digital electrical stimulus, including any combination of DC or AC components, sine waves to complex modulated signals and high-power RF signals. The PE42020 switch delivers the frequency range, high-power handling, superior linearity and insertion loss performance required to excel in T&M devices and ATE systems.

With its true DC capabilities, high linearity and low noise behavior, the PE42020 switch can be used in numerous low-frequency, analog-circuit applications. The PE42020 switch enables circuit reconfiguration while passing DC components. This capability can be leveraged in any analog circuit needing to change reference voltages or currents, voltage division ratios, pass DC offsets or handle more complex signal definitions. As the PE42020 switch is uniquely able to pass DC to 8 GHz signal information, engineers can now bundle DC power to the RF path selected. For example, this switch can provide real-time antenna connection monitoring and antenna selection capabilities.

Hot Switching

The PE42020 is capable of hot switching—switching states with RF signals applied. For $\pm 15\text{V}$ supply voltages, the switch is able to handle hot switching up to +27 dBm power levels. At $\pm 11\text{V}$, the maximum hot switching power level is +24 dBm. **Figure 16** depicts hot switching tests performed on the PE42020.

Figure 16 • Hot Switching Overview^(*)

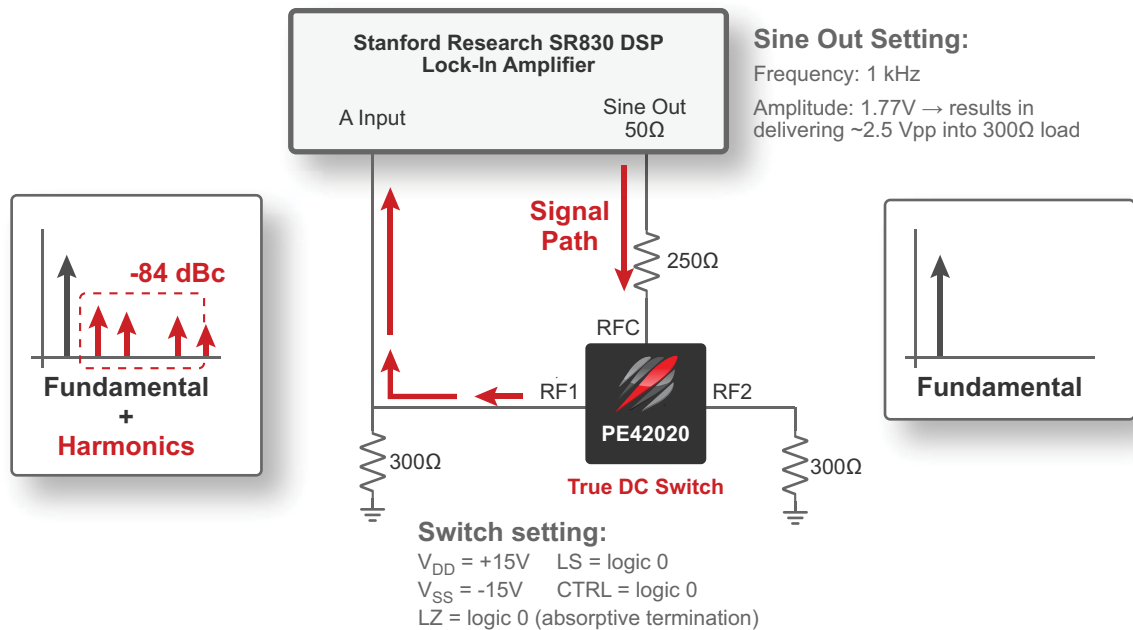


Note: * No performance degradation. Hot switching by toggling state every 200 μs for 21.5 hours.

Total Harmonic Distortion

In covering the low-frequency spectrum between DC and 9 kHz, the PE42020 THD is a significant consideration beyond the second and third harmonics typically reported for RF switches. For example, THD is a critical metric in audio applications in which numerous harmonics can readily contaminate and be sensed in the audio frequency range. The PE42020 switch achieves an impressive THD of -84 dBc. THD behavior is measured for the combined harmonic energy up to the fifth harmonic (**Figure 17**). Similarly, the PE42020 switch contributes minimally to broadband noise. With or without the PE42020 switch in a system, there is no difference in the -154 dBc noise behavior of a carrier tone at a fixed 10 MHz offset over a wide carrier range.

Figure 17 • Total Harmonic Distortion Measurement

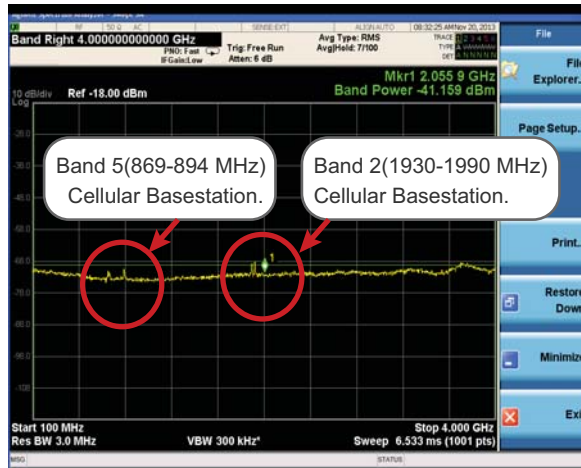


Noise Behavior

The internal circuitry of the PE42020 switch was designed with both stability and minimal noise contribution in mind. Noise figure test data at 1–4 GHz (**Figure 18**) and 4–8 GHz (**Figure 19**) demonstrate an identical value of insertion loss, indicating there is no spur or excess noise generated by the PE42020 switch.

Figure 18 • Noise Figures: 1–4 GHz^(*)

Cold (Noise Source OFF) Measurement



Hot (Noise Source ON) Measurement



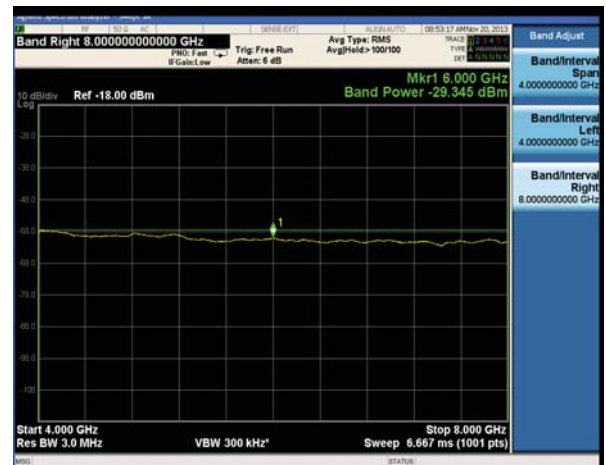
Note: * Control circuitry does not generate non-linear signals.

Figure 19 • Noise Figures: 4–8 GHz^(*)

Cold (Noise Source OFF) Measurement



Hot (Noise Source ON) Measurement



Note: * Control circuitry does not generate non-linear signals.

Additional Features

Switching Time

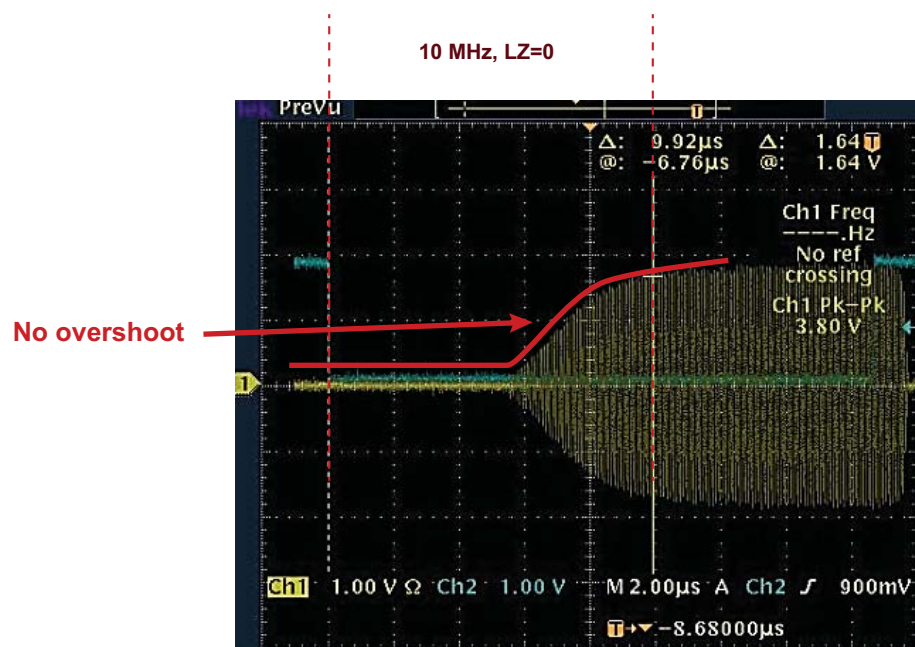
Several specification categories are critical for high-precision applications in T&M equipment, such as communication testers, spectrum analyzers and network analyzers. The PE42020 True DC RF switch exhibits high linearity of 62 dBm IIP3, high port-to-port isolation of 37 dBm at 6 GHz and a high power 0.1dB compression point of 38 dBm at 8 GHz. The PE42020 switch features a fast switching time of 10 μ s (Table 3 and Figure 20). This switch supports standard +1.8V and +3.3V control logic interfacing, eliminating the need for custom, power-hungry control circuits. It also operates at a temperature range of -40 to $+85$ $^{\circ}$ C. In addition, the PE42020 switch offers several performance gains unique to UltraCMOS technology including repeatability, long-term reliability and 1 kV human body model electrostatic discharge rating on all pins. The monolithic die fits into a 20-lead 4 x 4 mm QFN package.

Table 3 • Switching Time Measurement^(*)

RF Input Frequency (2V Amplitude)	LZ Logic State	Switching Time (μ s, 90%, 10%)
10 MHz	0	9.92
10 MHz	1	9.88
1 MHz	0	9.64
1 MHz	1	9.56

Note: * Measured switching time (90%/10% final value) of ~ 10 μ s with the OFF to ON case being the longest.

Figure 20 • Switching Time Measurement



Conclusion

Peregrine Semiconductor's PE42020 True DC RF switch based on UltraCMOS technology is the industry's first and only RF integrated switch to operate at true DC (0 Hz). This switch represents a significant breakthrough in solid state switching performance. The PE42020 switch features high power handling and maintains exceptional RF performance from DC through 8 GHz. The PE42020 switch handles the complex combination of DC, RF, analog and digital signals. It exhibits high port-to-port isolation, a high power compression point and fast switching and settling times. The PE42020 switch features intelligent integration, offering RF, digital and analog functions on a monolithic die. The many benefits of Peregrine's technology include superior reliability, markedly improved flexibility, enhanced performance, greater system capability and a smaller form factor. The PE42020 switch is ideal for T&M and ATE applications and is the first high-performance alternative to mechanical relay systems and MEMS. The ability of the PE42020 switch to handle any signal composition enables innovative and reliable solutions that address more complex signaling functions, such as bundling DC power with RF signaling and parallel DC and RF functionality as in antenna connection monitoring.

Sales Contact

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

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