Technical Article

# Design the Best Front End for UHF Partial Discharge Online Monitoring Systems

**Van Yang**, RF Product Applications Engineer,
**Meng Wang**, RF Product Applications Engineer,
**Lance Wu**, RF Product Applications Engineer, and
**Aaron He**, RF Product Applications Engineer

## Abstract

This article describes the design of an RF front end for ultrahigh frequency (UHF) partial discharge online monitoring systems using an Analog Devices signal chain. The front end has low sensitivity and high dynamic range, which meets the requirement of the state grid corporation of China enterprise standard Q/GDW11059.8-2013 "Technical Specification for Energized Test Device of Electrical Equipment Part 8: Technical Specifications for an Ultrahigh Frequency Partial Discharge Detector" with great margin.

## Introduction

According to the IEC 60270 standard, partial discharge (PD) is an electrical discharge that occurs across a localized area of the insulation between two conducting electrodes without completely bridging the gap. PD is widely regarded as the best early warning indicator of electrical insulation deterioration of electrical assets within power networks.

When PD happens, it will generate a signal with wide frequency range, so there are four PD detection techniques that are focused on different frequency ranges. The ultrasonic detection technique is focused on the frequency range of 20 kHz to ~200 kHz, the high frequency current transformer (HFCT) detection technique is focused on the frequency range of 3 MHz to ~30 MHz, the transient earth voltage (TEV) detection technique is focused on the frequency range of 3 MHz to ~100 MHz, and the ultrahigh frequency (UHF) detection technique is focused on the frequency range of 300 MHz to ~1500 MHz. Due to the high detection sensitivity, the UHF technique is widely used in PD online monitoring systems for gas-insulated switchgears (GISs), transformers, and ring main units (RMUs).

## PD Signal Analysis

According to the Q/GDW11282-2014 standard "Onsite Inspection Specification for Partial Discharge UHF Coupler of Gas Insulated Metal-Enclosed Switchgear" section 7.1, the standard PD signal generator can generate the following PD pulse signal characteristics: a pulse rise time no greater than 300 ps and a pulse width between 10 ns and 500 ns. This information is then used to build a PD simulator signal in Python. The rise time is 300 ps and the fall time is 10 ns. The pulse signal peak magnitude is 100 mV and the peak-to-peak noise is 10 mV. The sampling rate is 10 GSPS and the sampling time is 10 μs. The pulse is put in the middle of the sampling time and both the rise waveform and fall waveform are linearly fitted.

The simulated PD signal time domain waveform is shown in Figure 1 and the frequency domain waveform is shown in Figure 2. According to Figure 2, the PD signal with the most energy is within the frequency range of less than 1 GHz. For a pulse rise time less than 300 ps, more energy will be located at a higher frequency.

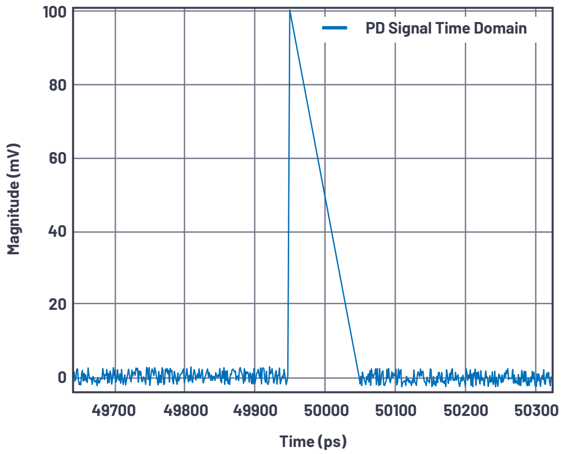


*Figure 1. PD signal time domain waveform.*

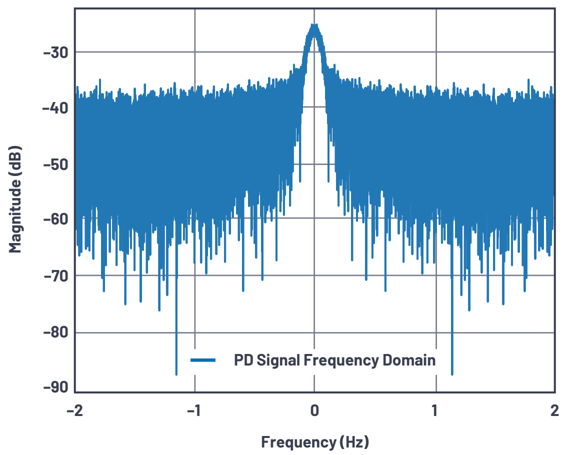


*Figure 2. PD signal frequency domain waveform.*

In a modern complex electromagnetism environment, there are many wireless interference signals between UHF PD with a working frequency range of 300 MHz to 1500 MHz. To combat this interference, customers will normally choose a sub-band within 300 MHz to 1.5 GHz to capture the PD pulses. Normally, wireless communication signals for GSM around 900 MHz will be the biggest interference signal. One solution to this problem is to implement a band reject filter (BRF) that rejects signals from 800 MHz to 1000 MHz. A typical sub-band division scheme is shown in Table 1. Of course, the sub-band division is flexible, and customers could make adjustments according to the real electromagnetism environment.

### Table 1. A Typical UHF PD Sub-Band Division Scheme

| Sub-Bands | Frequency Range |
|---|---|
| Full band | 300 MHz to ~1500 MHz |
| Low-pass band | 300 MHz to ~800 MHz |
| High-pass band | 1000 MHz to ~1500 MHz |
| Band reject band | 300 MHz to ~1500 MHz with 800 MHz to ~1000 MHz band rejected |

Based on the sub-band division in Table 1, we only keep the corresponding frequency components of the PD signal spectrum shown in Figure 2, and then we perform an inverse fast Fourier transform (IFFT) to investigate what the time domain waveform will be after the corresponding filtering. The time domain waveform postfiltering is shown in Figure 3. Based on Figure 3, after filtering, the PD pulse peak value will be decreased. After filtering, the PD pulse rise time will be increased and fall time will be decreased. Among all the waveforms after filtering, the full band has the biggest peak value, which is followed by the values for the band reject band and low-pass band. The high-pass band has the smallest peak value, but the PD pulse is still capturable.

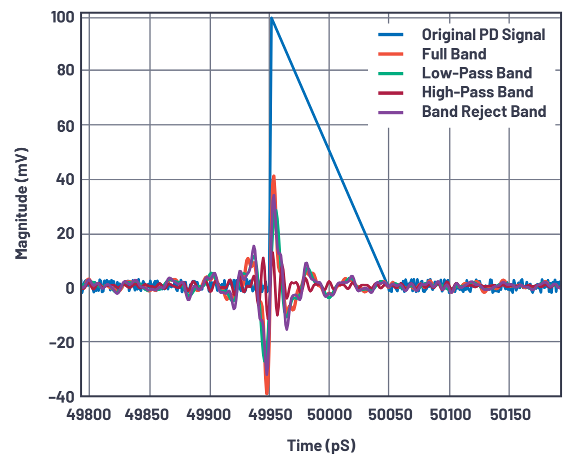


*Figure 3. PD signal time domain waveform after filtering.*

## A UHF PD Detection RF Front End Using an Analog Devices Signal Chain

A UHF PD detection RF front-end board with four channels can be developed using an Analog Devices signal chain. An example of one and its block diagram is shown in Figure 4, while its board front view is shown in Figure 5.

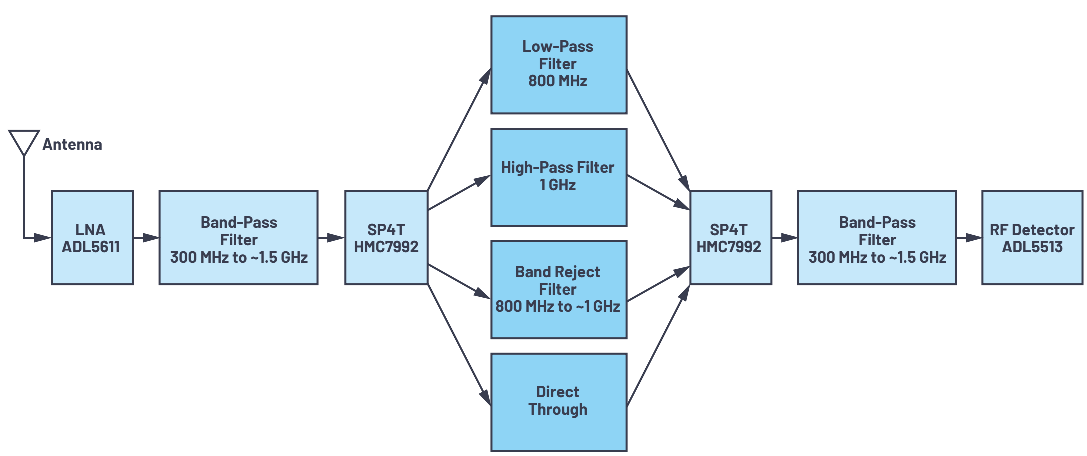


*Figure 4. A UHF PD detection RF front-end board block diagram.*

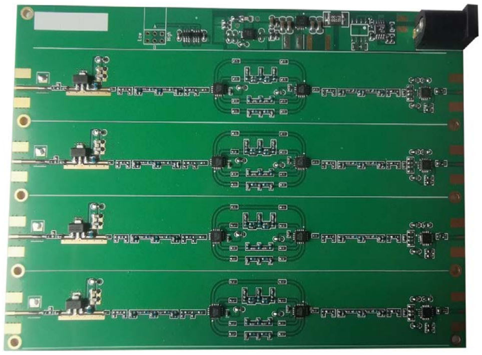

*Figure 5. The front view of a UHF PD detection RF front-end board.*

The first stage for developing this front end involves the ADL5611 RF gain block. The ADL5611 has a low noise figure (NF) of 2.1 dB and a high P1dB of 21 dBm, which provides high dynamic range. ADL5611 has 22 dB gain and its gain flatness across UHF PD working frequency of 300 MHz to 1500 MHz is extremely flat, with less than 0.4 dB gain ripple. All these characteristics make the ADL5611 quite suitable for UHF PD detection applications.

The second development stage involves inductors and capacitors based around a 300 MHz to 1500 MHz band-pass filter (BPF), which provides the out-of-band interference rejection.

The third stage uses two single-pole, four throw (SP4T) RF HMC7992 switches to implement the frequency band selection circuit. The first RF path is a DC-to-800 MHz low-pass path, the second RF path is a 1 GHz high-pass path, the third path is an 800 MHz to 1 GHz band reject path, and the fourth path is a direct through path. According to the different RF path selections, customers could choose a different RF frequency band to capture PD pulses within the frequency band with no or minimum interference. The HMC7992 has a low insertion loss of 0.6 dB, high isolation of 45 dB, and high P0.1dB of 33 dBm.

The fourth stage is a 300 MHz to 1500 MHz BPF, which is the same as the BPF used in the second stage and it provides further out-of-band interference rejection.

The final stage involves the RF logarithmic detector, ADL5513, which converts the UHF PD signal to a low frequency signal of several tens of MHz. This makes it possible to use an ADC with a sample rate of 40 MSPS or 65 MSPS to convert the analog PD signal to a digital signal. For PD detection applications, the main desired characteristics for an RF detector are response time and dynamic range. ADL5513 has as low as a 20 ns response time and as high as an 80 dB dynamic range, which makes it quite suitable for PD detection applications. The RF logarithmic detector AD8318 is suitable for PD detection applications as well. Compared to ADL5513, it has a quicker response time, but the dynamic range is slightly lower.

## Test Results

The board key performances are tested and screen captures are shown in Figure 6 through Figure 8.

Figure 6 shows the S-parameter from the first stage to the final stage's ADL5513 input in a direct through path. It shows that, from 300 MHz to 1500 MHz full band, the gain is around 14 dB with gain flatness better than 2 dB and the input return loss is better than –8 dB.

Figure 7 shows the measured output voltage vs. the input power of the middle frequency 900 MHz continuous wave signal. Two channels are measured with input power. According to the test result, the whole signal chain has a linear response across the input power range of –75 dBm to –5 dBm. The channel-to-channel performances is also consistent.

In Figure 8, a measured output waveform as the input is pulsed in a continuous wave signal of 900 MHz. The signal power is –75 dBm, the pulse width is 5 µs and the pulse period is 10 µs. According to the waveform, when the signal power is as low as –75 dBm, the output signal still has a considerable signal-to-noise ratio.


*Figure 6. The S-parameter from the first stage to the final stage's ADL5513 input in a direct through path.*

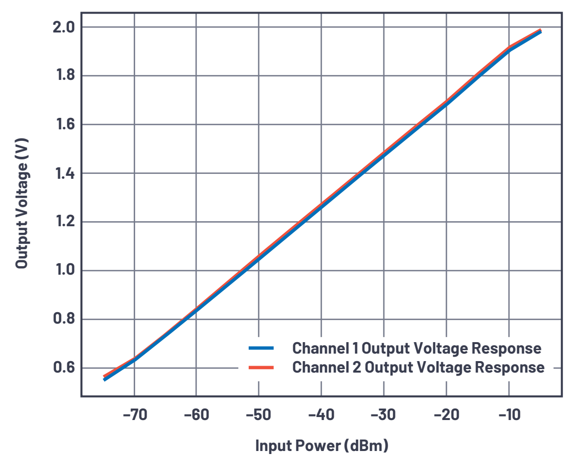


*Figure 7. Output voltage vs. input power.*

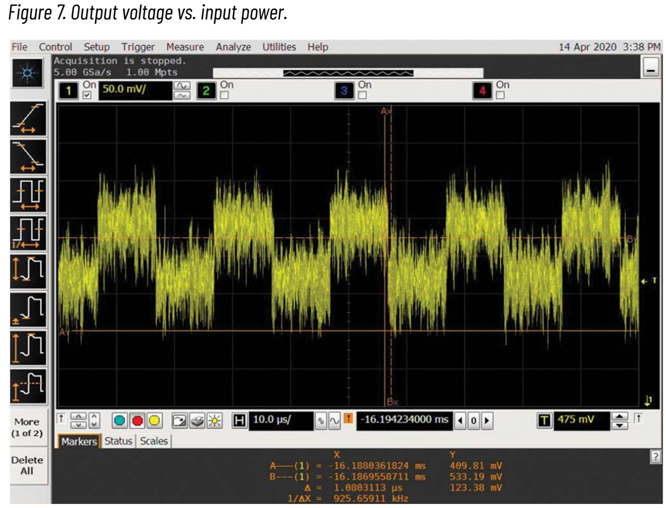

*Figure 8. The output response of a –75 dBm pulse continuous wave input*

## Conclusion

This article has demonstrated how to build a UHF PD detection board using an Analog Devices signal chain. This complete reference design offers the flexibility to choose different frequency bands to combat the interference in complex electromagnetism environments. It also meets the Q/GDW11059.8-2013 standard of China.

## References


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Q/GDW11059.8-2013 "Technical Specification for Energized Test Device of Electrical Equipment Part 8: Technical Specifications for an Ultrahigh Frequency Partial Discharge Detector."


## About the Authors


Van Yang was a field applications engineer at Analog Devices in Shanghai, China. He joined ADI in 2015 to support regional medical and industrial customers in China. Prior to joining ADI, Van worked at TI as an FAE for four years. Van earned his master's degree in communications and information systems from Huazhong University of Science and Technology in Wuhan in 2011. In his spare time, he is a superfan of basketball and enjoys hiking.

Meng Wang is a product applications engineer at ADI, Beijing. Meng has 10 years of experience in applications, hardware, and embedded system development. Meng joined ADI in 2014, providing technical design support for industrial test, IoT, and 3D camera systems. Meng received a B.S. degree and an M.S. degree in mechanical design and theory from the University of Science and Technology, Beijing in 2011. He can be reached at meng.wang@analog.com.

Lance Wu is a field applications engineer at ADI Shanghai. He joined ADI in 2018, starting as a field applications engineer supporting communications customers in China. Prior to joining ADI, Lance worked as an RF engineer at Lattice. Lance received his master's degree in microelectronics from Shanghai Institute of Microsystem and Information Technology, Chinese Academy of Sciences in 2016. He can be reached at lance.wu@analog.com.

Aaron He is a system applications engineer at ADI Shanghai, who joined ADI in 2017. Prior to joining ADI, Aaron worked as a senior RF engineer at Ericsson. Aaron has more than 10 years' experience working on wireless communication base station design, integration, and production test system development. Aaron received a B.S. degree in telecommunication engineering from Xi'an Jiaotong University in 2001, and an M.S. degree in microwave engineering from Huazhong University of Science and Technology in 2006. He can be reached at aaron.he@analog.com.





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