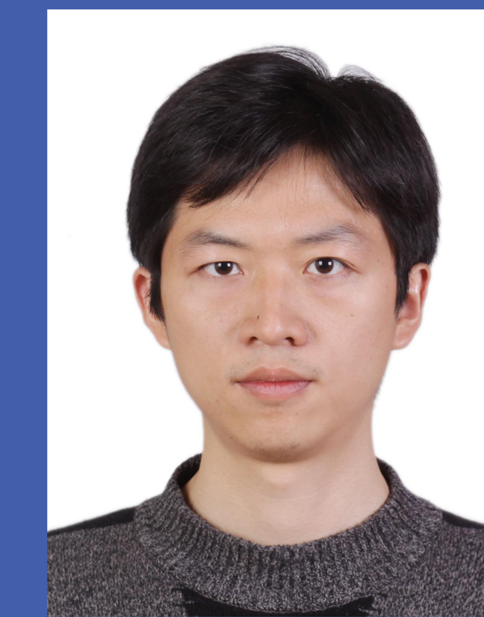
Design of a High-speed Large Dynamic Range Programmable Gain Amplifier

Cheng Li, Zhe Cao, Jiadong Hu, Changqing Feng, Shubin Liu, Qi An

State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China, Hefei City, Anhui Province, China



Cheng Li

1. Introduction

Processing the detector signal to the amplitude suitable for readout module is always an important task for front-end electronics in physics experiments. For experiments that detector signals have large dynamic range, traditional method uses multi-channel amplifiers of different dynamic ranges. In Water Cerenkov Detection Arrary (WCDA) of Large High Altitude Air Shower Observatory (LHAASO) experiment, double number of amplifiers are required to achieve large dynamic range measurement, which is of high cost, low integration and inconvenient in maintenance and management. This paper proposes a programmable gain amplifier that not only can perform reliable and accurate signal processing, but also is versatile enough to adapt to large dynamic ranges. This amplifier is designed of changeable gain, from -20 dB to 33 dB, that is 0.1 V/V to 45 V/V. In order to in accordance with experiment requirements that require accurately processing fast signals, this amplifier is designed of wide bandwidth, from DC to 700 MHz. Also, single-ended input signal is converted to differential signals, which helps to eliminate the common mode noise pick-up and allows long-distance transmission. This amplifier possess dc-level shift, common mode level shift, maximizing its compatibility with various applications. Feature of remote programmability makes this amplifier convenient to use.

2. Description of the Amplifier

The proposed architecture, shown in Fig. 1, composes three main parts: variable attenuator, variable gain amplifier and differential amplifier. The first stage, variable attenuator, is designed to weaken large signal, thus increasing its dynamic range. Variable gain amplifier (VGA) is the core component in this amplifier to realize variable gain. The amplified signal is then fed into a differential buffer, which can further amplify the signal and increase output drive capability.

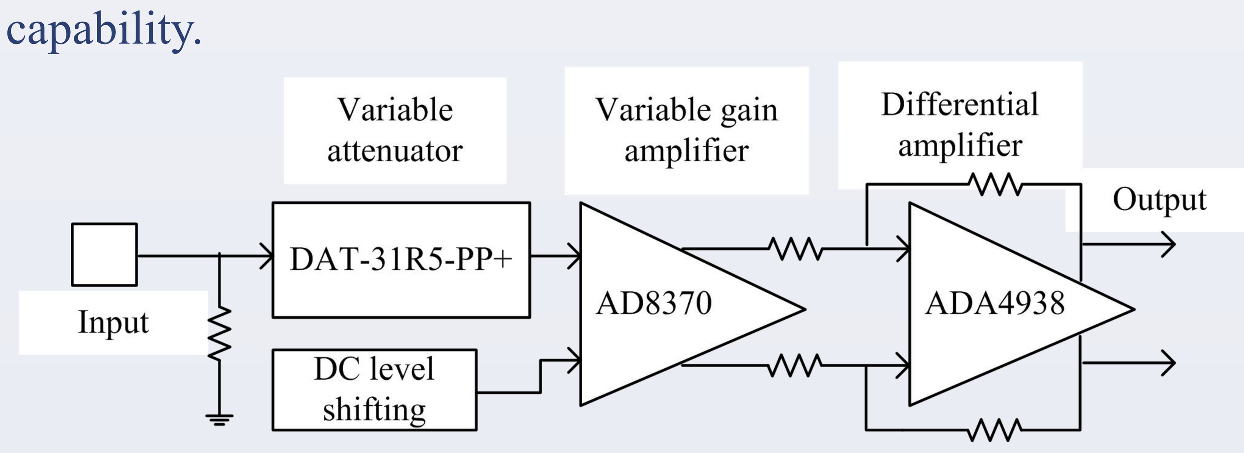


Fig. 1. Schematic description of amplifier, comprised of three main parts: variable attenuator, variable gain amplifier and differential amplifier.

To realize high-speed and low distortion, each module of this amplifier should have a wide bandwidth and a low noise. After comparison of single pole double throw (SPDT) switch resistance network attenuation and programmable attenuator chip, a programmable attenuator DAT-31R5-PP+, with better frequency response and smaller control step, is selected. The DAT-31R5-PP+ is a 50 ohm RF digital step attenuator that offers an attenuation range up to 31.5 dB in 0.5 dB step with bandwidth from DC to 2400 MHz. Due to the possibility of sparks from detectors, diodes are used to provide a fast and effective over-voltage protection. These diodes are high-performance transient voltage suppressor (TVS) diodes (TVS3V3L4U) for transient suppression, with capacitance as low as 2 pF and bi-directional protection. For the VGA stage, we use a digitally controlled variable gain amplifier AD8370, with a DC to 750 MHz bandwidth and gain range from 6 dB to 34 dB. It converts single-ended input signal of positive input to differential signal. Negative input of AD8370 is driven by a digitally controlled DC level shifting module, comprising of a 12-bit digital to analog converter (DAC). By DC level shifting, signals of different DC levels can be adjusted to the desired level, thus maximizing the measurement resolution without loss of measurement range. Amplified signal is buffered by a differential amplifier ADA4938, whose feedback loop can be changed for extra amplification. A 1.2 V/V voltage gain is realized in this stage. Common mode of the differential output signal can be adjusted to the level required by different digitization modules. The differential amplifier provides sufficient current to drive output transmission line of at least 2 meters long.

3. Amplifier Performance

The amplifier performances are summarized in Table I and figures from Fig. 2 to Fig. 5.

Table 1. Summary of Amplifier Performance

Bandwidth	DC to 700 MHz
Gain Range	-20 dB to 33 dB
Input Noise Density	2.3nV/(33 dB gain at 10 MHz)
Integrated Input Noise	54 μV (33 dB gain)
Total Harmonic Distortion	-69.4 dBc (33 dB gain at 10 MHz)
Signal Polarity	Positive and negative
DC level shifting	+2.5 V to -2.5 V
Common Mode Level	+2.5 V to -2.5 V
Differential Output Range	10 Vpp maximum

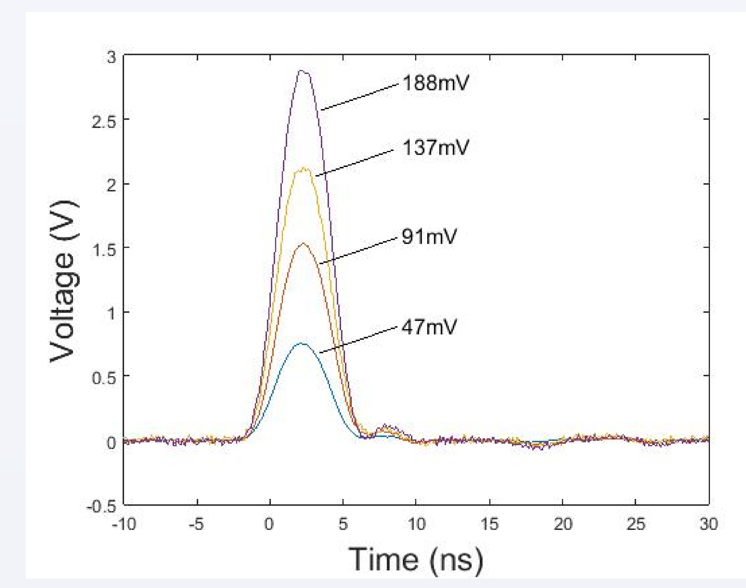


Fig. 2. Measured output pulse waveforms for different input amplitudes (47 mV, 91 mV, 137 mV, 188 mV). Gain of the amplifier is 15 V/V.

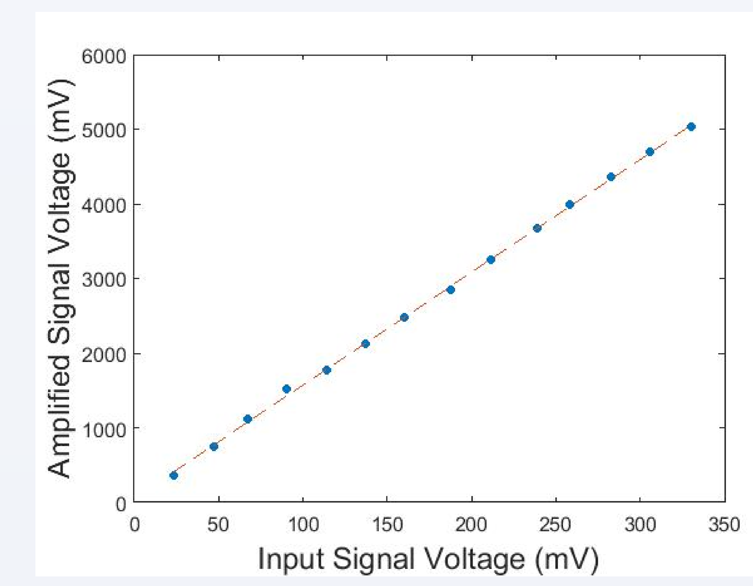


Fig. 3. Amplified signal voltage versus input signal voltage at 15 V/V gain setting.

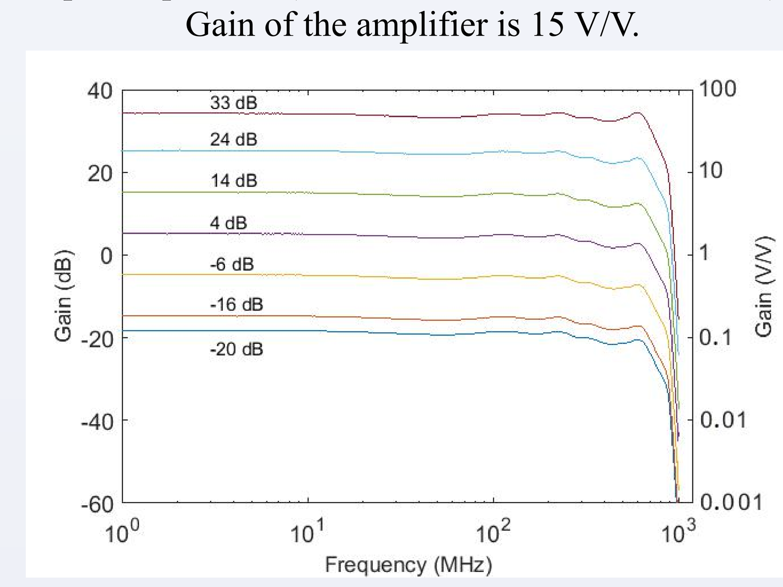


Fig. 4. Frequency responses of the amplifier in different gain settings (-20 dB, -16 dB, -6 dB, 4 dB, 14 dB, 24 dB, 33 dB).

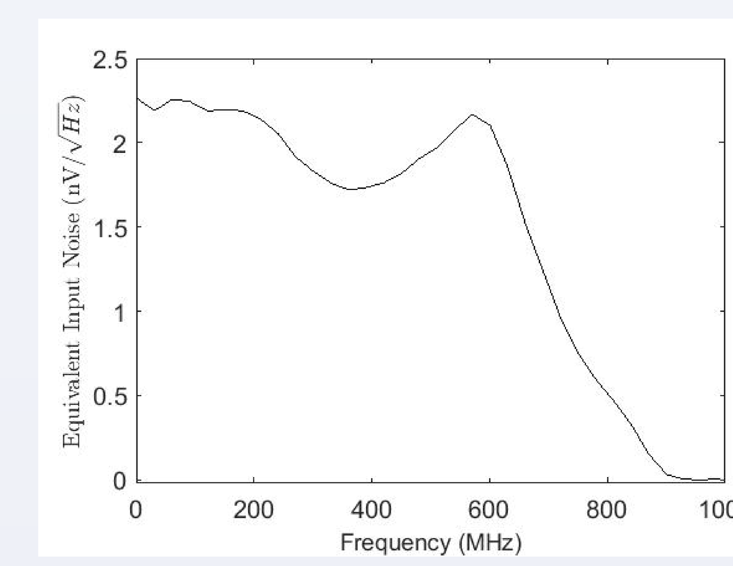


Fig. 5. quivalent input noise density from 10 MHz to 1000 MHz at gain of 33 dB.

4. Test with BaF_2 Detector

BaF_2 crystal coupled with a photomultiplier tube (PMT) generates signal with fast and slow components. To make comparison of original signal and amplified signal, the anode of PMT is connected with a power divider to separate original signal into two identical signals: one is sent to the amplifier and its output is sent to oscilloscope, the other is sent directly to oscilloscope. Fig. 6 shows the diagram of experiment set-up of BaF_2 signal amplification. Fig. 7 is the photograph of the BaF_2 detector signal test platform.

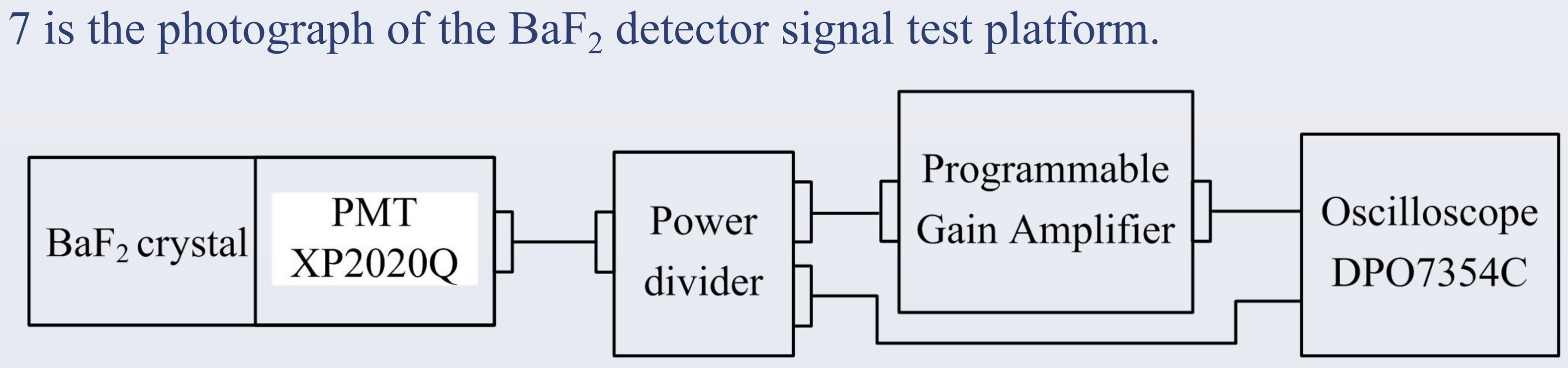


Fig. 6. Diagram of experiment set-up of BaF_2 detector signal amplification.

Fig. 8 shows the waveform of one typical BaF_2 detector sampled by the oscilloscope signal with amplifier gain setting of 33 dB (45 V/V). The upper waveform is the original signal and the downer one is the amplified signal. These signals appear exact waveform but of different amplitudes, indicating that the amplifier works well in BaF_2 detector signal amplification. The upper figure is in 9 mV/div, while the downer figure is in 330 mV/div. The amplitude of the original signal is 23 mV, and the amplified is 1.043 V, thus the gain calculated is 45.3, which corresponds with the amplifier gain setting.

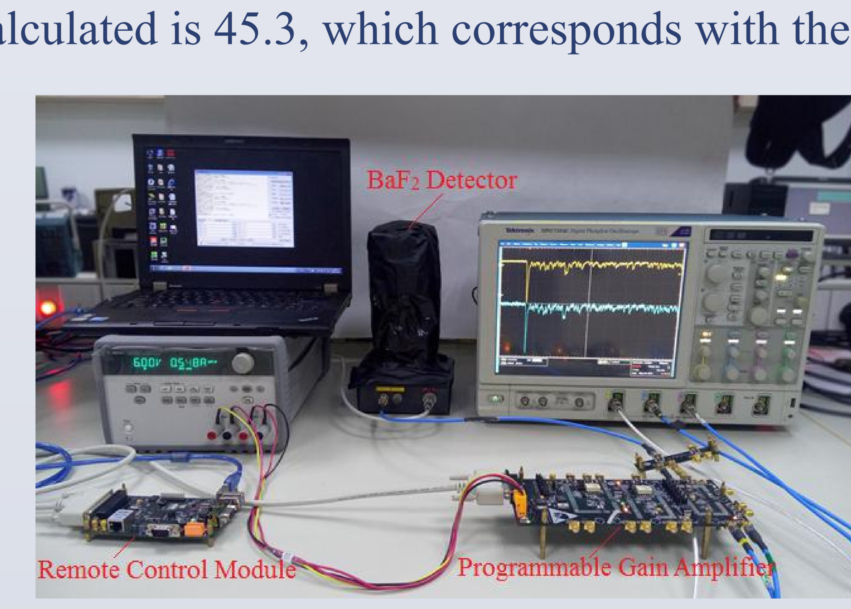


Fig. 6. Photograph of experiment setup for BaF_2 detector waveform amplification.

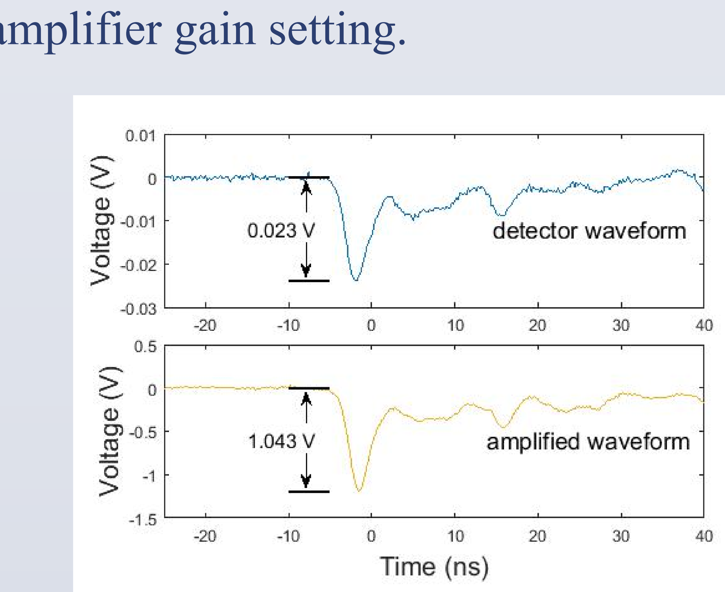


Fig. 7. Typical pulses from BaF_2 detector. The upper one comes directly from BaF_2 detector and the downer one is the amplified signal.

5. Conclusion

This paper presented a high-speed programmable gain amplifier system suitable for large dynamic input range. It consists of three main stages: a digital control attenuator, a programmable gain amplifier and a fast differential amplifier. Systematic measurement results reveal that this system has a gain range from -20 dB to 33 dB, DC to 700 MHz bandwidth, integrated noise 54 μV at the gain of 33 dB and low distortion. PMT detector signal amplification proves its ability in waveform conditioning. Programmable gain amplifier rarely uses in physics experiment. This amplifier confirms its advantages of good performance, remote programmability and convenience to use. This prototype shows a promising application in physics experiment signal amplification, especially in those system requires accurate signal conditioning like waveform digitization.

 Author e-mail: licheng8@mail.ustc.edu.cn