A 300-MHz OPTICAL DISCRIMINATOR-COUNTER

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Abstract

The prediction of future CO2 content in the atmosphere is not completely credible because the oceanographers and terrestrial ecologists do not agree on the global CO2 balance. Very precise measurements of O2/N2 ratio using Raman scattering over a few years' period could provide important information and lead to the explanation of the disparity in the atmospheric CO2 balance. An optical discriminator-counter has been developed to count closely spaced optical events in the few photon level. Simulated events as close as 2.5 ns apart had been positively detected by using selected photomultipliers and optimized discriminators. Testing of the optical discriminator-counter was done by using an electrical pulse pair spaced 3 ns apart and also by a similar optical pulse pair generated by fast light-emitting diode. The photomultiplier is capable of counting an average single photoelectron pulse frequency of 5 MHz and has a sensitive detecting area of 50 mm in diameter. The discriminator performance will be discussed.

Introduction

Global activities in the combustion of fossil fuels produce more and more carbon dioxide (CO2) in the atmosphere. The ever-increasing concentration of CO2 may create the infamous greenhouse effect and cause catastrophic weather changes, leading to disastrous economic and social problems.

The prediction of future CO2 content in the atmosphere is not completely credible because the oceanographers and terrestrial ecologists do not agree on the global CO2 balance, (1). While there is no disagreement on the ever-increasing CO2 in the global atmosphere, very precise measurements of O2/N2 ratio over a few years' period could provide important information and lead to an explanation of the disparity in the atmospheric CO2 balance.

Such experiments employing Raman scattering to determine O2/N2 molecular ratio have created the need for an optical counter able to detect single photon events with the best possible resolution and an average pulse counting capability of 50 MHz and which has, at the same time, a sensitive detecting area approximately 50 mm in diameter. A search of available detectors with single photon detection capability and all the aforementioned characteristics points to the RCA photomultiplier type C31024, (2). This five-stage RCA photomultiplier has a single photoelectron pulse width at half maximum of not more than 2 ns, making it possible for this device to detect events spaced approximately 3 ns apart. The single photoelectron pulses of this photomultiplier, however, having amplitude of only a few millivolt, require some amplification before they can be used to reliably, and positively, trigger a fast tunnel diode discriminator. To make the output of the discriminator acceptable to lower frequency scalers, a divide-by-four counter was incorporated into the discriminator so that the output pulse width could be stretched to 10 ns to meet the input requirement of a typical 10 MHz scaler.

The optical discriminator-counter was tested with electrical pulse pairs spaced 2.5 ns to 3 ns apart and also with similarly spaced optical pulse pairs generated by fast, light-emitting diode.

Electrical and Optical Test Pulses

Since the optical discriminator-counter is intended to be used to detect optical pulses as close together as 3 ns, electrical and optical pulses in this time range were generated for testing. Fig. 1 shows the system block diagram of our pulse generator.

A pulse generator, HP 215A, provided a fast pulse, having a FWHM width of 1.2 ns. A power divider split this pulse into two parts. One part was fed directly into one leg of a power combiner and the other was delayed by 3 ns with a delay cable before going to the other leg of the power combiner. The output pulse amplitude of the pulse from the combiner could be varied by an attenuator which followed it. The electrical pulse pair at this point was used in the development of the discriminator-counter. Fig. 2 shows a typical electrical pulse pair generated by this system.

To obtain an optical pulse pair the electrical pulses were amplified by a 10W linear amplifier having a bandwidth of 500 MHz. The output pulses of the amplifier were then used to drive a light-emitting diode, type XP-21, which operated in the avalanche mode. The XP-21 diode required a minimum drive in excess of 9V. The actual operating electrical pulses ranged from 15V - 22V for a 10% yield of single photoelectron pulses, as detected by the C31024 and C31024A photomultipliers.

The Photomultiplier Detector

The single photoelectron pulse response of the photomultiplier determined the pulse pair resolution of the system. Although there are other types of photomultipliers, (3,4,8,9), which can provide pulse widths less than the typical 1.5 ns of the RCA C31024A, they can neither provide the high counting rate required for the large photocathode area offered by this device. The C31024A is a variant of the RCA C31024 and has five GaP dynodes. The C31024A has an RCA type 52AT ERMA II photocathode, which has a red response extending beyond 800 μm. The quantum efficiency of six C31024A's at 540 μm ranges from 8% to 11%. The average dark pulse count of four C31024A's ranges from 306 per sec. to 2880 per sec., summing from 1/8 photoelectron to 16 photoelectrons at room temperature. The single photoelectron pulse height ranges from 4 mV - 15 mV at the output of the photomultipliers terminated into a 50 ohm load. Fig. 2 shows a pair of typical single photoelectron pulses from a C31024A.
Two sets of double pulses were synthesized, simulating valley off the baseline. The discriminator threshold setting and the shape of the pulses did not change as Fig. 5 are wider, and their superposition lifts the valley between each pulse pair was varied to find the minimum and maximum pulse amplitude for resolving two pulses 3 ns apart. The discriminator was measured by using an electrical pulse pair frequency of 1 MHz (2 x 10^6 pulses per second), which allows the valley between them to be set to zero. The pulses in Fig. 5 are wider, and their superposition lifts the valley off the baseline. The discriminator threshold setting and the shape of the pulses did not change as the amplitude was varied in order to determine limits of stable operation. The case of Fig. 4 is illustrated in Fig. 6 for two different amplitudes. The discriminator fires each time the leading edge of a pulse crosses the threshold. The valley is slightly delayed due to hysterisis. The time between the recovery from the first pulse and the firing of the second (t_2 - t_1) grows smaller as the input pulse amplitudes are increased. At some point the recovery time is too short for the resolving capability of the circuits that follow the discriminator. At the lower amplitude end, however, the pulses that barely cross the threshold produce enough discriminator output to advance the counter. Proper threshold selection is thus important to obtain an optimum input amplitude dynamic range. Reducing the threshold may not increase the ratio between the highest and lowest accepted signals, since the recovery time, t_2, would be decreased. An optimum must be found for each individual photomultiplier-discriminator set.

The operating input signal level of the discriminator-counter may vary significantly, especially when triggered by the tip of a small input pulse. The signal is increased and inverted in a wideband amplifier, (Q1). Also, the amplifier shifts the baseline of the signal to an appropriate negative level, the bias, of the 350 MHz ECL counter stage (Motorola MC 1670). Optimum bias is obtained by adjusting R16. The counter is used only as a divide-by-two stage without any provision for read-out or clear. Next, one half of the 250 MHz ECL counter (MC 10231) provides one more divide-by-two stage counter. The positive transition of the Q output of this stage takes place each time after a total of four tunnel diode transitions, resetting the last binary position of the counter. A feedback from the Q output to the set input, going positive, sets the binary to its original state after a delay defined by a capacitor. The binary performs as a monostable multivibrator, producing a shaped, 10 ns wide negative pulse at the Q output. The output current switching pair provides a standard NIM signal of 0.8V and 10 ns on a termination load resistance of 50 ohms.

The tunnel diode negative output signal may vary significantly, especially when triggered by the tip of a small input pulse. The signal is increased and inverted in a wideband amplifier, (Q1). Also, the amplifier shifts the baseline of the signal to an appropriate negative level, the bias, of the 350 MHz ECL counter stage (Motorola MC 1670). Optimum bias is obtained by adjusting R16. The counter is used only as a divide-by-two stage without any provision for read-out or clear. Next, one half of the 250 MHz ECL counter (MC 10231) provides one more divide-by-two stage counter. The positive transition of the Q output of this stage takes place each time after a total of four tunnel diode transitions, resetting the last binary position of the counter. A feedback from the Q output to the set input, going positive, sets the binary to its original state after a delay defined by a capacitor. The binary performs as a monostable multivibrator, producing a shaped, 10 ns wide negative pulse at the Q output. The output current switching pair provides a standard NIM signal of 0.8V and 10 ns on a termination load resistance of 50 ohms.

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The operating input signal level of the discriminator-counter was measured by using an electrical pulse pair spaced 3 ns apart. The individual pulse width was 1.2 ns, measured at FWHM. The amplitude of the pulse pair was varied to find the minimum and maximum pulse height through which the discriminators operate properly. By using a pulse pair frequency of 1 MHz (2 x 10^6 pulses per second), the proper output pulse frequency of the discriminator is 5 x 10^6.

The ability of time-over-threshold discriminator to resolve two pulses 3 ns apart depends on their shape and on the relation of the amplitude to threshold setting. Two sets of double pulses were synthesized, simulating typical outputs of fast photomultipliers (Figs. 4 and 5). The pulses in Fig. 4 are narrower, which allows the valley between them to be set to zero. The pulses in Fig. 5 are wider, and their superposition lifts the valley off the baseline. The discriminator threshold setting and the shape of the pulses did not change as the amplitude was varied in order to determine limits of stable operation. The case of Fig. 4 is illustrated in Fig. 6 for two different amplitudes. The discriminator fires each time the leading edge of a pulse crosses the threshold. The recovery is slightly delayed due to hysterisis. The time between the recovery from the first pulse and the firing of the second (t_2 - t_1) grows smaller as the input pulse amplitudes are increased. At some point the recovery time is too short for the resolving capability of the circuits that follow the discriminator. At the lower amplitude end, however, the pulses that barely cross the threshold produce enough discriminator output to advance the counter. Proper threshold selection is thus important to obtain an optimum input amplitude dynamic range. Reducing the threshold may not increase the ratio between the highest and lowest accepted signals, since the recovery time, t_2, would be decreased. An optimum must be found for each individual photomultiplier-discriminator set.

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Acknowledgement

The large-area optical discriminator-counter described was capable of detecting single photoclectron events spaced as closely as 2.5 ns apart by using selected photomultipliers, tunnel diodes and other key components.

The preamplifier at the input of the discriminator-counter has a bandwidth of 500 MHz and a noise figure not higher than 2 dB. Optical detectors such as microchannel plate photomultipliers have much better pulse pair resolution capabilities, but they lack the ability of high frequency counting, which is usually limited between 0.1 - 1 MHz at single photon level.

References


Fig. 1 Block diagram of the electrical and optical pulse pair generation system

Fig. 2 Photomultiplier C31024A single photoelectron output pulses
Fig. 3 Discriminator-counter circuit diagram

Fig. 4 Electrical pulse pair with 1.2 ns pulse width at FWHM

Fig. 5 Electrical pulse pair with 2 ns pulse width at FWHM
Fig. 6 Discriminator triggering thresholds with the 1.2 ns pulse pair

Fig. 7 Discriminator triggering thresholds with the 2 ns pulse pair

Fig. 8 Discriminator-counter trigger threshold as a function of ambient temperature