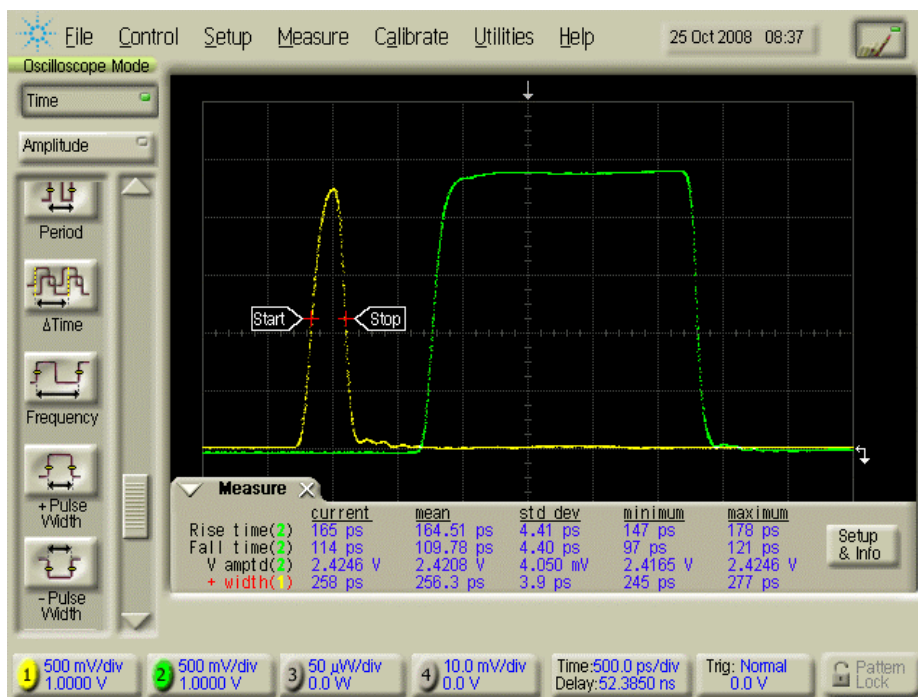


## Generation of Novel Waveforms Using PSPL Pulse Generators

James R. Andrews, Ph.D, IEEE Fellow & Bob McLaughlin  
PSPL Founder & former President (retired) PSPL Sales Engineer



Picosecond Pulse Labs (PSPL) has recently introduced a new 12000 series of very versatile pulse/pattern generators. The model 12000 is capable of producing adjustable rise/falltime, 10 V pulses up to 165 MHz. The model 12020 is capable of producing 2.5 V pulses at speeds up to 1.6 GHz. The oscilloscope screen image in Figure 1 below shows a couple of typical pulses illustrating the 1.6 GHz, model 12020 pulse/pattern generator's performance.

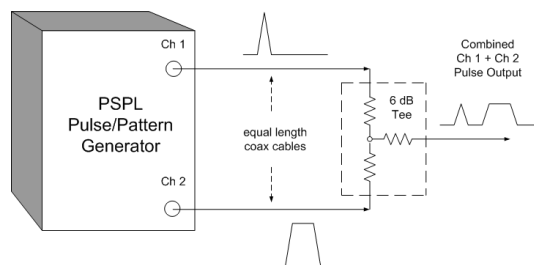


**Fig 1** Typical pulse of the Model 12020 pulse/pattern generator

These generators share many common features. They can function as conventional pulse generators, but also are capable of generating user-programmable words or PRBS data word streams in either NRZ, RZ, or R1 formats. They have a full compliment of pulse control functions, including: rep. rate, delay, width (duration), amplitude, offset, and polarity. Rise and falltimes are adjustable on the 165 MHz, model 12000 (2.5 ns min.). They are fixed on the 1.6 GHz model 12020 (125 ps typical).

An extra-cost, optional feature on these generators is a second output channel. The second channel output is more than just another output connector providing an extra, identical pulse to the main output. It is in reality a totally separate pulse/pattern generator with independently adjustable pulse parameters. Both pulse/pattern generator channel modules, however, share the same common rep. rate clock.

Having the second, independent channel available in these generators allows the user to create some much more exotic, "novel" waveforms than just simple pulses like those shown on page 1. Because the pulse waveform coming from channel 2 can be manipulated and made much different from that of channel 1, adding these two waveforms together can create some dramatically different waveforms.



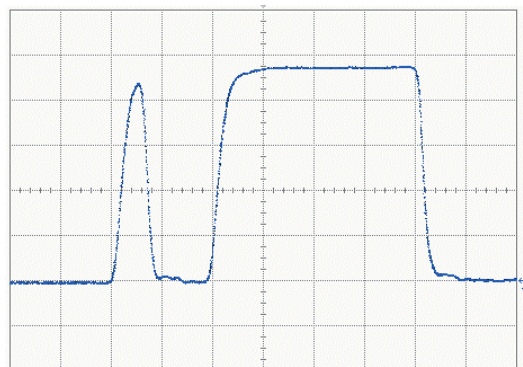
**Fig. 2** Addition of two waveforms using a 6 dB Tee power divider/combiner

A means must be provided to add channels 1 and 2 together. On the two-channel version of the 165 MHz, model 12000, this can be accomplished internally with a simple push of a button on the menu "ChAdd". For the two-channel version of the 1.6 GHz, model 12020, or the 800 MHz, model 12010, this must be accomplished externally as shown in Figure 2. A wide-band, 6 dB resistive Tee, power divider is used to combine the outputs from channels 1 and 2. The Tee consists of three, 16.7  $\Omega$ , microwave resistors. The 6 dB Tee provides excellent impedance matching to maintain the system's 50  $\Omega$  output impedance. A suitable 6 dB

Tee is the PSPL model 5333 Power Divider (DC-25 GHz). Using the 6 dB Tee will result in the output voltages being one half of the input voltages. Equal length cables should be used to connect the generator outputs to the 6 dB Tee. The generator's dual channel delay controls are independently adjustable and will allow the user to skew one pulse relative to the other pulse.

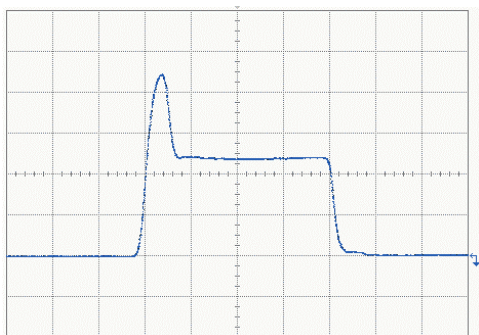
**DIFFERENTIAL SIGNALS:** While the examples shown in this application note are all single-ended pulses, differential signals can also easily be generated. The PSPL model 12020 (and 12010) pulse/pattern generator provides four outputs with differential outputs for each channel, i.e., True and Complement. To generate differential versions of the various signals shown in this application note, simply add a second 6 dB Tee and a second pair of equal-length cables to the complement outputs.

**DISTORTED PULSES:** To demonstrate what can be accomplished, we will first start with the two model 12020 pulses shown in Figure 1 on the first page. The channel 1 pulse (yellow) was programmed to be a 250 ps wide impulse with its delay set to 0 ps. The channel 2 pulse (green) was programmed to be a 2.5 V, 2 ns wide, rectangular pulse with its delay set to 1 ns. When these pulses are combined in the 6 dB Tee, the result is shown in Figure 3. At this point, we have a pulse sequence of a narrow impulse followed by a rectangular pulse. The amplitude is now 1 1/4 V.

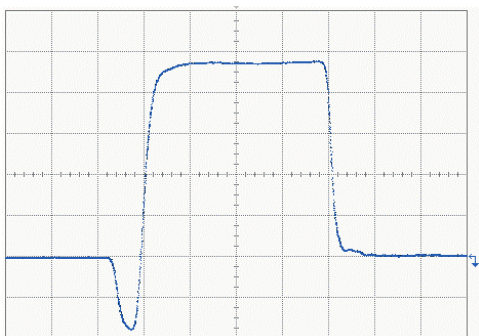


**Fig. 3** Two pulses from Fig. 1 combined using a 6 dB Tee. 250 mV/div & 500 ps/div

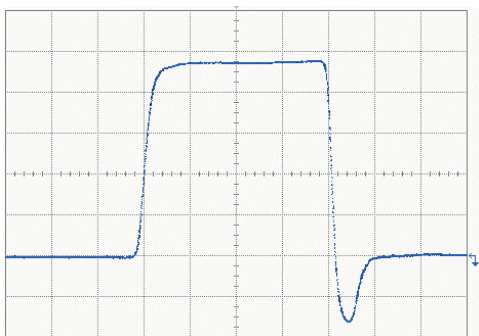
If one now starts to adjust the relative "Delay" between the two channels, the narrow impulse can now be added (or subtracted) onto the rectangular pulse to create various pulse waveform "defects" such as severe "OverShoot", Figure 4; severe "PreCursor", Figure 5; and trailing edge "Under-Shoot", Figure 6. Positioning the impulse within the rectangular pulse width, one can simulate an interference "Spike" or "DropOut", Figures 7 and 8. The amplitude, polarity, offset, duration, and delay of the interfering pulse can be adjusted totally independent of the rectangular pulse.



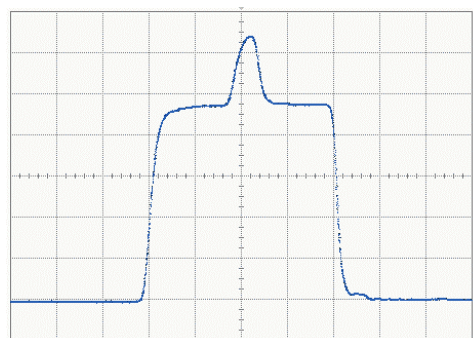
**Fig. 4** Pulse with large controlled amount of "Overshoot". 500 mV/div & 500 ps/div



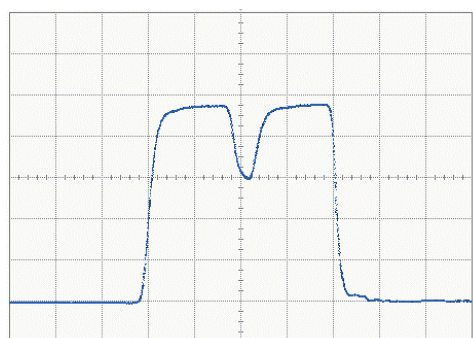
**Fig. 5** Pulse with large controlled amount of "PreCursor UnderShoot". 250 mV/div & 500ps/div



**Fig. 6** Pulse with large controlled amount of Trailing Edge "UnderShoot". 250mV/div & 500ps/div

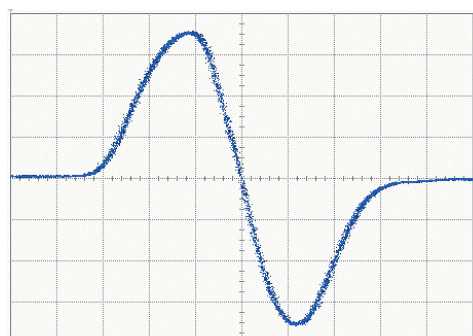


**Fig. 7** Pulse with controlled interference "Spike". 250mV/div & 500ps/div



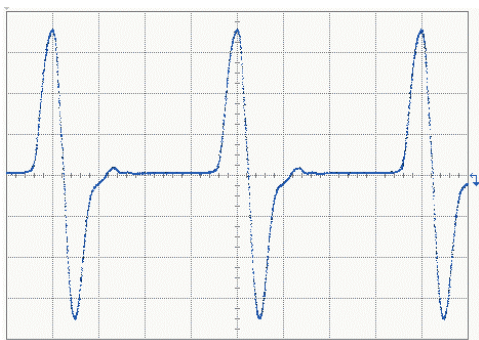
**Fig. 8** Pulse with controlled interference "Drop-Out". 250mV/div & 500ps/div

**MONOCYCLES:** If one sets the Width (duration) of both channel 1 and channel 2 pulses to the minimum of 250 ps, a very nice, 600 ps, "MonoCycle" pulse can be generated. See Figure 9. In this case, the channel 2 pulse's compliment (i.e., inverted) polarity was used. The channel 2 "Delay" was then adjusted to position the inverted, 250 ps impulse just behind the positive polarity, 250 ps impulse. Figure 10 shows a 500 MHz train of MonoCycles. If the channel 2 delay is set to 1 ns, then the waveform becomes a 500 MHz train of "Bi-Polar" pulses, Figure 11.

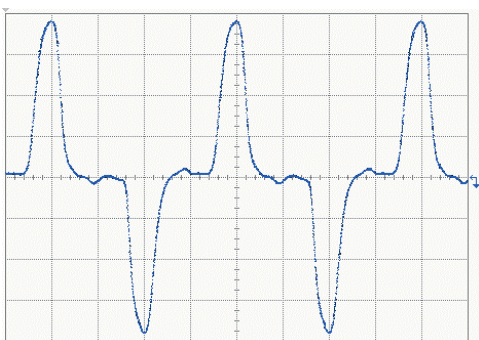


**Fig. 9** A "MonoCycle" pulse. 300mV/div & 100ps/div





**Fig. 10** A train of "MonoCycle" pulses at 500 MHz rep. rate. 300mV/div & 500ps/div

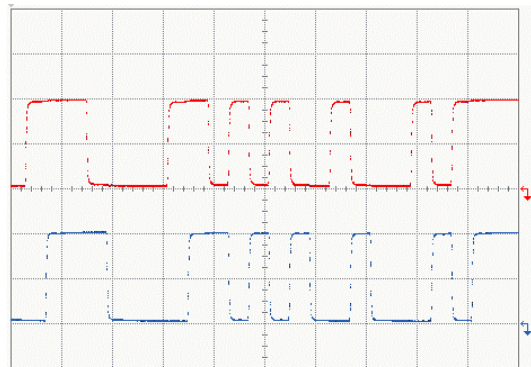


**Fig. 11** A train of "Bi-Polar Impulses" at 500 MHz rep. rate. 300mV/div & 500ps/div

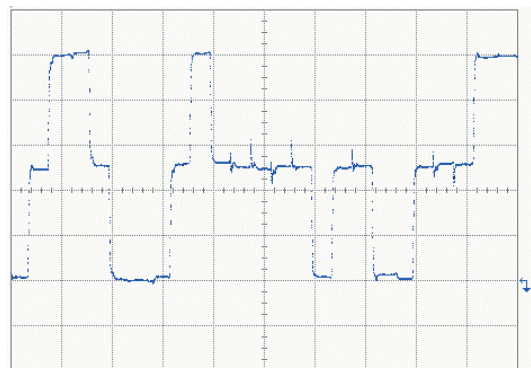
**TRI-STATE LOGIC:** In the word, pattern mode of operation of these generators, they put out standard, bi-state logic levels (i.e., either a "1" or a "0"). Figure 12 shows an example of an NRZ, PRBS, 500 MHz data stream from the model 12020 generator. It is possible to adjust the relative timing between channels 1 and 2 of the PRBS data streams, as shown in Figure 12. This was done using the "Delay" control. In Figure 12, channel 2 was offset from channel 1 by one Unit Interval (UI) (one period), i.e., a delay of 2 ns. If the two separate NRZ PRBS waveforms of Figure 12 are then added together in a 6 dB Tee, the tri-state logic, PRBS waveform of Figure 13 is created. The minor 'glitches' noted on the waveform are caused by the slight asymmetry (unequal rise and fall times) of channel 1 and channel 2 pulses moving in opposite directions. A fine, vernier adjustment of the delay control will minimize these 'glitches'. Figure 14 is the "Eye" diagram of the PRBS waveform in Figure 13.

Another method that can be used to generate the two data streams is to put the generator into the "Data" mode rather than the PRBS mode and independently program the data word contents for channel 1 and channel 2.

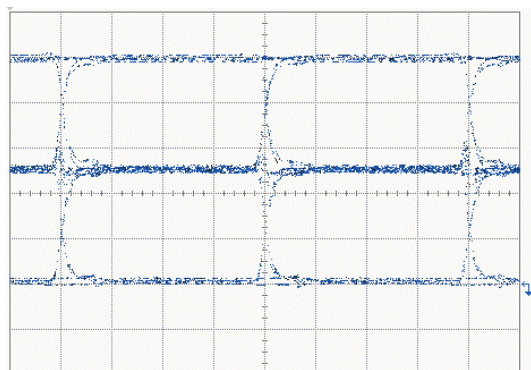
Tri-Level logic waveforms can also be created using RZ pulses in the same manner as the above PAM-NRZ modulation was created. It is a simple matter on the 12020 generator to switch between NRZ, RZ, and R1 modes. Figures 15-17 show PAM RZ PRBS data streams.



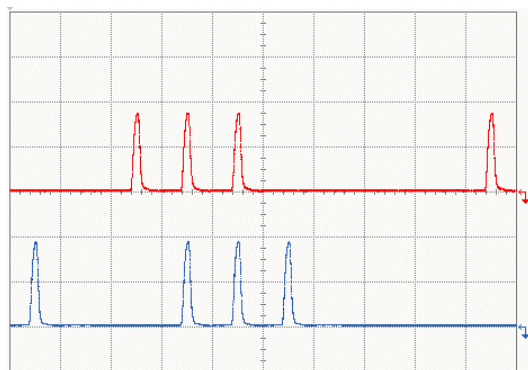
**Fig. 12** Chan 1 (red) & Chan 2 (blue) NRZ PRBS at 500 MHz. Channel 2 is offset by 1 UI (2ns) using the Delay control. 5ns/div



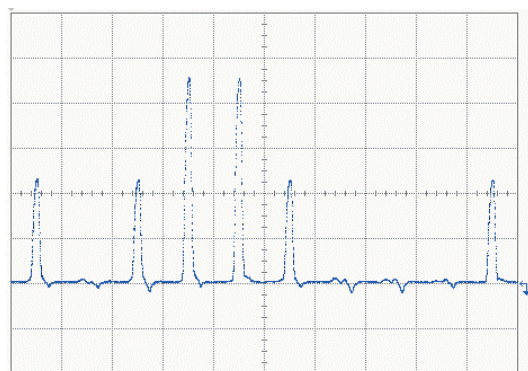
**Fig. 13** Above 500 MHz PRBS signals added with 6dB Tee. Created tri-level PAM-NRZ code. 500mV/div & 5ns/div



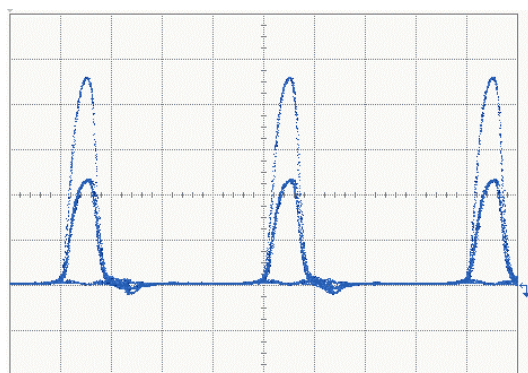
**Fig. 14** Eye Diagram of above tri-level PAM-NRZ PRBS data stream. 500mV/div & 500ps/div



**Fig. 15** Chan 1 (red) & Chan 2 (blue) RZ PRBS at 500 MHz. Channel 2 is offset by 1 UI (2ns) using the Delay control. 2ns/div



**Fig. 16** Above 500 MHz PRBS signals added with 6dB Tee. Created tri-level PAM-RZ code. 500mV/div & 2ns/div

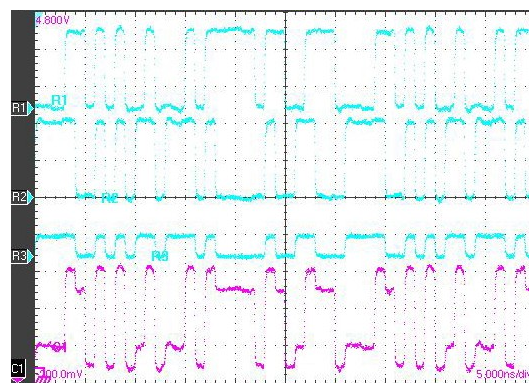


**Fig. 17** Eye Diagram of above tri-level PAM-RZ PRBS data stream. 500mV/div & 500ps/div

**PRE-EMPHASIS:** When data streams are transmitted through a lossy channel, severe waveform distortion occurs that can severely impact the Bit Error Rate (BER). For lossy channels that appear as a low pass filter, one technique that has been found useful is to add "Pre-Emphasis" to the data stream.

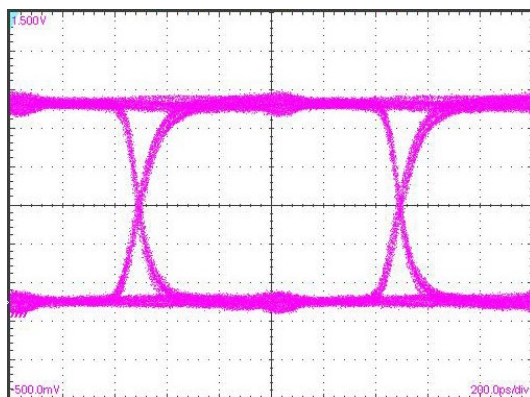
This is the equivalent of adding "Overshoot and Undershoot" as shown in Figures 4 and 6. Simple, One Bit, Pre-Emphasis is generated by adding to a data stream its compliment, which has been delayed by 1 UI. The pre-emphasis weighting is determined by the amplitude ratio of the delayed data relative to the original data stream.

One Bit Pre-Emphasis can easily be accomplished with the PSPL 12020 Pulse/Pattern Generator using the 6dB Tee, Figure 2. This time, however, connect one arm of the 6dB Tee to the Channel 2 compliment output instead of the Channel 2 normal output. See Figure 18 for the sequence of operations (top to bottom). First set both Channels 1 and 2 to output a PRBS data stream. (Figure 18 top waveform, channel 1, R1.) Next set the Channel 2 delay control to 1 UI (for the Figure 18 example, Ch 1 delay = 0ps, Ch 2 delay = 1ns). (Figure 18 waveform R2.) The third step is to set the Channel 2 Amplitude to the desired level of pre-emphasis peaking (Figure 18 waveform R3). The final step is to turn on simultaneously both Channels 1 and 2 to add the one bit pre-emphasis from Channel 2 to the main PRBS Channel 1 data stream. See Figure 18 bottom waveform. Figures 19 and 20 show the eye diagrams for the normal PRBS data stream and with one bit pre-emphasis. The pre-emphasis is particularly noticeable on a data pattern with a long string of either "1s" or "0s".

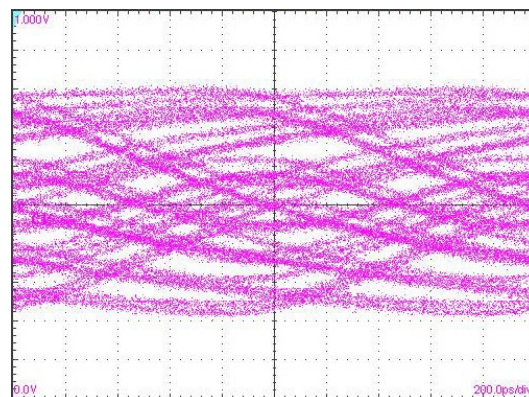


**Fig. 18** Sequence of operations to create "One-Bit Pre-Emphasis" on PRBS data. See text for details. 1 GB/s PRBS at 5 ns/div

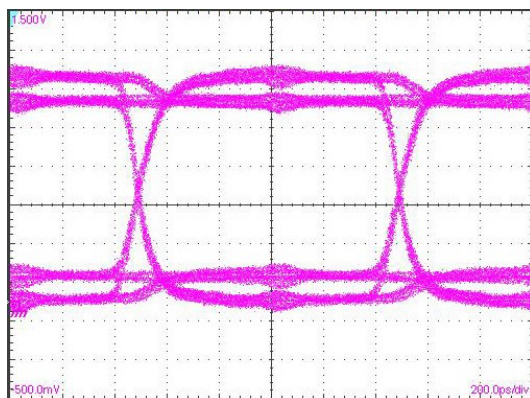




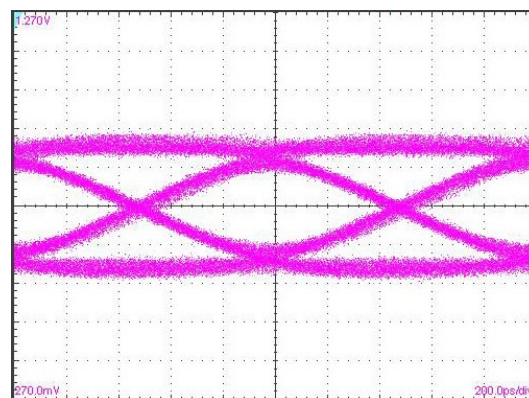
**Fig. 19** 1 GB/s normal PRBS eye diagram.  
0.2V/div & 200ps/div



**Fig. 21** Eye diagram of 1 V, 1 GB/s PRBS data stream  
after passing through 125 ft. of RG-58.  
0.1V/div & 200 ps/div

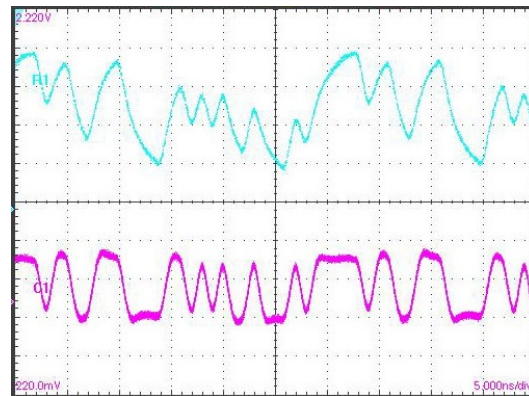


**Fig. 20** 1 GB/s, PRBS, data sequence with 12%  
Pre-Emphasis added. 0.2 V/div & 200ps/div



**Fig. 22** Eye diagram of 1 V, 1 GB/s PRBS data stream  
through 125 ft. of RG-58 with 55%, one-bit, pre-  
emphasis added. 0.1V/div & 200 ps/div.

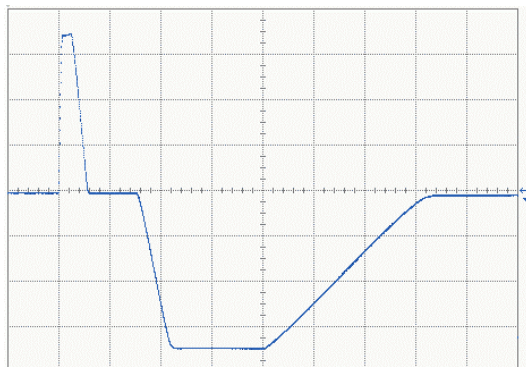
As an example of the benefits of Pre-Emphasis on a lossy data transmission channel, the 1 GB/s PRBS of Figure 19 was passed through a long length (125 ft  $\approx$  38 meters) of ordinary RG-58 coaxial cable. Figures 21-23 show the eye diagrams and pulse patterns for the received waveforms both with and without pre-emphasis. The eye diagram of Figure 21 shows that the normal data stream is totally corrupted and unusable. However, with only a single bit of pre-emphasis, Figure 22 shows that the eye is opened up very well, and low BER data can now be transferred. The proper amount of pre-emphasis weighting was determined experimentally by observing the received eye and adjusting the Channel 2 Amplitude control.



**Fig. 23** Pulse patterns of 1 GB/s PRBS data through  
125 ft. of RG-58 coax cable with (bottom) and without  
(top) Pre-Emphasis. 0.2V/div & 5ns/div

**8 VOLT PULSES:** The max. pulse amplitude output from the 1.6 GHz, model 12020 pulse/pattern generator is 2.5 V. After combining pulses in a 6 dB Tee, the max. pulse amplitude is reduced to 1.25 V. If the user needs higher amplitudes, PSPL recommends using the PSPL LABware model 8001 Broadband Amplifier. This amplifier has 26 dB gain, 30 ps rise/falltimes and can output up to 8 V<sub>ptp</sub>. For further details on using this amplifier with these pulse generators, see the PSPL application note "Model 8001 LABware Module Boosts Output of 12010 and 12020 to 8 V<sub>ptp</sub>". Also see p. 7 of AN-12 "RZ vs. NRZ". PSPL application notes are available from [www.picosecond.com](http://www.picosecond.com).

**ADJUSTABLE RISE/FALLTIMES:** All of the above examples used the 1.6 GHz, model 12020 pulse/pattern generator. If rise/falltimes slower than 125 ps are needed, then low-pass, risetime filters need to be added to the output(s) of the pulse/pattern generator. PSPL makes custom Low Pass, Risetime Filters, model 5915, for any desired risetime from 10 ns to 13 ps. For additional information, see PSPL's application note, AN-7a "Low-Pass Risetime Filters for Time Domain Applications".



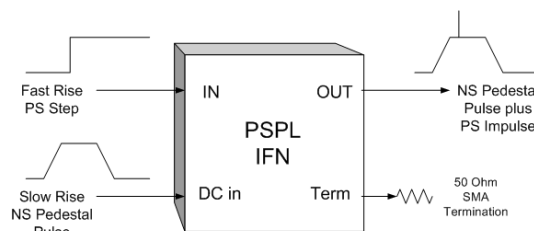
**Fig. 24** Example of model 12,000 Ch 1 & Ch 2, adjustable rise/falltime waveform.  
3 V/div & 200ns/div

For slower speed pulse waveforms, the 165 MHz, model 12000 pulse generator can be used to create the same type of waveforms as shown previously. It can also be used to create even more "Novel" waveforms because its rise and falltimes can be independently adjusted. Figure 24 is an example.

The built-in "Channel Add" feature of the model 12000 does not have the full risetime (2.5ns) capability of the basic generator. For well-defined waveforms with rise/falltimes less than 10 ns, PSPL

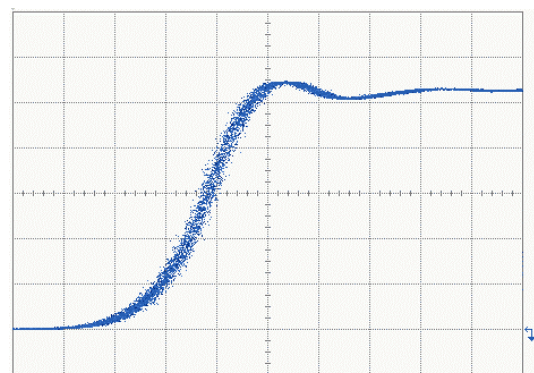
recommends that an external 6 dB Tee be used instead to combine the outputs from channels 1 and 2, as shown previously in Figure 2. It should also be noted that the generator's risetime is compromised when generating pulses larger than 10 V, at which time the internal 50 Ω source resistor is switched out ( $R_g = 1 \text{ k}\Omega$ ).

**PS PULSES ON TOP OF NS PULSES:** PSPL also has a specialized coaxial component that allows the user to superimpose a narrow, picosecond duration Impulse upon a slower Pedestal Pulse. These networks are called Impulse Forming Networks (IFN). See Figure 25. IFNs are four-terminal networks. They ordinarily function as a simple differentiator ( $V_{out} = K \cdot dV_{in}/dt$ ). If the input port is driven by a fast rising step function, then the output is a narrow impulse. The output impulse duration is approximately the same as the input step's risetime.



**Fig. 25** Impulse Forming Network

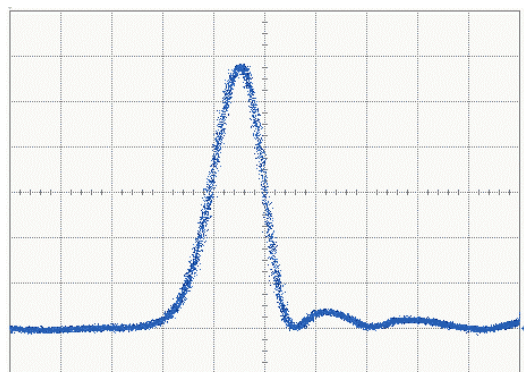
Normally the two extra ports on PSPL IFNs are terminated in 50 Ω. However, one of these ports is labeled as "DC". This port is dc-coupled to the impulse output port. This connection is a very wide bandwidth path. Other sources or signals can be injected into this DC port. They could be something such as a dc bias voltage or a *Pedestal Pulse*.



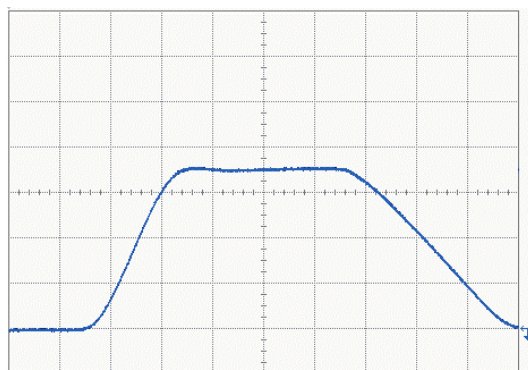
**Fig. 26** PSPL 4050 10V, 45ps risetime Step Generator.  
2 V/div & 25ps/div



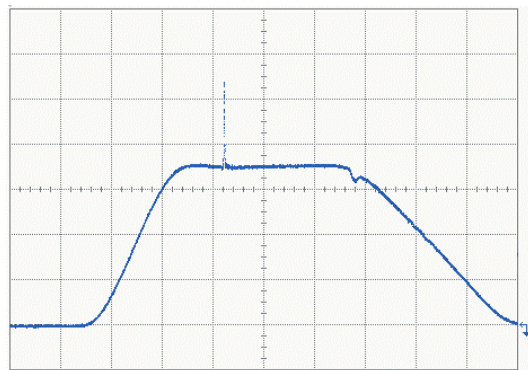
Figures 26-29 show an example of using an IFN. The fast, ps step function was generated by a PSPL model 4050, Figure 26. This is a 10 V step with a 45 ps risetime. A much slower *Pedestal Pulse* was generated by a PSPL model 12000 pulse/pattern generator. This was a +5V, 5 ns rise, 10 ns fall, 20 ns wide pulse. See Figure 27. Both generators were triggered by a common source. The two generators' outputs were combined in a PSPL model 5210 IFN. The output from the IFN is shown in Figure 28. If you examine this figure closely, you will find an extremely, narrow "*Spike*" riding on top of the "*Pedestal Pulse*". Figure 29 shows this "*Spike*" in more detail. It is a 2.8 V, 55 ps wide "*Impulse*".



**Fig. 29** 2.8 V, 55 ps *Impulse* output from IFN riding on top of 5 V, slow-rise, *Pedestal Pulse*. 500mV/div & 50ps/div. See also Fig. 28.



**Fig. 27** Pedestal Pulse from PSPL 12000 Pulse/Pattern Generator. 1.5 V/div & 4ns/div



**Fig. 28** Output from IFN. Note narrow *Spike Impulse* on top of *Pedestal Pulse*. 1.5 V/div & 4ns/div