Picosecond Pulse Labs

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Picosecond Pulse Generators for UWB Radars

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Classical RADARs have used, as their transmitters, microwave, GHz, oscillators which were gated on and off with a pulse with a duration of 100s of nanoseconds to a few microseconds. The resultant spectrum occupies a narrow bandwidth of a few MHz at most, centered on the carrier frequency of the oscillator. The radar receivers were tuned radio receivers with a few MHz bandwidths and simply AM detected the envelope of the radar pulse. Because of the known radar carrier frequencies and the relative narrow bandwidths, "stealth" technology for making aircraft "invisible" has been successful. As always, a successful countermeasure ultimately leads to efforts to find a new counter-counter-measure. **U**ltra **W**ide**B**and (**UWB**) Radar is now being researched as the counter measure to stealth aircraft. It also has application for Ground Penetrating Radar for buried land mine detection and other geo-physical applications.

UWB Radars, by contrast, radiate pulsed signals which occupy extremely broad bandwidths relative to the center, carrier frequency. The bandwidths range from >10% to 100%. These UWB signals tend to excite natural resonances in the target structure which are very hard to disguise using classical stealth techniques. Some forms of UWB radar utilize very wide band sweeping FM signals. Another popular technique, and the one to be discussed in this application note, is the radiation of UWB baseband pulses. A "baseband" pulse is a pulse signal that does not use a carrier frequency. The transmitter is not a gated oscillator, but is instead a baseband pulse generator. Very broadband antennas are required. The receiver is typically a digitizing oscilloscope followed by a powerful computer. Because an oscilloscope is used, the complete waveform received from the target contains both amplitude and phase information. The exact transmitted waveform, $v_t(t)$, is known. The computer processes the data and is able to not only determine the target's position and velocity, but also can extract the natural resonances from the target and thus identify the nature of the target.

The fundamental concepts of UWB radar are not new. During the Vietnam war, the USA military and NBS investigated and built experimental ground penetrating UWB radars for detecting buried plastic land mines. The basic UWB principles were proven in the 70s. However, the test instruments and in particular the computers available in the 60s and 70s were not powerful enough to enable building field deployable UWB radars then. Today with the massive computer power in small laptop computers and GigaBit/sec digital oscilloscopes, UWB radars are now practical.

Several types of baseband pulses are typically used in UWB radars. They include step functions, rectangular pulses, impulses, doublets, and limited duration RF pulses. Figure 1 shows several of these pulses and their corresponding spectrums. A rectangular pulse, Figure 1c, has a spectrum which follows a sin(X) / X curve. Its first null occurs at the reciprocal of the pulse duration, i.e., $f_o = 1 / T_o$. For frequencies < ½ f_o, the spectrum is quite flat. Other impulses, such as the triangular pulse and the sine-squared pulse, Figures 1d and 1e, have similar spectrums with their first nulls occurring at 1 / T_o, but their spectrums roll off faster than the sin(X) / X. The rectangular RF pulse, Figure 1f, can be considered to be the spectrum of the rectangular pulse, Figure 1c, translated to a higher frequency by the RF carrier frequency, f_c. If the number of RF cycles is small, then the resultant spectrum is very broad and flat and centered on f_c. A step waveform, Figure 1a, has a spectrum which falls proportional to 1 / f . A step wave with a finite risetime, Figure 1b, has a spectrum which initially falls as 1 / f . It then has a null at the reciprocal of the risetime, i.e., $f_o = 1 / T_r$. Beyond f_o, the spectrum follows a curve similar to a $[\sin (x) / x]^n$.

Several PSPL pulse generators have been successfully used by UWB researchers. They typically have been used for scale modeling research on UWB antennas and also characterizing the natural resonances of scale models of aircraft, ships, tanks, etc. Some ultra-high resolution operational radars have also been built using PSPL pulse generators. The most popular PSPL generators for this purpose have been the models 1000D, 4050B, and the 4015C. Figures 2 - 10 show the time domain waveforms and their corresponding spectrums. These waveforms were measured with an HP-54750A, 50 GHz, digital sampling oscilloscope. These waveforms were then transferred over the GPIB to a p.c. computer. The spectrums were then calculated in Matlab using FFTs.

An early NBS ground penetrating radar developed in the 70s used a pulse generator designed by the author which was similar to PSPL's model 1000D Impulse Generator. The 1000D produces dual, simultaneous, positive and negative output impulses of 35 V amplitude and 500 ps duration. The dual impulses are useful for driving both halves of a

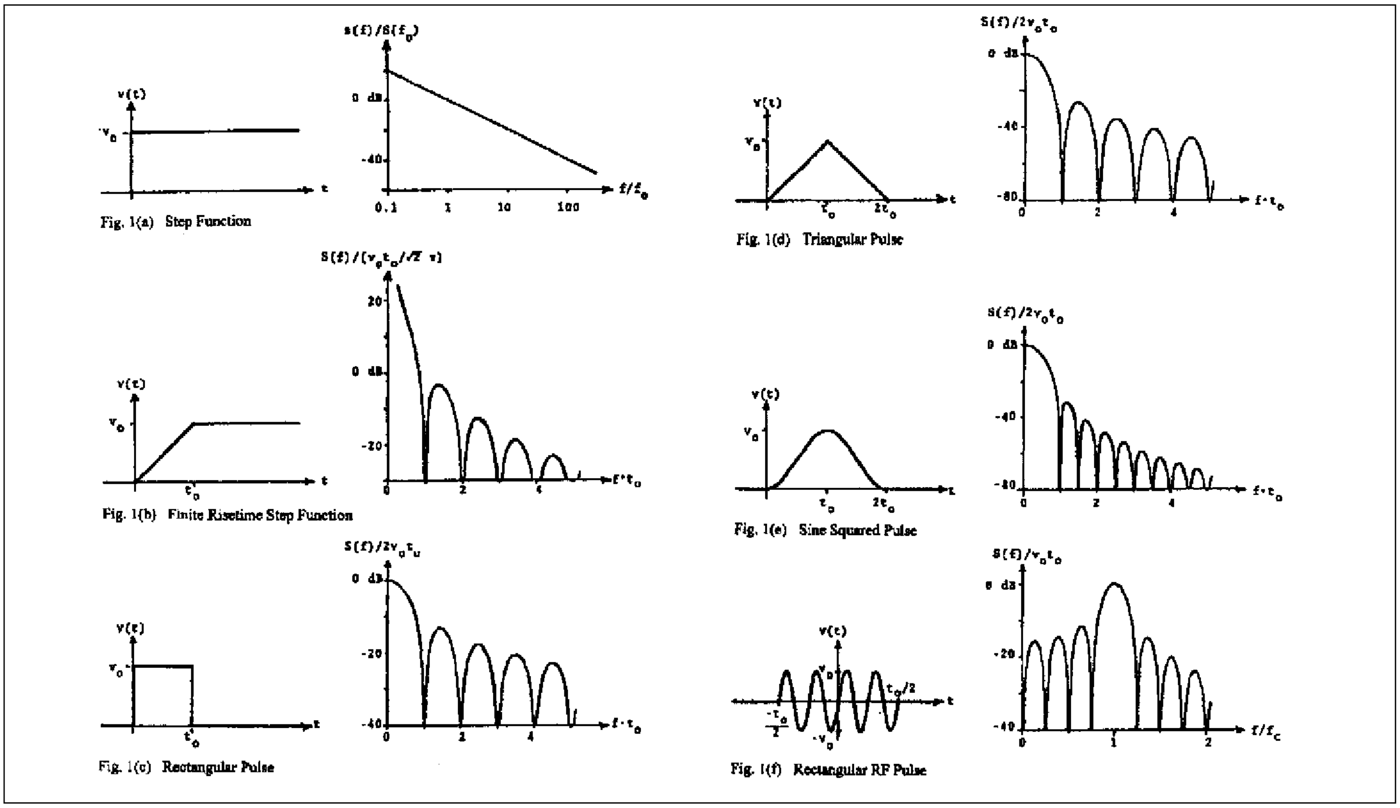

Figure 1: Idealized Pulse Waveforms and Their Respective Spectrums

dipole antenna. The frequency spectrum of the 1000D's impulse is quite strong at 90 dBµV/MHz. It is flat to 500 MHz and is useful up to 2.5 GHz.

The PSPL Models 4050B and 4015C are both step function generators which produce amplitudes of +10 V and -9 V, respectively. The risetime of the 4050B is 45 ps. The falltime of the 4015C is 15 ps. Their waveforms and spectrums are shown in Figures 3 and 4. Their spectrums fall proportional to 1 / f and are useful up to 20 GHz and 40 GHz, respectively.

PSPL has developed some unique modules, called Impulse Forming Networks (IFN). These are passive networks whose outputs are a very good approximation to the first derivative function, dVin/dt . They are not a simple small differentiating capacitor. Instead, they are a more complex network which also provides excellent input and output impedance matching to 50 Ohms. When an IFN is driven by a step function, its differentiated output is an impulse. When an IFN is driven by an impulse, its output is then a doublet. The doublet is essentially a monocycle sine wave. The Model 5210 IFN was optimized for use with the 45 ps model 4050B pulse generator. Likewise, the model 5208 IFN was optimized for use with the 15 ps model 4015C pulse generator.

Figures 5 and 6 show the impulse and monocycle waveforms obtained using (1) and (2) 5210 IFNs on the output of the 45ps, 10 V, Model 4050B pulse generator. The impulse, Figure 5, has 3 V amplitude and 50 ps duration (fwhm). The impulses' spectrum at low frequencies is +51 dBµV/MHz. It is 3 dB down at 6 GHz and provides useful spectrum up to about 20 GHz. The monocyle, Figure 6, has 1.8 Vptp amplitude and a center frequency of 5 GHz. The monocyles' spectrum peaks at +41 dBµV/MHz. It is 3 dB down at 2.5 GHz and 11 GHz. It provides useful spectrum from 100 MHz to 22 GHz.

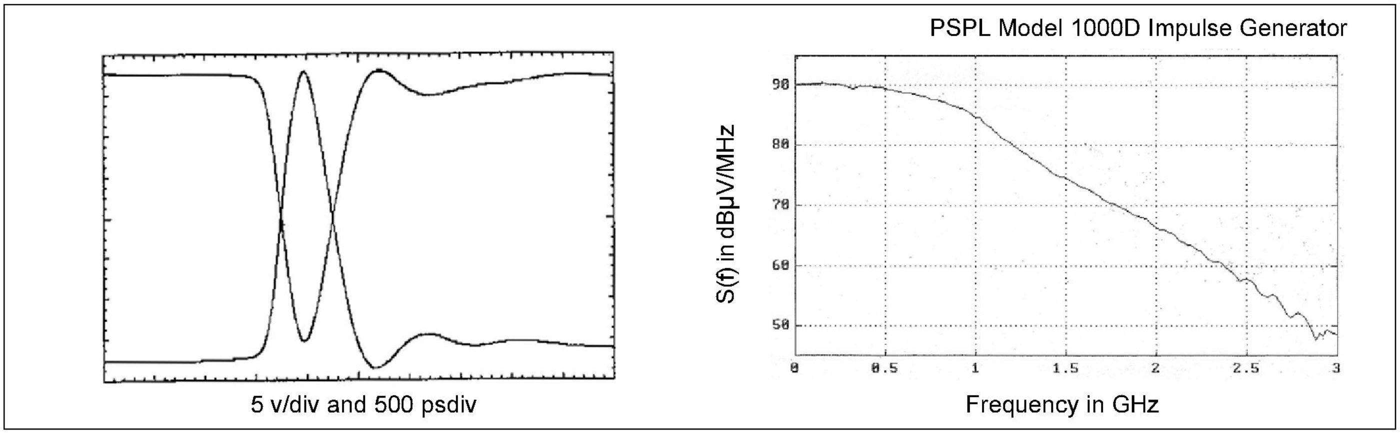

Figure 2: PSPL Model 1000D Impulse Generator Impulses are 35 V peak, 500 ps Duration

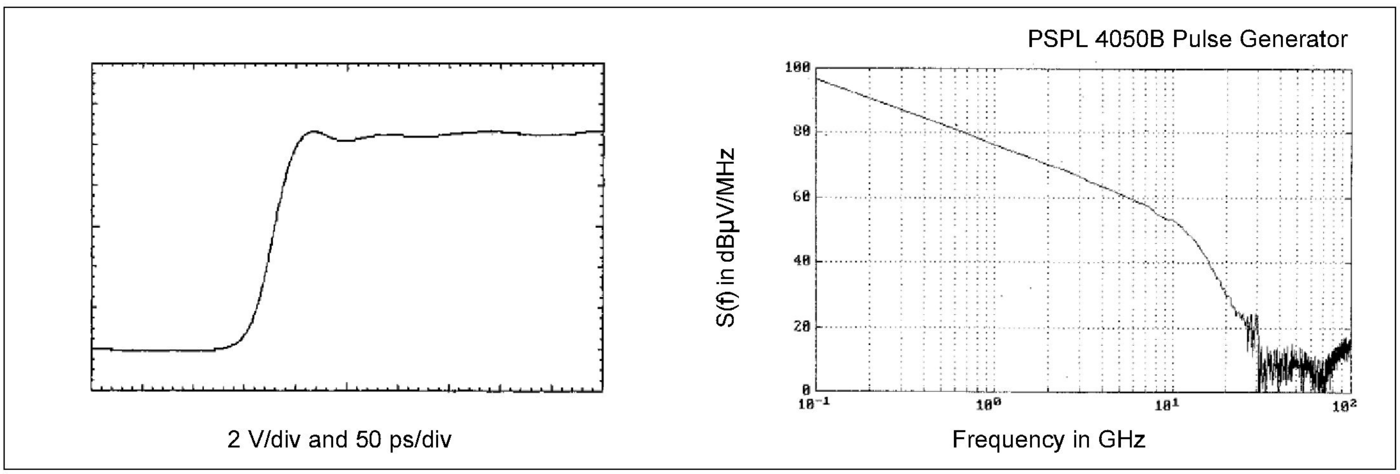

Figure 3: PSPL Model 4050B Pulse Generator, 10 V Amplitude, 45 ps Risetime

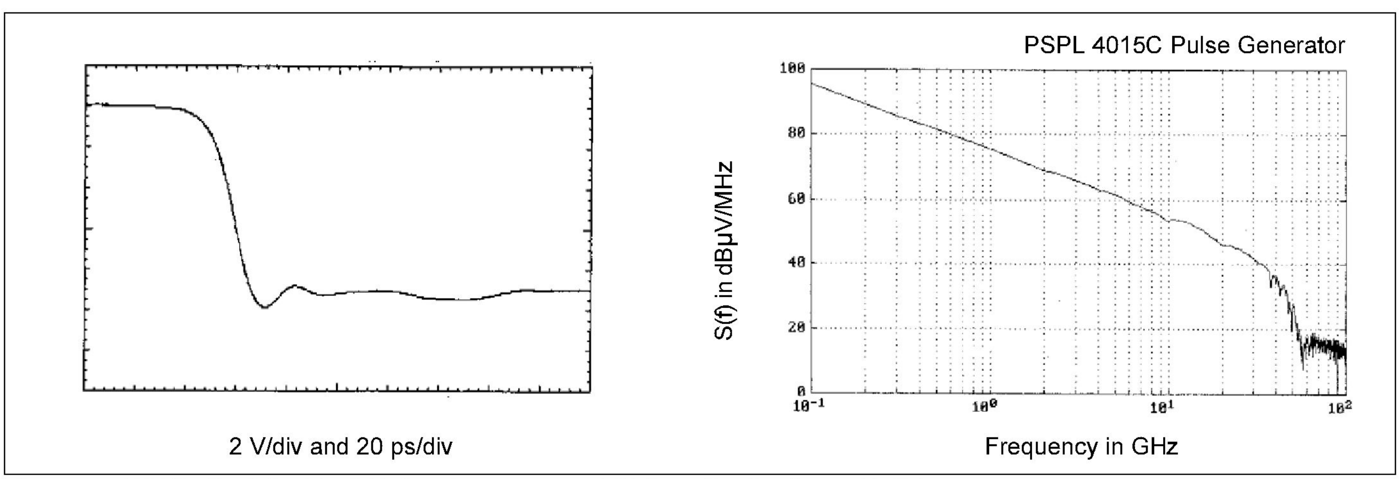

Figure 4: PSPL Model 4015C Pulse Generator, -9 V Amplitude, 15 ps Falltime

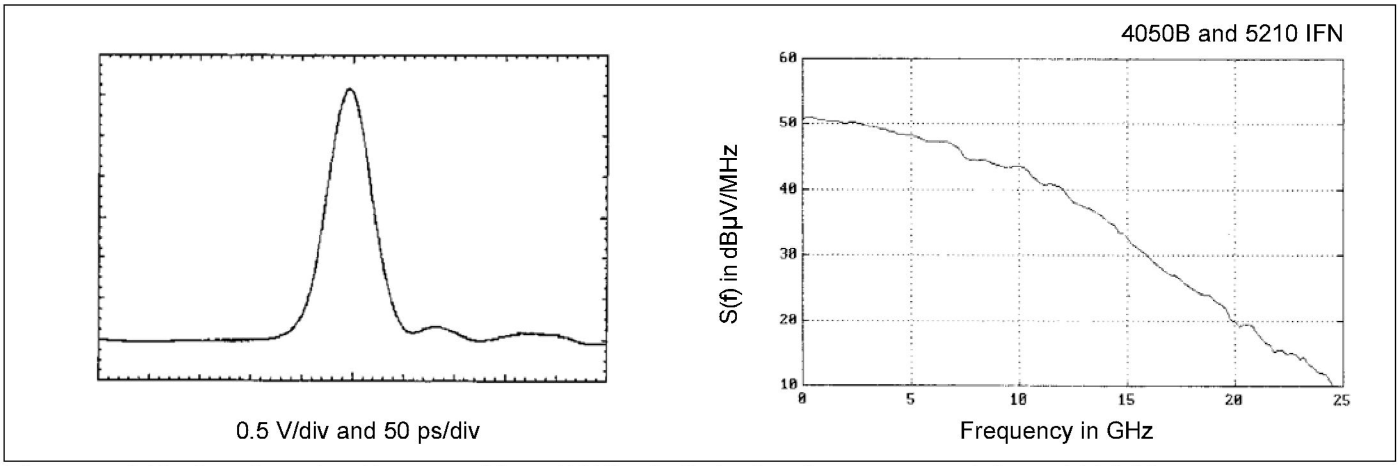

Figure 5: 3 V, 50 ps Impulse Generated by a PSPL 4050B Pulse Generator and One 5210 IFN

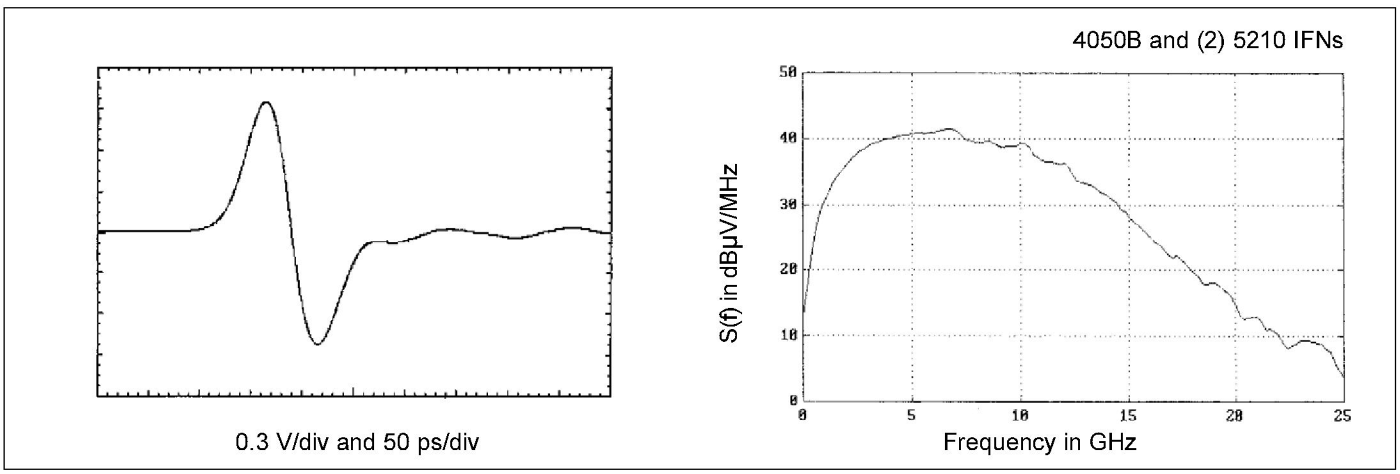

Figure 6: 1.8 Vptp, 6.5 GHz Monocycle Generated by a PSPL 4050B Pulse Generator and Two 5210 IFNs Connected in Cascade

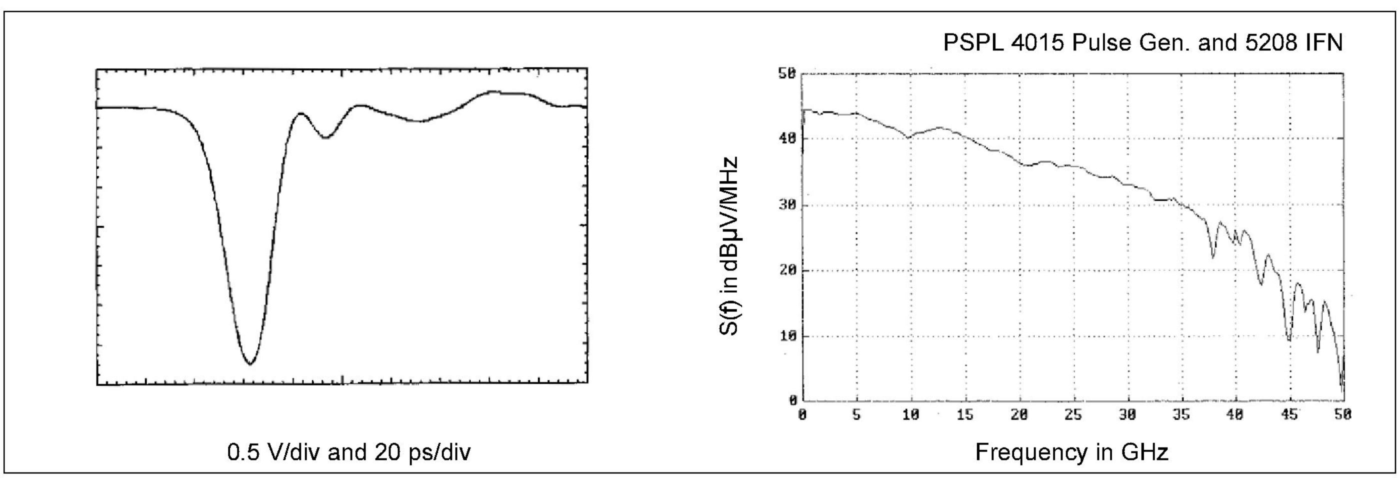

Figure 7: -3.25 V, 21 ps Impulse Generated by a PSPL 4015C Pulse Generator and One 5208 IFN

Figures 7 and 8 show the impulse and monocycle waveforms obtained using (1) and (2) 5208 IFNs on the output of the 15 ps, -9 V, Model 4015C pulse generator. The impulse, Figure 7, has -3.25 V amplitude and 21 ps duration (fwhm). The impulse's spectrum at low frequencies is +44 dBµV/MHz. It is 3 dB down at 14 GHz and provides useful spectrum up to beyond 40 GHz. The monocycle, Figure 8, has 2 Vptp amplitude and a center frequency of 12.5 GHz. The monocycle's spectrum peaks at +37 dBµV/MHz. It is 3 dB down at 5 GHz and 18 GHz. It provides useful spectrum from 500 MHz to beyond 40 GHz.

Several of PSPL's UWB radar customers have inquired about methods to get even higher output powers from PSPL pulsers. The C and X band monocycles shown in Figures 6 and 8 only produce about +10 dBm peak power. A simple technique we have been recommending to customers is to use a Traveling Wave Tube Amplifier (TWTA) to boost the power of the PSPL pulse generators. The output is a high powered, 3 cycle RF pulse. The output RF pulse is always the same waveform and is phase coherent with the input impulse. A TWTA is basically an octave bandwidth, band-pass filter with lots of gain (typically >30 dB). When a band-pass filter is driven by an impulse, its output is a phase coherent RF pulse with damped ringing. The frequency of the output RF is near the center frequency of the filter. The number of RF cycles in the output is inversely proportional to the filter's bandwidth. For an octave bandwidth filter, the output typically only contains about 3 RF cycles.

Figures 9 and 10 show the results of some experiments driving high power TWTAs with PSPL impulses. For Figure 9, we drove a 3 V, 50 ps impulse (see Figure 5) into a Hughes model 1277H, 20 watt, C band TWTA. The resultant output was a 100 Vptp, 3 cycle rf burst with a center frequency of 5 GHz. The peak power was 25 watts (+44 dBm). The spectrum closely followed the theoretical curve shown in Figure 1d. The peak spectrum was +85 dBµV/MHz. The dominant spectral energy was as expected in the region from 3 GHz to 7 GHz, with significant energy extending from < 1 GHz to 16 GHz. Severe spectral nulls occurred at 7.5 GHz and 12.5 GHz.

For Figure 10, we drove a -3.25 V, 21 ps impulse (see Figure 7) into a Logimetrics model A330, 10 watt, X band TWTA. The resultant output was a 73 Vptp, 3 cycle RF burst with a center frequency of 10 GHz. The peak power was 13 watts (+41 dBm). The peak spectrum was about +76 dBµV/MHz, with useful spectrum covering from 2 GHz to 23 GHz. A minor null occurred at 14 GHz.

This application note has shown several PSPL pulse generators which have been used successfully by UWB radar researchers. It has also demonstrated a technique of using octave band, traveling wave tube amplifiers to significantly increase the peak powers of impulsive UWB radar transmitters. Additional details concerning the PSPL products mentioned here are available from PSPL's web site: www.picosecond.com Demonstration video tapes for PSPL's pulse generators are also available.

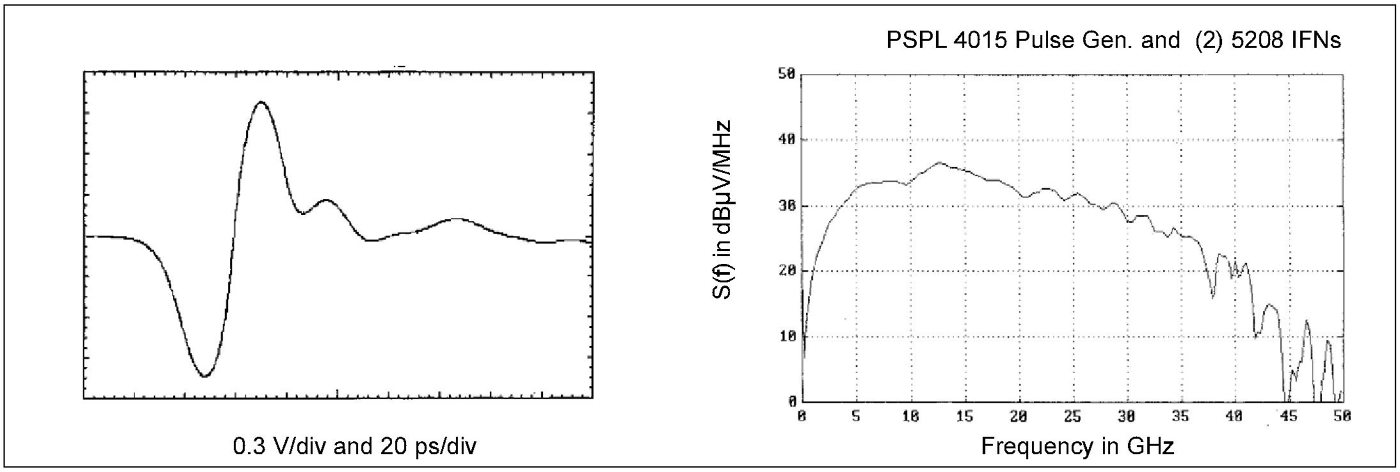

Figure 8: 2 Vptp, 12.5 GHz Monocycle Generated by a PSPL 4015C Pulse Generator and Two 5208 IFNs in Cascade

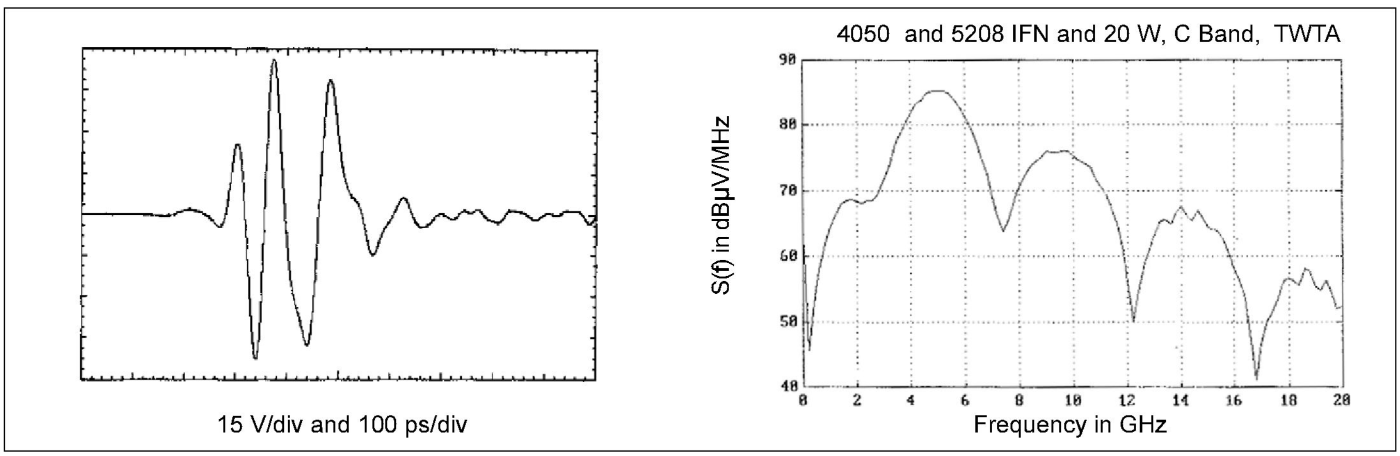

Figure 9: 100 Vptp, 5 GHz RF Pulse Generated by Driving a 20 W, C band TWTA with a 3 V, 50 ps Impulse

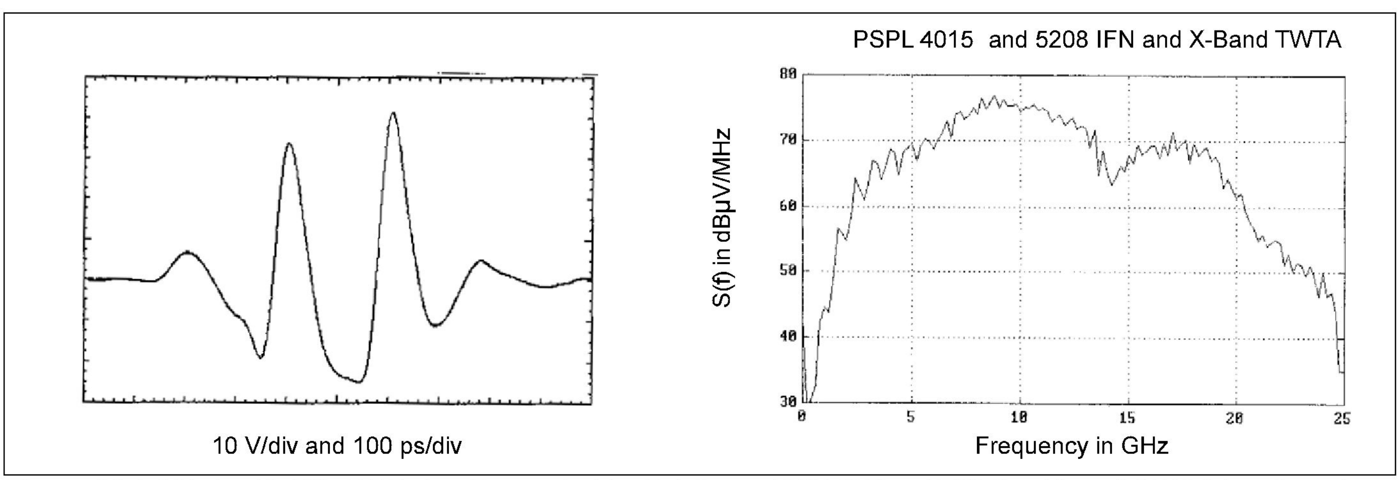

Figure 10: 73 Vptp, 10 GHz RF Pulse Generated by Driving a 10 W, X Band TWTA with a -3.25 V, 21 ps Impulse