Tektronix

Application Note

New Techniques for Complex Modulation Analysis

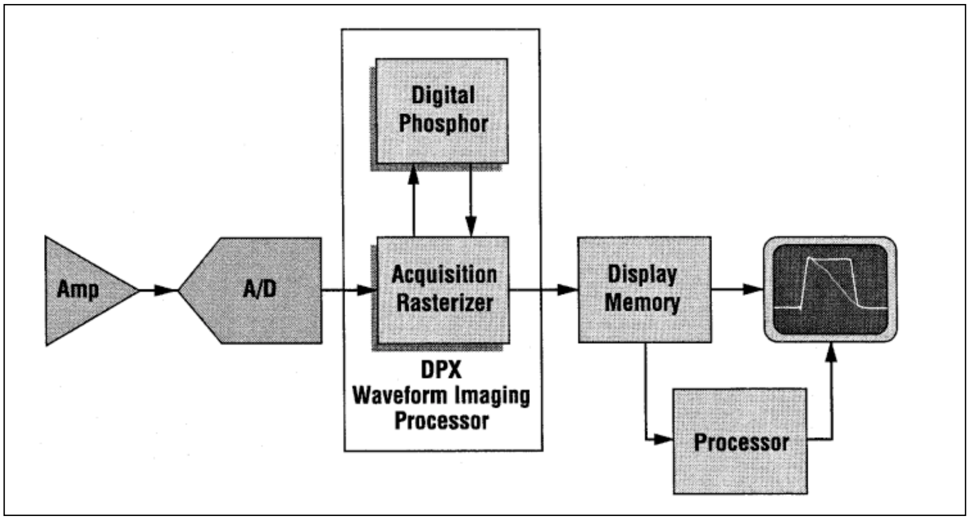

Figure 1. Tektronix DPO Architecture.

Traditional oscilloscopes have had limited application for RF measurements in the wireless designer's lab. The rapidly changing nature of digitally modulated signals makes them difficult or impossible to capture and display with conventional digital oscilloscopes. Analog oscilloscopes continue to be used to examine IQ diagrams of baseband signals because of their gray-scale XY display performance. As the 2 GHz PCS bands have developed, oscilloscopes are hard pressed to keep pace with adequate sampling rates and trigger bandwidths.

This application note examines the wireless applications of a new acquisition and display technology – the Digital Phosphor Oscilloscope. Examples of new measurements enabled by this technology are described.

Digital Phosphor Oscilloscope (DPO) Technology

The Digital Phosphor Oscilloscope (DPO) is a new type of oscilloscope that combines the best of analog and the best of digital storage oscilloscope (DSO) technology in one instrument. The DPO results from recent technological advances in oscilloscope acquisition and display technology.

Acquiring PCS band signals increases the bandwidth requirements of an oscilloscope to 2 GHz and beyond. Likewise, the complexity of a digitally modulated signal requires display and analysis features that were not previously available in analog oscilloscopes or DSOs. A DPO is able to display, store, and analyze complex signals in real time, using three dimensions of signal information: amplitude, time, and distribution of amplitude over time. The real time, three-dimensional display of a DPO, combined with analog bandwidths as high as 2 GHz, make these oscilloscopes very powerful tools for observation and analysis of digitally modulated signals.

Tektronix DPOs are enabled by the new DPX™ Waveform Imaging Processor (WIP). The DPX WIP allows Tektronix DPOs to continuously capture and display waveform images. A simplified block diagram of a DPO is shown in Figure 1. In a Tektronix DPO, the signal is digitized and input to the DPX WIP. Data in the DPX WIP is rasterized and sent to a dynamic three-dimensional database called the digital phosphor. Thirty times a second, a snapshot of the digital phosphor is taken and sent to the display. Meanwhile, the acquisition system continues to capture waveforms. With DPX, the oscilloscope's microprocessor is not burdened with signal acquisition and display tasks. Instead, the microprocessor is used for tasks such as math and automatic measurements. So in a DPO, the acquisition system is fed directly to the display system.

A real-time, three-dimensional (3-D) view of signal behavior has traditionally been one of the strengths of analog real-time oscilloscopes. Many engineers prefer analog oscilloscopes because of the scope's ability to display frequency-of-occurrence information in a "gray scale" format. Also, analog oscilloscopes do not exhibit the signal aliasing that commonly occurs with a DSO. In a DPO, a very high display sample density of up to 100 Mpoints per second is accumulated and displayed. With this high display sample density, DPOs can effectively show gray scale information and avoid signal aliasing.

Waveform Storage and Analysis. DPOs go beyond analog oscilloscopes by not only displaying real-time 3-D waveforms, but also capturing and storing the data in a 3-D database. By storing the waveform data, DPOs allow extended viewing of the data. Analog scopes only maintain the waveform image for an instant until their phosphor decays. DPO displays, like those of DSOs, can be paused and observed for extended periods of time. In addition, waveform analysis can be done on the stored data. Automatic measurements and histograms are also possible on the DPO waveforms.

Figure 2 shows a square wave and a histogram waveform (near the left edge of the screen). The histogram waveform shows the statistical distribution of the noise occurring at the top of the first pulse. The rectangle drawn around the top of the pulse controls the portion of the waveform where the histogram data is collected.

The frequency of occurrence in portions of the square wave are represented by different colors. Other figures in this paper use color-graded intensity displays.

XY Displays. Another advantage an analog oscilloscope offers when compared to DSOs is the ability to show two waveforms simultaneously as an XY plot. Using two input channels, the analog oscilloscope is able to easily show the phase and amplitude differences between the two waveforms in real time. This method of analyzing two channels is often used in IQ vector diagrams. The continuous acquisition, and high display sample density of DPOs work in XY display mode as well. With a pixel accumulation rate of 1 Mpixel/s, DPOs eliminate the processing bottlenecks found in a DSO's XY mode. With full bandwidth performance in XY display mode, DPOs extend oscilloscope XY display and analysis capabilities beyond what analog oscilloscopes are able to offer.

In addition to vector diagram (XY) displays, it is often useful to analyze the signals amplitude and phase at discrete times in a constellation plot. Analog oscilloscopes provide a Z-axis input that intensifies the displayed data only when a clock is high. Likewise, DPOs offer an XYZ display mode that collects and displays samples that occur when an input such as a symbol clock exceeds the desired threshold. Using a DPO for a constellation plot, it's possible to observe and analyze a digitally modulated signal when the symbols are valid.

Time Domain Measurements of CDMA Signals

The effect on peak-to-average ratio and Cumulative Distribution Function (CDF) as a result of the Walsh coding of IS-95 base station signals has been well described (see References 1 and 2). There is general agreement that a complete definition of a CDMA base station signal must include either the Walsh codes and power levels used in the signal, or that a CDF measurement of the test signal be provided.

The statistics capability of the DPO allows for a quick examination of the amplitude distribution in the RF envelope of the CDMA signal. Figure 3 shows both the time domain and a logarithmic histogram of a CDMA pilot signal at 1.85 GHz carrier frequency. Figure 4 is the same display of a nine-channel CDMA signal with Walsh codes selected to provide worst case peak-to-

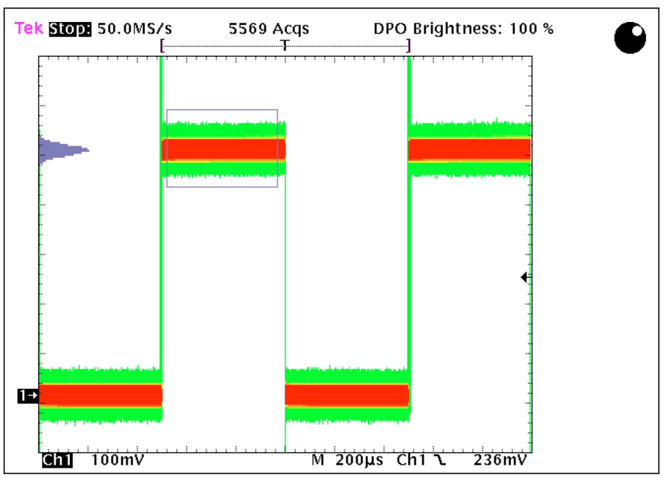

Figure 2. Histogram of noise on a square wave.

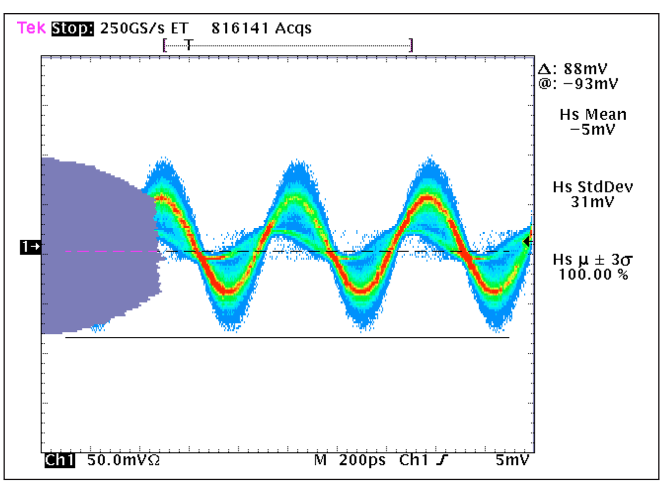

Figure 3. 1.85 GHz carrier and amplitude distribution of CDMA forward link, pilot only.

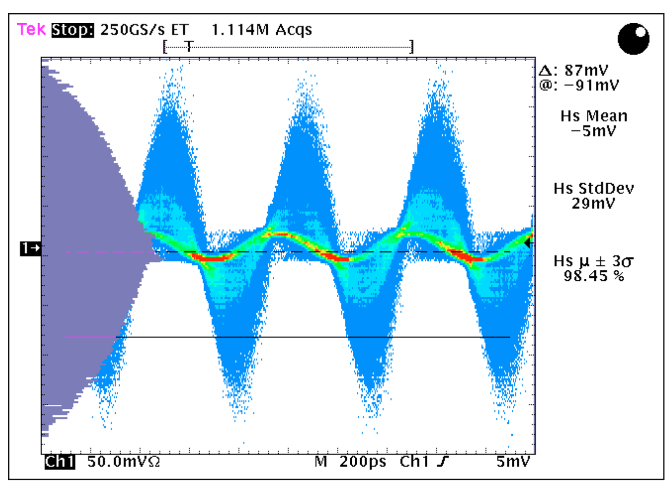

Figure 4. 1.85 GHz carrier and amplitude distribution, CDMA forward link. Walsh codes 0, 1, 8, 16, 24, 32, 40, 48, 56 at power levels per IS-97 recommendation.

average ratios. The histogram in Figure 3 demonstrates that 100% of the carrier is contained within three standard deviations (3σ) of the mean value (µ). By contrast, the nine-channel waveform exceeds its 3σ value 1.55% of the time, and contains peak voltages twice that of the pilot-only signal.

The DPO, due to it's high bandwidth and fast statistical processing, provides a quick check of the stress imposed on a device-under-test by varying signals.

IQ Vector (XY) Measurements on Demodulated RF Signals.

Examination of vector diagrams is often accomplished using a vector signal analyzer. Most instruments of this type produce a vector diagram by down-converting the RF signal to baseband, digitizing the result, and performing post-capture processing of the waveform. This provides valuable information with regards to error vector magnitude and demodulated symbol values. This post-processing causes interruption of acquired data. Such instruments typically throw away 99% of the incoming signal.

To achieve a live IQ display, an IQ demodulator can be employed with an oscilloscope and local oscillator as shown in Figure 5. If the RF carrier is within the bandwidth of the oscilloscope, it's necessary to bandwidth limit the inputs to suppress carrier feed-through from the demodulator. Further information regarding IQ demodulators can be found in Reference 3.

An application of the demodulated IQ vector diagram is seen in Figure 6. Here, an unmodulated transient has occurred in the modulation envelope. This transient occurred over a period of less than 20 ms and would not have been captured with a post-processing vector analyzer.

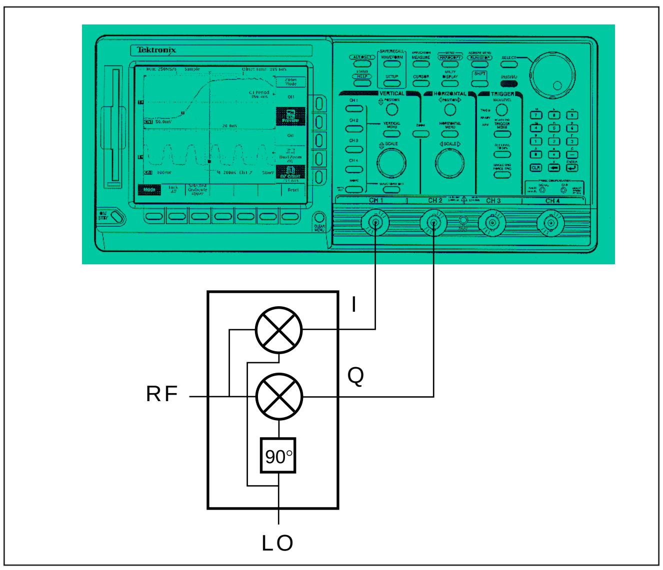

Figure 5. RF demodulation for live IQ displays.

Commanding a RF signal generator to perform an Automatic Level Control (ALC) power search created the signal in Figure 6. This causes the generator to turn modulation off while the level control circuitry measures the CW level. This transient does not occur in normal operation of the generator when the ALC Table mode is used for level correction.

Constellation (XYZ) Measurements

As described earlier, DPOs can be used for constellation displays. XYZ displays use a clock signal to enable data acquisition during the period of interest. In Figure 7, an eye diagram of a CDMA signal is shown on channel 1 of the DPO. In this case, pilot, sync, and paging are transmitted on Walsh codes and power levels indicated in Table 1.

Table 1. Walsh Codes and Power Used in Figure 7

Walsh Code	Power Relative to Carrier (dB)
0	–7.7
32	–7.7
1	–12.8

The Z-axis trigger is aligned to display the constellation diagram during the symbol-valid portion of the display. In this example, the trigger is derived from the symbol clock of a signal generator. The symbol clock was differ-

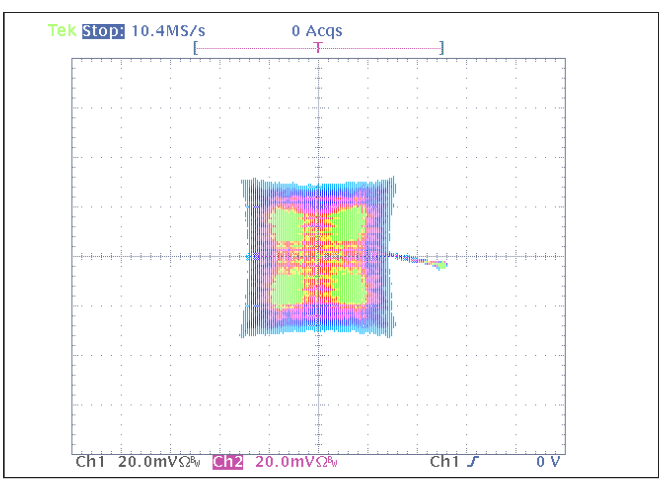

Figure 6. Unmodulated transient in demodulated CDMA forward link signal.

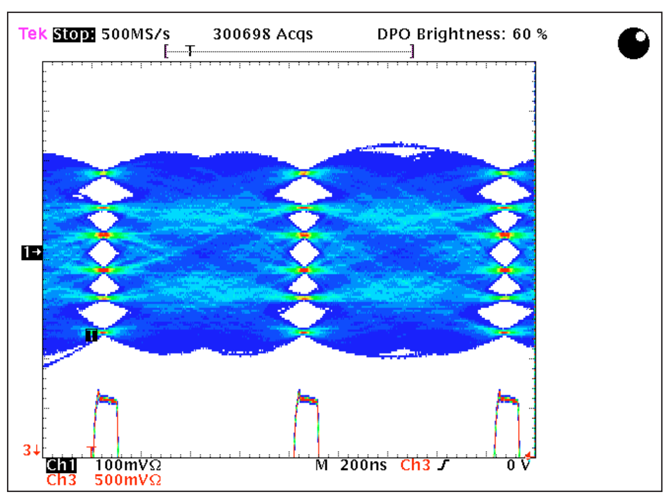

Figure 7. Eye Diagram and Z-axis trigger Synchronization for constellation display.

entiated with a 0.1 µF series capacitor to provide the desired trigger width.

The resultant constellation display is seen in Figure 8. The power levels that result from the combination of the three Walsh-coded channels is clearly seen.

Constellation Measurements. Analog oscilloscopes provide a gray-scale display of information based upon the frequency of occurrence. In this way, the user can determine how often the trace is at a particular location on the display based on the intensity of the phosphor. The DPO provides this intuitive display, and adds statistical analysis to the measurement. In Figure 9, a 100 ksymbol/s QPSK signal is displayed as a contour plot. Acquisition was triggered using the method described for Figure 7. A color scale is used to distinguish the number of hits in each quadrant of the IQ diagram. A pseudo random bit sequence (PRBS) was used to modulate the data, and equal distribution can be seen in each quadrant of the display.

An analog oscilloscope indicates distribution of data in the varying intensity of the display. The DPO provides this same information, and yields additional information in the form of a three-dimensional display that can incorporate signal statistics in the display.

Summary

Traditional DSOs are limited by their waveform processing time in their ability to capture and display rapidly changing signals as are present in digitally modulated signals. Analog oscilloscopes provide a better picture of signal dynamics with gray scale display, but are limited in bandwidth and lack the ability to save signal statistical data.

The DPO provides the best of analog display and digital acquisition technologies. This enables new measurements with oscilloscopes for RF applications. Examples of new measurements are CDMA amplitude distributions, real-time vector diagrams, symbol triggered IQ displays, and IQ diagram statistics.

References

(1) Klaus Tiepermann, ***CDMA Signals, a Challenge for Power Amplifiers***, RF Design, July 1996.

(2) Bob Buxton, Steve Stanton, Josef Wolf, ***ACP Measurements on Amplifiers Designed for Digital Cellular and PCS Systems***, Proceedings of Sixth Annual Wireless Symposium.

(3) ***Optimization of Quadrature Modulator Performance,*** RF Micro Devices Application Note AN0001.

Acknowledgements

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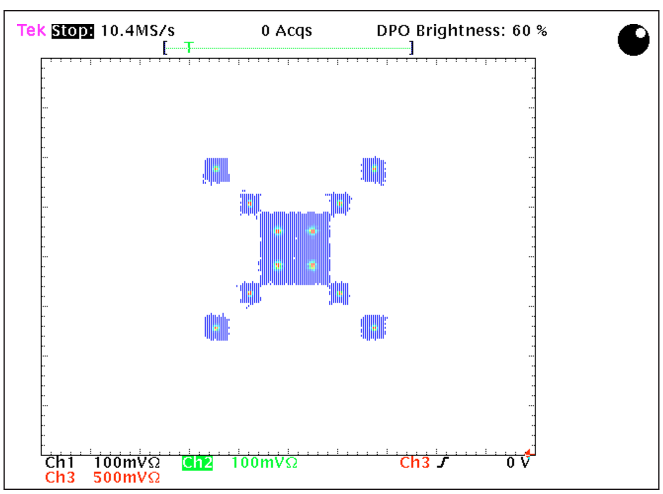

Figure 8. XYZ display of CDMA Forward Link.

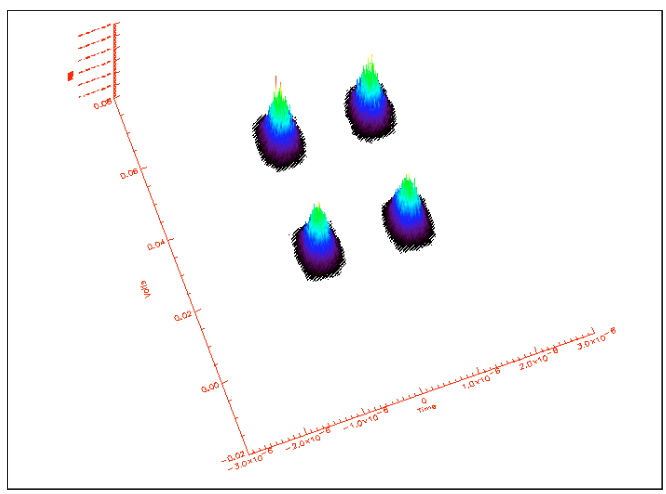

Figure 9. Distribution of symbols, QPSK with PRBS data.

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