TOWARDS THE DEFINITION OF RF-PULSE POWER-ENVELOPE TRANSITION-DURATION

David A Humphreys, James Miall

National Physical Laboratory

Hampton Road, Teddington, Middlesex, TW11 0LW, UK

Abstract

RF pulse power envelope transition duration parameters can be described using IEEE standard 181-2003. Traceability for RF transition duration parameters is based on direct measurement of the RF waveform. We consider the definitions and the effect of different analysis techniques used to recover the RF power envelope from the voltage waveform.

Introduction

Accurate Peak RF Power measurements are important for the mobile communications industry and so some manufacturers specify transition duration parameters for their instruments. Traceability of the RF pulse envelope parameters is derived from CW RF power, impedance and electrical risetime (oscilloscope) measurements [1]. However, at present there is no agreed method for determining the RF power envelope parameters.

In this paper we consider the definitions required and how existing waveform metrology standards can be adapted to characterise an RF envelope.

Electrical waveform metrology standards

IEEE standard 181-2003[2] provides methodology for analysing transition durations of an arbitrary waveform. It caters for single transitions (step), and multiple transitions (pulse or more complex waveform). It could therefore be applied with equal ease to the voltage envelope or the power envelope.

As some manufacturers of wide-bandwidth RF power meters already define RF power transition duration in terms of the IEEE standard 181, it would be advisable to retain a power envelope definition rather than developing a standard based on RF voltage envelope.

Differences between electrical waveform and RF envelope

A pulsed RF waveform is the product of a time-dependent (t) envelope function and a carrier frequency. The carrier frequency may also have frequency or phase modulation but in this instance, we are only concerned with the amplitude variations.

In the case of an electrical pulse, superposition can be applied directly but in the case of RF pulsed signals the situation is more complex. Superposition of modulated RF signals give rise to high instantaneous peak powers, $P_{pk}(t)$, due to coherent addition of the RF voltages.

$$P_{pk}(t) = \left(\sum_{i=1}^{n} \sqrt{P_i(t)} \right)^2 \qquad \text{Equation 1}$$

where $P_i(t)$ are the individual RF power envelope functions. However, the evolution of the average power envelope ($P_{env}(t)$), neglecting the coherent addition terms, can be described by the sum of the RF power envelope functions.

$$P_{env}(t) = \sum_{i=1}^{n} P_i(t) \qquad \text{Equation 2}$$

In the worst-case scenario (n equal powers), the peak-to-average ratio is proportional to n. Typically, the bias voltage for diode sensors used in wide-bandwidth RF power meters is dynamically controlled to ensure that the sensor is correctly biased. If multiple signals are present with carrier separations that exceed the loop bandwidth, there is the possibility that the sensor may be driven into a nonlinear operating regime when the signals are in phase, introducing a systematic error in the results.

Filtering

Filtering is required to isolate the signal of interest from other interference signals and to reduce noise. The bandwidth of the filter must be sufficient to capture the signal components and the phase response of the filter should be linear to avoid introducing distortion of the pulse envelope. The choice of the filter band-shape will depend on the application and is beyond the scope of this paper.

Algorithms and measurement techniques to determine the RF power envelope

The RF power envelope can be measured directly using a sampling oscilloscope provided that there is no significant correlation between the RF carrier phase and the pulse trigger event [1]. At each measured time point, the variance of the individual samples is proportional to the RF envelope power.

The characteristics of the RF power envelope can also be determined using a digitising oscilloscope to measure the waveform. Four methods of calculating the RF power envelope are compared and potential sources of error are identified.

Hilbert transform

The Hilbert transform (H) can be used to generate $\pi/2$ phase-shifted copy of the filtered, measured waveform

$s_{BP}(t)$. The Hilbert transform can be realised in terms of the Fourier transform as:

$$H(x(t)) = F^{-1}\left(\frac{j\omega}{|\omega|} \cdot F(x(t))\right) \qquad \text{Equation 3}$$

where H is the Hilbert transform. F(x(t)) is the Fourier transform, resulting in X(ω) in the frequency domain where ω is the angular frequency. $F^{-1}(X(\omega))$ is the inverse Fourier transform.

The envelope function can be recovered by combining the original signal and the Hilbert transform processed signal in quadrature:

$$y'(t) = (s_{BP}(t))^2 + (H(s_{BP}(t)))^2 \qquad \text{Equation 4}$$

where y'(t) is the estimate of the envelope function y(t) and $S_{BP}(t)$ is the filtered signal s(t).

The limitations of this technique are:

1. The Fourier transform must be applied to the full data set
2. The RF pulse envelope must be the same value at both the start and end of the epoch. If the RF pulse envelope is non-zero at the extremities, the underlying RF signal must have an integer number of cycles in the epoch.

Complex exponential

If the measured voltage waveforms $s(t)$ is multiplied by a complex exponential $exp(-j\omega_0 t)$ at a frequency ω_0, then the result will comprise of sum $(\omega + \omega_0)$ and difference $(\omega - \omega_0)$ frequency components A low-frequency filter is then applied to this result to remove the sum frequency and dc terms (see Figure 1).

$$y'(t) = \left|f_{LP}(s(t)\exp(-j\omega t))\right|^2 \qquad \text{Equation 5}$$

where f_{LP} is a low pass filter to exclude the sum components. The complex exponential frequency must be chosen so that it is outside the RF components of the pulse to avoid introducing aberrations into the result.

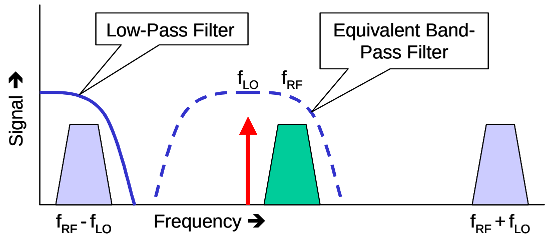

Figure 1. Multiplication by a complex exponential generates phase and quadrature components at the sum and difference frequencies.

This technique may offer several benefits when applied to long epoch measurements:

1. There is no need to use a Fourier Transform on the full trace.
2. A Finite Impulse Response filter could be used, allowing the results to be obtained from a single pass through the data values.

Peak-finding and integration methods

Peak-finding methods find the maximum and minimum values for each cycle. The envelope can be determined by fitting a curve through the square of the results. High levels of oversampling are required to ensure that the maximum and minimum values are well described as the results are systematically lower than the true value.

The integration method performs the dc corrected RF power calculation on a cycle-by-cycle basis. Again, this technique relies on oversampling of the data but to a lesser extent. If the number of cycles occurring within a transition is low then the amplitude will vary significantly during a cycle.

Both of these techniques are attractive because of their simplicity but rely on higher levels of oversampling than the other techniques. They offer the advantage that they are simple to implement and can be applied as a single-pass operation.

Summary

The IEEE standard for defining transition properties is a good starting point for describing the evolution of RF power with time. Defining the transition durations in terms of RF power envelope function is recommended. The RF signal is a modulated carrier, and so filtering must be included to isolate the required RF signal.

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References

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[2] IEEE Standard on Transitions, Pulses, and Related Waveforms, IEEE Std 181, 2003