Datod Comments on NTIA

Spectrum Sharing Innovation Test-Bed

Phase II/III Test Plan

April 27, 2012

1) Introduction:

This submission has been prepared in response to the US NTIA Federal Register invitation to comment on the Spectrum Sharing Innovation Test Bed Pilot Program and the type and depth of testing it indends to conduct.

2) Background:

The US NTIA is seeking to advance the state of the art in Dynamic Spectrum Access technologies in order to implement Spectrum Sharing strategies for enabling coexisting communication system topologies. In this respect it is also seeking to advance the state of the art of Spectrum Sensing measurement techniques.

In this response I call into question the technical capability and consequences of applying the Discrete Fourier Transform as a basis for obtaining accurate frequency, amplitude and phase information in order to advance the state of the art for spectral component estimation for both devices and for stand alone measurement instrumentation, such as the Vector Signal Analysers called out in the Draft Phase II/IIITest Plan.

In respect of the above I would also call attention to a published Datod criteque on this Fourier Analysis field in the September 2011 printed edition of Electronics World magazine article entitled **Spectrum Analysis : Opening Another Can of Worms**; in which I posed a series of open questions and introduced Benchmark Test Signals.

In this submission I also pose a further series of technical questions on Spectrum Sensing Measurements

3) NTIA Assessment of the State of the Art in Spectral Measurement:

The NTIA assesment of Spectrum Sensing analysis measurement technology is outlined in the published report by Rodger Dalkie's work from NTIA Technical Report TR-10-470: **Radio Spectrum Estimates Using Windowed Data and the Discrete Fourier Transform,** published September 2010.

This report, as with Rodger Dalkie's other published body of work by the NTIA, is primarily aimed at establishing a firm appreciation of the State of the Art associated with the technical measurement requirements for future Dynamic Spectrum Access technology and especially the crucial initial signal acquision Spectrum Sensing element stage required when a wireless communication device is activated.

Dalkie states in his introduction *"Digital signal processing algorithms are commonly used to obtain radio spectrum estimates based on measurements. Such algorithms allow the user to apply a variety of time-domain windows and the discrete Fourier transform to RF signals and noise. The purpose of this report is to provide a description of how signal processing options such as window type, duration, and sampling rate affect power spectrum estimates. Power spectrum estimates for periodic RF signals and random processes (stationary and cyclostationary) are analyzed. The results presented can be used to select signal processing parameters and window types that minimize errors and uncertainties."*

Dalkie also states his conclusions as follows *"In this report, we have described how the application of a window in conjunction with the DFT to periodic radio signals and radio noise affect power spectrum estimates. The results are used to describe how window characteristics and related signal processing parameters affect measurement errors and uncertainties.*

In the case of periodic radio signals, we show that there are errors due to spectral leakage and window scalloping. These errors depend on the window type and related signal processing parameters. In particular, error bounds for various windows are presented. In all cases, the leakage error can be reduced by increasing the number of signal periods in the window (i.e., the window duration). By far, the leakage error decreases most rapidly (as a function of the window duration) for the Gaussian window. The scalloping error is independent of window duration and is smallest for the flat top window.

In the case of stationary noise, we describe how the window and related signal processing parameters affect both the estimated power spectral density and the total power in the measurement bandwidth. It is shown that the window should be selected so that the noise power spectral density is essentially constant over the bandwidth of the window. Also, the window duration should be long enough so that the noise power spectrum is adequately sampled.

Cyclostationary random processes were also considered. In this case, we examined estimates of the time average of the power spectrum. It was found that in addition to the considerations described for stationary processes, the window bandwidth should be less than (one-half) the repetition rate of the covariance function."

Taking note of all the above, then consequently in real engineered systems, at the initial signal acquisition stage, especially as we journey towards deploying DSA Spectrum Sensing technology for sharing spectrum, the technical measurement problems posed by Dalkie's window technique solution become apparent for both devices and instruments.

Note: any (implied) assumptions about clock recovery and synchronisation techniques made at this initial signal identification stage are irrelevant, especially for a coexistence environment, where there are multiple independent emitters present in a Radio Frequency environment.

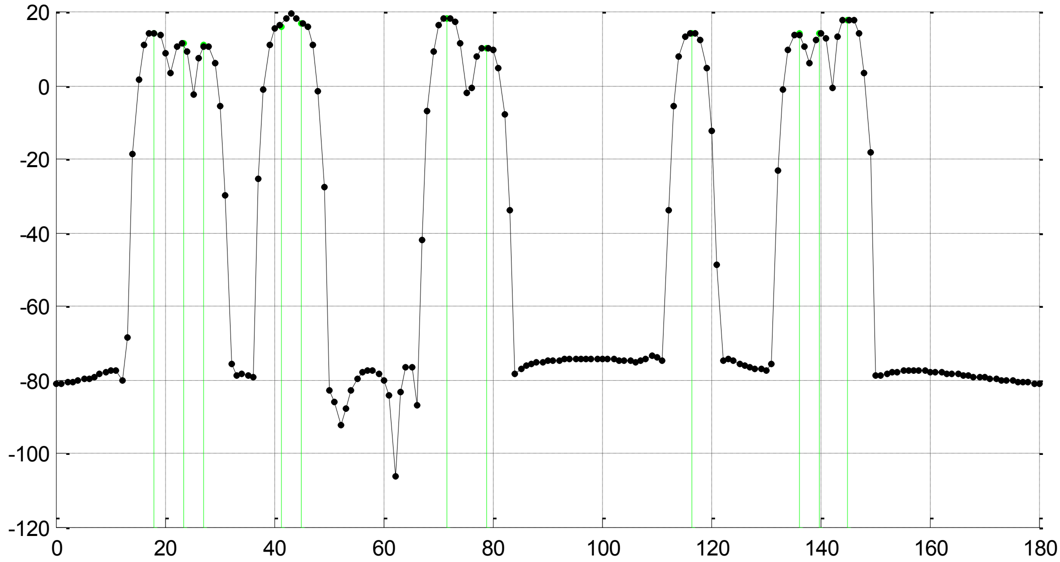
Fundamentally, Dalkie's work neglects the fractional signal aspect as described in the Datod article but Dalkie correctly concludes that for the application he is seeking to address for DSA Spectrum Sensing that the Flat Top Window is currently the State of the Art for Spectrum Estimation open to the NTIA.

A future Datod article, to be published in Electronics World, shall critique fully Dalkie's NTIA approach and outline the technical limitations and the consequences of adopting such an approach. The article is entitled:
Fourier Analysis : The State of the Art of US Spectrum Sensing Capability?

4) Datod Benchmark Test Signal :

In Figure 1 we apply Dalkie's Flat Top Window and the FFT to a standard Datod Benchmark Test Signal, cited in the article, composed of eleven fractional frequency parameters specified to two decimal places.

Figure 1 : Datod Test Signal with Flat Top Window Applied



This figure is derived from 1000 half-interval samples of the Datod Test Signal. The green lines indicate the location of the actual underlying signal frequencies.

An appreciation of the difficulty of attaining accurate parameter estimates via the DFT/FFT and Windowing approach becomes apparent from a study of this Datod Benchmark Test Signal.

An alternative analysis with the Gaussian window exhibits similar Spectrum Estimation limitations.

Observe that only the eighth spectral component at 116.35 Cycles per Observation Interval is clearly individually discernable.

Note that the application of Dalkie's Flat Top window has infact broadened this recovered spectral component at the attenuated response levels by the frequency margins detailed in Table 1. These are estimated to be the values below the eighth spectral peak component value attained:

response	*Frequency*
-20 dB	**3.3404**
-40 dB	**4.1297**
-60 dB	**4.5976**
-80 dB	**4.8651**
-100 dB	**4.9750**

Table 1

However these values are actually single sided response estimations and are thus required to be doubled in practice for use in engineered systems.

Observe also in Figure 1 that when the fourth and fifth spectral components run into each other they give a single erroneous central positioned spectral peak which is above the actual amplitudes of these two spectral components.

The really serious point to address here is the waste of a precious asset called Spectrum and recognising and accepting that windowing is a work-a-round procedure developed by engineers to overcome a specific problem with the Applied Mathematics that has still to be fundamentally addressed in the Art of Signal Processing for Fourier Analysis.

Now give consideration to what happens when interfering signals are present and how you identify wanted from unwanted spectral components, dominant, sub-dominant or otherwise dynamic range constraints at this initial Spectrum Sensing analysis stage. This problem is at the heart of what DSA technology seeks to both address and overcome.

The Datod EFTrunc Algorithm cited in the Electronics World article can accurately identify each of these eleven spectral components, to two decimal places in respect of frequency, amplitude and phase without recourse to windowing or filtering by the application of differencing techniques for evaluating a Radio Frequency environment and especially for determining which frequencies are available for use on a non-interference basis.

As for current 3G and 4G technologies how have they been engineered to address spectral efficiency and operation in this type of spectrum environment for tackling the coexistence problem?

So, the question arises as too exactly how much spectrum do they actually waste?

Concluding Remarks:

The NTIA should be seeking to explore DSA Technology, which is still in its infancy, to a higher standard than that which is commercially available with the current generation of Vector Signal Analysers and especially their Joint Time Frequency Spectrogram estimation techniques for accurate signal crossover tracking, alignment, detection and recovery in order to gain a fuller appreciation of the technical limitations and true potential of DSA technology for Spectrum Sharing.

The issues at stake are the NTIA's technical excellence and technical leadership in this field.

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