Application Note

74-0046-160517

Understanding and Calculating Probability of Intercept

This application note explains the Probability of Intercept (POI) pertaining to a radio-frequency (RF) signal analyzer, including the context of product export controls. It further explains the BNC RTSA7550 wireless signal analyzer's mechanism for triggering and capturing a signal in real-time, and calculates the signal durations corresponding to a 0% POI and 100% POI.

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Understanding Probability of Intercept

In the context of a wireless RF signal analyzer, the Probability of Intercept (POI) represents the amount of time that a signal needs to be present, such that there is a probability that the signal will be intercepted and adequately captured for the purposes of analysis. At a minimum, the captured and analyzed data must be continuous and gap-free for there to be a 100% probability of intercept, otherwise the signal of interest would be missed if it occurred within a gap.

For reference, the "*Guide to Canada's Export Controls – December 2013*" provides the following definition. "*Probability of discovery is also referred to as probability of intercept or probability of capture. The duration for 100% probability of discovery is equivalent to the minimum signal duration necessary for the specified level measurement uncertainty.*"

Keysight's 5991-4317EN application note "*Understanding and Applying Probability of Intercept in Real-time Spectrum Analysis*" provides further clarification in the following excerpt "*In the specifications for a signal analyzer, POI is often expressed as the minimum duration of a signal that can be observed with 100 percent probability—and accurately measured—if that signal is a specific amount above the instrument's noise floor.*"

Wireless RF signal and spectrum analyzers typically support multiple and different means of capturing a signal, which in turn may impact the calculation and/or interpretation of POI. The BNC RTSA7550 supports three different means of capturing signals which are pertinent to POI, those being: streaming, store-and-forward, and triggering. With streaming, captured data is continuously streamed from the RTSA7550 to the host computer and that stream must be gap-free to support 100% POI. Typically, the network connection defines the upper limit of signal bandwidth that can be streamed gap-free. Using store-and-forward, data is captured gap-free to local memory for subsequent download to a host computer and post analysis. The RTSA7550 supports up to 32 MSa of storage and 100% POI can be achieved to the extent of the resolution bandwidth but only for the duration of the 32 MSa.

The remainder of this application note considers POI when using triggering with the RTSA7550.

The RTSA7550's Trigger Mechanism

The RTSA7550's digitizer has an embedded real-time hardware trigger mechanism that provides user-defined frequency-domain level triggering capability. The trigger mechanism enables the user's definition of frequency range and power spectrum level threshold. If a signal exceeds the user-defined power level within the user-defined frequency range, then the trigger mechanism begins storing the time-domain data to memory.

Referring to the RTSA7550's digitizer architecture in Figure 1, when a signal of interest occurs, a sequence of events takes place. The digitized time-domain signal from the analog-to-digital converter (ADC) is transformed to frequency-domain using a 1024-point FFT engine embedded within the RTSA7550's FPGA. The capture control and trigger mechanism compare the FFT output data with the user-defined triggering conditions (frequency range/threshold). A trigger event occurs. Data is captured. Since no memory is involved in this process, the time spent during this sequence of events until the data is offloaded to the host processor, results in discontinuities (gaps) in captured signal.

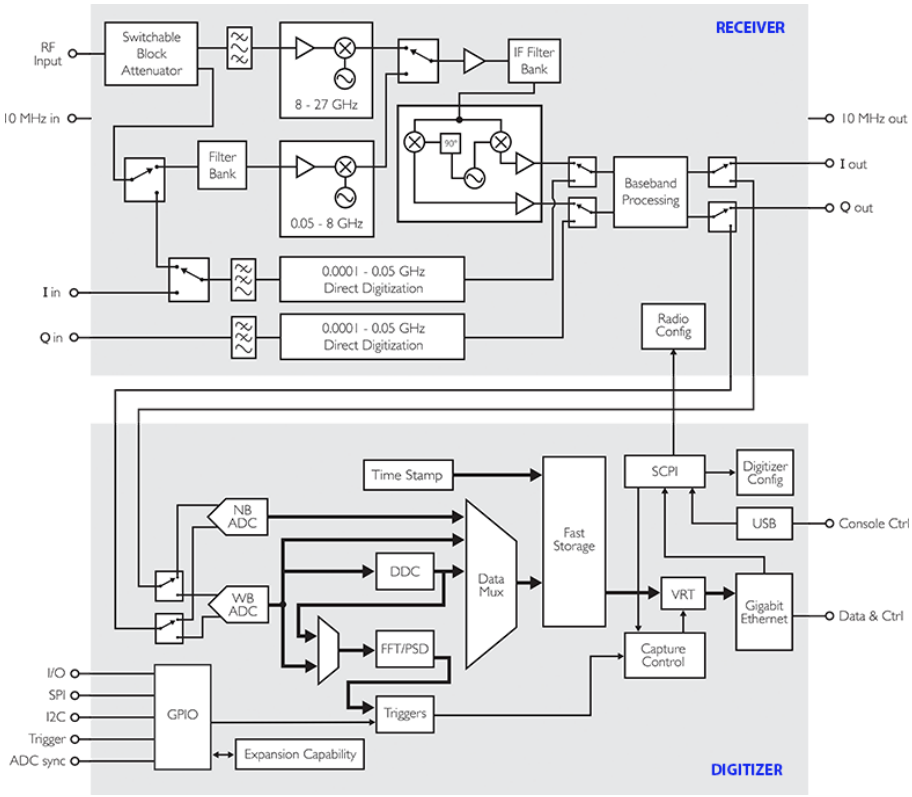

Figure 1: RTSA7550 Receiver and Digitizer Architecture

Calculating 0% and 100% POI

A POI represents the signal duration such that there is a probability that the signal will be intercepted. For the purposes of this application note, this signal duration will be calculated for both 100% POI and 0% POI, where a 0% POI represents the maximum signal duration such that there is no probability of signal capture, intercept, and triggering.

The FFT engine takes sequential frames of time-domain data and transforms that data to sequential data FFT-frames in frequency-domain. The FFT engine is clocked at the rate of the 125 MHz (equivalent to ~8 ns sample-clock period). The time-domain input data and frequency-domain output data are pipelined and tightly coupled by a fixed latency associated with the FFT processing time.

The FFT engine has a subtle nuance in that the FFT-frame emerges from the engine in the sequence of points 512-1023 followed by points 0-511. The illustration in Figure 2 shows the frame emerging in the sequence of points 0-1023 for the sake of simplification.

Referencing the RTSA7550 trigger mechanism timeline in Figure 2:

- F represents the FFT engine latency, which is the total number of sample clocks corresponding to the time spent in FFT engine from the instant the time-domain data is input to the engine to the instant the frequency-domain data frame is output from the and equals 3187 sample-clocks.
- S represents the amount of time the signal shall be present within the time-domain frame (equivalent to 1024 sample clocks) to ensure enough signal energy in the corresponding FFT-frame to cause a trigger. In this context, three example situations can be highlighted.

- If the signal is present for zero clocks within the time-domain frame (i.e. S = 0), then there will be no signal present in the corresponding FFT-frame to cause a trigger and hence the POI is 0%.
- Likewise, if the signal is present for all 1024 clocks within the time-domain frame (i.e. S = 1024), then there will be full signal energy present in the corresponding FFT-frame ensuring the occurrence of a triggering event. This means that S > 0 is a necessary but not sufficient condition for a 100% POI.
- It's worth noting that, for a fixed signal energy, the less the value of S, the lower the power spectrum is. This means that the worst case scenario, where the signal is only present for one sample out of 1024, leads to a power spectrum level reduction of approximately 30dB. Accordingly, the user shall take care when setting the triggering conditions.

- T represents the number of sample clocks corresponding to the number of bins from the beginning of the FFT-frame to the bin position at which the trigger occurs assuming the signal of interest satisfies the user-defined triggering conditions (frequency range and threshold).
  - The value of T is conditional on both the user-defined triggering conditions and on the characteristics of the signal of interest.
  - T may be any value from 0 to 1024 sample-clocks. If the trigger does not occur at any bin of the FFT frame (i.e. T=0), then the POI is 0%. Likewise, the trigger must occur at the last bin of the FFT frame (T=1024) to satisfy 100% POI.
- There are additional 6 sample clocks of latency in the triggering logic and another 1 sample clock of latency to begin data capture.
- C represents the minimum amount of time-domain signal samples captured after the trigger to provide adequate signal analysis. There must be at least one sample in order to satisfy 100% POI and hence C must be greater than one sample-clock.

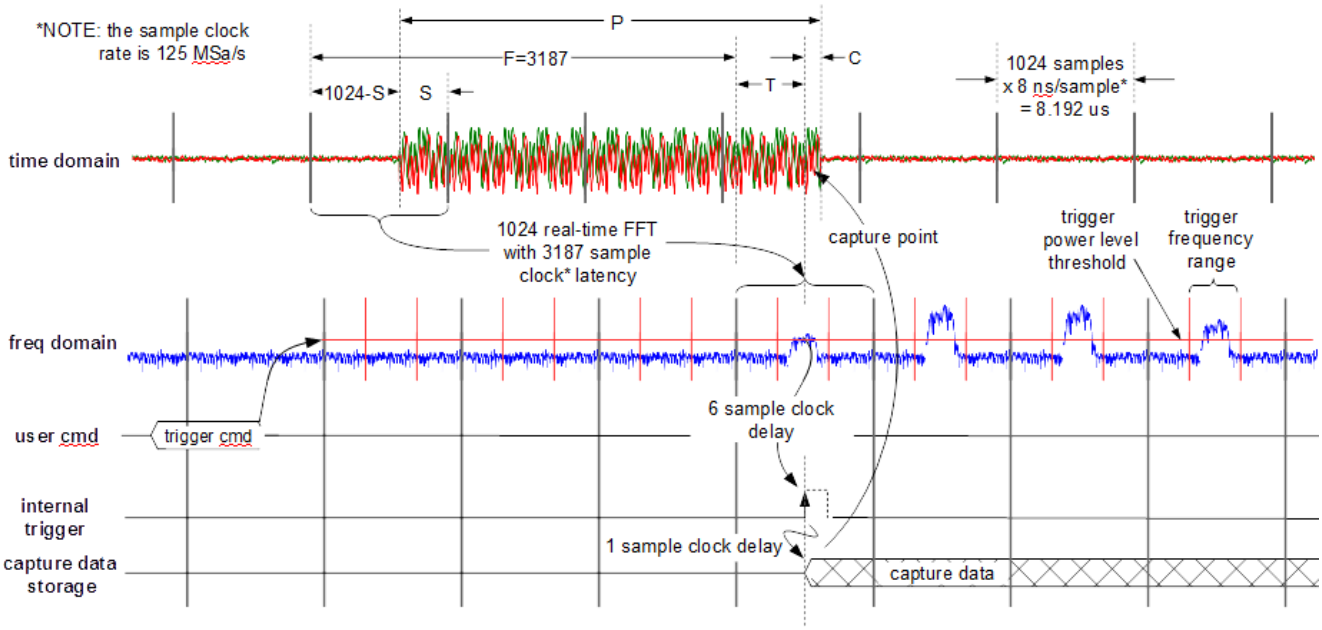

Figure 2: RTSA7550 Trigger Mechanism Timeline

Based on the aforementioned explanations, the signal duration, P, corresponding to a certain POI can be formulated as follows:

$$P = \frac{1}{R}(F - (1024 - S) + T + 6 + 1 + C)$$

Therefore, a 0% POI occurs if S=0, T=0, and C=0, and 100% POI occurs when S>0, T=1024, and C>0. Substituting F=3187 samples and the clock rate R =125 MHz gives:

$$P <= 17.360\ \mu s \text{ for } 0\% \text{ POI}$$

$$P > 25.552\ \mu s \text{ for } 100\% \text{ POI}$$

The remainder of this application note considers POI when using triggering with the RTSA7550.

Conclusion

The RTSA7550 has 0% POI if a signal's duration is less than 17.360 µs. Hence, any signal that is not present for at least 17.360 µs might initiate a trigger event but no portion of that signal will be captured to memory.

The RTSA7550 has 100% POI if a signal's duration is greater than 25.552 µs plus some duration for capture of that signal into memory. Hence, the signal will be guaranteed to initiate a trigger event and begin capturing that signal into memory.

Both of the 0% and 100% POI behaviors have been demonstrated experimentally. A pulsed signal with different durations was injected from a signal generator to the RTSA7550. Signals of duration less than 17.360 µs were never captured to memory and those of duration greater than 25.552 µs were always captured to memory. Any signals of duration between these values were demonstrated to be intermittently captured to memory.

These specifications are preliminary, non-warranted, and subject to change without notice.