Application Note

74-0046-180605

Understanding Frequency-domain Level Trigger and Calculating Probability of Intercept

This application note explains the Probability of Intercept (POI) pertaining to a radio-frequency (RF) signal analyser, including in the context of product export controls. It further explains the ThinkRF Real-Time Spectrum Analyser's mechanism for frequency-domain level 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 analyser, 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.

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."*

Frequency-domain Level Trigger Mechanism

ThinkRF RTSA's digitizer has an embedded real-time hardware trigger mechanism that provides for user-defined frequency-domain level triggering. The triggering mechanism enables the user's definition of frequency range and power level threshold in the frequency-domain. 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.

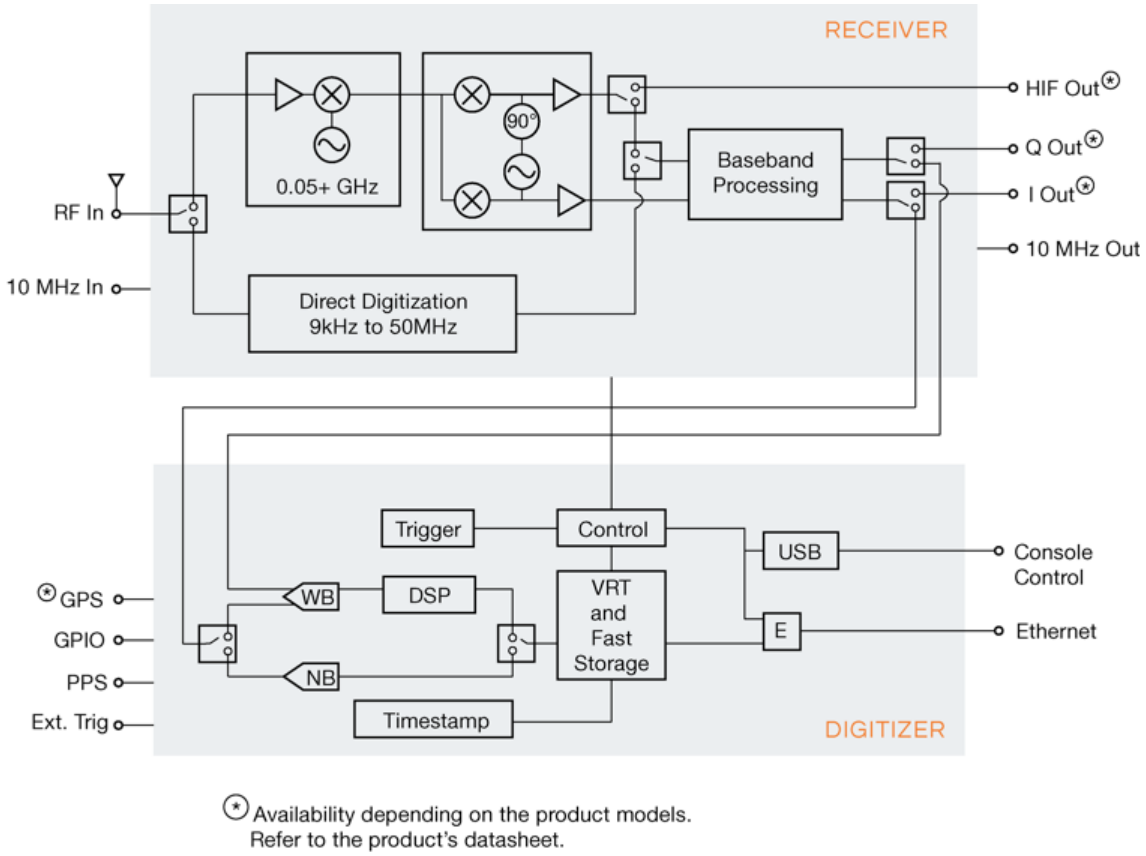

Figure 1: ThinkRF RTSA's Receiver and Digitizer Architecture

Referring to the RTSA's digitizer architecture in Figure 1, when a signal of interest occurs, a sequence of events take place. The digitized time-domain signal from the wibeband (WB) analog-to-digital converter (ADC) is transformed to frequency-domain using a 1024-point FFT engine embedded within the RTSA's FPGA. The capture control and triggering mechanism compare the FFT output data with the user-defined triggering conditions (frequency range and threshold). A trigger event occurs, data is captured. Since no storage memory is involved in the time spent during this sequence of events, the data captured is thus of post-triggered nature.

Trigger Responsiveness

For a given trigger level, the trigger mechanism will response within ±3 dBm of that specified threshold. In other words, if the specified trigger level is -40 dBm for example, the trigger events would happen for signals occurred within a desired frequency range with power level within -43 to -37 dBm.

Table 1 shows the maximum and minimum trigger thresholds for different attenuation levels. The responsiveness of the trigger mechanism for trigger levels set outside these thresholds is saturated and, thus, might result in no or false trigger events. For best trigger performance, set the trigger level within these max and min thresholds.

Table 1: Max and Min Trigger Thresholds for Different Attenuation Levels

Attenuation (dB)	Max Threshold (dBm)		Min Threshold (dBm)
	SH	ZIF	
0	-25	-35	-25 above the noise floor
10	-15	-25	
20	-5	-15	
30	5	-5	

Trigger SCPI Commands

The frequency level trigger could be used with trace block capture or in conjunction with the sweep capture. To use with a trace capture, issue the following commands:

```
:TRIGger:LEVel <start>,<stop>,<level>
TRIGger:TYPE LEVEL
```

And to use with a sweep capture, issue these similar commands:

```
:SWEep:ENTRy:TRIGger:LEVel <start>,<stop>,<level>
:SWEep:ENTRy:TRIGger:TYPE LEVEL
```

See the *Programmer's Guide* of your RTSA product for more information.

Calculating 0% and 100% POI

Referencing the RTSA triggering mechanism waveforms in Figure 2:

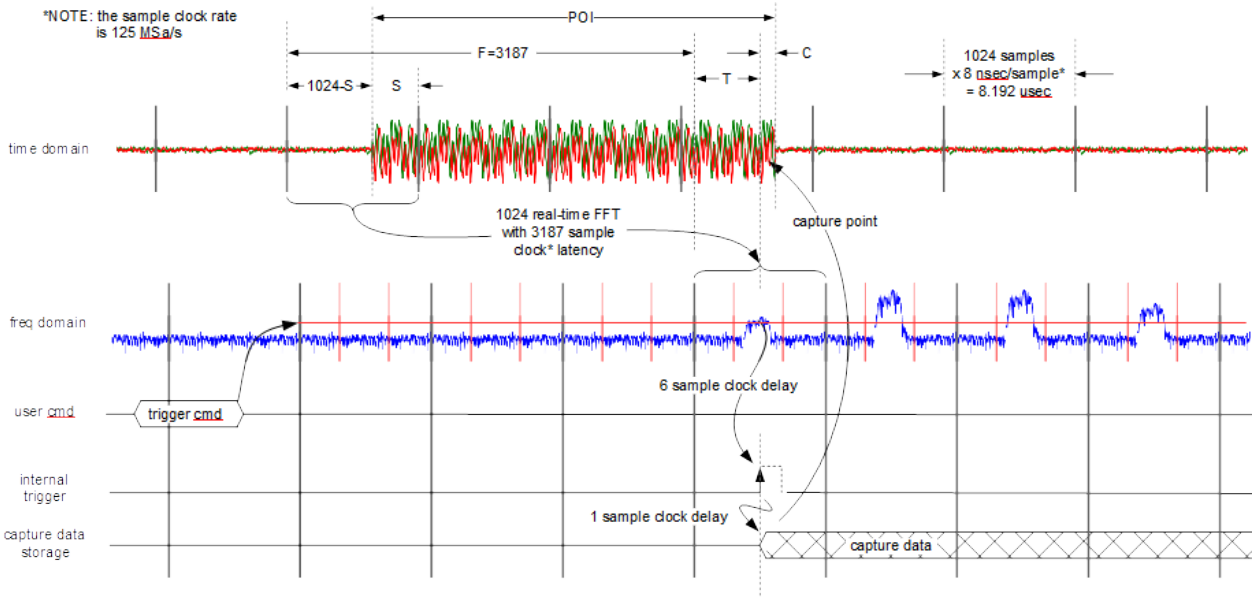

Figure 2: ThinkRF RTSA's Triggering Mechanism Waveforms

- *POI* represents the minimum signal duration such that there is a probability that the signal will be intercepted. In this app-note, this signal duration will be calculated for both 100% POI and 0% POI. For the purposes of this application note, 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 waveform data and transforms that data to sequential frames of frequency-domain waveform data. The FFT engine is clocked at the rate of the 125 MHz sample clock (8 nsec sample-clock period) and the time-domain input and frequency-domain output data are pipelined and tightly coupled by a fixed latency associated with the FFT processing time.
    - *F* represents FFT engine latency from start of the 1024 sample-clock time-domain FFT-frame to start of the 1024 sample-clock frequency-domain FFT-frame and equals a constant 3187 sample-clocks.
    - The FFT engine has a subtle nuance in that the frequency-domain FFT-frame emerges from the engine in the sequence of points 512-1023 followed by points 0-511. The illustration shows the frame emerging in the sequence of points 0-1023 for the sake of simplification only.
- *S* represents the minimum amount of signal present within the time-domain FFT-frame ensure enough corresponding signal energy in the frequency-domain 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 then there will be no signal present in the frequency-domain FFT-frame and hence $S=0$ is a requirement for 0% POI.

- Likewise, if the signal is present for all 1024 clocks within the time-domain frame then there will be full signal energy present in the frequency-domain FFT-frame and there is 100% POI.
- Finally, if the signal is present for only some portion of the 1024 sample-clocks of the time-domain FFT-frame then there will be some equivalent amount of signal energy present in the frequency-domain FFT-frame. For the purposes of calculating 100% POI, it will be assumed that there is enough signal energy such that a single sample of the signal will transform into a frequency-domain waveform sufficient to exceed the trigger amplitude threshold. Hence it is assumed that S=1 is sufficient as a requirement for 100% POI. It's noted that if the signal was indeed only present for one sample out of 1024 in the time-domain FFT frame then the resulting waveform transformed to the frequency-domain will be attenuated approximately 30dB.

- T represents the position (frequency) within the frequency-domain FFT-frame (otherwise referred to as the bin within the FFT-frame) at which the trigger occurs assuming the signal of interest satisfies the user-defined triggering conditions (frequency range and power threshold).
  - The value of T is conditional on the user-defined triggering conditions and conditional on the shape of the signal.
  - T may be any value from 0 to 1024 sample-clocks. The trigger must occur at the first bin of the FFT frequency-domain frame (T=0) to satisfy 0% POI. Likewise, the trigger must occur at the last bin of the FFT frequency-domain frame (T=1023) to satisfy 100% POI.
  - There is an additional 6 sample clocks of latency in the triggering logic and another 1 clock of latency to begin data capture.
- C represents the minimum amount of time-domain signal samples capture 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.

Based on the aforementioned variables' definitions and explanations and referring to the timing chart in Figure 2, the signal duration, P, corresponding to a certain POI can be formulated as follows.

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

Based on the previous definitions, a 0% POI occurs if S=0, T=0, and C=0, and 100% POI occurs when S=1, T=1023, and C>0. Substituting F=3187 samples and the sampling rate Rs=125 MSps in (1) gives

POI = (3187 – (1024 – 0) + 0 + 6 + 1 + 0) / 125 0% POI

POI = 17.360 us

POI = (3187 – (1024 – 1) + 1023 + 6 + 1 + C) / 125 100% POI

POI > 25.552 us

Conclusion

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

The RTSA has 100% POI if a signal's duration is greater than 25.552 us 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 behaviours have been demonstrated in test. A signal pulse of fixed duration was generated by a signal generator and repeatedly input to the RTSA. Signals of duration less than 17.360 were never captured to memory and those of duration greater than 25.552 us were always captured to memory. Any signals of duration between these thresholds were demonstrated to intermittently captured to memory, the reliability of capture varying directly with the signals duration.

Document Revision History

This section summarizes document revision history.

Document Version	Release Date	Revisions and Notes
v1.0	Aug 15 2017	First release
v1.1	June 05 2018	Updated Figure 1
v1.3	July 25, 2018	Added Trigger Responsiveness and Trigger SCPI Commands section

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