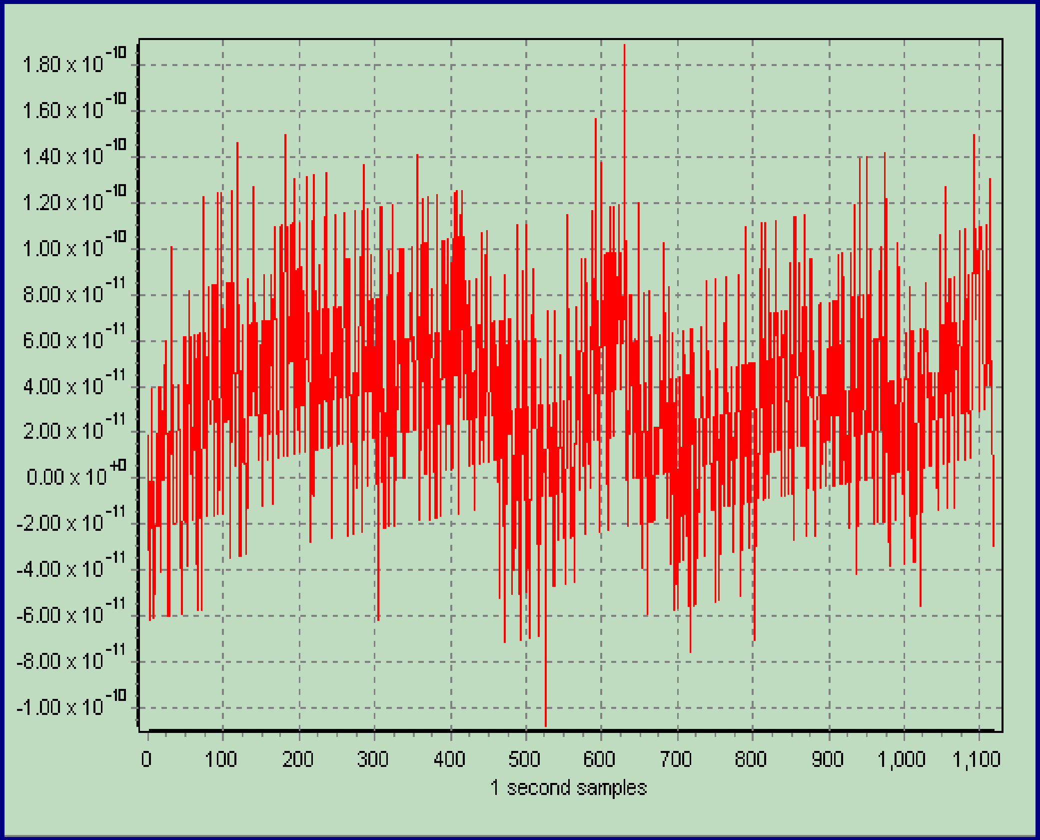

Oscillator Frequency Performance Measurements

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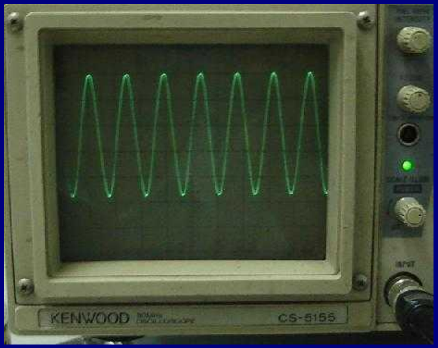
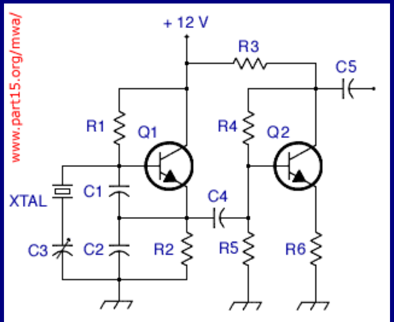
http://ve2zaz.net

THIS PRESENTATION



- Oscillator Performance Definitions
- Frequency Offset Measurement Methods
- Anatomy of:
  - Frequency Counter
  - Time Interval Analyzer
- Types of Crystal Oscillators
- Concept of Stability
- Stability Measurement (Short, Long term)
  - Practical Setups
  - Results
- Web References

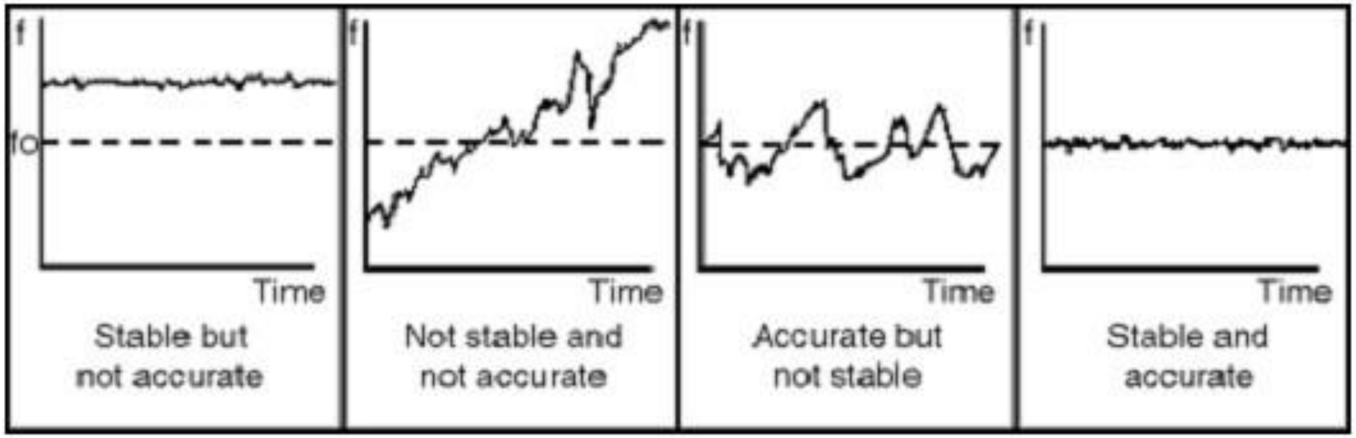


Oscillator Performance Definitions

- Very Short Term Variations
  - Occur within a second or less. They usually manifests themselves as frequency (or phase) modulation (or amplitude modulation), and they are usually measured in the frequency domain using spectrum analyzers or phase noise meters.
- Short Term Variations
  - Occur between one second and several minutes to an hour. Usually we consider short term variations to include the effects of temperature variation, but to exclude the effects of aging for instance.
- Long Term Variations
  - Go from minutes to hours or days, sometimes months or more. Aging is the prime cause.

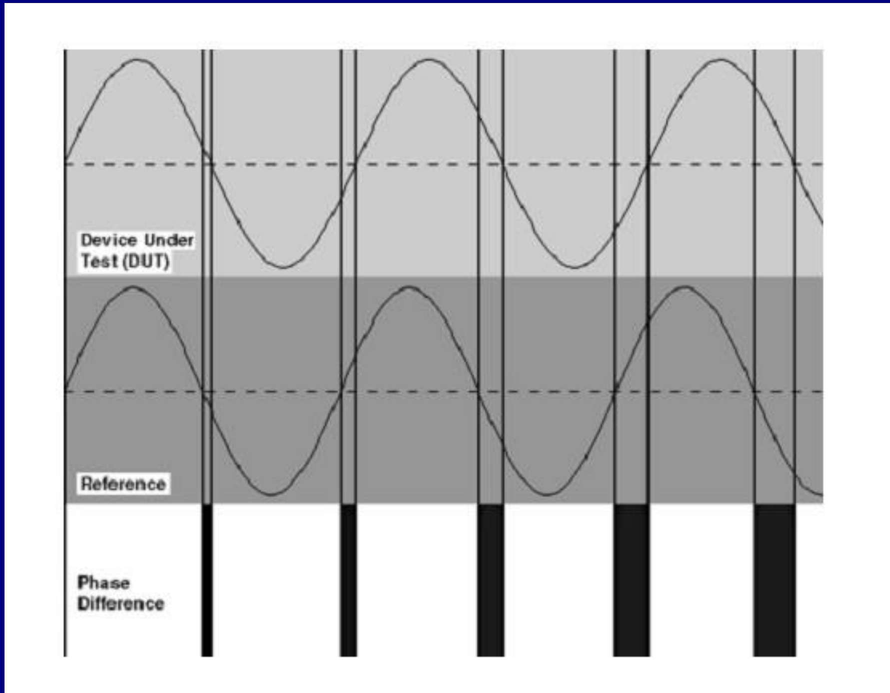
Oscillator Performance Definitions

- Stability
  - indicates how well an oscillator can produce the same time or frequency **<u>offset</u>** over a given time interval.
- Accuracy
  - is the degree of conformity of a measured or calculated value to its definition. Accuracy is related to the offset from an ideal value.

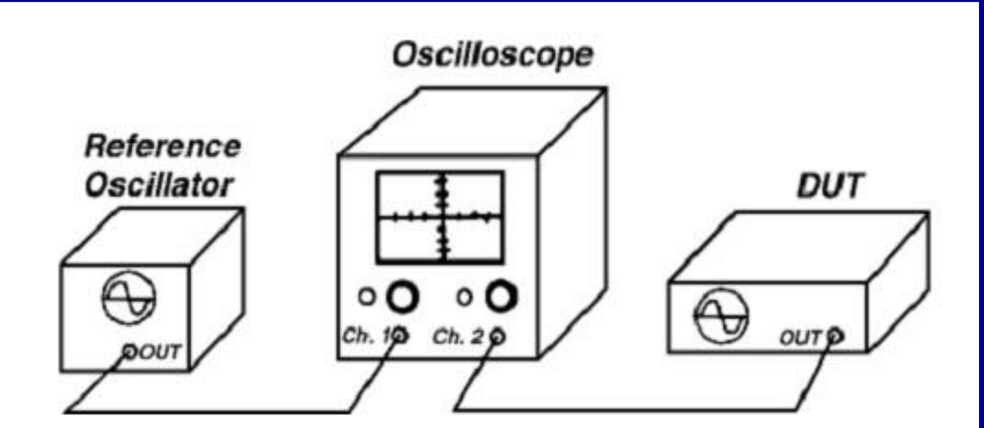


The relationship between accuracy and stability.

Frequency Offset: Oscilloscope Method



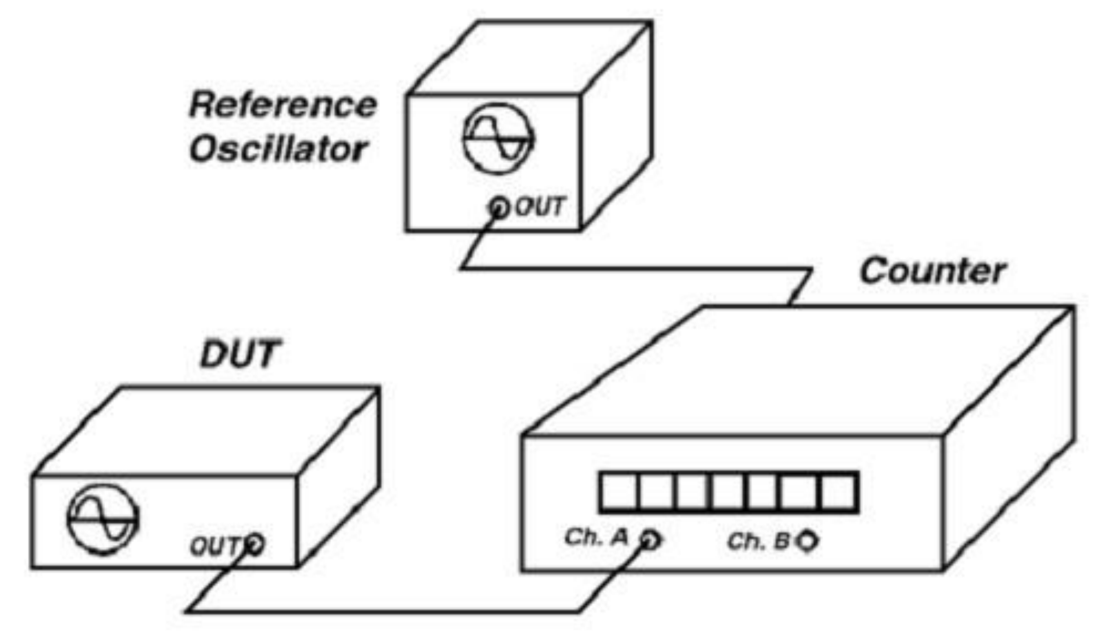
Two sine waves with a changing phase relationship.



Phase comparison using an oscilloscope.

$$f(\text{offset}) = \frac{-\Delta t}{T}$$

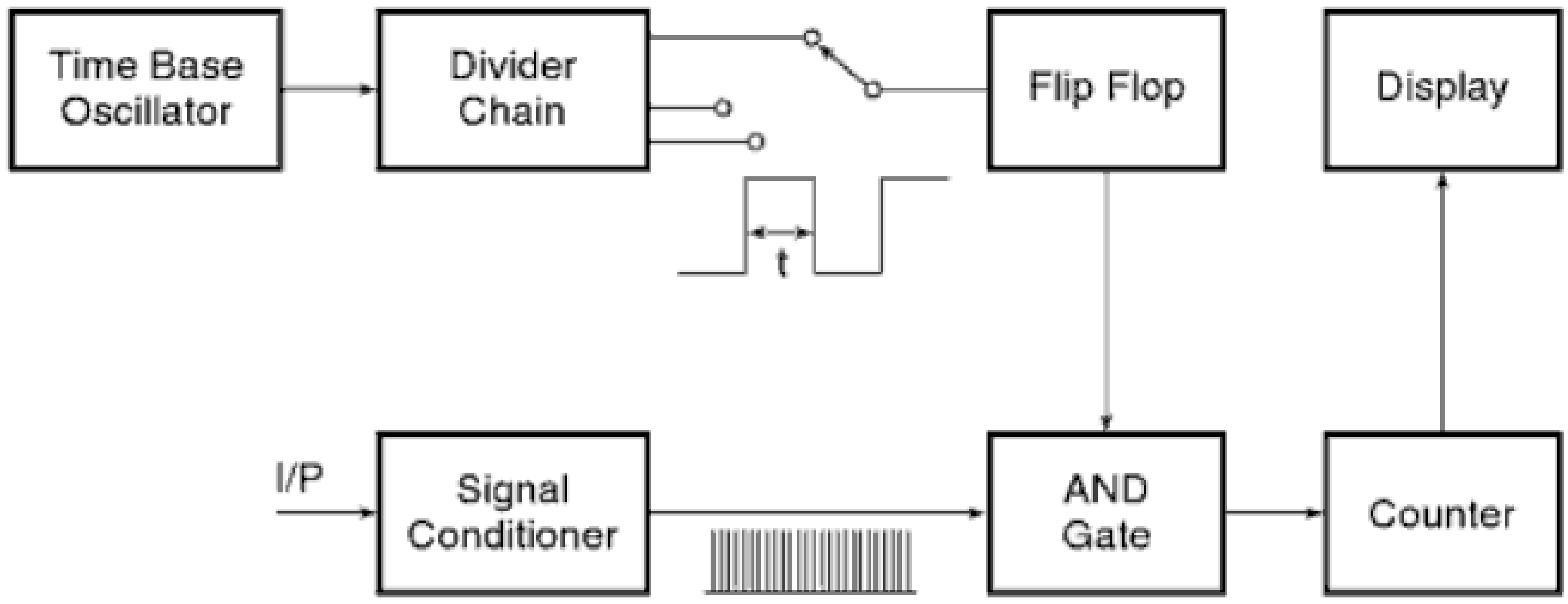
Frequency Offset: Frequency Counter Method

- 

Measurement using a frequency counter.

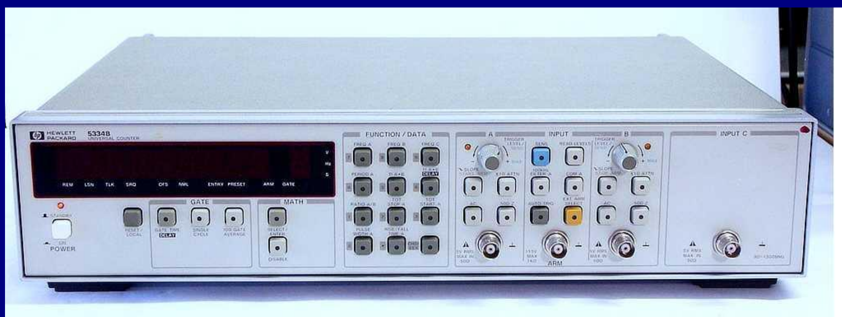
$$f(\text{offset}) = \frac{f_{\text{measured}} - f_{\text{nominal}}}{f_{\text{nominal}}}$$

Anatomy of Basic Frequency Counter



Counter architecture.

Some Suitable Frequency Counters



HP 5334A / B

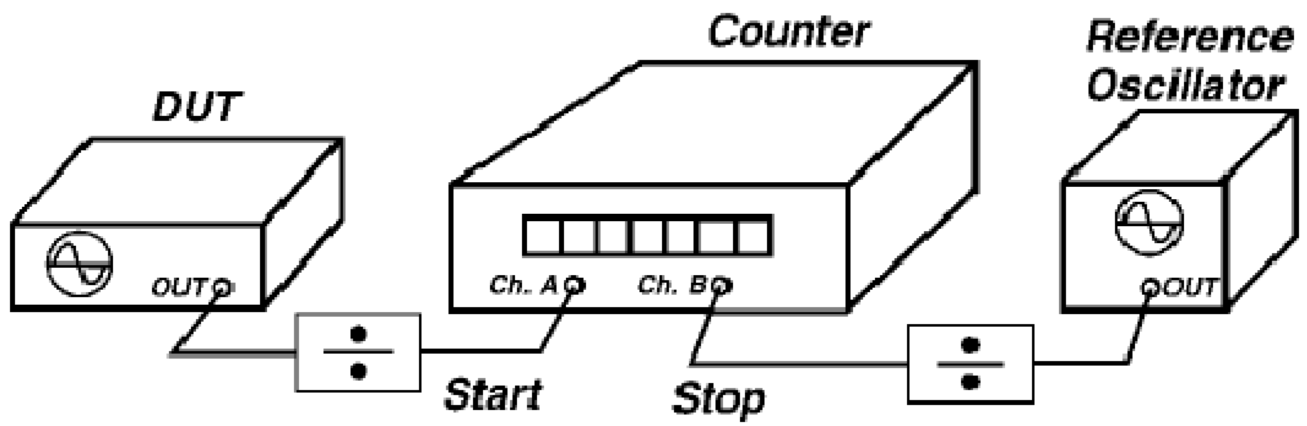
HP 5386A

HP 53131A / 53132A

HP 5335A / B

HP 5345A

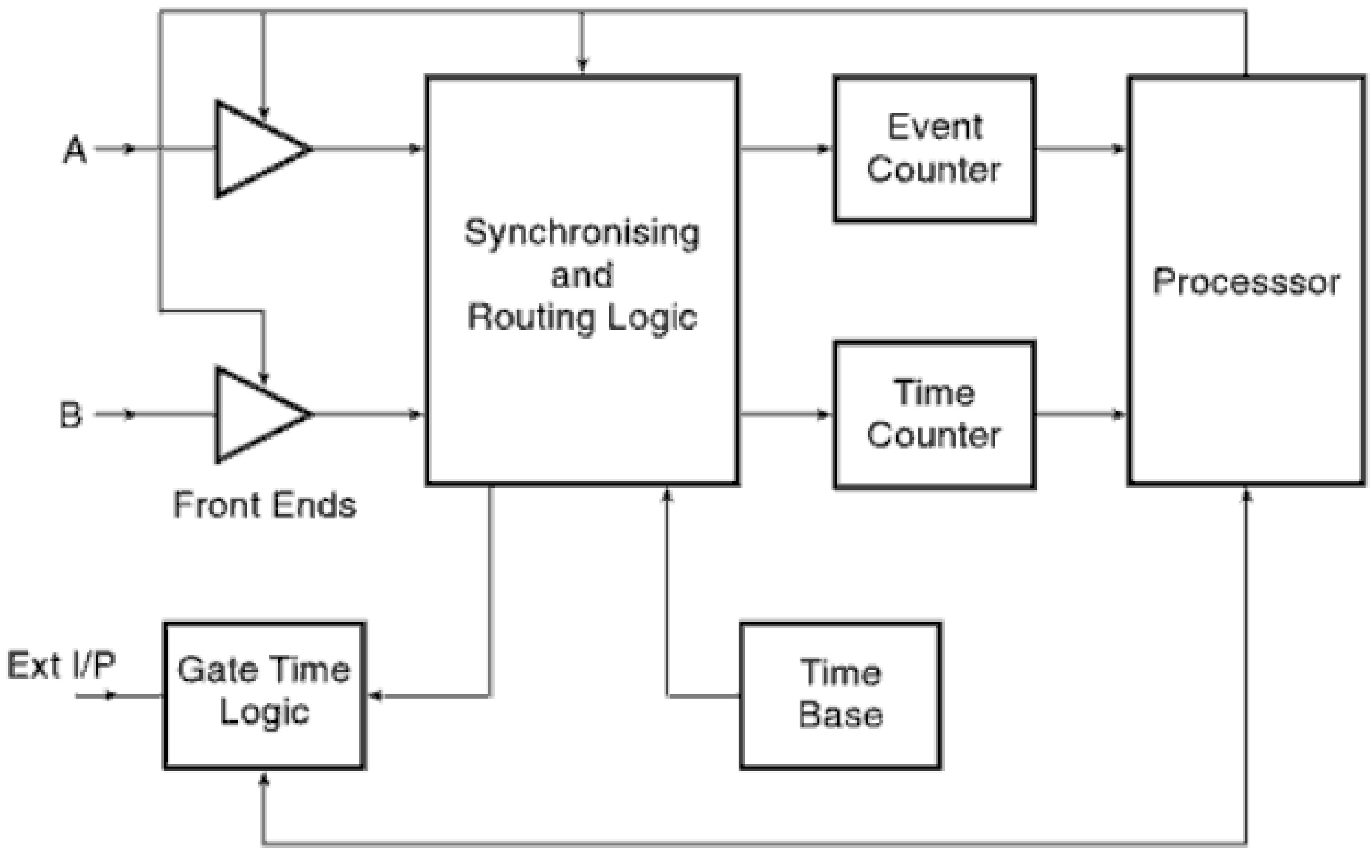
Frequency Offset: Time Interval Counter Method



Measurement using a time interval counter.

$$f(\text{offset}) = \frac{-\Delta t}{T}$$

Anatomy of Time Interval Analyzer



Reciprocal counter architecture.

Some Suitable T.I. Counters / Analyzers

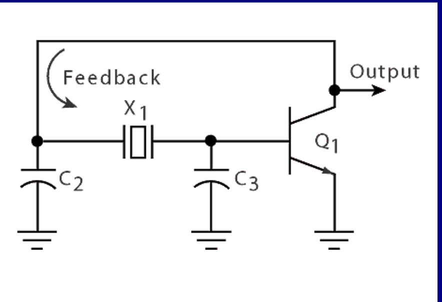
HP 5370A / B

HP 5371A / 5372A

Stanford Research SR620

Types of Crystal Oscillators

- Crystal Oscillator (XO)



10. This classic Pierce crystal oscillator includes feedback and output ports.

- Temperature Compensated XO

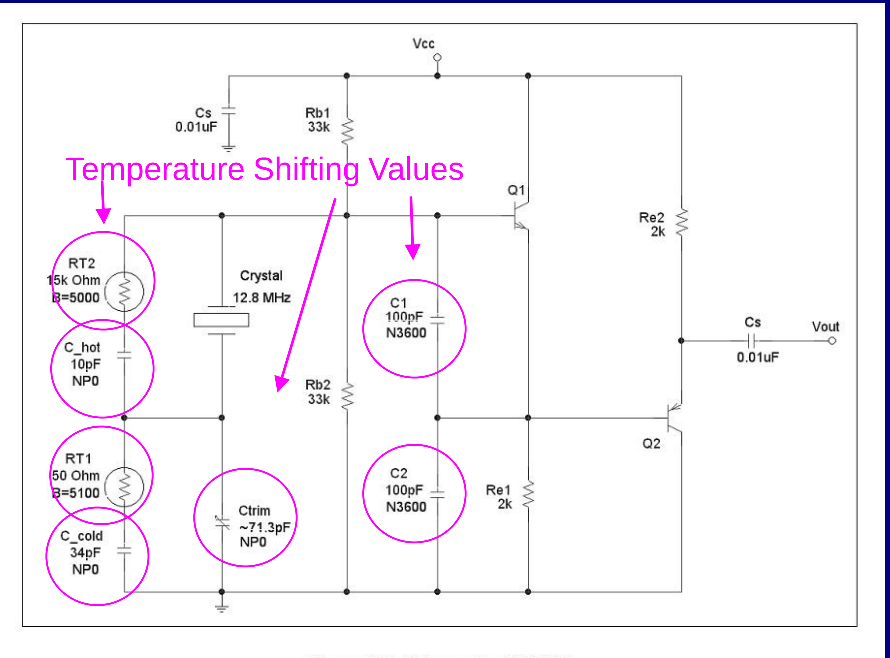
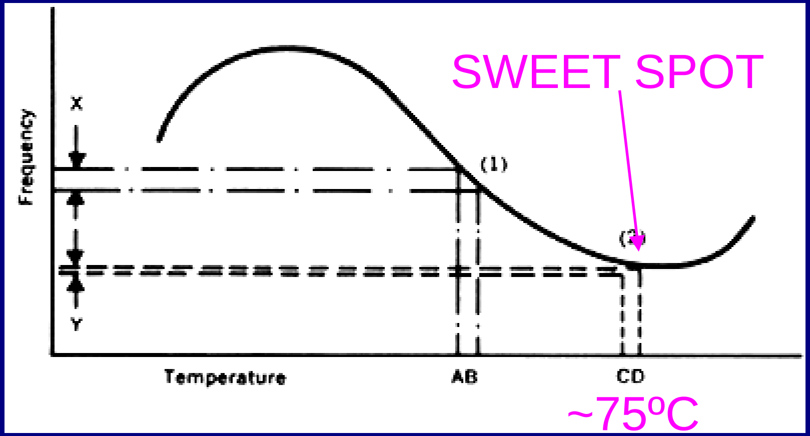
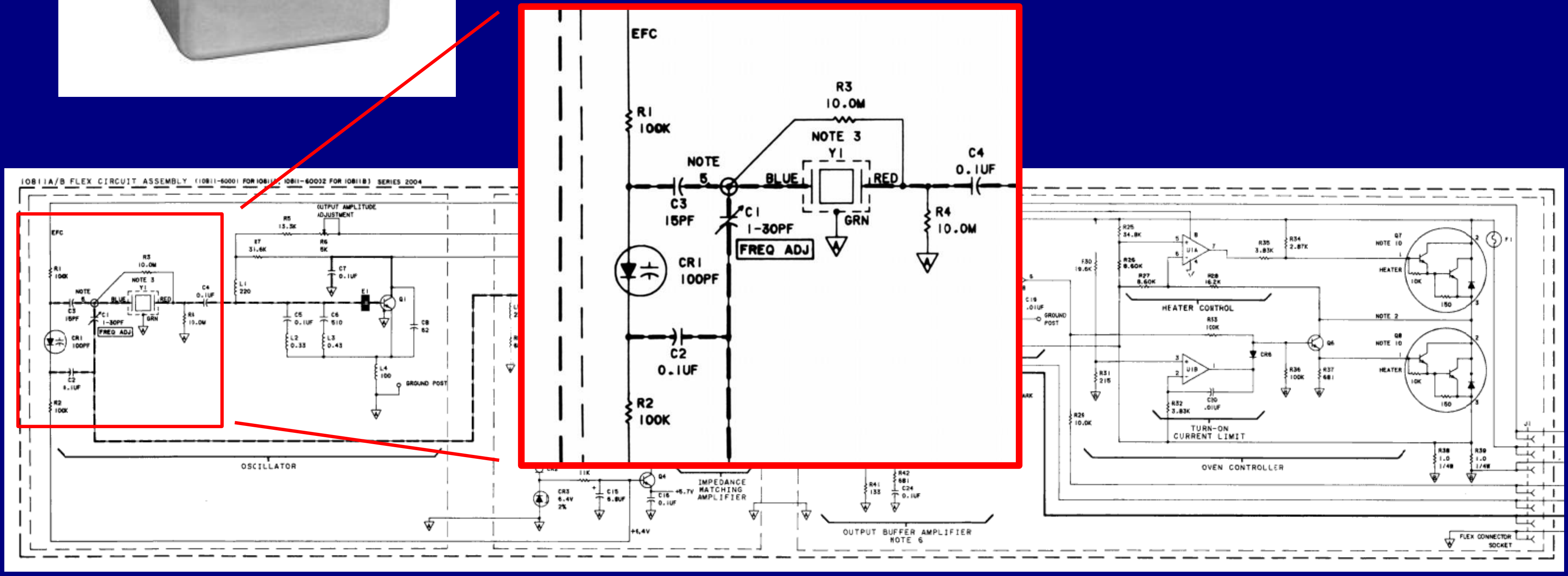


Figure 6.5: Schematic of TCXO

Types of Crystal Oscillators (Cont.)

- Oven-Controlled XO





Oscillator Comparison

	Quartz Oscillators			Atomic Oscillators		
	TCXO	MCXO	OCXO	Rubidium	RbXO	Cesium
Accuracy* (per year)	2×10^{-6}	6×10^{-8}	1×10^{-8}	5×10^{-10}	7×10^{-10}	2×10^{-11}
Aging/year	5×10^{-7}	2×10^{-8}	5×10^{-9}	2×10^{-10}	2×10^{-10}	0
Temp. Stab. (range, °C)	5×10^{-7} (-55 to +85)	3×10^{-8} (-55 to +85)	1×10^{-9} (-55 to +85)	3×10^{-10} (-55 to +68)	5×10^{-10} (-55 to +85)	2×10^{-11} (-28 to +65)
Stability, $s_y(t)$ (t=1s)	1×10^{-9}	3×10^{-10}	1×10^{-12}	3×10^{-12}	5×10^{-12}	5×10^{-11}
Size (cm^3)	10	50	20-200	800	1200	6000
Warmup time (min.)	0.1 (to 1×10^{-6})	0.1 (to 2×10^{-8})	4 (to 1×10^{-8})	3 (to 5×10^{-10})	3 (to 5×10^{-10})	20 (to 2×10^{-11})
Power (W) (at lowest temp.)	0.05	0.04	0.6	20	0.65	30
Price (~$)	100	1,000	2,000	8,000	10,000	40,000

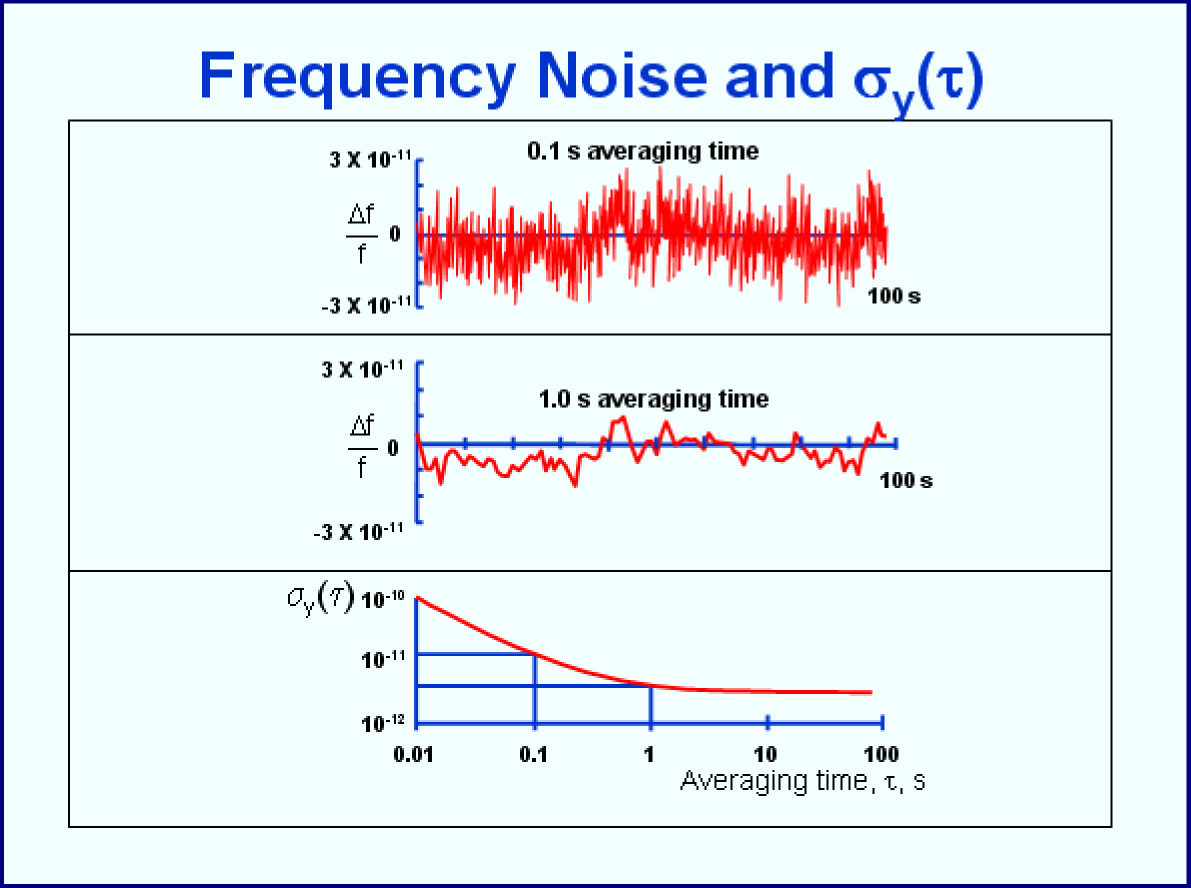
*Including environmental effects (note that the temperature ranges for Rb and Cs are narrower than for quartz).

Table 1. Comparison of frequency standards' salient characteristics.

Best of Both Worlds: GPS-Disciplined OCXO !

Illustration of Short Term Stability

- Depends on Integration (Averaging) Time



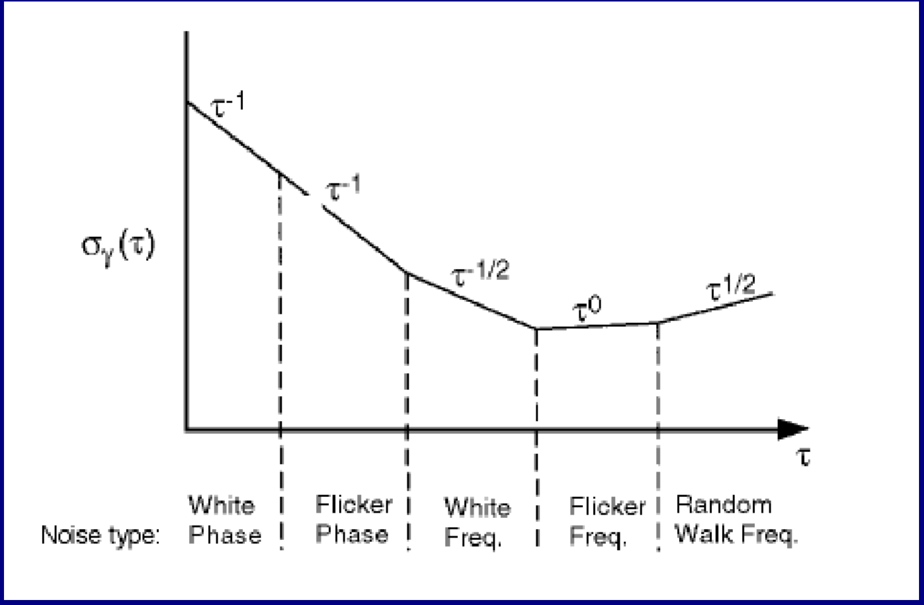
The Allan Deviation

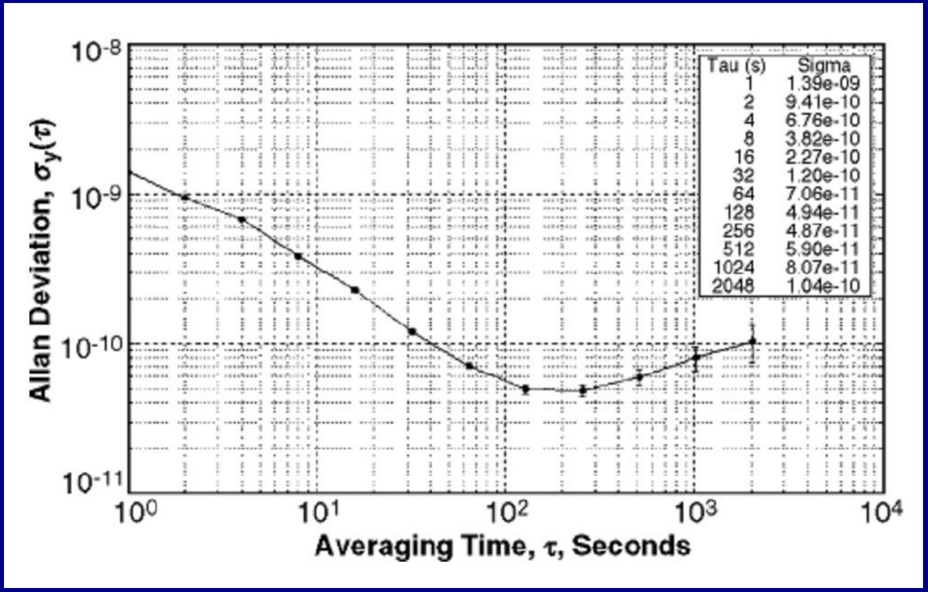
- Allan Deviation
  - A statistical tool that calculates how accurately you can predict the occurrence of the next pulse, transition or event, based on measurements made on previous pulses, transitions or events.
  - For instance, you may have an oscillator that drifts in a predictable way, and it's Allan Deviation would be good (low), or you may have an oscillator that has little drift on average, but wanders a lot around its nominal frequency (phase noise), and its Allan Deviation would be bad (high).

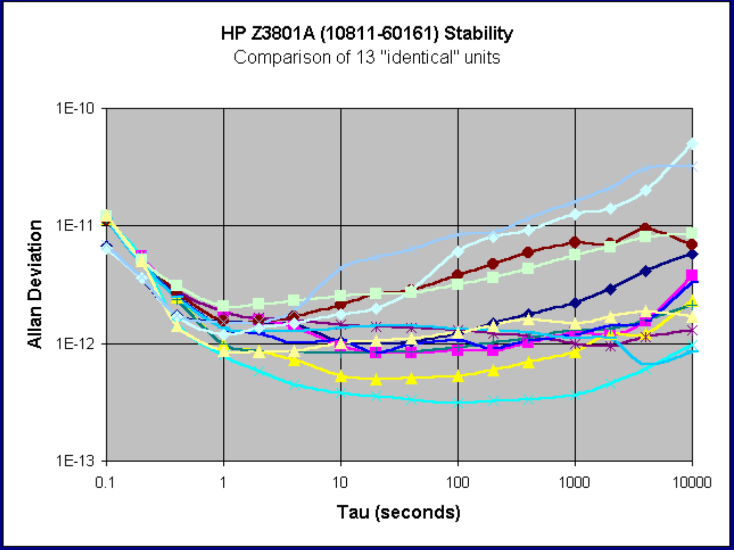
$$\sigma_y(\tau) = \sqrt{\frac{1}{2(M-1)}\sum_{i=1}^{M-1}(y_{i+1}-y_i)^2}$$

The Allan Deviation

- Typical Allan Deviation Curves

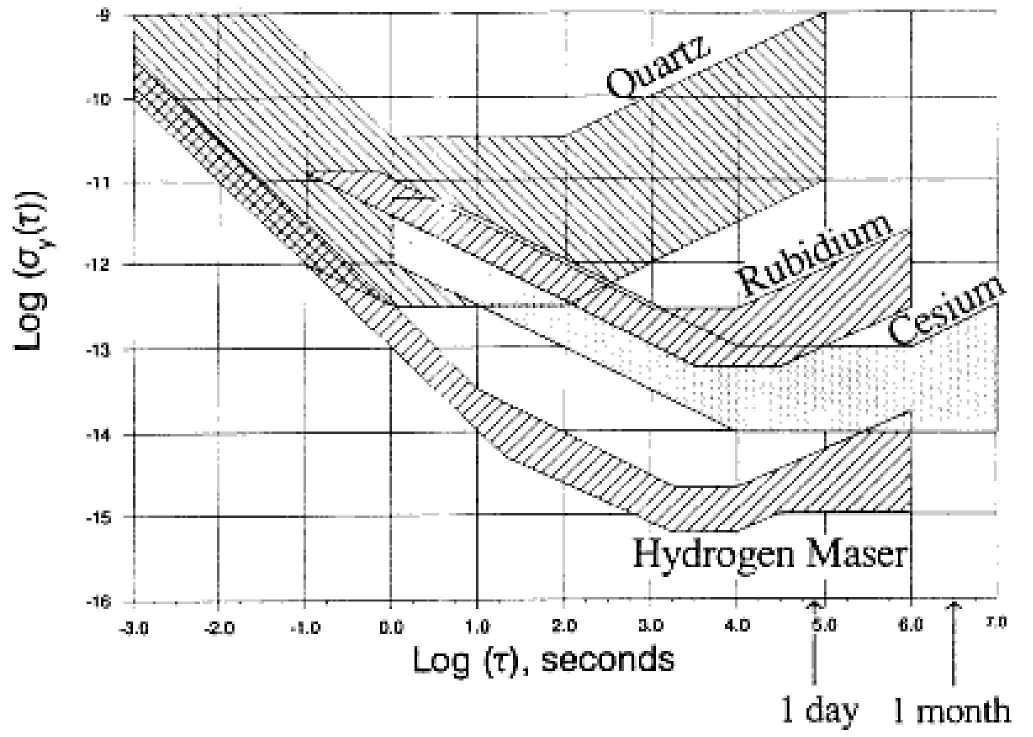




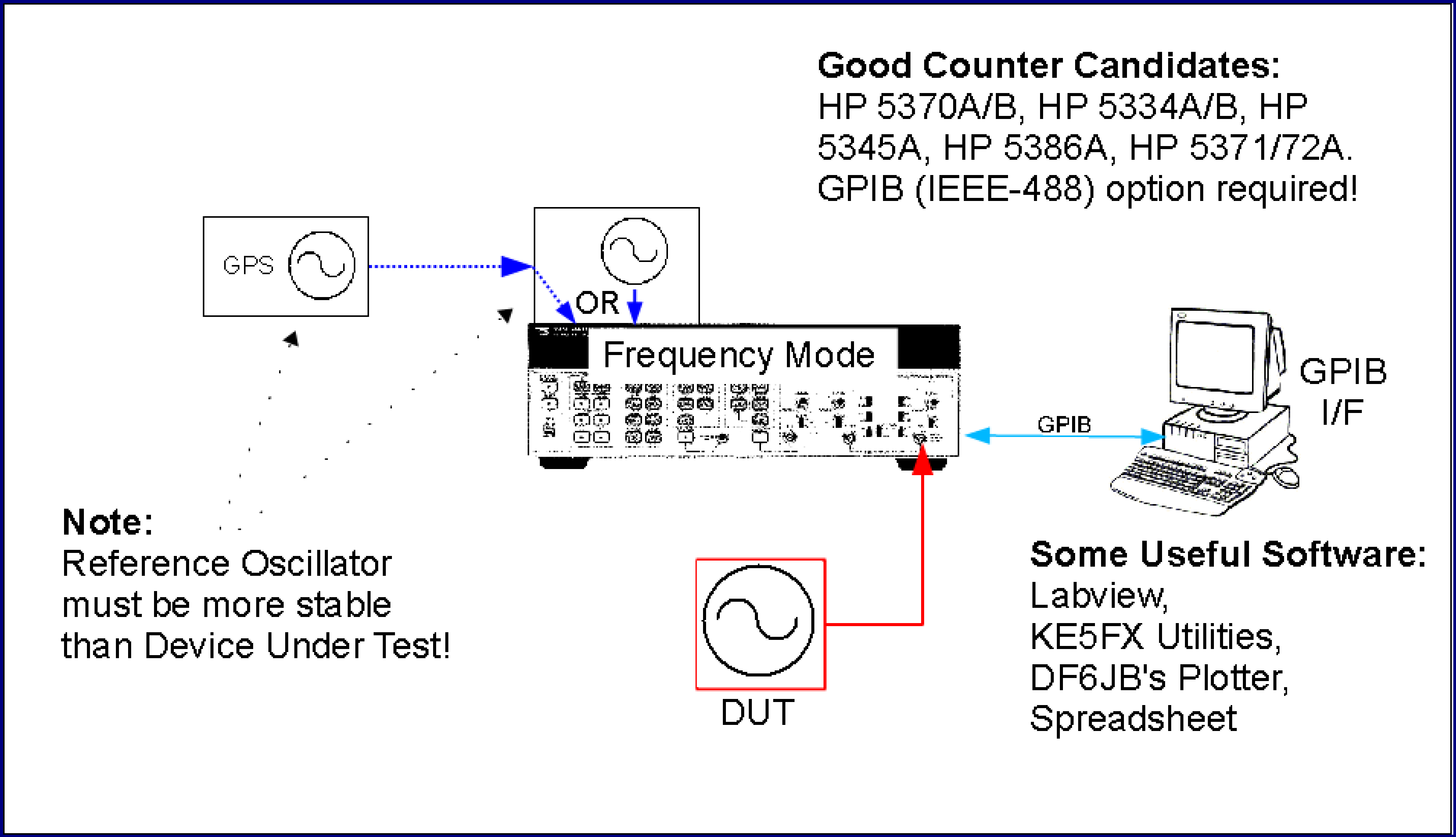


Oscillator Comparison (cont.)

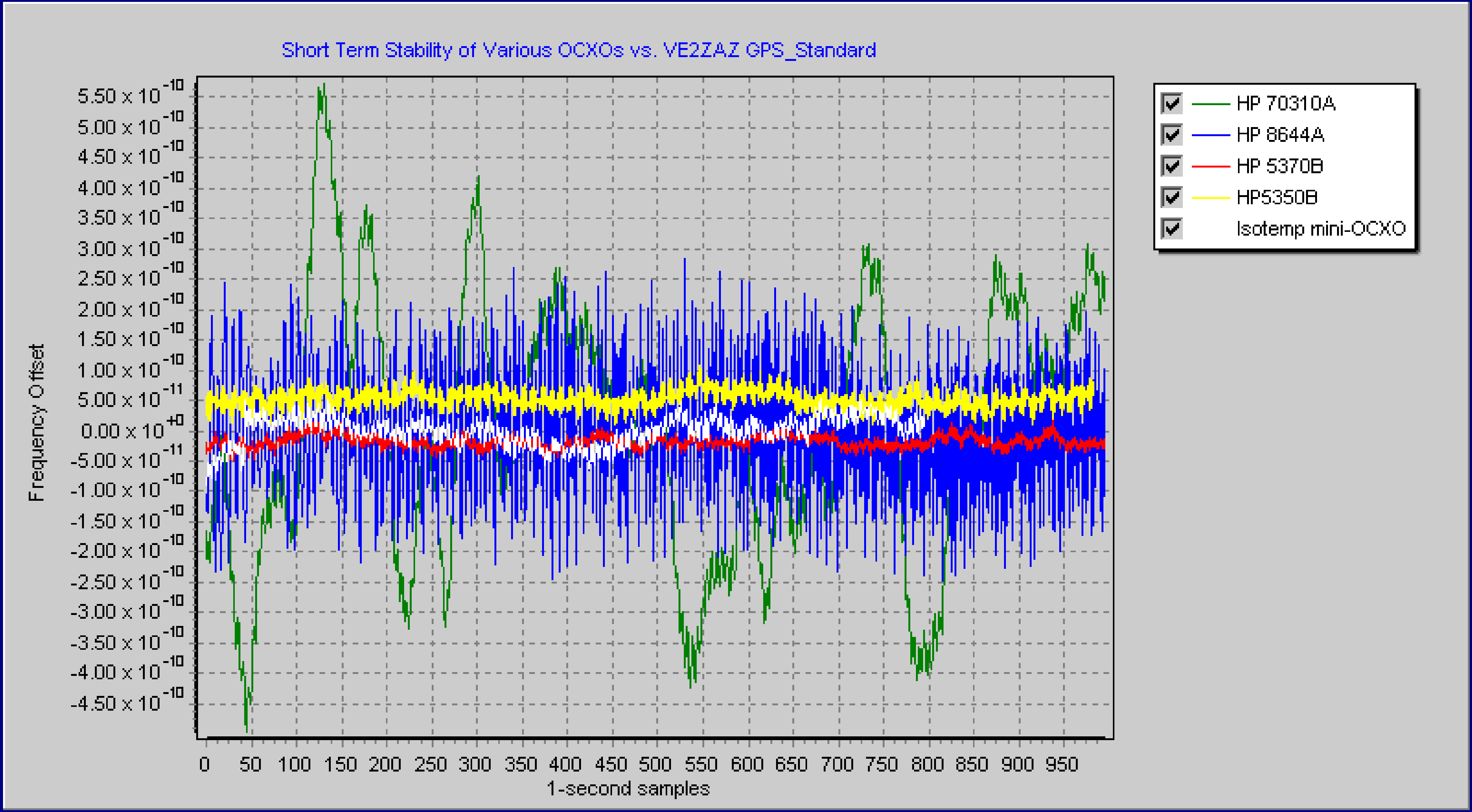
- Relative Allan Deviation of Various Oscillator Technologies



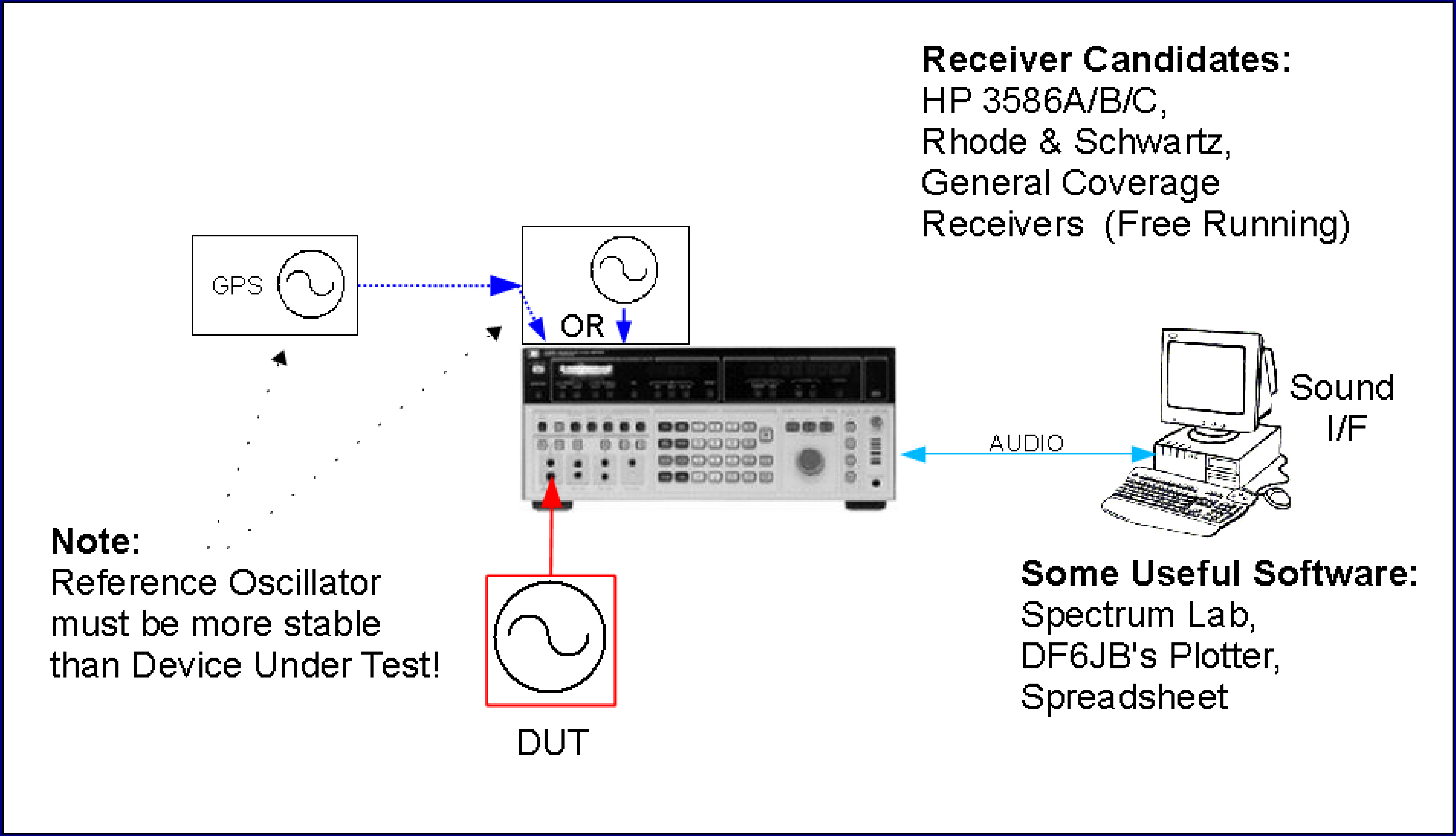
Method 1: Frequency Measurements using a Time Interval Counter



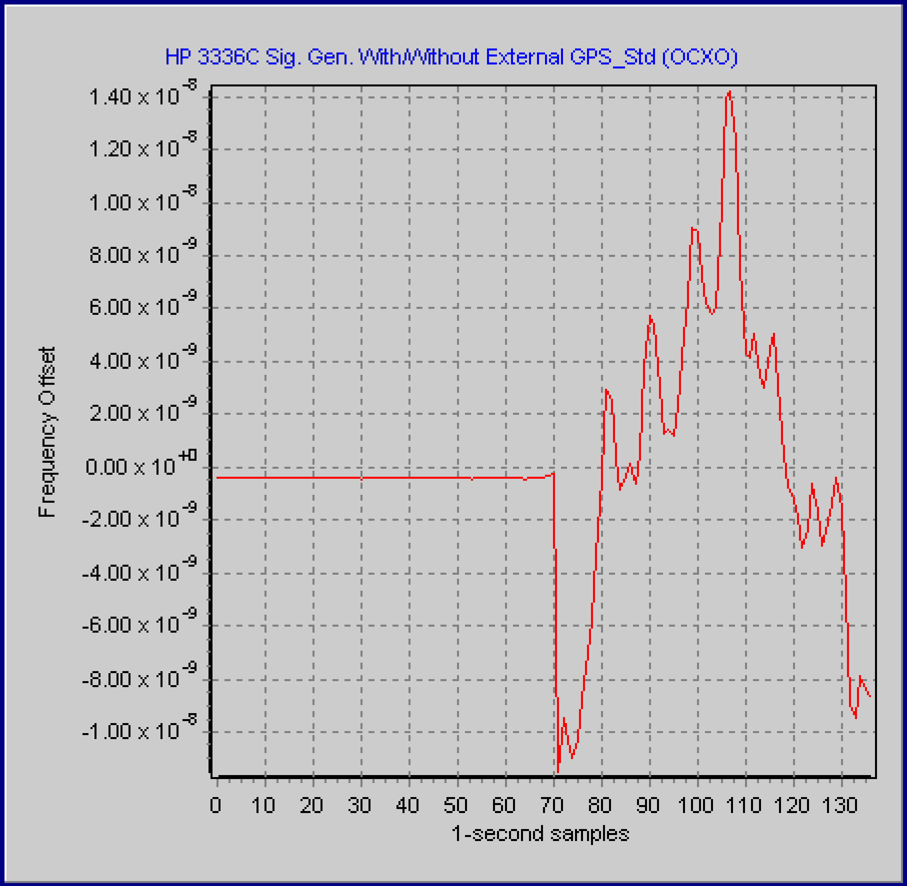
Method 1: Short Term Results

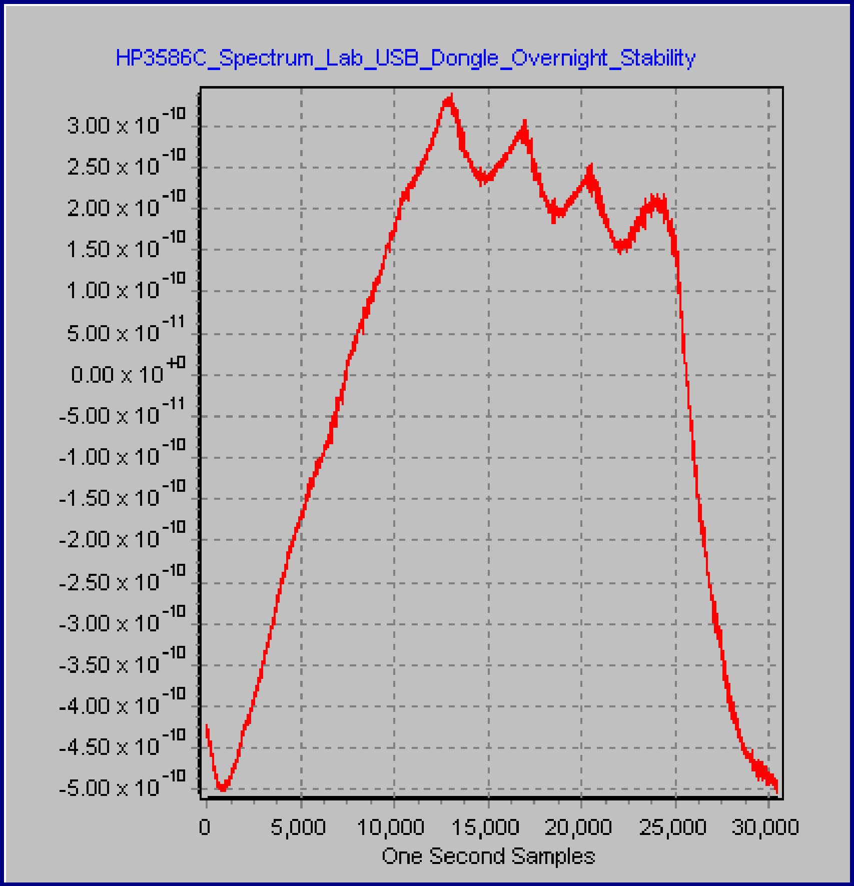


Method 2: Frequency Measurements using a Receiver / Sound I/F / PC

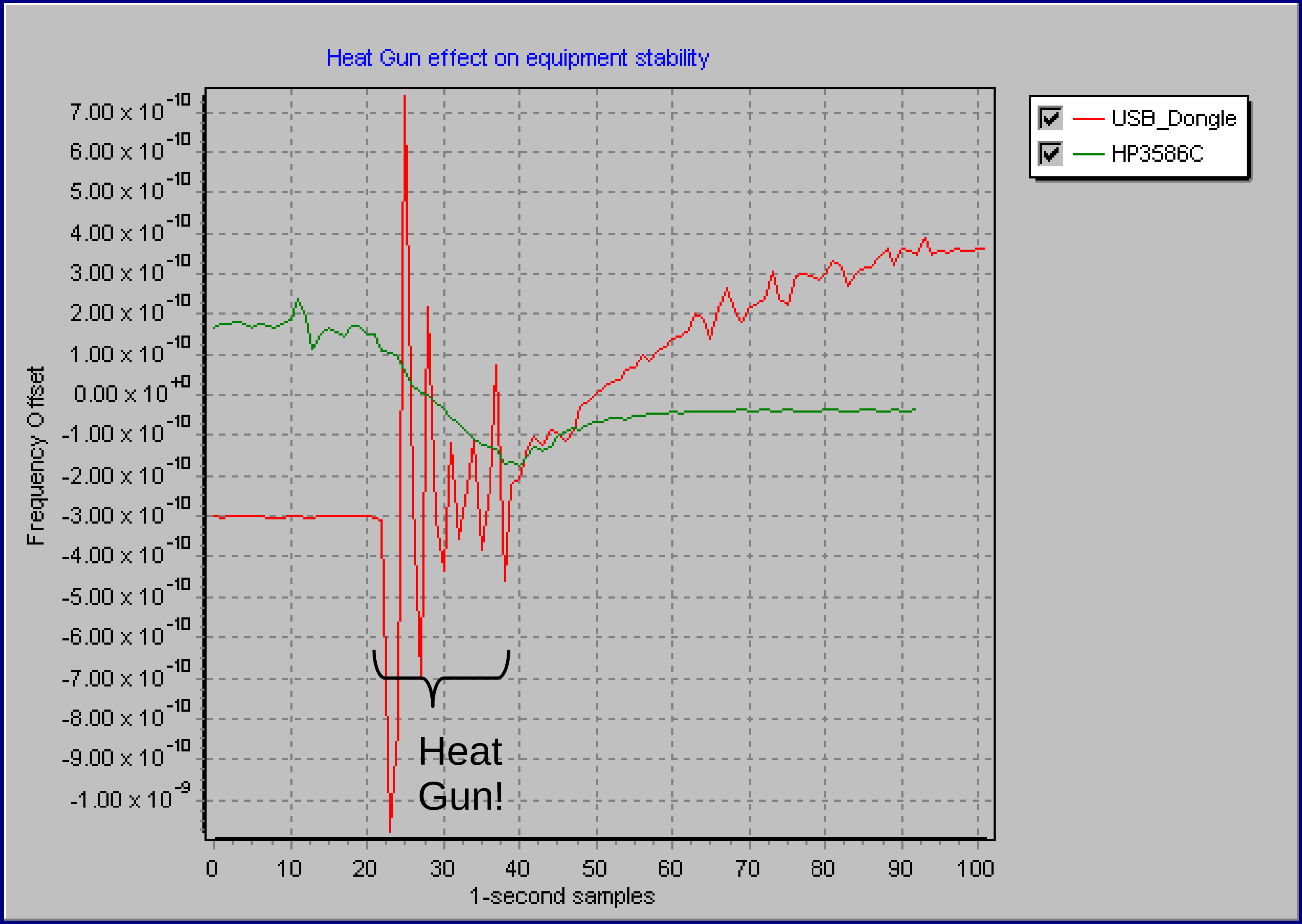


Method 2: Short / Long Term Drift

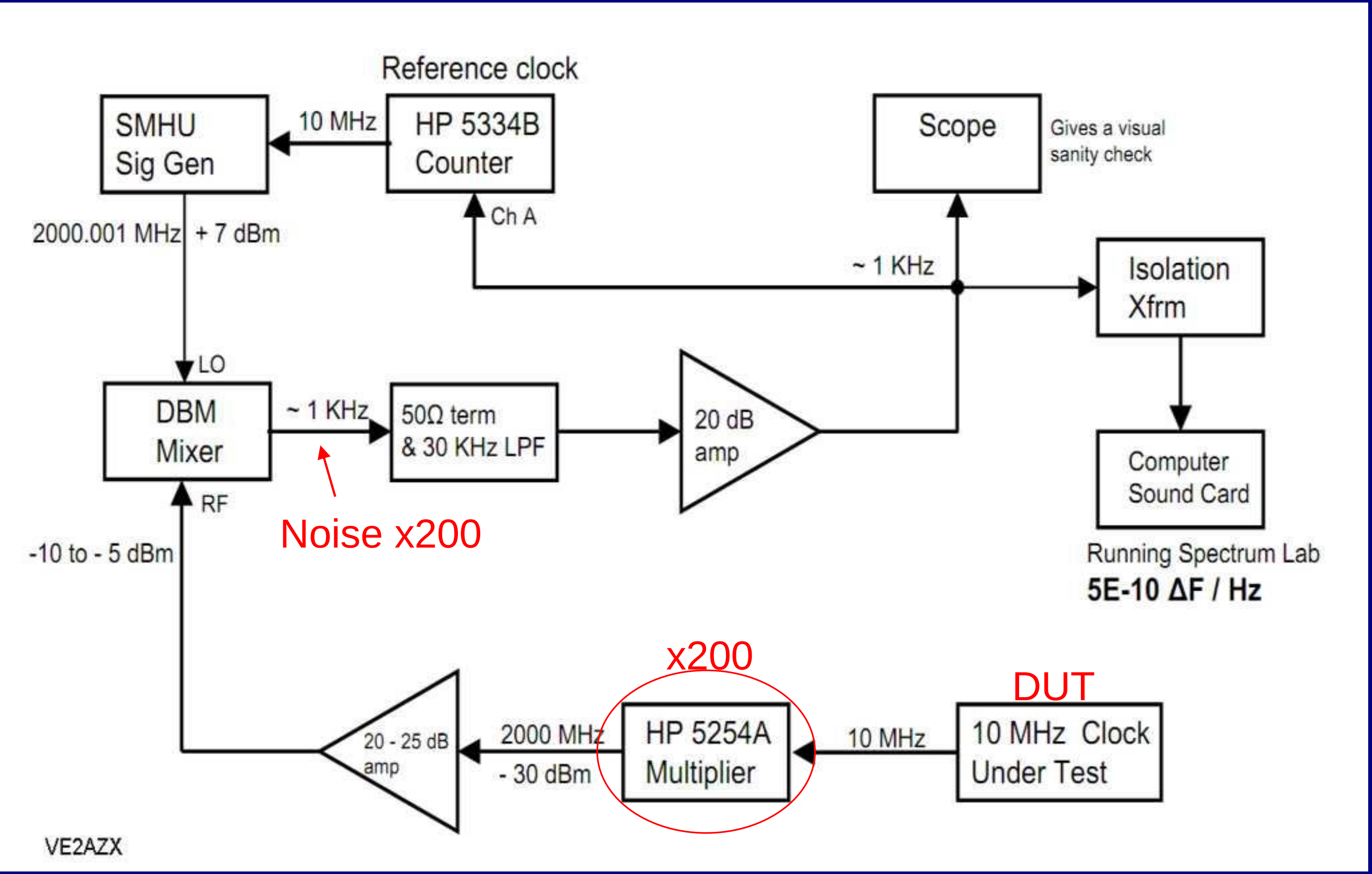




Method 2: Effects of Temperature



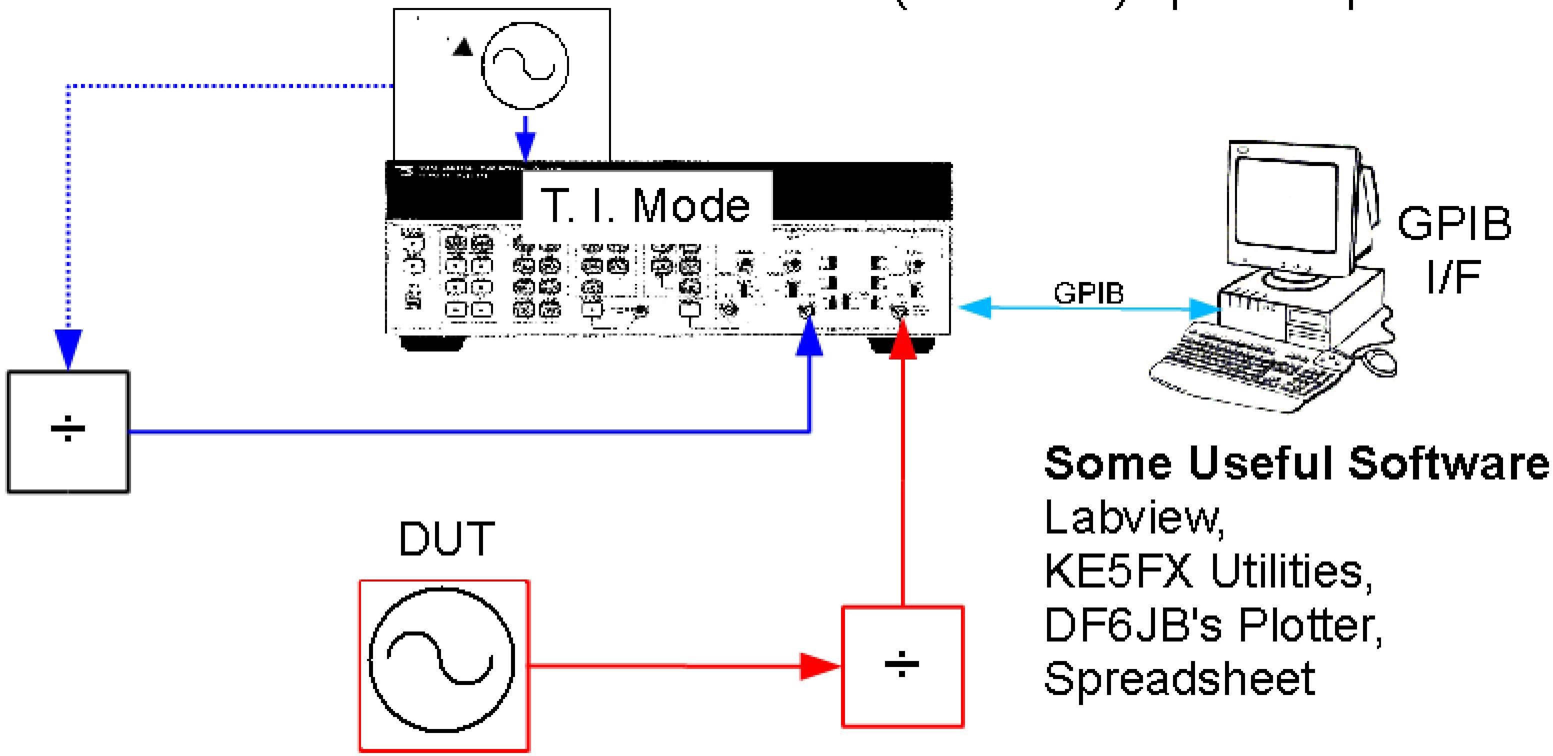
Method 3: Frequency Measurements Freq Mult. / Mixing / Sound I/F / PC (VE2AZX)



Method 4: Time Interval Measurements using a Time Interval Counter

Note:
Reference Oscillator must be more stable than Device Under Test!

Good Counter Candidates:
HP 5370A/B, HP 5334A/B, HP 5345A, HP 5371/72A.
GPIB (IEEE-488) option required!



Some Useful Software:
Labview,
KE5FX Utilities,
DF6JB's Plotter,
Spreadsheet

Some Facts of Stability Measurement

- Short Term Measurements
  - Need a <u>clean and stable</u> reference, not an accurate reference.
  - Mix-and-Match measurement of various OCXOs will reveal the best units.
- Long Term / Very Long Term Measurements
  - Need a <u>stable</u> reference, not an accurate reference.
    - Free running OCXO References will drift if not disciplined.
  - Averaging math will remove short term stability components.
  - GPS disciplining or Atomic clock best.
- All Cases
  - Need to let Instruments and PC (Sound Card) warm up a few hours.
  - Be prepared to purchase several OCXOs and/or Instruments equipped with OCXOs.
    - Ebay: ~ 20$ to $80 each OCXO.

Some References

- Spectrum Lab Software
  - http://www.qsl.net/dl4yhf/spectra1.html
- DF6JB's Plotter Software
  - http://www.ulrich-bangert.de/html/downloads.html
- HP: Fundamentals of Time Interval Meas. (AN 200-3)
  - http://cp.literature.agilent.com/litweb/pdf/5965-7663E.pdf
- NIST: Fundamentals of Time and Frequency
  - tf.nist.gov/general/pdf/1498.pdf
- KO4BB: FAQ#1: Measuring Oscillators Stability
  - http://www.ko4bb.com/Timing/FAQ-1.php
- VE2ZAZ's Website
  - http://ve2zaz.net
- VE2AZX's Website
  - http://ve2azx.net