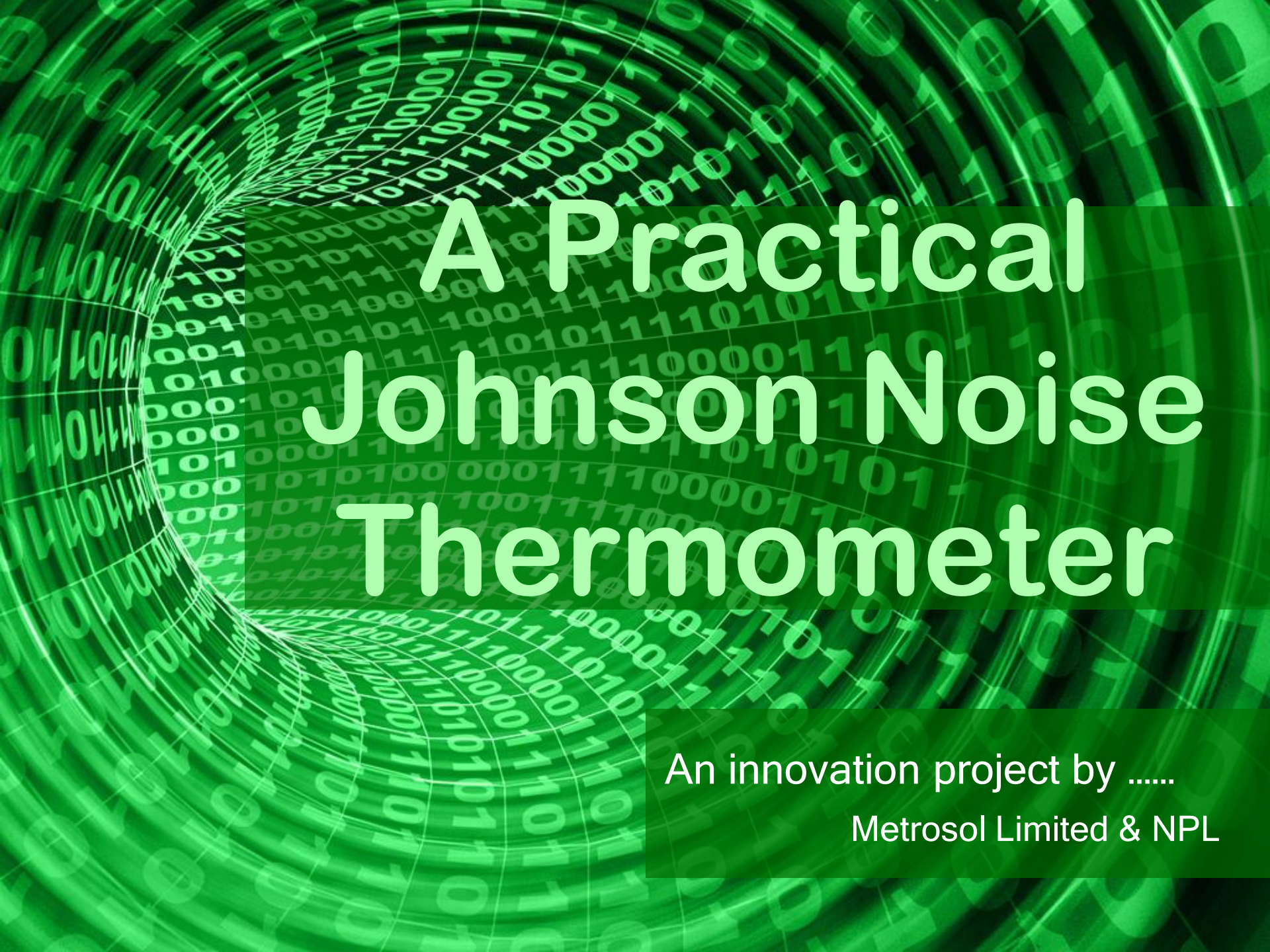




A Practical Johnson Noise Thermometer

An innovation project by

Metrosol Limited & NPL



“We don’t measure temperature with a thermometer 🌡 ”

Conventional Thermometers

Measure property
affected by temperature

Things other than
Temperature can affect
this property

Calibration

Temperature scale

ITS-90

True thermodynamic
temperature

Johnson Noise Thermometers

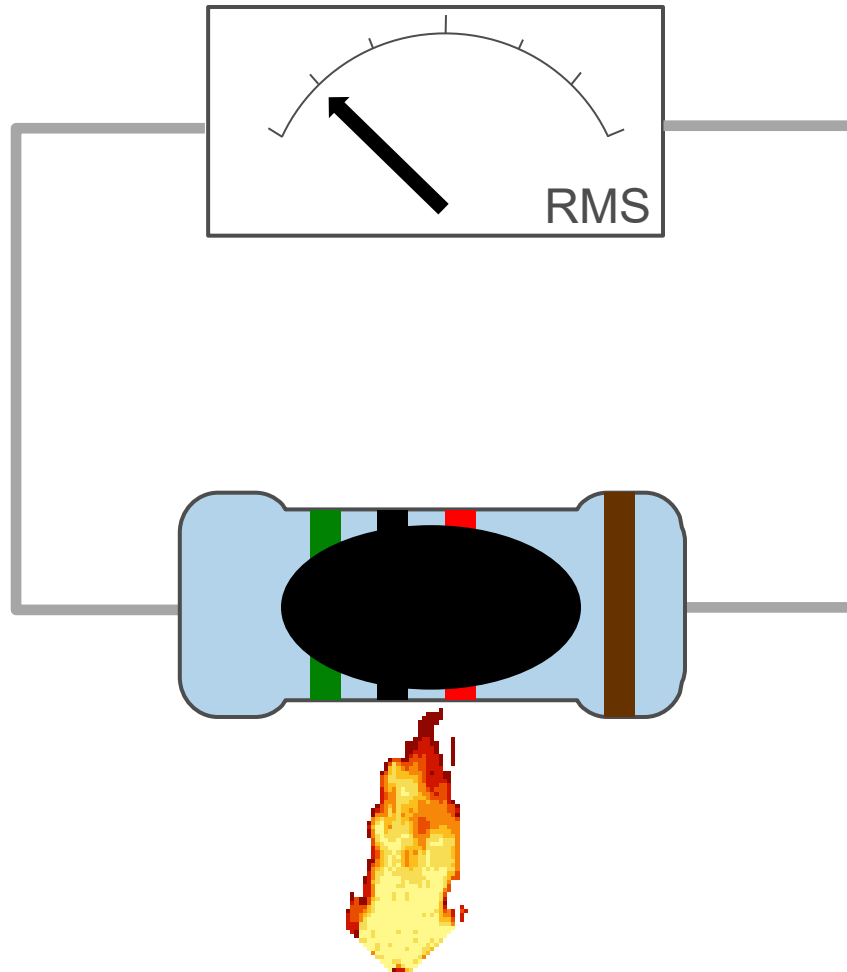
Measure Johnson
Noise

Fundamental
Equation

True
thermodynamic
temperature



Using Johnson Noise to Make a Thermometer



The Johnson-Nyquist Equation

$$\bar{V}_n = \sqrt{4kTR\Delta f}$$

- $\bar{V}_n$ = the RMS voltage
- k = Boltzmann's constant
- T = the thermodynamic temperature of the resistor
- R = the resistance of the resistor
- Δf = the measurement bandwidth

Problems:

- $\bar{V}_n$ extremely small (at limits of measurement)
- Δf hard to define/determine

The Johnson-Nyquist Equation

$$T = \frac{1}{4k} \left\{ \frac{\overline{V}_n^2}{R} / \Delta f \right\}$$

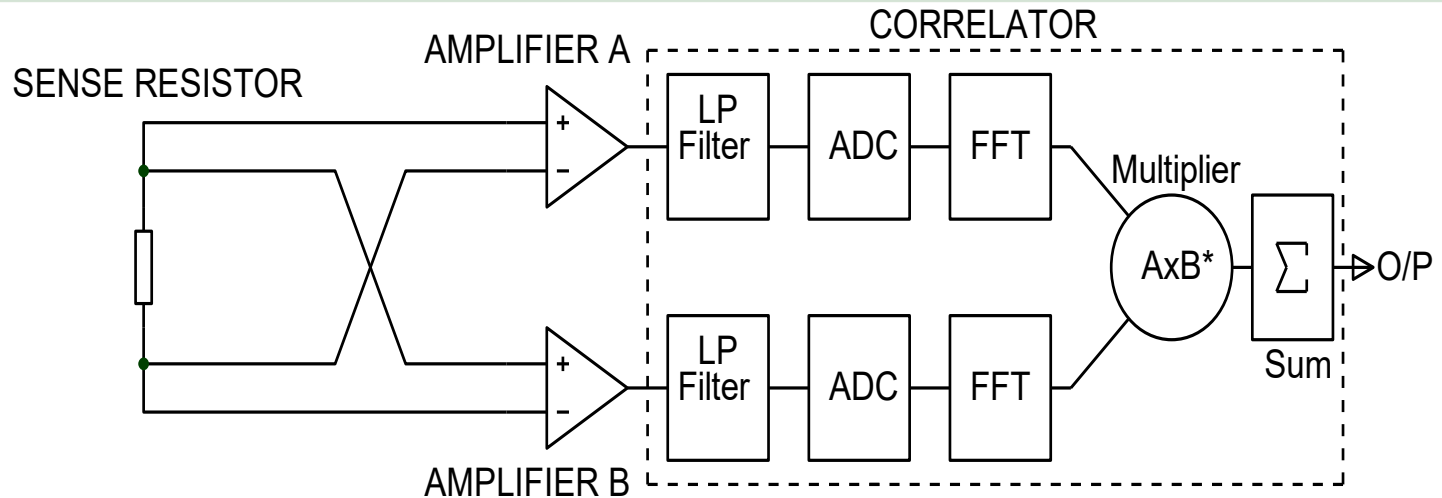
- $\overline{V}_n$ = the RMS voltage
- k = Boltzmann's constant
- T = the thermodynamic temperature of the resistor
- R = the resistance of the resistor
- Δf = the measurement bandwidth

Problems:

- $\overline{V}_n$ extremely small (at limits of measurement)
- Δf hard to define/determine



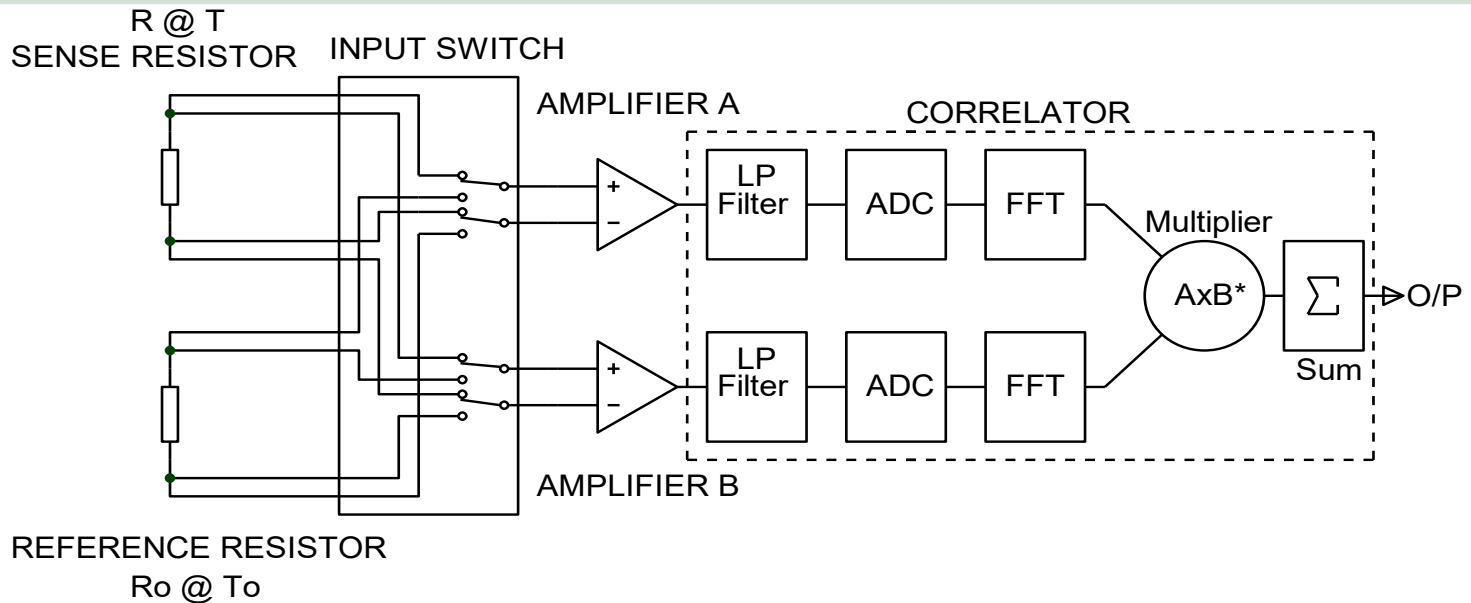
Prior Art Johnson Noise Thermometer



- Amplifiers A & B amplify the same signal from the sense resistor but add their own noise
- The correlator suppresses uncorrelated noise and detects only the signal common to both channels i.e. the sensor's Johnson noise
- This allows us to measure the extremely small Johnson noise signal provided the correlation time is sufficiently long



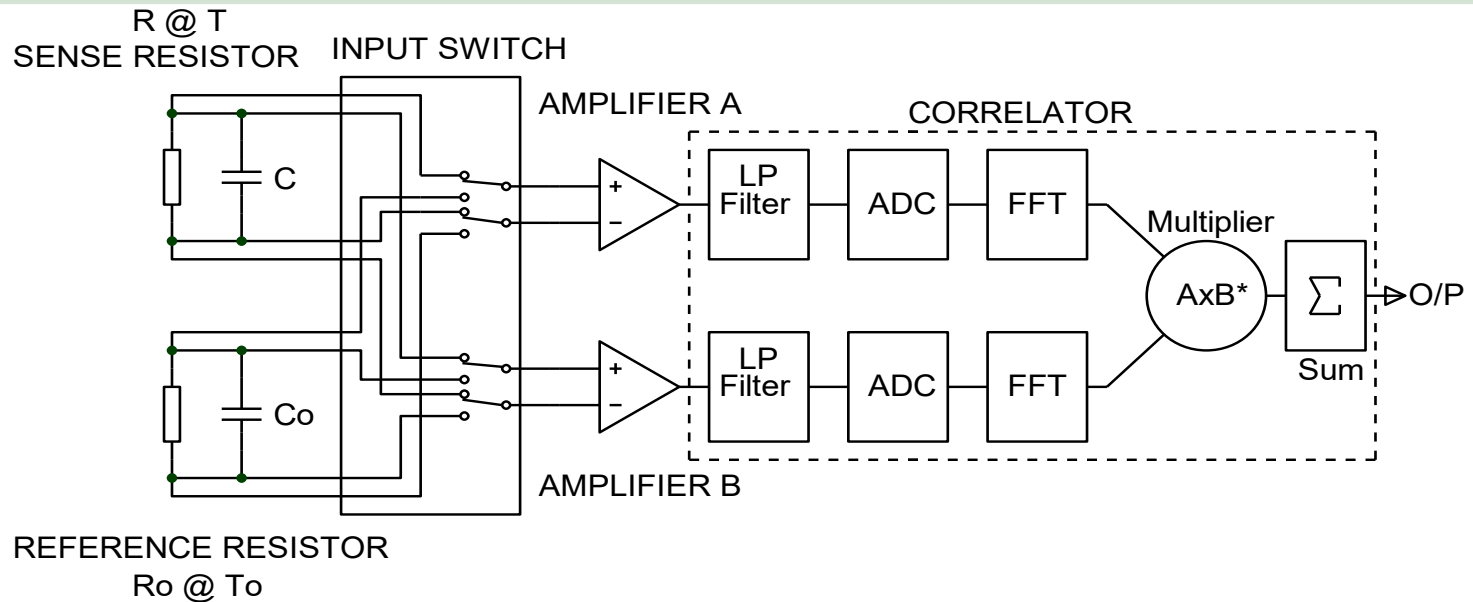
Prior Art Johnson Noise Thermometer



- The amplifiers switch between measuring the Johnson noise and a known calibration signal (a “white noise” source of known power density)
- The ratio of the measurements allows the Johnson noise power spectral density to be determined **provided Δf is constant**



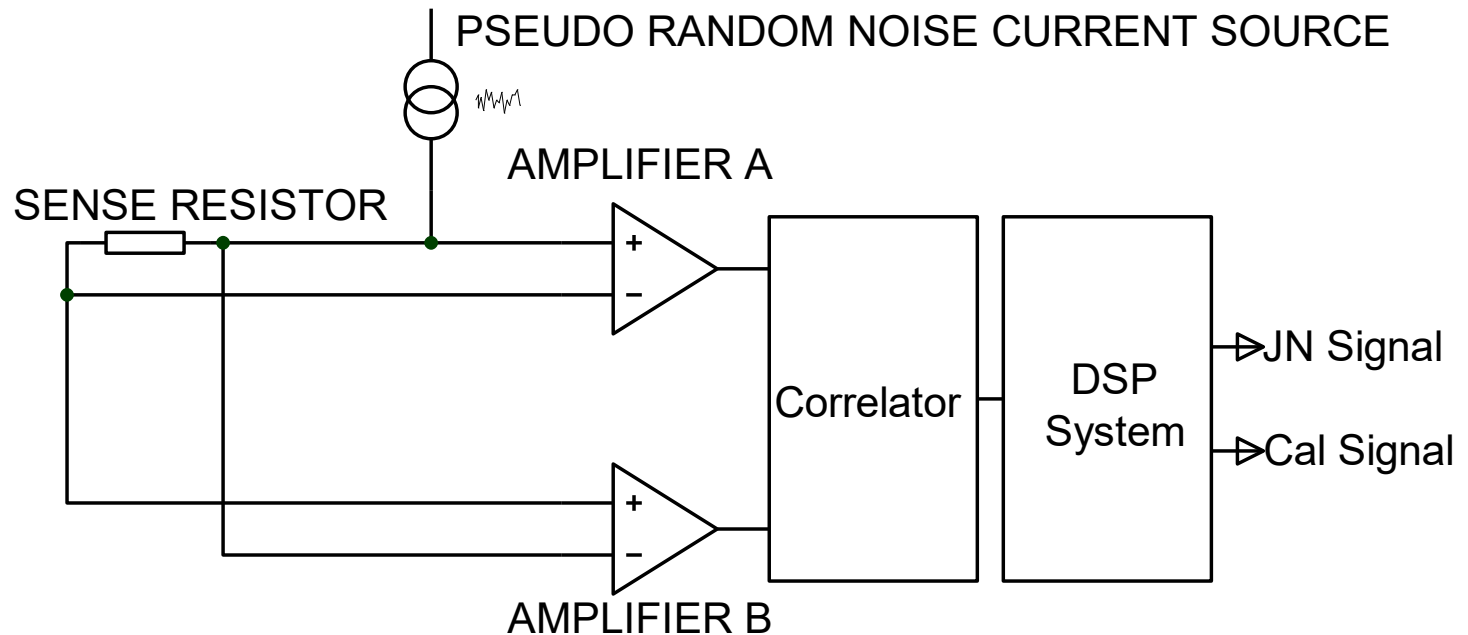
Prior Art Johnson Noise Thermometer



- The switching between the 2 measurements means that Δf changes, mainly due to the capacitance of the cables
- Solution has been to match the characteristics of the transmission lines carefully
- Typical short cables means this limits system to around 100Ω & 100kHz



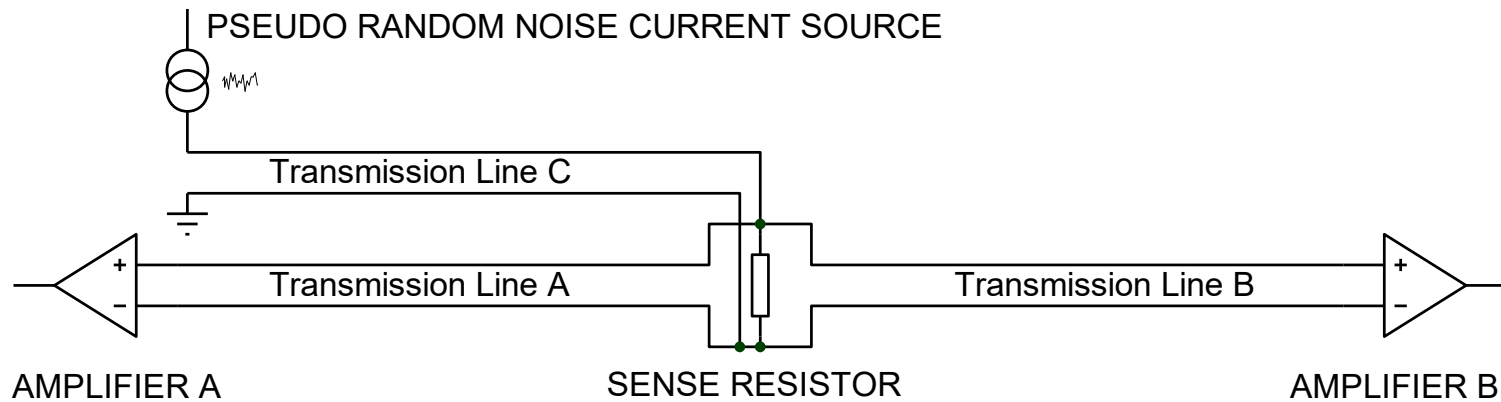
Metrosol Johnson Noise Thermometer



- Calibration signal injected as current, which generates a calibration voltage in the sensor
- The Johnson noise & calibration signal experience the same frequency response
- The signals are subsequently separated completely using digital signal processing



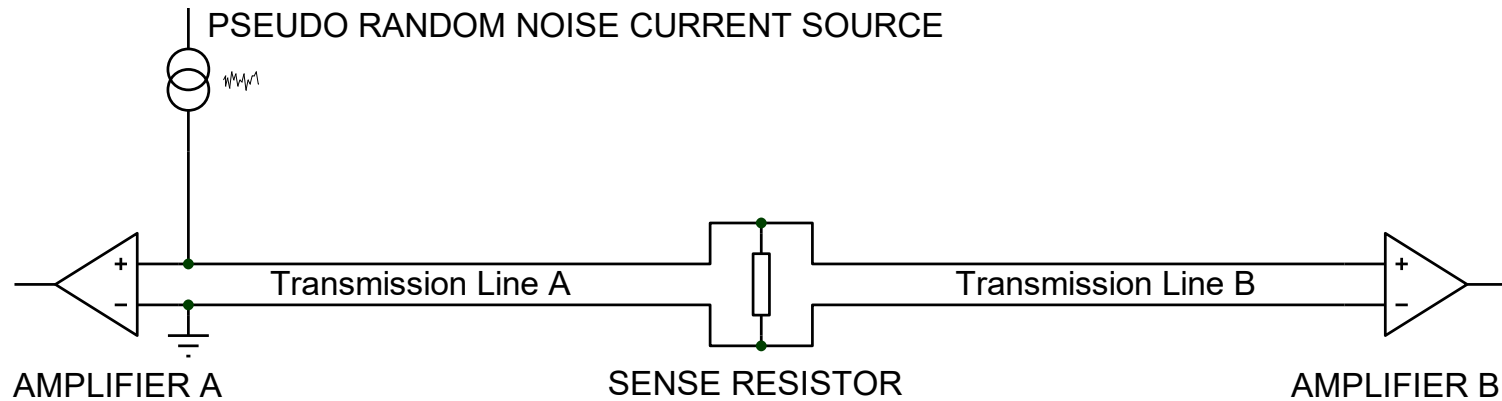
Metrosol Johnson Noise Thermometer



- Transmission line connecting PRN current source to sense resistor will attenuate higher frequency components of calibration current signal
- Connecting current source directly to sense resistor will cause unacceptable measurement uncertainty



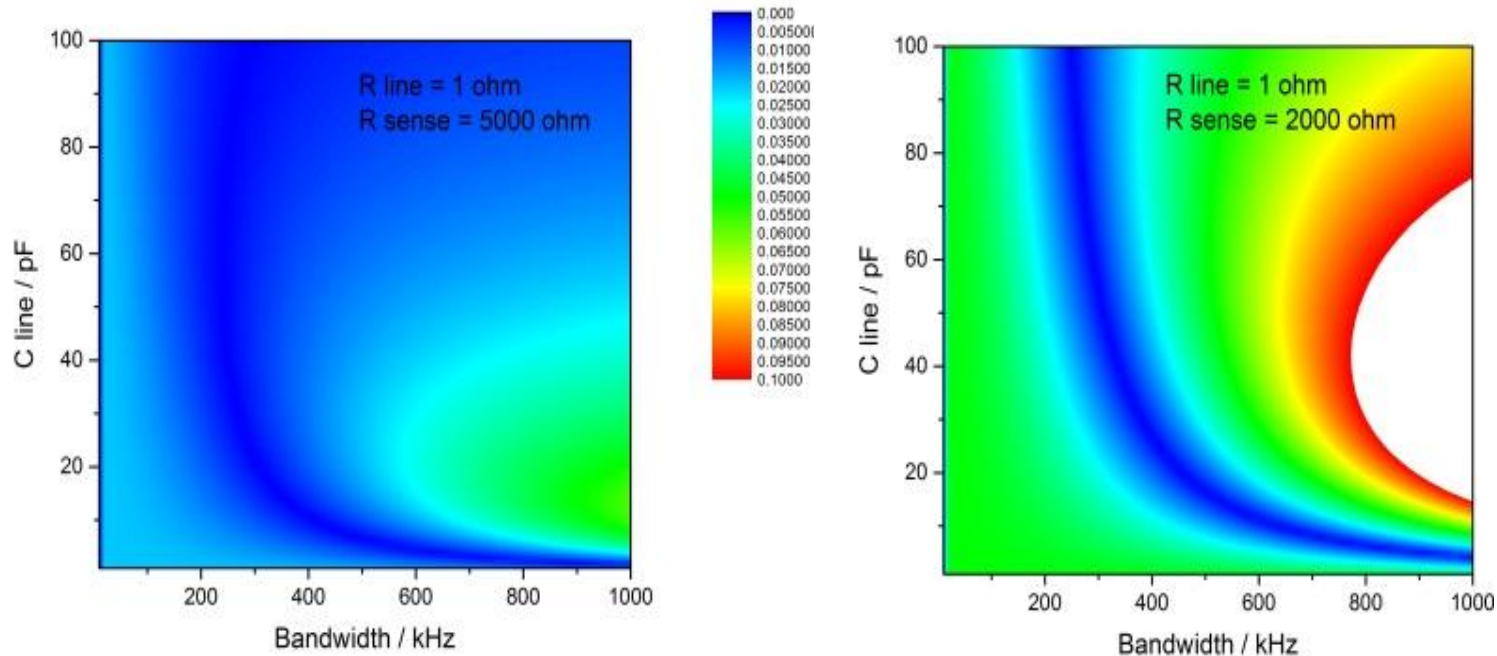
Metrosol Johnson Noise Thermometer



- Injecting calibration signal at centre:
 - measured signal power = $V_C(1 - x) \cdot V_C(1 - x)$.
- Injecting calibration signal at “A”:
 - measured signal power = $V_C \cdot V_C(1 - x)^2$
- There appears to be a cancellation of the error, but the model is grossly oversimplified



Metrosol Johnson Noise Thermometer



- Sensitivity analysis of full model shows that errors are small for higher values of sense resistor - which is what we want in the JNT!

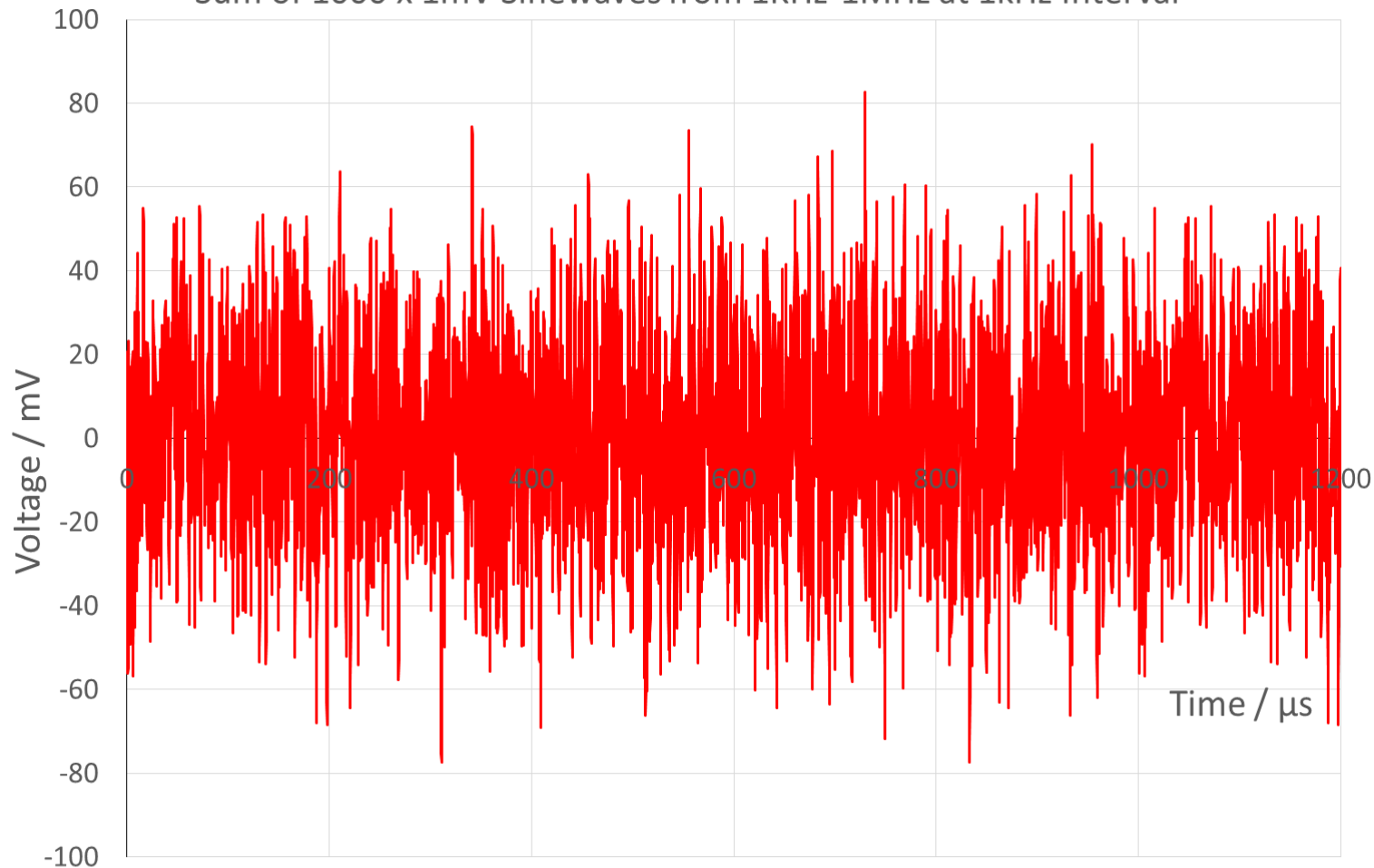
Signal Improvement

Prior Art	Metrosol JNT	Improvement
100 Ω	5k Ω	x50
100kHz	1MHz	x10
Switching	No Switching	x2
		TOTAL = x1000



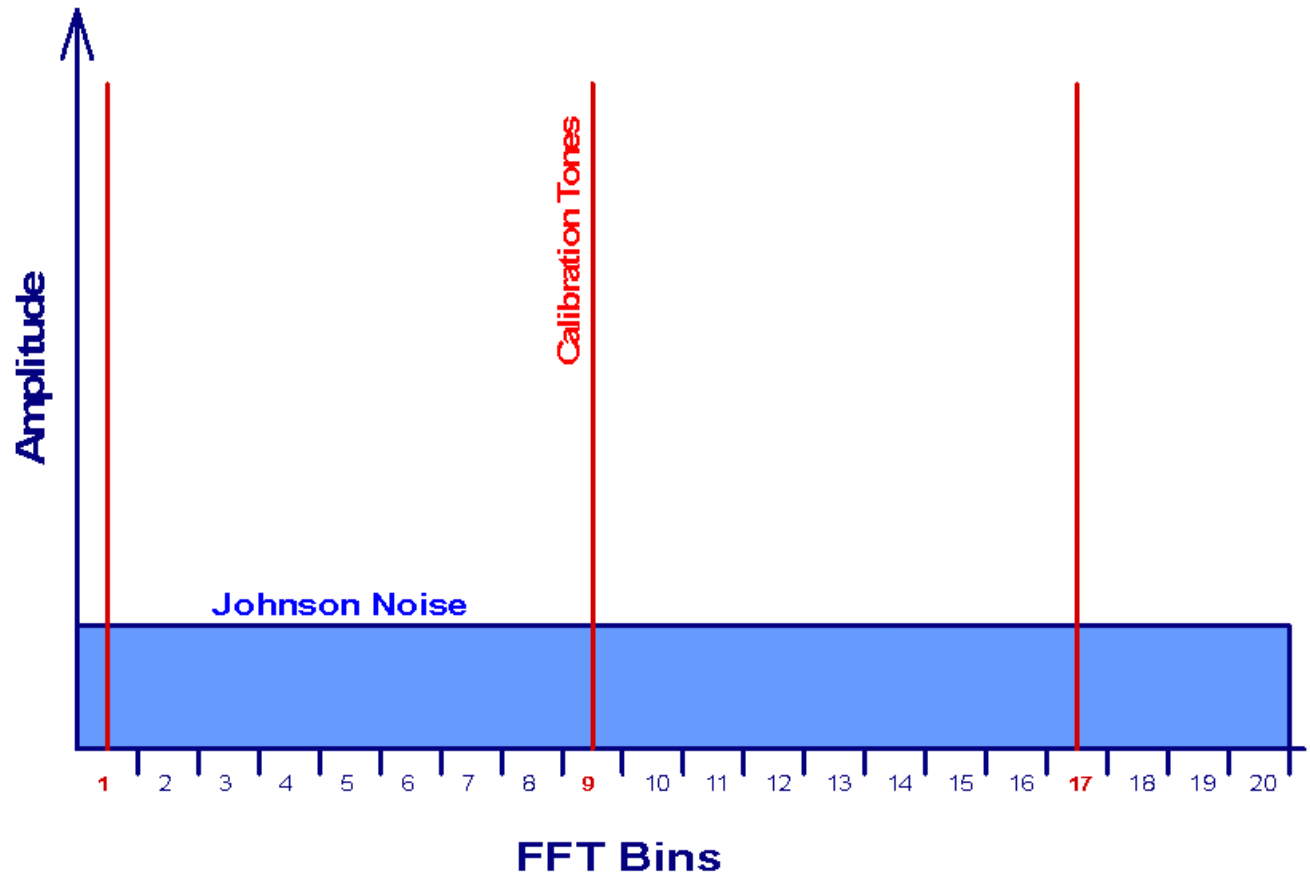
Pseudo Random Noise Calibration Signal

Sum of 1000 x 1mV Sinewaves from 1KHz-1MHz at 1kHz Interval



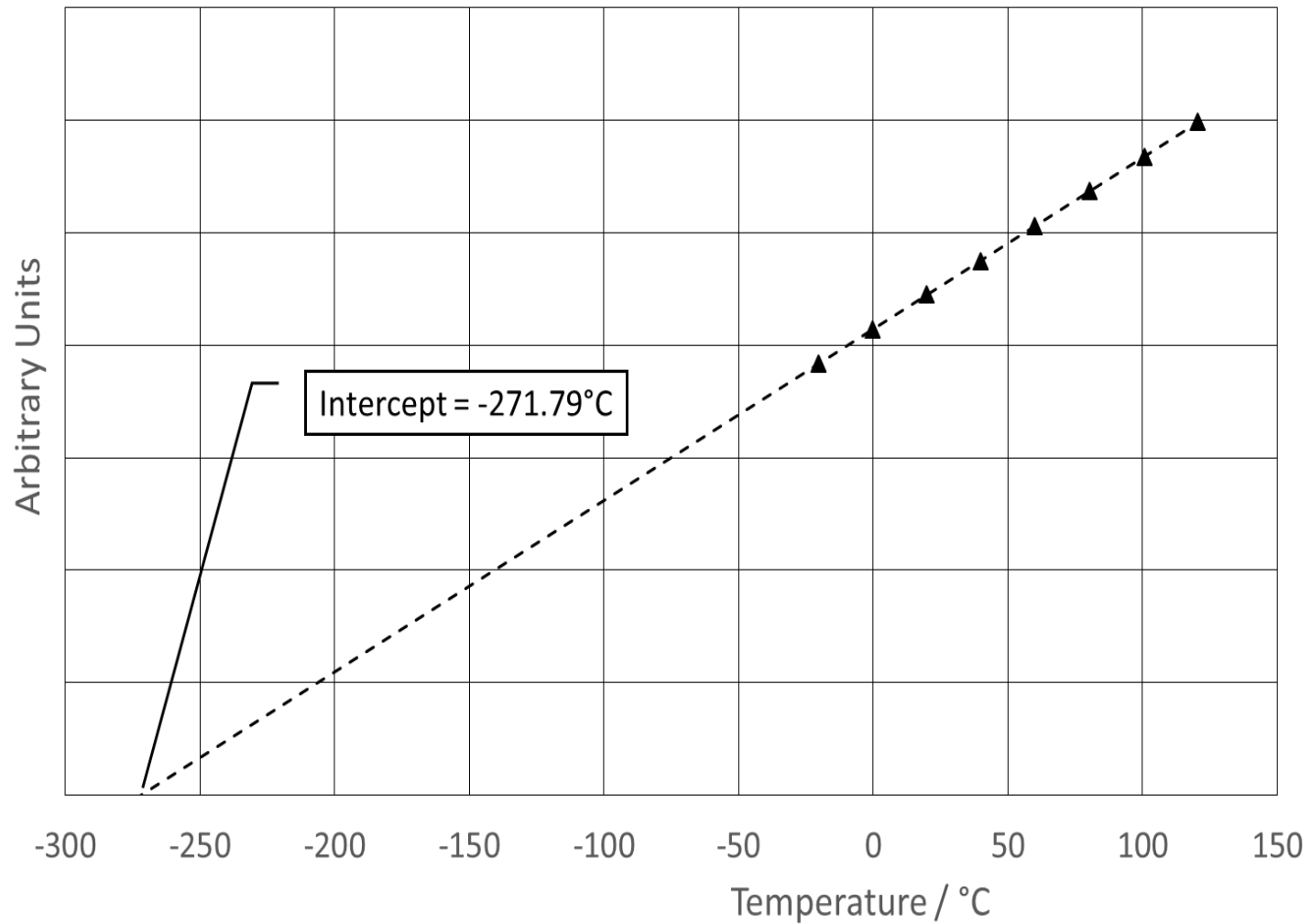


Pseudo Random Noise Calibration Signal



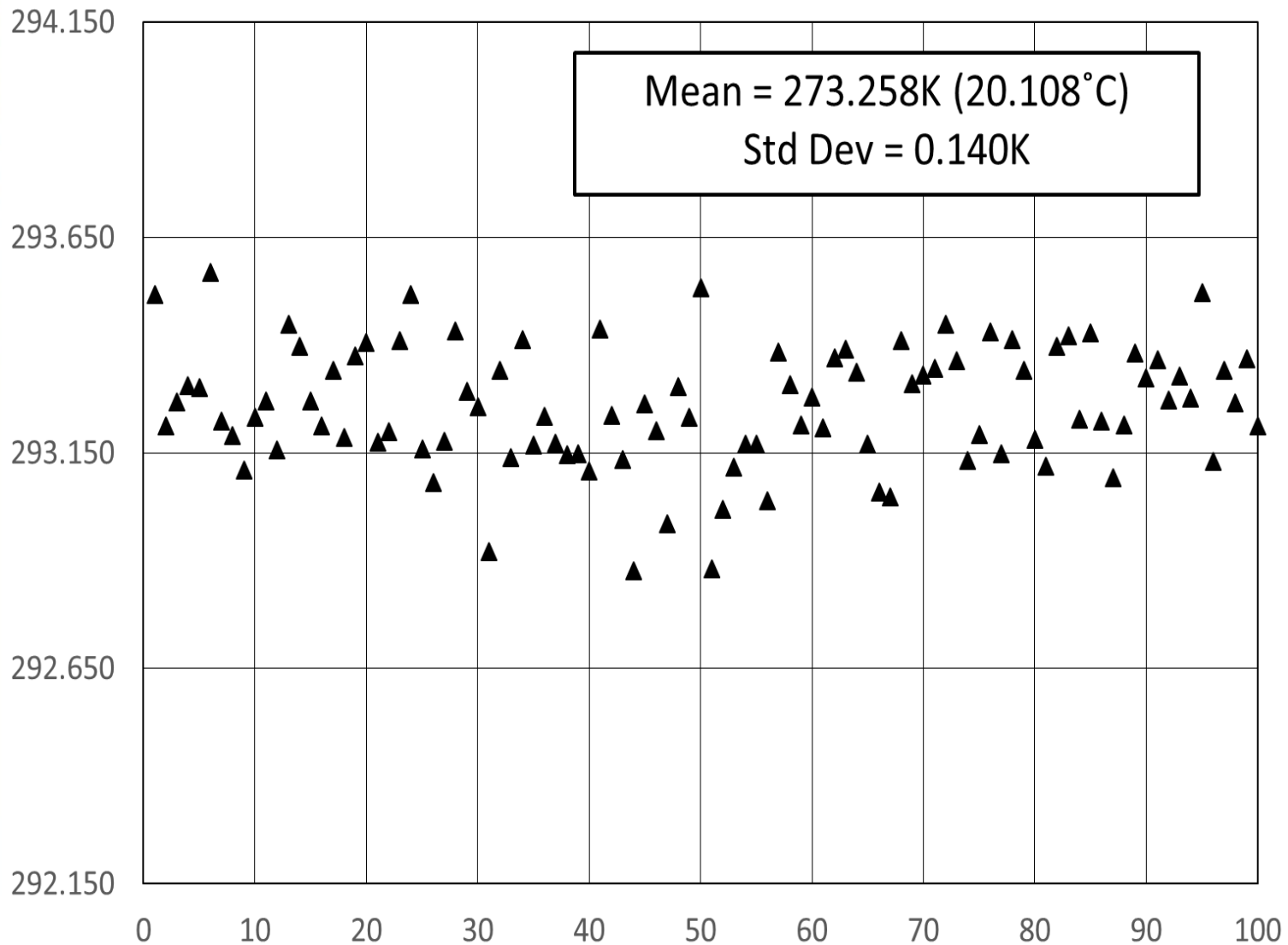


Results = Linearity & Offset





Results: Accuracy



Johnson Noise

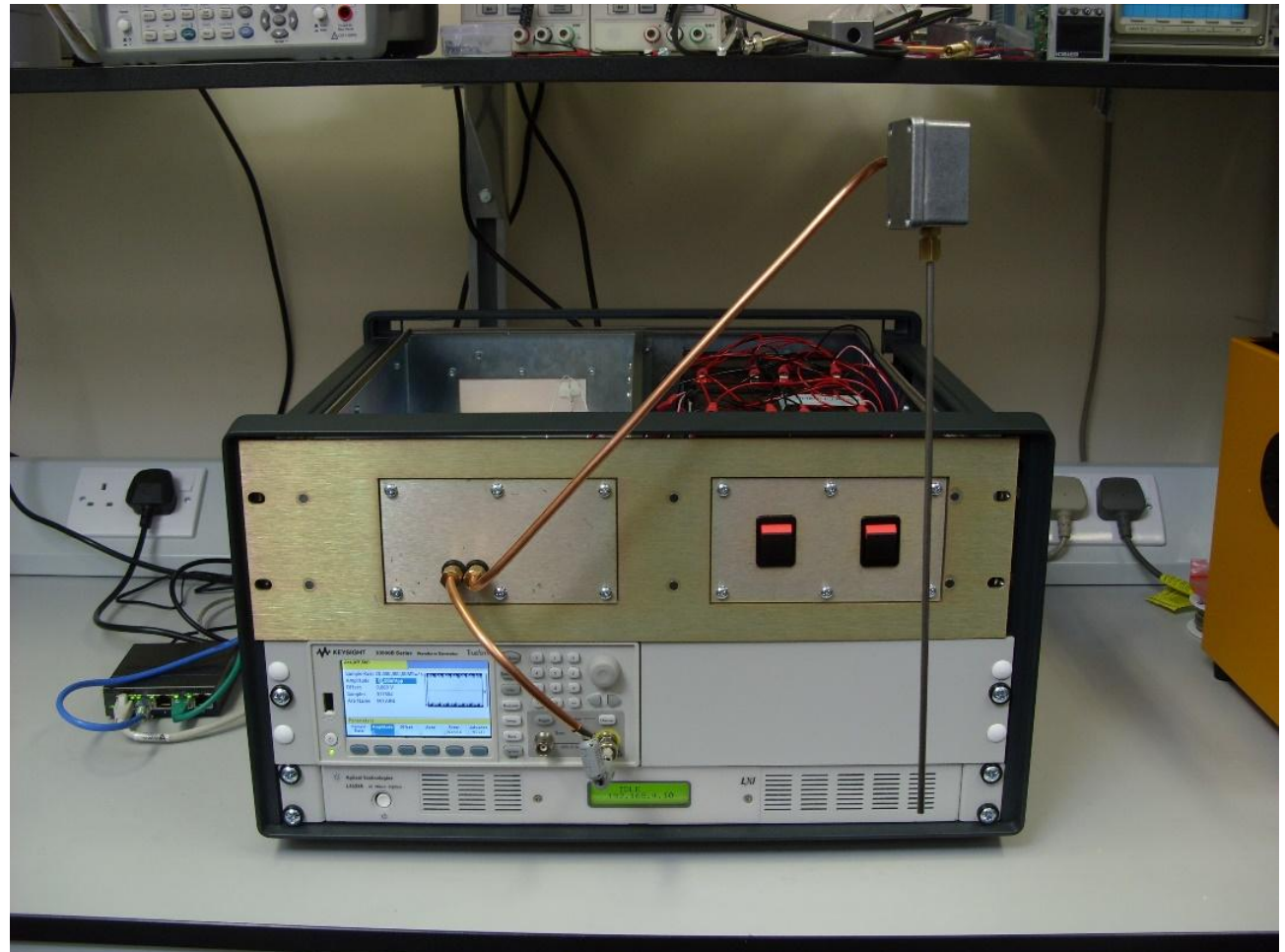


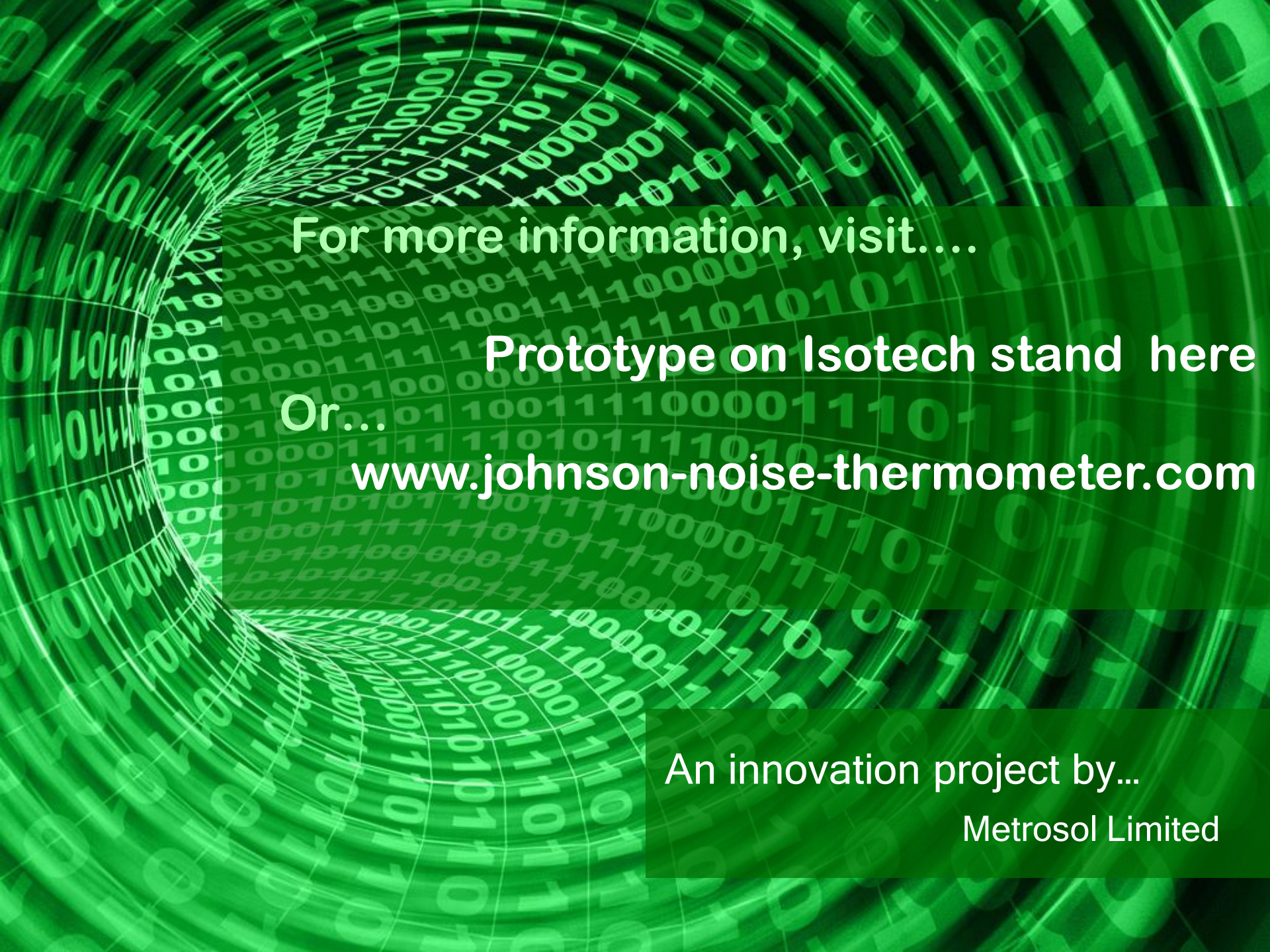
Thermometer



Progress So Far

- Proof of principal prototype, working in normal laboratory environment:





For more information, visit....

Prototype on Isotech stand here
Or...
www.johnson-noise-thermometer.com

An innovation project by...

Metrosol Limited