Gotchas in AC Power Analysis

Power Analyzers, Voltage & Current Transducers

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TECRep
CONNECT TO THE BEST IN TEST

TecRep Corporation

- Exclusive Manufacturer's Representative with a focus on Test & Measurement
- About 25 Manufacturers
- Founded in 1989, team of 9 today
- Bound Geography: MN, ND, SD, WI, IL, IA, MO, NE, KS
- This presentation is based on firsthand, in laboratory experience within this geography since 2010, and T&M manufacturer training.

Key Points

- Beware of Marketing Information
- Do your Research
- Specifications to Look For
- Every bullet point is a longer conversation
- Voltage Transducers can Kill your High Accuracy Power Measurements
- Current Transducers can Kill your High Accuracy Power Measurements

Not Discussed: Safety, CAT ratings, Techniques, Ease of Use, Test Methods, Set-Up, Support, Training.

"Power Quality Analyzer"

- **Presupposition for Electronics Design Verification : Is it the best for Electronics?**
- **Limited Frequency Range : 45-65 Hz & Harmonics**
- **Low Sample Rates : Power Grid Faults**
- **Clamp-On AC Only Current Transducers : Clamp is generally 1% at its best, Power Accuracy specification or just voltage?**

What is an AC Power Analyzer?

- **Measurement Instrument Calibrated to Voltage, Current, and AC & DC Power**
- **Trusted Numerical Results**
- **Simple Set Up : Few Decisions to Make**
- **100s of Measurements Averaged Over Milliseconds to Minutes**
- **Isolated Differential Voltage Input**
  - ***600 Volts to 1500 Volts***
- **Isolated Current Input**
  - **1 Milliamp to 10s of Amps**

Power Analyzer Specifications (Datasheet)

- **Basic Accuracy (error) : RMS % of Reading + RMS % of Range → in watts, *complicated***
- **Sample Rate : Never < 10x Carrier Frequency**
- **Maximum Bandwidth (100 kHz to ~ 10 MHz) : Harmonics & Fast Rise Times (SiC, GaN)**
- **Bits : 16 (65,536) or 18 (262,144) typ.**
- **Ranges Available : Range Error Contributor**
- **Formulas Used : No Assumptions!, Check**

Power Analyzer Specifications (No Datasheet)

- **Calibration Data : Frequency of Power, Uncertainty & Uncertainty Ratios**
- **Industry Standards for Calibration & Instruments : How high in frequency can a calibrator go?**
- **Secret Sauce: Internal Shunt Design, Special Firmware**
- **“Apples-to-Apples” : Not really that simple.**

Power Analyzer Specifications

❖ Simpler : Talk to Multiple Vendors, Try a Demonstration Unit

Power Analyzer Accuracy	Number of Pages in the Datasheet Describing Accuracy
Vendor A - large font	1
±(RMS % of reading + RMS % of range)	
Vendor B - small font	4
±(RMS % of reading + RMS % of range)	
Vendor C - complicated number matrix	4
± (% of measured value + % of maximum peak value)	
Vendor D - confusing	1
[0.03%+0.03%/pf+(0.005%×kHz)/pf] Rdg+0.03%VA Rng	

Transducers or Probes – Terminology & Specs

- **Be careful of Acronyms**
  - ***PT = Potential Transformer…or a Probe/Transducer?, what about DC?***
  - ***CT = Current Transformer…oh wait, or was it Current Transducer?***
- **Amplitude, Frequency, & Accuracy absolutely do not tell the whole story**
- **Alert: Silicon Carbide (SiC) & Gallium Nitride (GaN) in power electronics are changing the game, big time.**

Transducers or Probes – Voltage

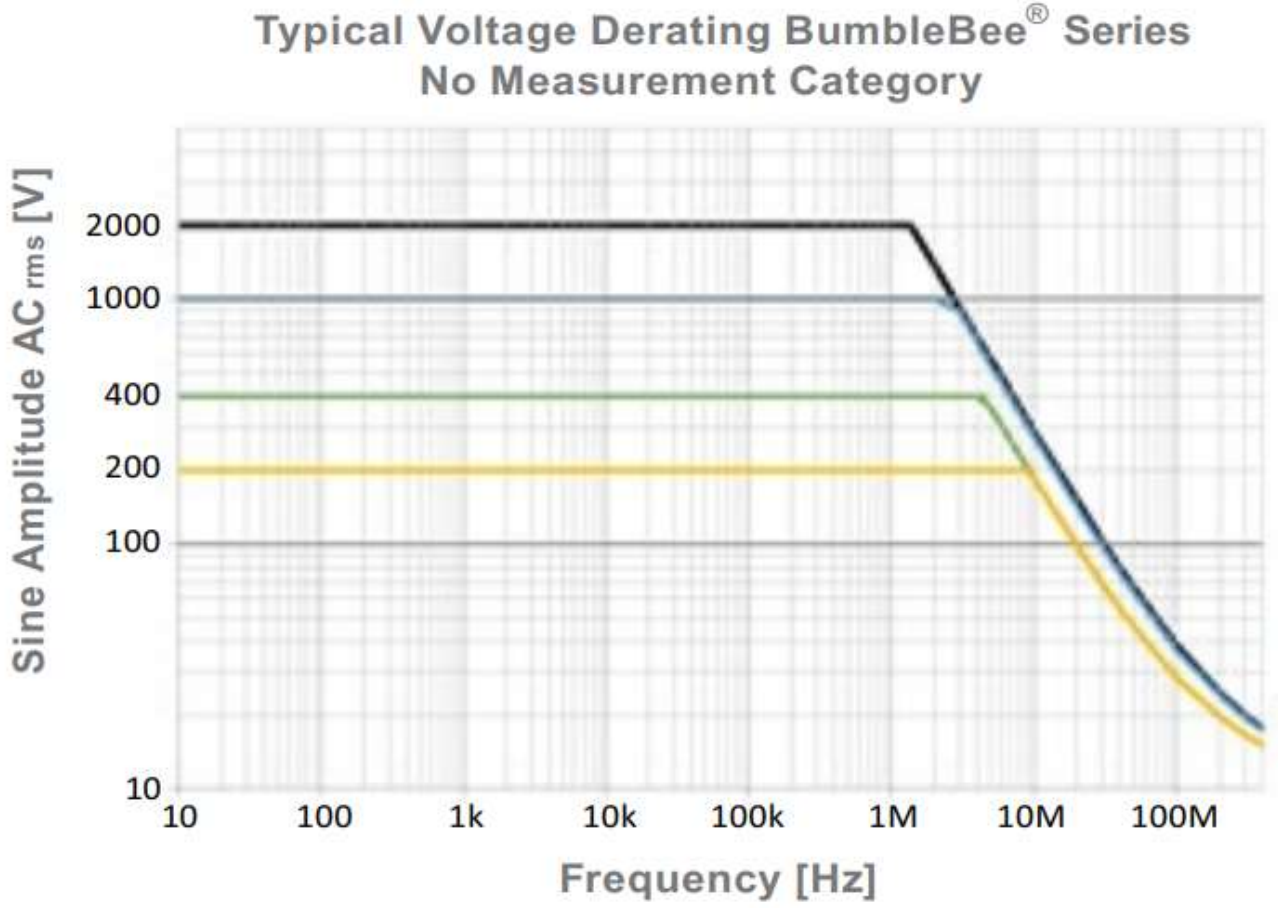
- **Exceed direct input voltage of power analyzer**
- **‘Oscilloscope’ Probes (> 1500 volts)**
  - ***1% Typically***
  - ***Derating Curves: Amplitude vs. Frequency***
  - ***Input Impedance: Ohms vs. Frequency***
  - ***Best on Planet Earth Today commercially available: Fiber Optically Isolated up to 1.5 GHz (PMK, Tektronix, Teledyne LeCroy)***

Transducers or Probes – Voltage

❖ Derating Curves: Amplitude vs. Frequency

PMK – BumbleBee® HV Differential Probe, Up to 500 MHz, Up to 2 kV

Note that the max. input voltage rating of the probe decreases as the frequency of the applied sine signal increases.

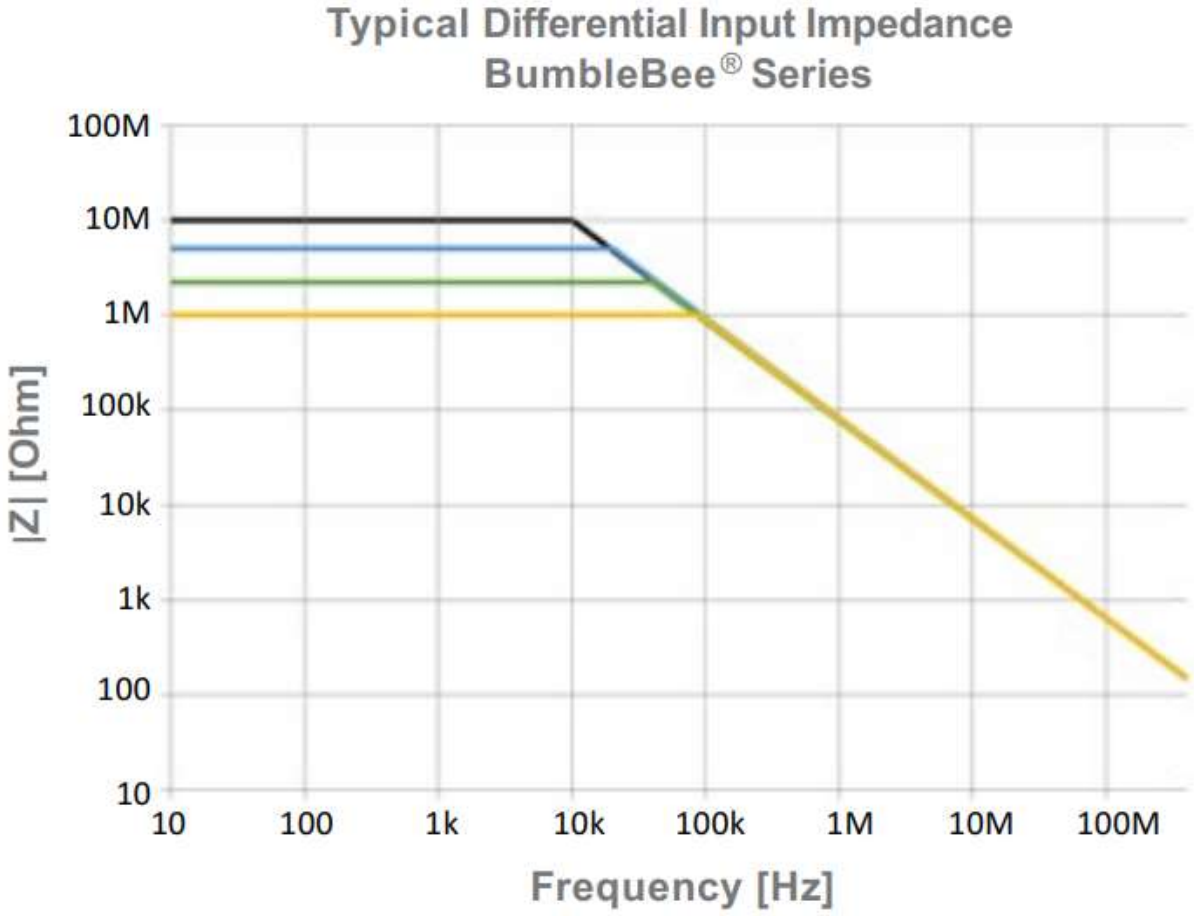


Transducers or Probes – Voltage

❖ Input Impedance: Ohms vs. Frequency

PMK – BumbleBee® HV Differential Probe, Up to 500 MHz, Up to 2 kV

Note that the input impedance of the probe decreases as the frequency of the applied signal increases.



Transducers or Probes – Voltage

- **Voltage Divider – Better than 1%**
- **Ross Engineering**

https://www.rossengineeringcorp.com/hv-measurement/hv-voltage-dividers/high-accuracy.html

- **Hioki**

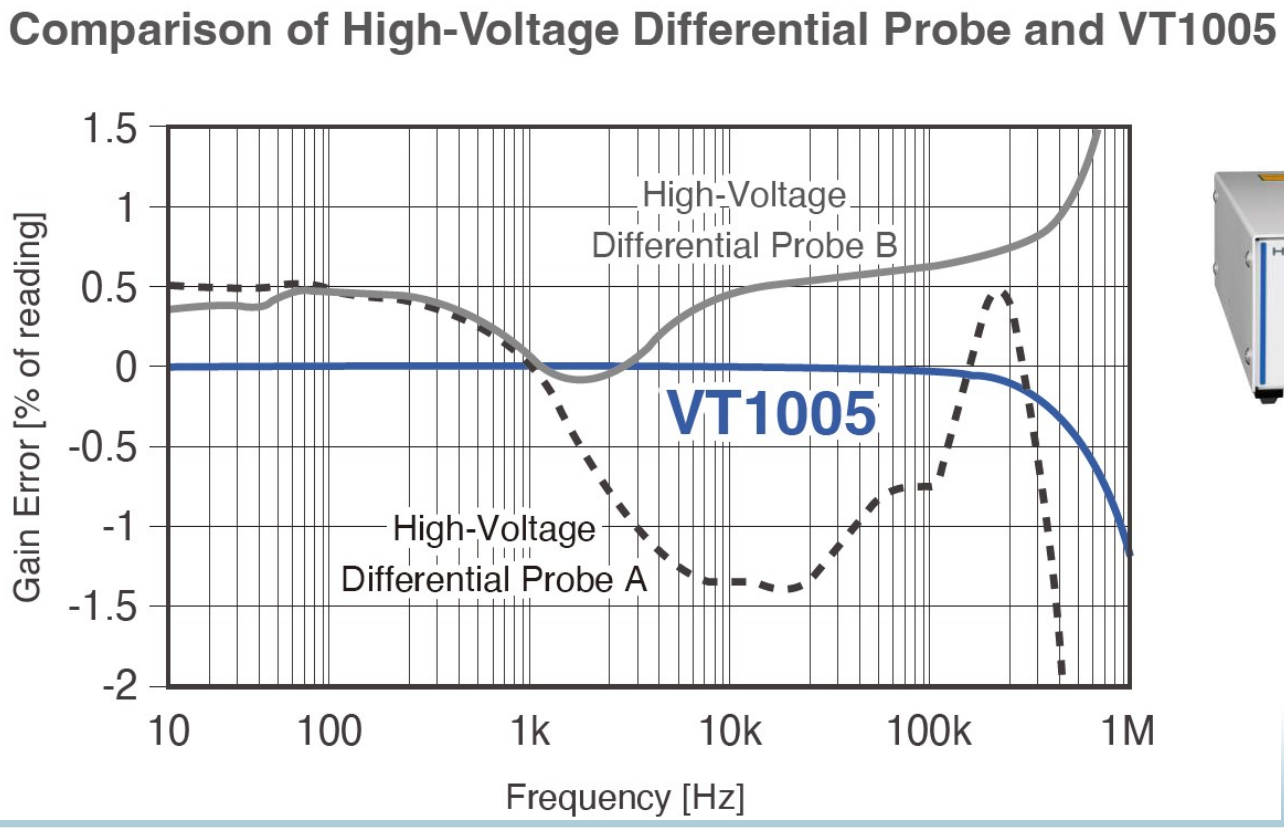
https://www.hioki.com/us-en/products/power-meters/power-analyzer/id_1265307

Transducers or Probes – Voltage

❖ Voltage Divider

[Hioki AC/DC High Voltage Divider VT1005]

https://www.hioki.com/us-en/products/power-meters/power-analyzer/id_1265307

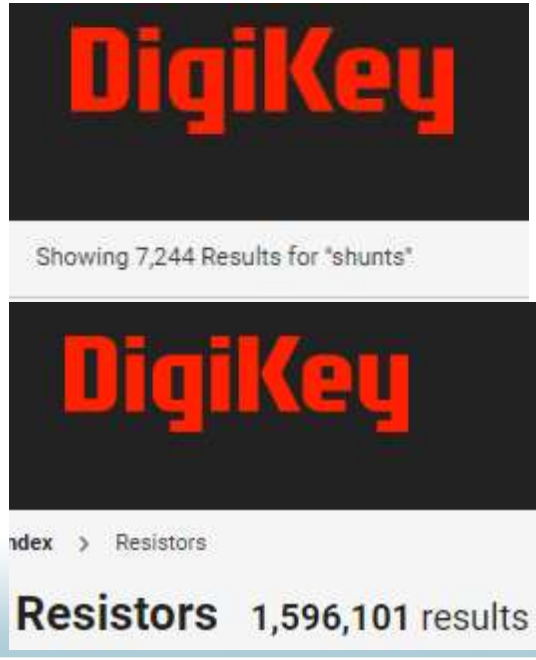


Transducers or Probes – Current

- **Shunts**
- **Clamps**
- **Non-Clamps**

Transducers or Probes – Current

- **Shunts : You better know what you're doing**
  - **Generally by far the lowest cost**
  - **Just Try It, Really! : Sometimes it is by far the best option**
  - **Low Resistive Isolation from Primary Current**
  - **Power Dissipation High**
  - **Reduced Insertion Impedance**
  - **Noisy**
  - **Environment or EUT**
    - ***LED Lighting in Lab***
    - ***Temperature Stability***
    - ***DV/DT coupling***



Transducers or Probes – Current

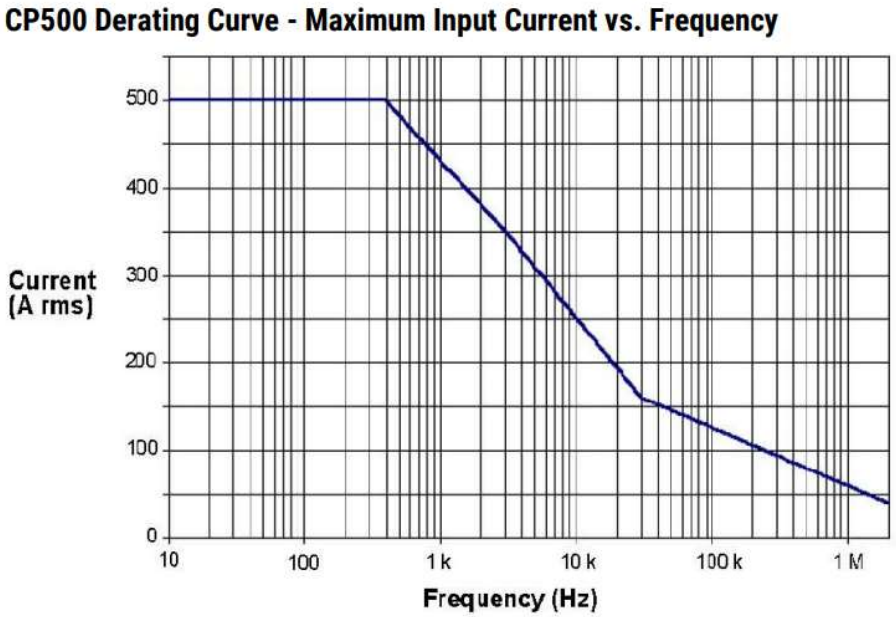
- **Clamps**
  - Always preferred : why not, easy to connect
  - Nearly never guaranteed < 1% Error
  - Often but not always the highest bandwidth option
  - Many Technologies & Trade-Offs : All have Gotchas
  - Hall Effect is expensive but often the best for general purpose starting point
  - Far more technology choices than any one company offers
  - Whatever one company/manufacturer or brand tells you is by far not the whole story

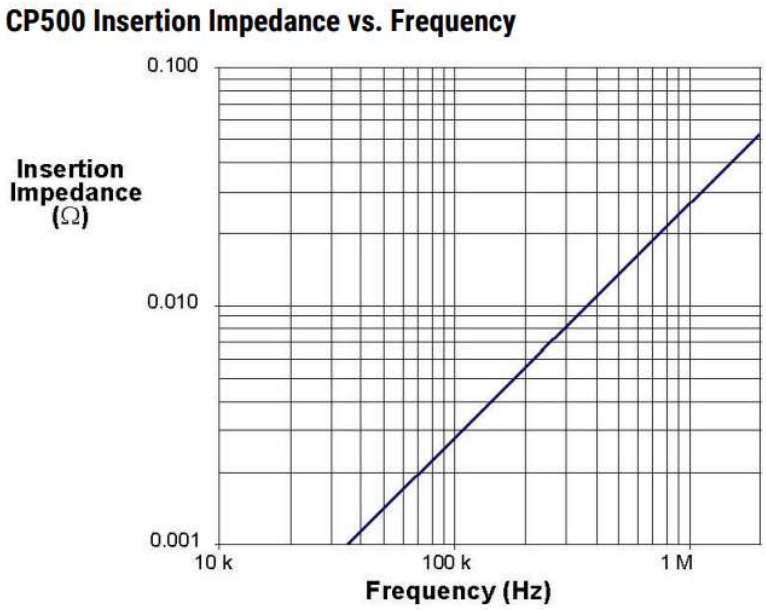
Transducers or Probes – Current

- **Clamps – more gotchas**
  - ***Great specs are often too good to be true***
  - ***Omit Amplitude Linearity but instead highlight full amplitude best case, which is almost never real world***
  - ***Amplitude Accuracy Decreases***

Transducers or Probes – Current

- **Clamps : Hall Effect Gotchas**
  - *Marketing Pushed : Flexible yes, but very expensive*
  - *Is the current Real?, or DV/DT coupling?*
  - *Derating Curves (above 1mΩ mostly core loss. I2R is mostly heat)* https://cdn.teledynelecroy.com/files/manuals/cp150-cp500-probes-manual.pdf





Transducers or Probes – Current

- **"Super Probe" ~ 1% Accuracy Clamp both DC & AC without the same derating : Multiple Probe Approach**
  - ***Would need instrument filters (High & Low Pass) to not overlap frequencies***
  - ***Deskew correction***

Example

- ***DC & Low Frequency AC: GMW's CPC Probe***
  https://gmw.com/product/cpc/
  - No magnetic core, unique technology
  - DC & AC options < 1 amp to 2 kA
  - AC to 20 kHz or to 75 kHz
  - Low Cost
- ***AC & High Frequency: Rogowski Coil***
  - Air Core
  - Up to 100 MHz and at high current
  - Low Cost

OEMs for best ones (with Integrator box) are **PEM** and **Iwatsu**, which are largely private labeled

Transducers or Probes – Current

- **Non-Clamps**
  - ***Transformers (not clamp versions)***
    - Pretty good for AC Only, < 1% Accuracy Error
    - Relatively Inexpensive
    - Very high frequency, 100s of Megahertz
    - No DC, gotcha!
  - ***AC & DC Requires a Combination of Technologies***
    - DC to X frequency, then > X a current transformer
    - PPM level Accuracy (10 ppm or less)
    - 10 MHz or less, usually < 1 MHz
    - About always 200 kHz or higher
    - Heating is a gotcha

Transducers or Probes – Current

- **Non-Clamp Gotchas for High Currents**
  - *Small aperture relative to a connector size*
  - *Connectors are connected to cable shield : disassembly/reassembly can be an undesirable task*
  - *If your Current Transducer is Linear & Accurate Enough at low currents (far better than clamps!!), get a larger one*

- **Best on Planet Earth Today Commercially Available**

[DaniSense Wide Band, Released in 2022: https://gmw.com/wp-content/uploads/2023/03/DW500UB-2V.pdf]

  - *Can do DC (Like a Hall Effect)*
  - *Can do High Currents (500 amps)*
  - *Accurate to Comparatively Low Currents <0.5% (unlike Hall Effect)*
  - *Highly Accurate 10 ppm (compare to 1% or worse Hall Effect)*
  - *High Frequency 10 MHz (> 5x more than Hall Effect Clamp)*
  - *Costs the same as a 500 Amp 2 MHz Hall Effect Clamp*

Transducers or Probes – Current (specs)

So, you want to be both thorough and really accurate?...

- Aperture Size
- Secondary Noise with respect to frequency
- Linearity Error on Secondary with respect to Amplitude
- Bandwidth (Both ± 1 dB and ± 3 dB)
- Offset Error
- Amplitude Error with respect to Frequency
- Phase Shift with respect to Frequency
- Current Output or Voltage Output
- Temperature Derating
- Accuracy at Lowest Amplitudes Curve

Transducers or Probes – Current

- **Best for Last Gotcha**
  - **Voltage Output**
    - **More easily picks up DV/DT Noise Coupling**
    - **Is this Real?, is a more complicated question**
    - **The only choice for many instruments**
  - **Current Output**
    - **Power Analyzers have Current Inputs**
    - **Not susceptible to DV/DT Noise Coupling**
    - **Should always be the preferred if possible**

Acknowledgements for Patient Teachers

- Many, Many Customers – Thank You
- Yokogawa – too many to mention + Dan Kasamis
- Ian Walker – Co-Founder and the "W" in GMW
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- Barry Bolling – Hioki today, formerly with Yokogawa
- Mike Mende – President of PMK America, >50 probe design patents over 30 years
- TecRep Corporation team