Use of a Power Monitor with Multiple Inputs to Improve Opportunities for System Accuracy and Power Savings

Mitch Polonsky
Microchip Senior Product Marketing Manager
Mitch.Polonsky@microchip.com
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Agenda

- **Monitoring power and energy – why?**
- **Monitoring power and energy – how?**
  - Traditional methods
  - A more modern approach
- **Current sensor market overview**
- **Use case to measure multiple voltage rails in a Kaby Lake Intel System**
- **Discussion**

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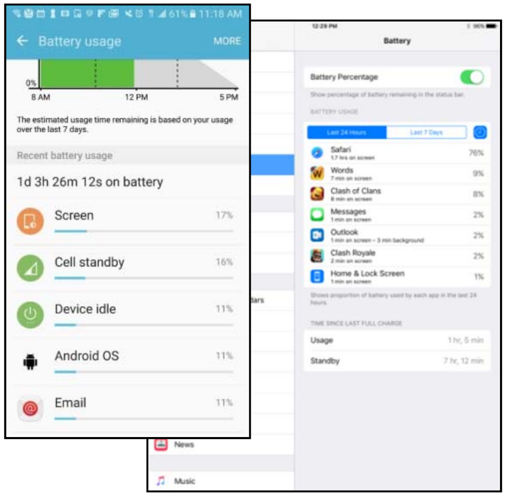
Industry Trends and Insights

- Cell Phones report on application power usage
- Laptops & some tablets report on application power usage



- Windows 10 systems are <u>only 70%</u> accurate <u>without a power monitor IC</u>

E3 Software Estimation vs. Hardware Measurement

E3 Configuration	Approximate accuracy per power model			
	CPU	Storage	Display	Network
Software Estimation *	87%	<70%	<70%	<70%
Hardware Measurement **	98%	98%	98%	98%

Source: Microsoft Fall WINHEC 2017

Windows PC, Power Measurement and Error

- Software estimation
  - Relies on the CPU measurement
  - Relies on system modeling power in WIN10 OS
- Hardware estimation and requirements
  - Series resistors (1%) are used to measure power
    - Kelvin connectors
    - Sense resistor 2-20 mΩ (for the case of a PC)
      - Value based on the full scale load and current desired
      - Full scale voltage was based on 100mV (in this case)
  - Simultaneous sampling (ADC for V & I desired)
  - Known time stamp and always sampling
  - Synchronizing multi-rail measurement
  - High common mode range up to 20V rail to rail

Measurement Accuracy of Vsense and Vbus

V_{SENSE} Measurement Accuracy						
V_{SENSE} Gain Accuracy	$V_{SENSE\_GAIN\_ERR}$	—	±0.2 ±1	±0.9	% %	At +25°C typical, –40 to +85°C
V_{SENSE} Offset Accuracy, referenced to input	$V_{BUS\_OFFSET\_ERR}$	—	±0.02 ±0.2	±0.1	mV mV	At +25C° typical, –40 to +85°C
V_{BUS} Measurement Accuracy						
V_{BUS} Gain Accuracy	$V_{BUS\_GAIN\_ERR}$	—	±0.02 ±0.2	±0.5	% %	At +25°C typical, –40 to +85°C
V_{BUS} Offset Accuracy, referenced to input	$V_{BUS\_OFFSET\_ERR}$	—	±1 ±2	—	LSB LSB	At +25°C typical, –40 to +85°C

- Resistor error and device error should be added linearly for maximum error
- On the following slides we will review the device error

Vsense Error vs Input Voltage and Temperature

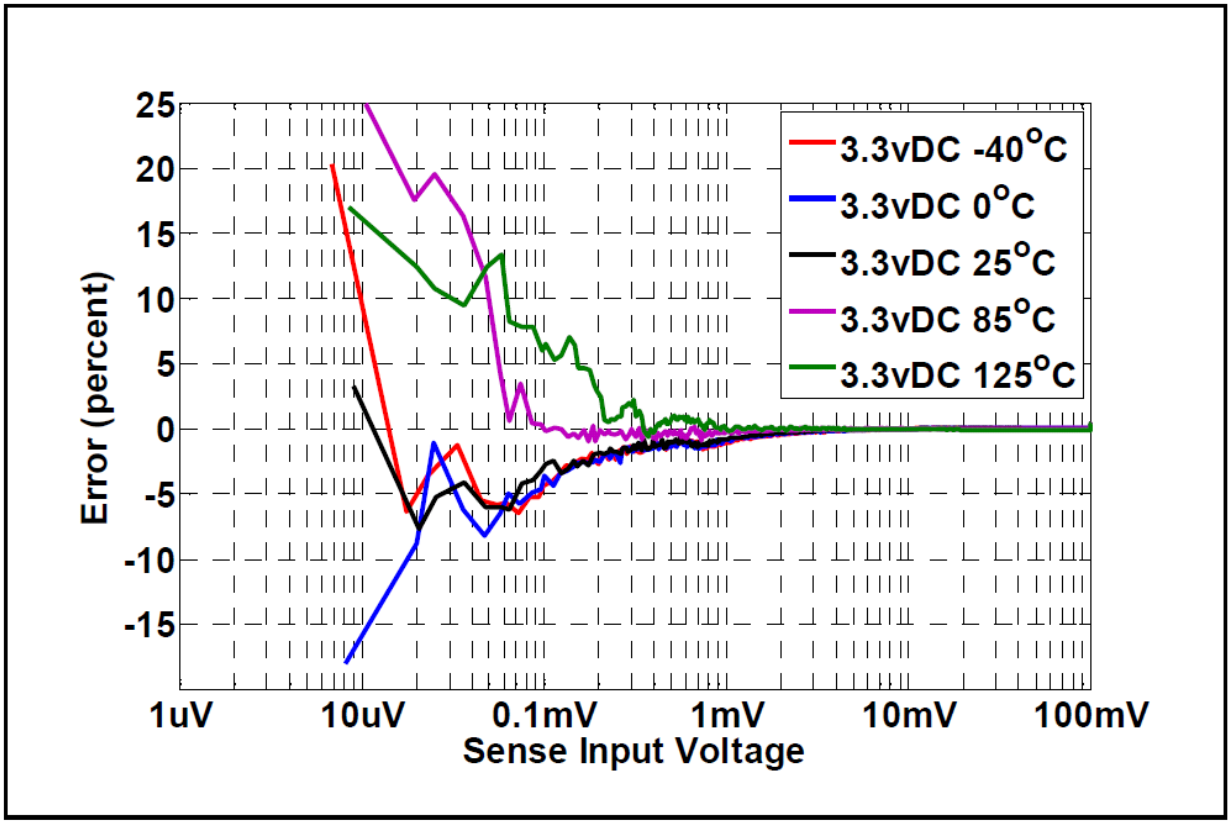


FIGURE 2-4: *V_{SENSE} Error vs. V_{SENSE} Input Voltage and Temperature.*

- Error converges after 0.5 mV Vsense input voltage
- Data sheet is for a 0 to 32 V common mode voltage

Vbus Error vs Vbus Input Voltage and Temperature

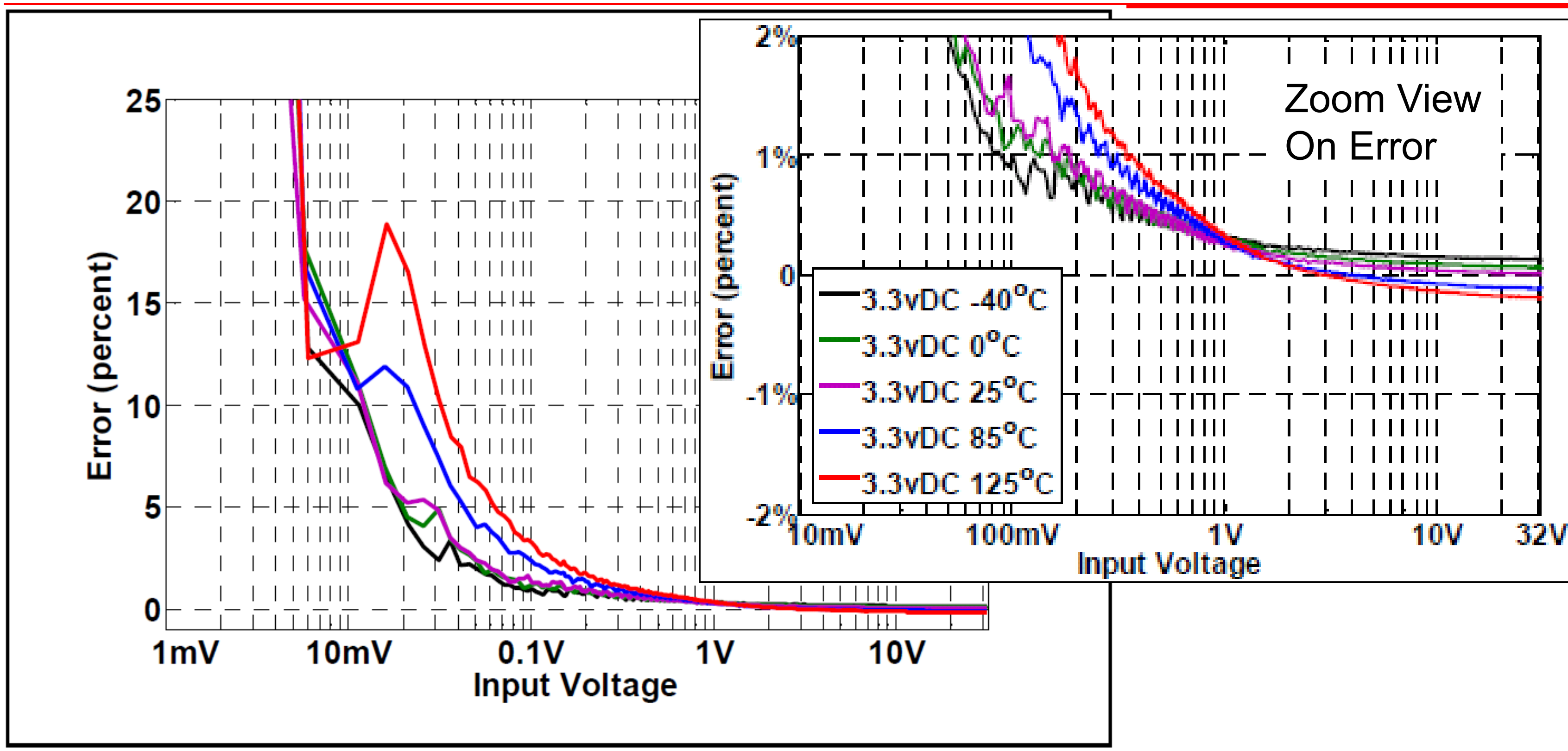


FIGURE 2-10: *V_{BUS} Error vs. V_{BUS} Input Voltage vs. Temperature.*

- Error converges after 0.5 V Vbus input voltage

Measurement Error Example

Actual power = 12V x 1A = **12W**

Vbus =12V at I = 1A

Vsense = 50mV (Rsense= 50 mohm)

Measured power:

Vbus = 12(1+gain error) +offset = 12(1.005) +976uV =

12.06098V

Vsense = Vsense(1+gain error) + offset = 50mV(1.009)+0.1mV =

50.55mV

Rsense = .05 ohm (.99) = .0495 ohm [1% resistor]

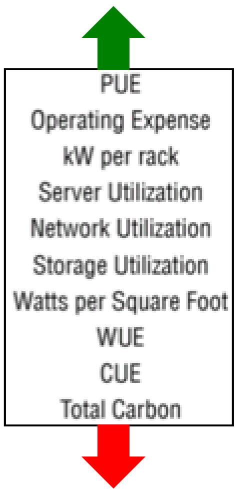
Current = 50.55mV/(.0495) ohm = 1.0212A

Measured Power = 12.06098 x 1.0212A = **12.31666W**

Error = .317W = .317/12 = .0264 = **2.64%**

Industry Trends and Insights

Data Center Management



- Cost of server ownership is in the utility cost
- Power Use Effectiveness (PUE)
  - Non-computing energy takes 45% - 60% of total energy
  - Top ranked concerns of executives in the industry
  - Thermal and energy management has become a key challenge in the design and operation of data centers.
- Office of Management and Budget (2016) set target PUE <1.5

PUE	DCiE	Efficiency Level
3.0	33%	Very Inefficient
2.5	40%	Inefficient
2.0	50%	Average
1.5	67%	Efficient
1.2	83%	Very Efficient

Data Center Infrastructure Efficiency

$$\frac{\text{IT Equipment Power}}{\text{Total Facility Power}} \text{X}100\%$$

Why DC Power/Energy Monitoring

- **Why are companies using this feature**
  - Actively managing total system power & limits
    - Inform end user and help alter their behavior
      - Running out of power and battery
      - Power providers are assessing out of range conditions
    - C-connectors enable adaptable power scenarios
  - Configuring for different run conditions saves power
  - Measurement and reporting
    - The laptop, tablet & cellular WIN10 battery utility
    - Monitor efficiency, aging, and faults

Measuring Power

- **Traditional methods**
  - Use op amp circuits for high side current sensing and voltage monitoring
  - Outputs of these circuits are fed to and ADC followed by a processor/controller
  - Controller controls the ADC and multiplies current x voltage to get power
  - Take many measurements over time
  - Store results, and calculate energy usage
  - Discrete resistors mean reduced accuracy or expensive calibration

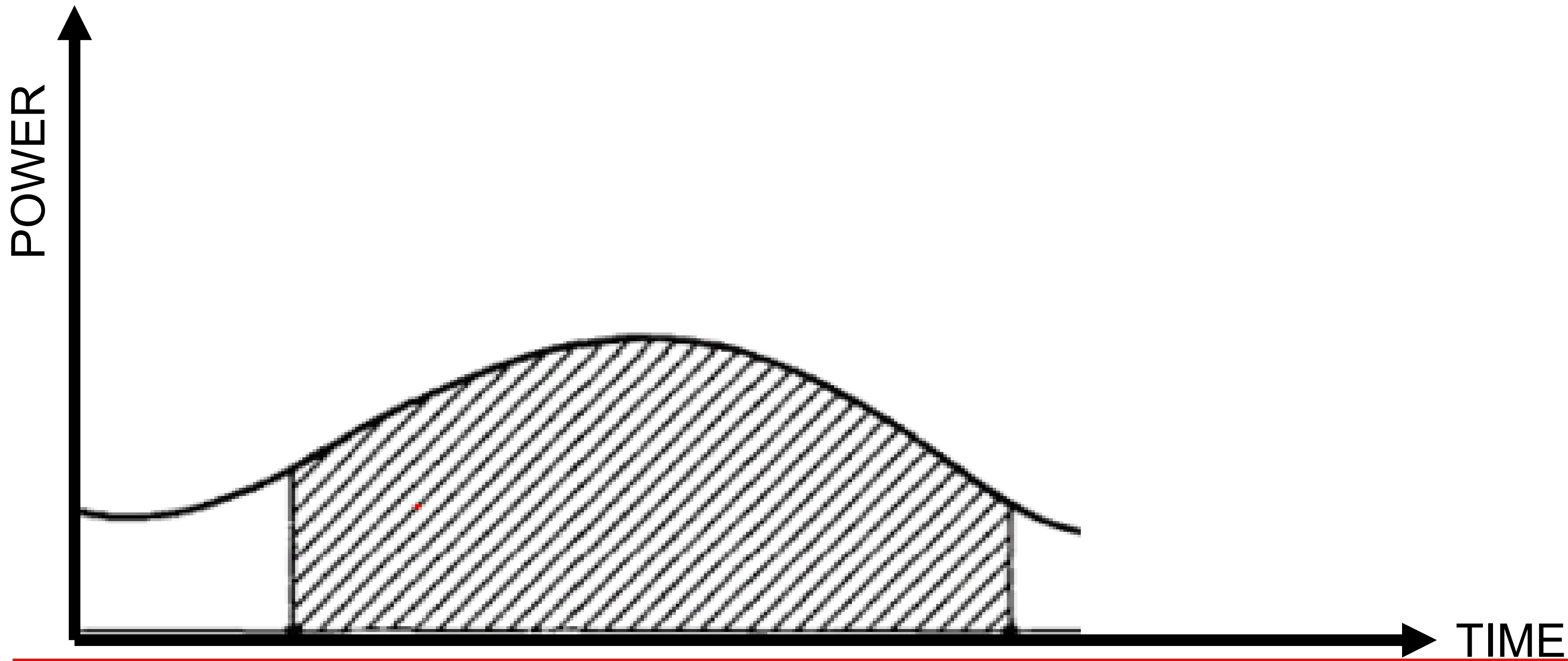
Instantaneous vs Acummulatd Power

Instantaneous Power

Instantaneous power (in watts) : the power at any instant of time

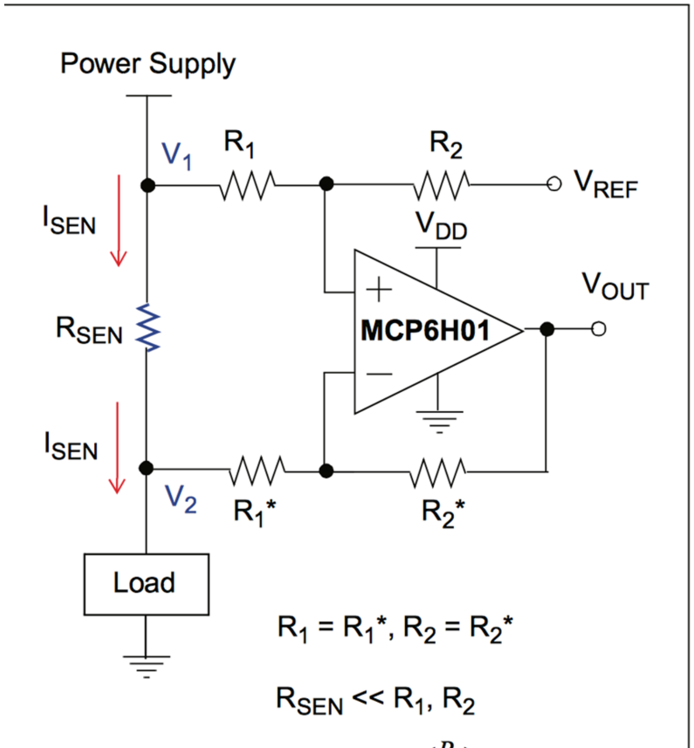
$$p(t) = v(t) \times i(t)$$

Versus Accumulated Power (Energy)



Measuring Power

- **Discrete Current Sense Amplifier example**



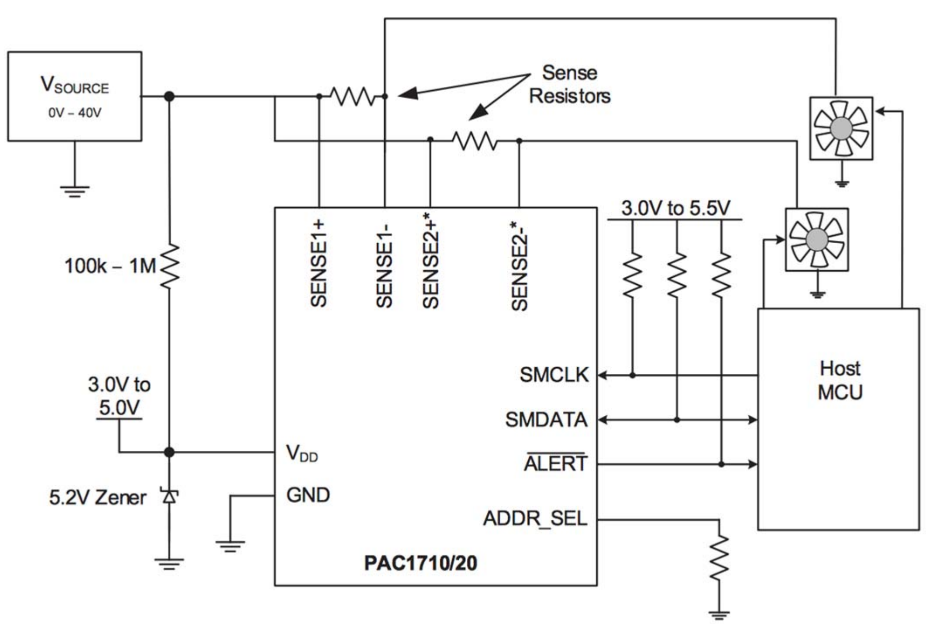
$$V_{OUT} = (V_1 - V_2) \cdot \left(\frac{R_2}{R_1}\right) + V_{REF}$$

Discrete resistors add error
Requires ADC at output

ADC errors also contribute to final error via quantization

A More Modern Approach

- **Use a Power Monitoring IC**
  - Incorporates high side current monitor, bus voltage monitor, and ADC
  - Factory calibrated



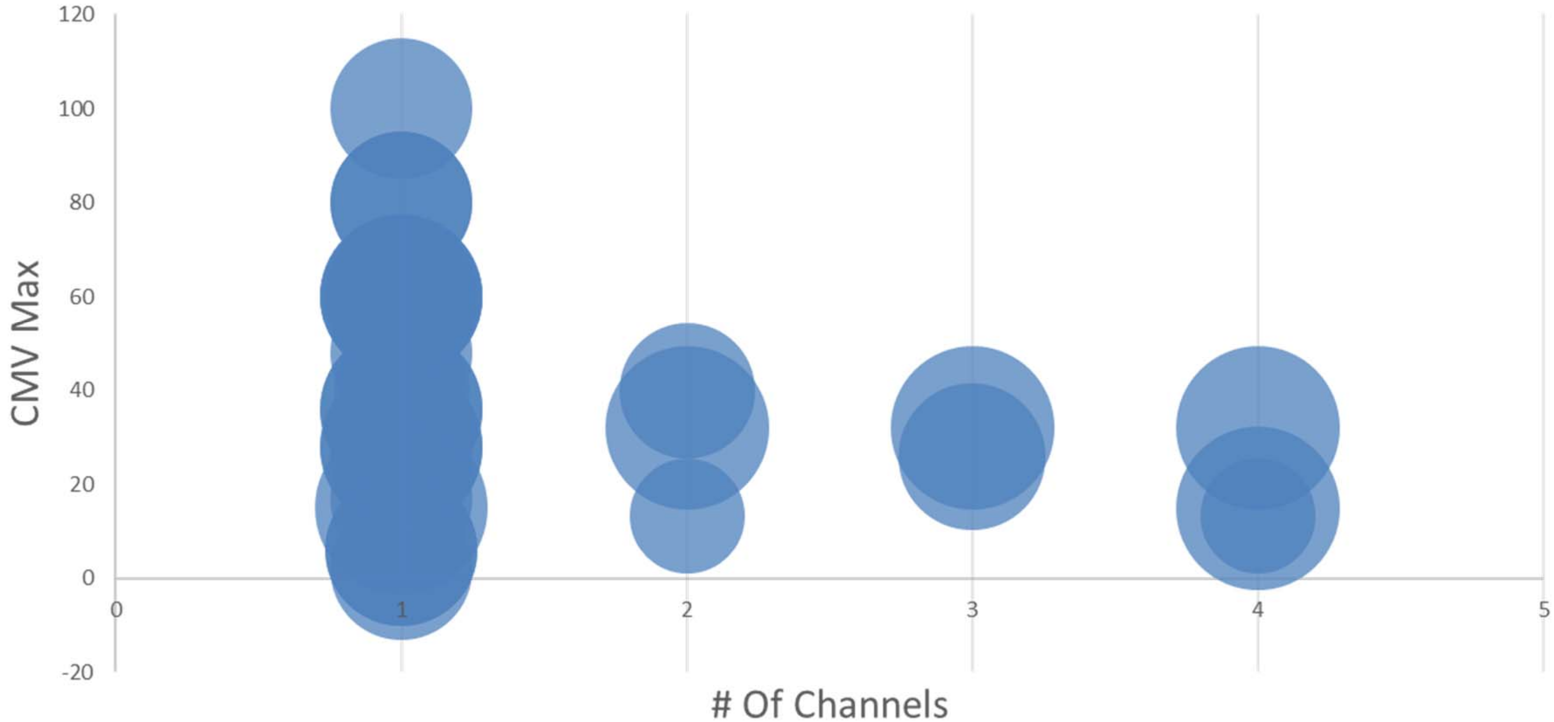
PAC1720 example
Only sense resistors affect accuracy

Energy Measurements

- The easy way to do energy measurements: use a power monitoring chip
  - I2C/SMBus interface
  - Most report on current, voltage and power
  - Simplifies energy calculation when used with a known time stamp from the system host
    - Host can command the beginning and end of the integration period
  - There are on the order of 40 I2C current sensor devices in the market
    - This does not include ASSPs (i.e. hot swap controllers)

High Level I2C Current Sensor Market Offerings

Common Mode Voltage of Current Sensor

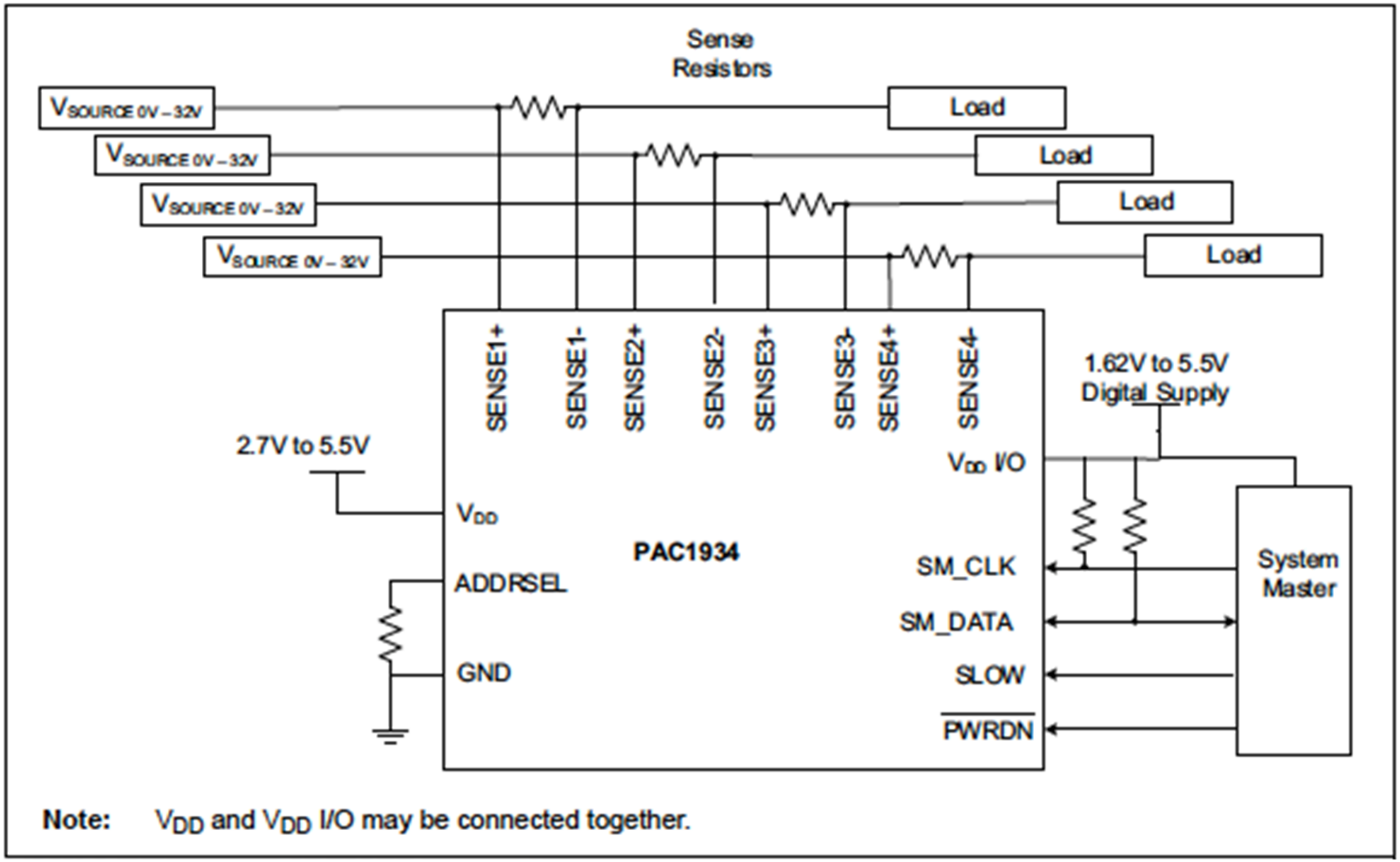


- Circle size is resolution 8 to 18 bits
- Full scale range is normally 10 mV to 100 mV

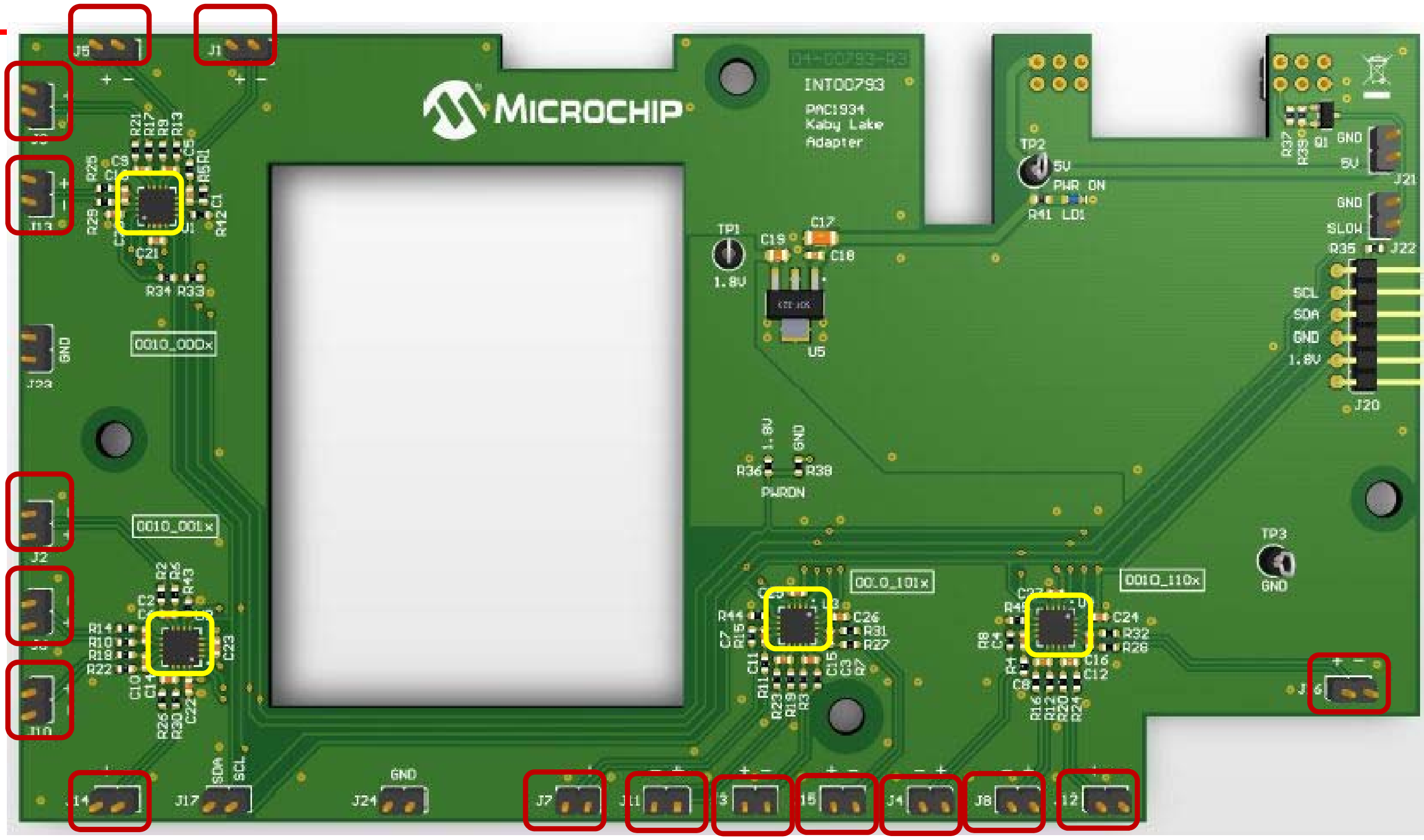
Tracking Power in Intel Reference Design

- 4x PAC1934 installed on an add-on board for Intel Kaby Lake validation system
- Sense resistors on the motherboard are wired to the add-on board
- Windows 10 driver used to facilitate data collection and interface to Windows E3 application via Energy Metering Interface
- These acronyms are explained shortly

Basic Applications Circuit



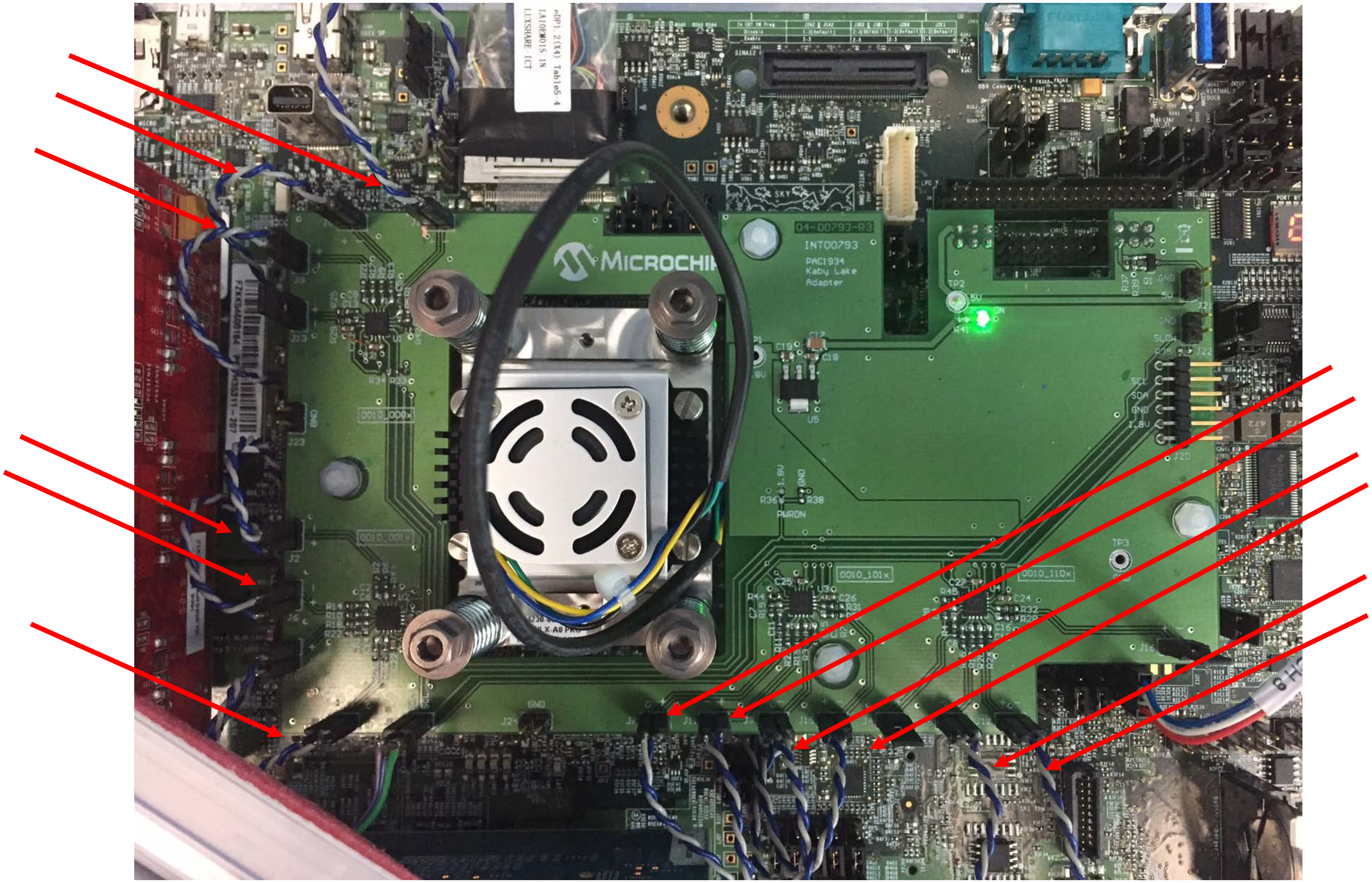
Kaby Lake Modification to Read 12 Current Sensors



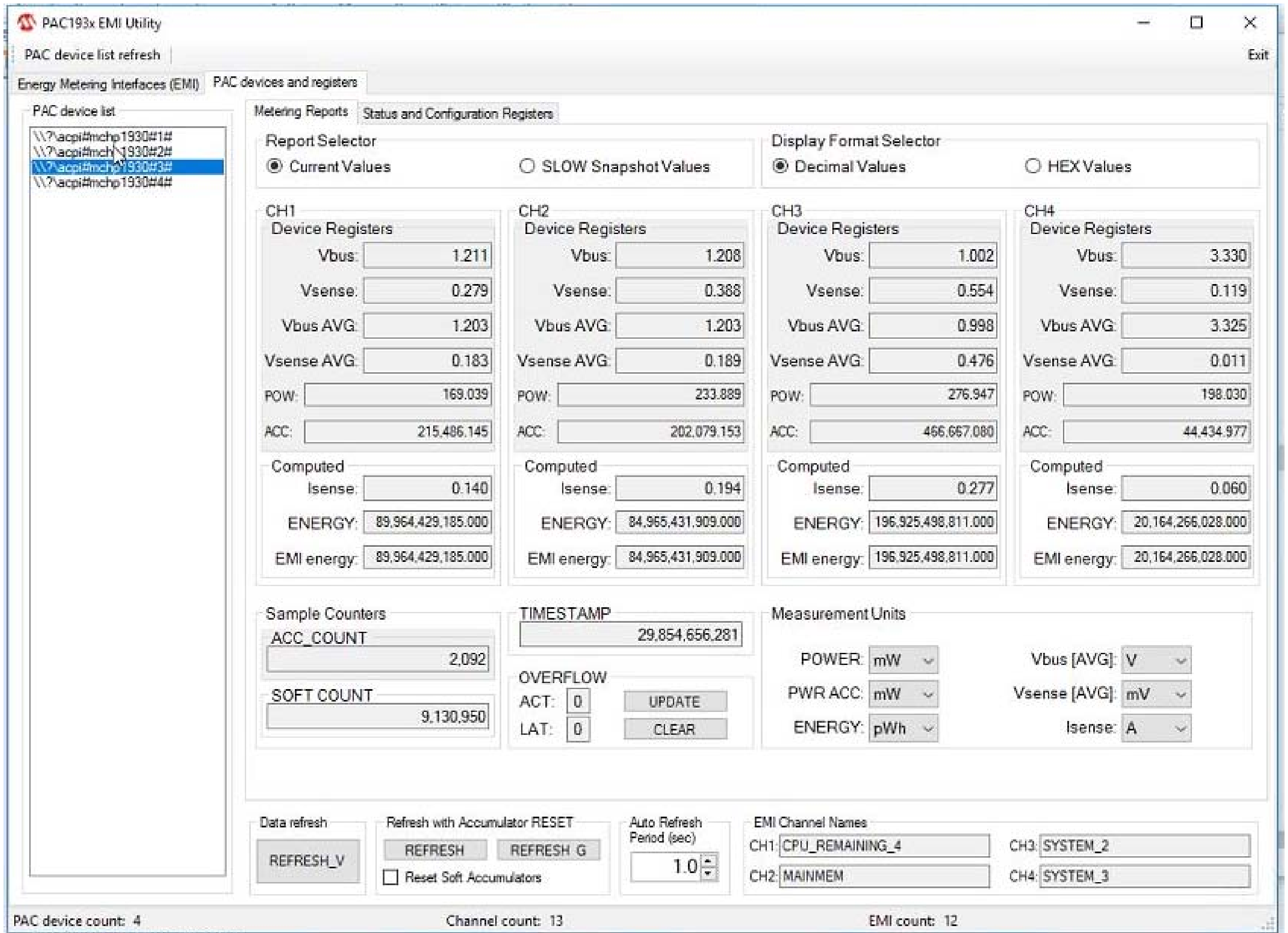
The square hole fits over the heatsink on the processor. The two pin terminals around the outside are for the pairs of sense resistor wires.

- QFNs are 4 channel PAC1934 devices

4 x 4 channels = Only 12 Channels Used



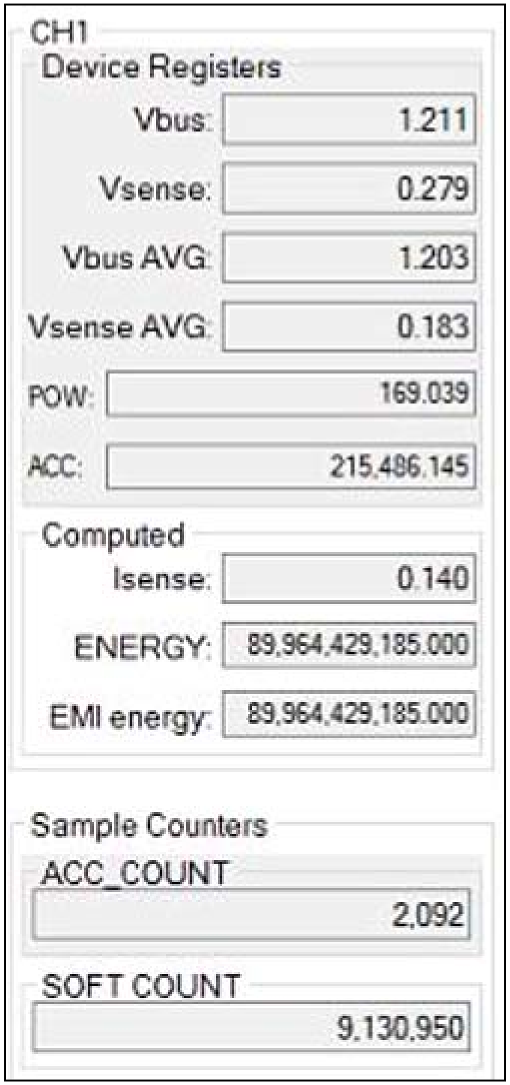
PAC1934 EMI Utility (Energy Metering Interface)



This Metering Reports tab lists all PAC devices in the system at upper left.

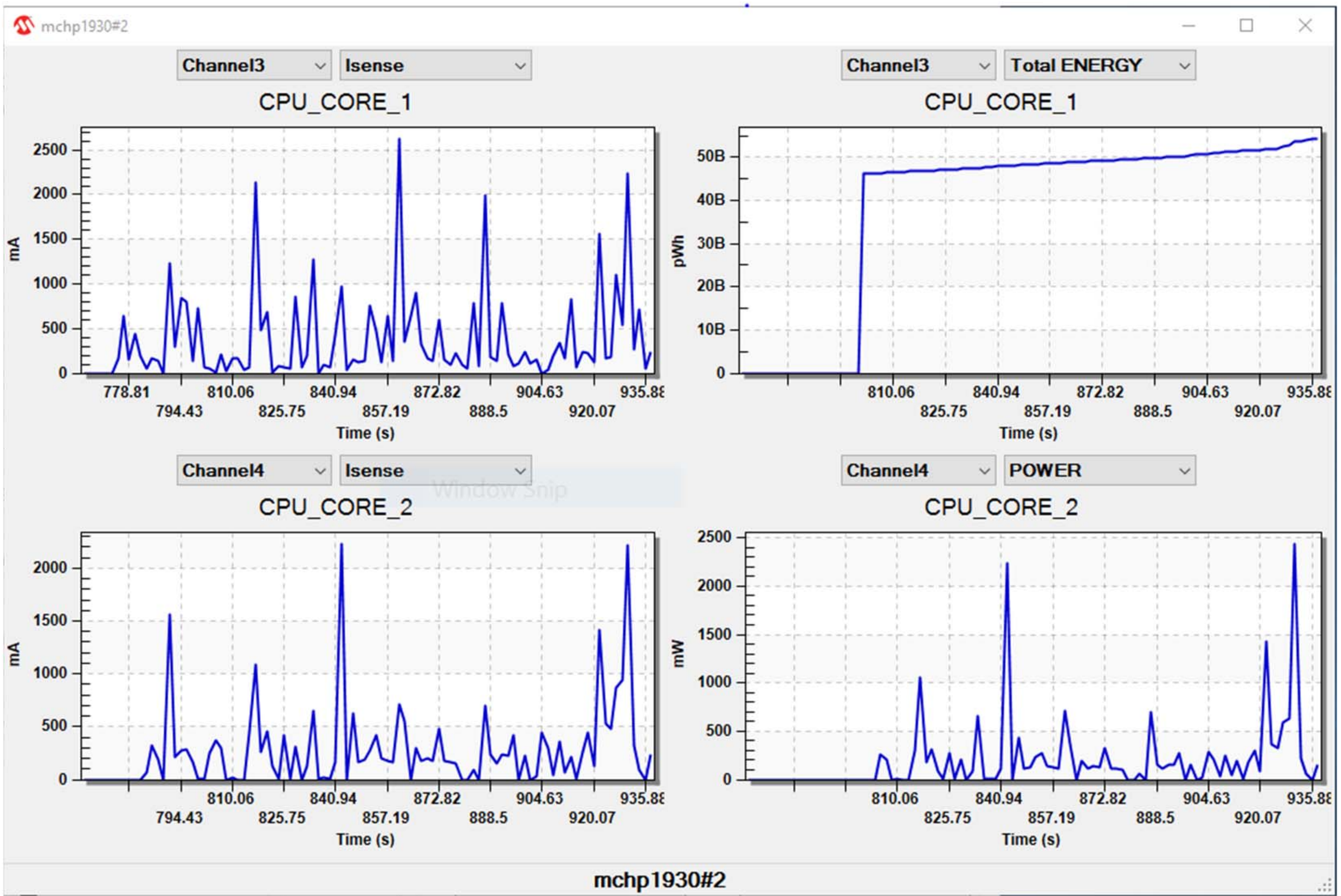
Detailed results are shown for all four channels of the selected devices.

Channel 1 Zoomed In



- **Vbus**
- **Vsense**
- **Power**
- **Accumulated Power**
  - EMI Energy can be shown in a windows PC OS
  - Soft Count is an ongoing count of samples after a refresh

PAC1934 Energy Metering Interface Utility

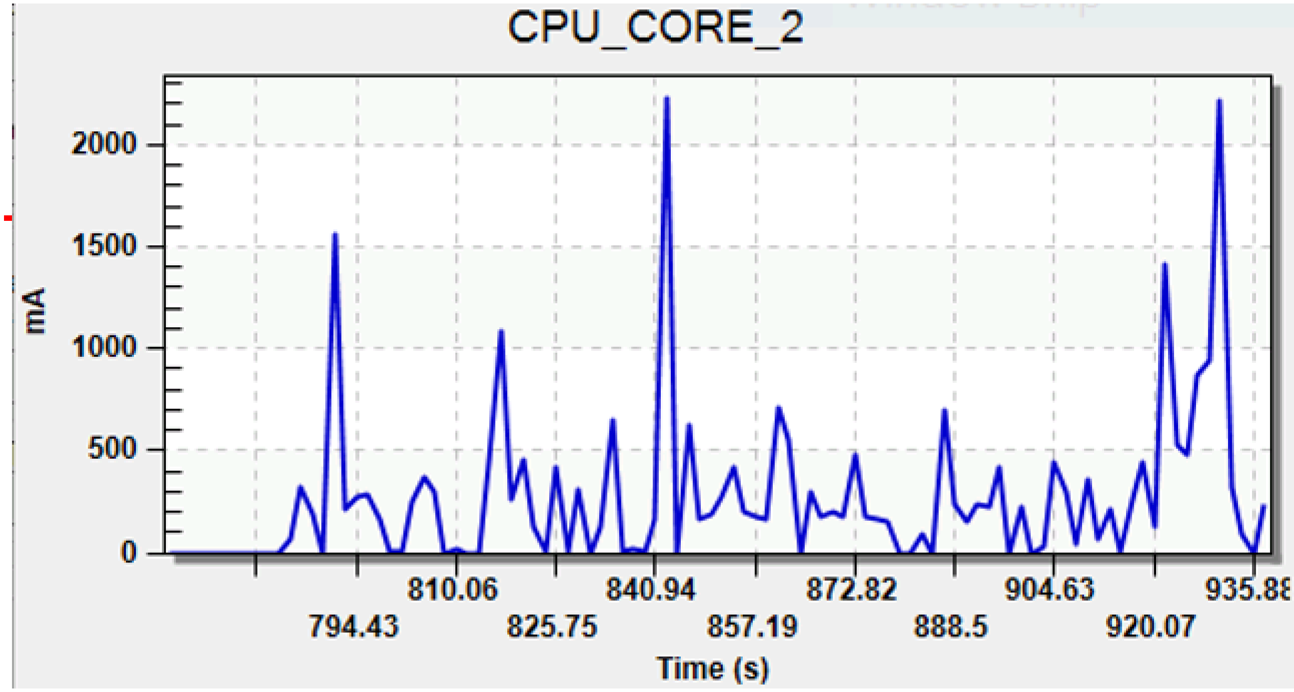


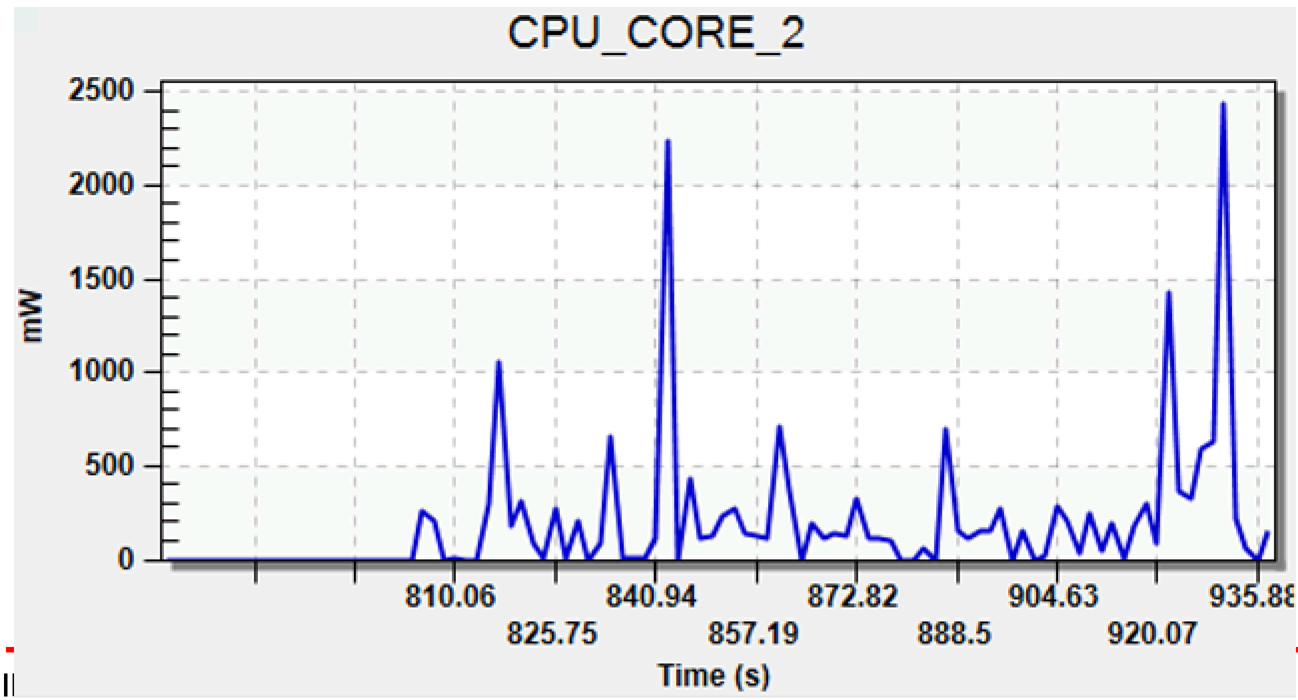
This Utility has versatile plotting capabilities.

You can see that power tracks Isense well, but Energy tells a a different story.

- You can see this tracks Isense well

Energy Metering Utility





ZOOM Image

Tracks Isense with power

Microsoft Power View
Single Application Use Data

EnergyLoss	CPU	Soc	Display	Disk	Network	MBB	Other	Emi	Total (millijoules)
0	995780	0	924564	82402	42609	0	0	0	2045355

View | Log File | Compare+ | X | AppID | ScreenOn | OnBattery | BatterySaver

e3report-estimated-10 | ALL | ALL | ALL

1	Tier1 %		Tier2 %		A|	App	Oc	TimeInM	Microwatts	En	CPU	Sc	Display	Disk	Netwo	MBB	Other	Emi	Total
42.6 %	CPU	95.8 %	DISK	4.2 %	Mi	Microsoft.ZuneVideo_10.1	9	540001	1614871.08	0	835516	0	0	36516	0	0	0	0	872032
24.4 %	DISP	100 %	CPU	0 %	\D	LogonUI.exe	10	599987	830584.66	0	100	0	498240	0	0	0	0	0	498340
18.3 %	DISP	98.9 %	CPU	1.1 %	\D	Taskmgr.exe	8	479991	778872.94	0	4015	0	369837	0	0	0	0	0	373852
8 %	CPU	74.3 %	NET	25.7 %	\D	svchost.exe [NetworkServi	10	599987	273540.93	0	121861	0	0	1	42259	0	0	0	164121
2 %	DISK	89.5 %	CPU	9.6 %	Sy	System	10	599987	67926.47	0	3919	0	0	36486	350	0	0	0	40755
1.8 %	DISP	94.9 %	DISK	4.9 %	\D	conhost.exe	2	119996	310735.36	0	61	0	35403	1823	0	0	0	0	37287
0.8 %	DISP	77.8 %	DISK	16.9 %	\D	doublecmd.exe	2	119996	132262.74	0	840	0	12345	2686	0	0	0	0	15871
0.7 %	CPU	99.5 %	DISK	0.5 %	\D	dwm.exe	20	1199974	12241.1	0	14614	0	0	75	0	0	0	0	14689
0.5 %	DISP	90.7 %	CPU	9.2 %	\D	explorer.exe	10	599987	15362	0	846	0	8357	14	0	0	0	0	9217

- Consolidated essential data on the next slide
- WIN10 allows for isolating the power consumed by key sources plus identified energy metering interface (EMI)

Microsoft Power View Single Application Use Data

- Power view
  - Reports in millijoules
  - CPU, SOC, display, disk, network, MBB, other, EMI
- Selected rows show total
  - Listening to music on headphones, network being assessed, and having the web open

Resource Application	CPU	SOC	Disp	Disk	Ntwk	MBB	Othr	EMI	Total millijoules
System	995780	0	924564	824564	42609	0	0	0	2045355
ZuneVideo	835516	0	0	36516	0	0	0	0	872032
svchost	121861	0	0	0	42259	0	0	0	164121
Explorer	846	0	8357	14	0	0	0	0	9217

Microsoft Power View Apps Show EMI Utility Use

View

EnergyLoss	CPU	Soc	Display	Disk	Network	MBB	Other	Emi	Total (millijoules)
0	2443536	0	1796150	73297	42690	0	0	5351616	9707289

Log File | Compare+ | X | ☑ | AppID | ScreenOn | OnBattery | BatterySaver

e3report-pac1934-10m | | ALL | ALL | ALL

1	Tier1 %		Tier2 %		A		App	Oc	TimeInM	Microwatts	En	CPU	Sc	Display	Disk	Netwo	MBB	Other	Emi	Total
21.2 %	CPU	98.3 %	DISK	1.7 %	Mi	Microsoft.ZuneVideo_10.1	10	599995	3424085.2	0	2019467	0	0	34967	0	0	0	0	2054434
18.5 %	EMI	100 %		0 %	EN	EMI_DISPLAY_BACKLIGHT	10	599995	2993618.28	0	0	0	0	0	0	0	0	1796156	1796156
9.7 %	EMI	100 %		0 %	EN	EMI_CPU_CORE_1	10	599995	1565836.38	0	0	0	0	0	0	0	0	939494	939494
9.7 %	DISP	100 %	CPU	0 %	\D	LogonUI.exe	10	599995	1563169.69	0	284	0	937610	0	0	0	0	0	937894
9.1 %	EMI	100 %		0 %	EN	EMI_CPU_CORE_2	10	599995	1467448.9	0	0	0	0	0	0	0	0	880462	880462
8.4 %	DISP	98.8 %	CPU	1.2 %	\D	Taskmgr.exe	9	539991	1515341.92	0	10047	0	808224	0	0	0	0	0	818271
7.2 %	EMI	100 %		0 %	EN	EMI_SYSTEM_1	10	599995	1168399.74	0	0	0	0	0	0	0	0	701034	701034
3.8 %	EMI	100 %		0 %	EN	EMI_CPU_REMAINING_3	10	599995	608023.4	0	0	0	0	0	0	0	0	364811	364811
3.4 %	CPU	87 %	NET	13 %	\D	svchost.exe [NetworkServi	10	599995	545871.22	0	284843	0	0	9	42668	0	0	0	327520

- **We are now able to separate and read the individual voltage rails on the EMI (energy metering interface)**

Microsoft Power View
Single Application Use Data

- Power view
- Selected rows now show measurements for the
  - Display Backlight
  - CPU Core 1

Resource Application	CPU	SOC	Disp	Disk	Ntwk	MBB	Othr	EMI	Total millijoules
System	2443536	0	1796150	73297	42690	0	0	5351616	9707289
ZuneVideo	2019467	0	0	34967	0	0	0	0	2054434
EMI_Display _Backlight	0	0	0	0	0	0	0	1796156	1796156
EMI_CPU_Cor e_1	0	0	0	0	0	0	0	939494	939494
svchost	284843	0	0	9	49668	0	0	0	327520

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Accurate Knowledge by Software Application Enabled

- The Kaby Lake modification uses sense resistors and a power monitoring IC to measure exact voltage rails
- A WIN10 driver and energy metering interface communicates specified rails to the OS
- These voltage rail can now be seen by Microsoft power view utility to report power by software application

Take Aways

- Adding a power monitoring IC enhances our ability to collect measurements and minimize measurement error.
- If you use a power monitor with an accumulator it enables you to see the energy use by rail over time

The power monitoring system demonstrated by this case study greatly enhanced visibility and understanding of power/energy utilization in key loads/subsystems.

Discussion/Q&A

- **Thank you! Questions?**