Cyntec

An Introduction to Current Sensing Resistor

Where Can They Be Used?

- General use
  - Power Supplies, Disk drives, Battery power management, Control of current detection or over-current detection, Motor start
- Consumer Goods
  - Power tools, Thermostats, Appliances, Televisions, Smoke detectors, Video Cassette recorders
- Automotive
  - Anti-lock brake system, Keyless entry systems, Air bags, Power Steering, Control systems, Voltage regulators, Power Train, Information centers as well as engine controls modules
- Telecom
  - Telephones, Cell Phone, Pagers, Mobile radios, Hand-held devices and laptops
- Medical & Instrumentation
  - Monitoring systems, Pressure sensors, Implant products, Electronic scales
- Military & Aerospace
  - Satellites, missiles, surveillance equipment, Sonar and avionic products

Designing with Current Sense Resistors

1. Value

Determine the minimum suitable resistance value. This is the lowest value of peak sense voltage consistent with an acceptable signal to **noise ratio**, divided by the peak current to be measured.

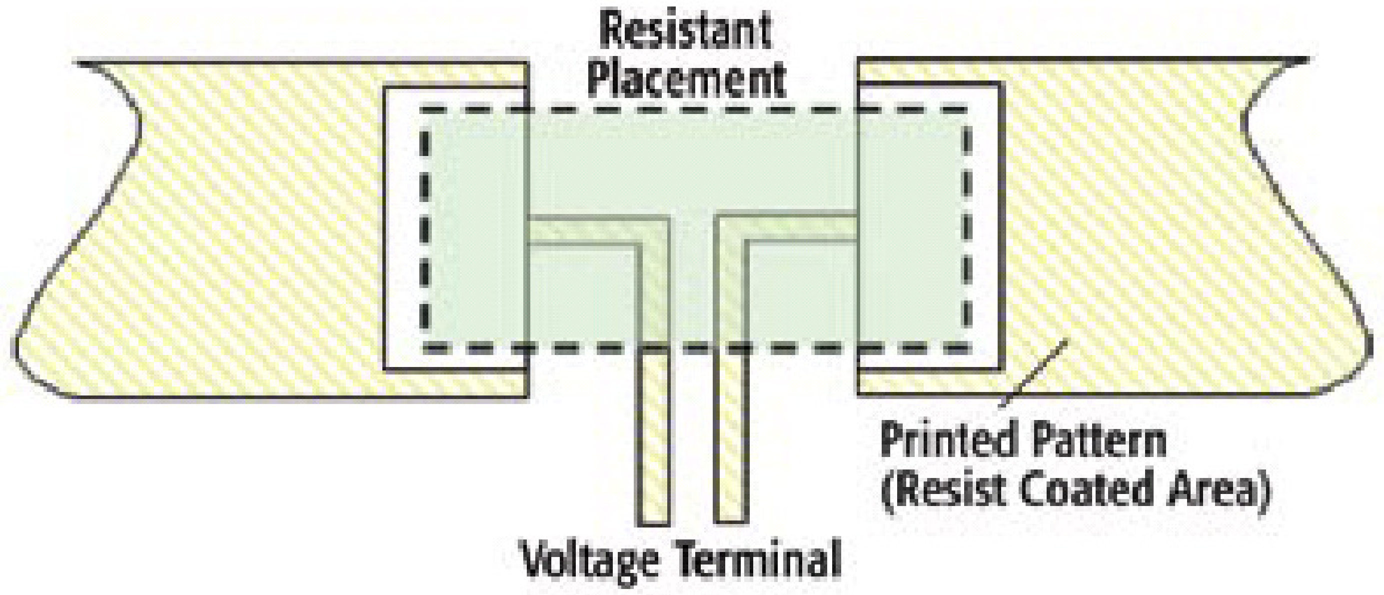
2. Tolerance & TCR

Establish the accuracy needed in terms of a tolerance on the value and of sensitivity to temperature. The latter factor is quoted as Temperature Coefficient of Resistance (TCR), **defined as the value change in parts per million for a 1°C temperature rise**. It is generally higher for **low** value resistors because the **metallic leads** or terminations, which have a very high TCR, make up a significant part of the total resistance value. To achieve acceptable **accuracy** it is normally necessary to make **four-terminal (Kelvin) connections to the resistor**. This means connecting the current carrying tracks and the voltage sense tracks directly to the component pads. Even when this is done, there is still some pad area and solder in series with the resistor, which may compromise the actual tolerance and TCR of the soldered part. For very high accuracy or very low values, **a four-terminal resistor type should be chosen**.

Practical Method to Measure The Current

Kevin's

Four Point Probe Method



It's convenient to add a resistor to the network to measure the electric current, Measuring the voltage across the resistor indicates the current that flows through it, But when the resistance is very low, the resistance of the printed circuit pattern may cause error to th measurement.

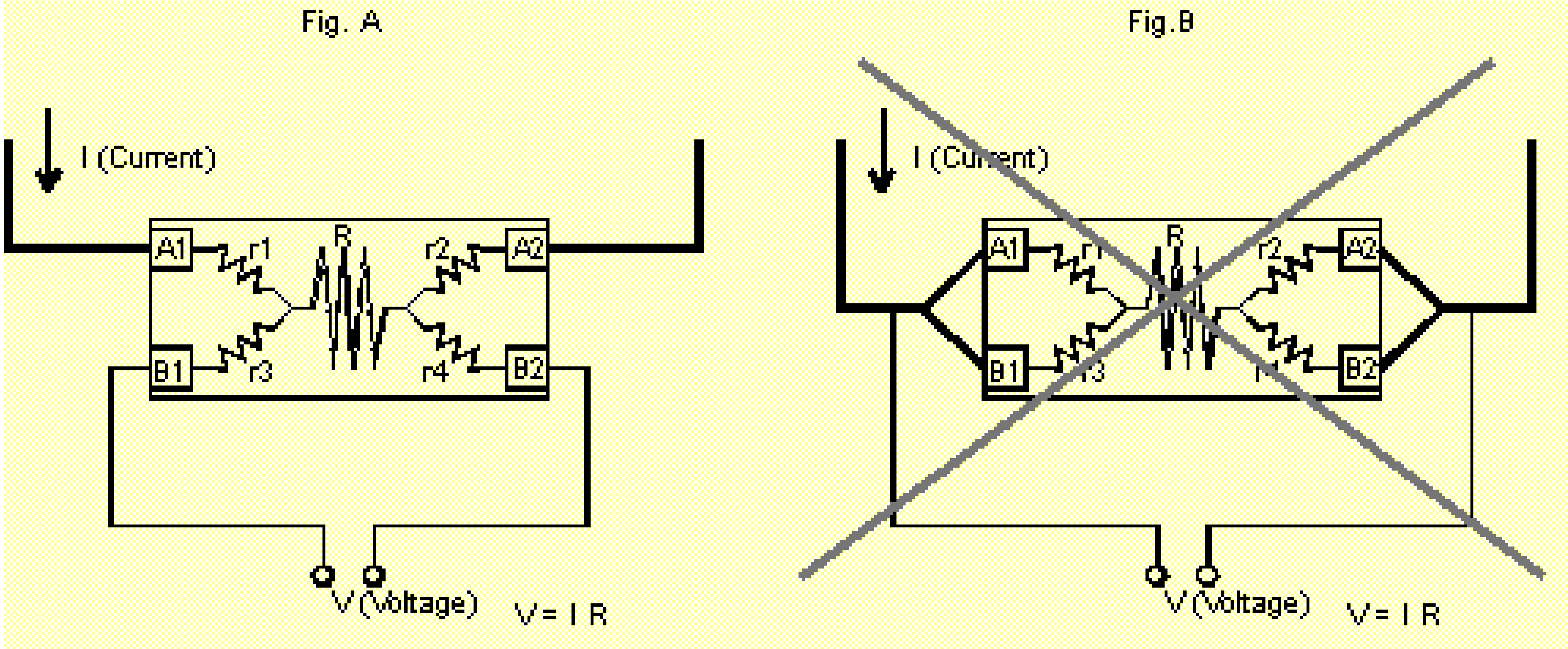
Current Sensor's Terminal Construction

As low as one milliohms, two-terminal construction is accepted for the DC/DC converter. However, when better accuracy is requite, four-terminal resistor are available. Four-terminal construction will reduce as mounted resistance tolerance variations

- Reduce lead resistance
- Reduce TCR of copper terminal
- Reduce TCR of solder joint

Four-Terminal Resistor and Kevin Conection

Four-Terminal **Kevin Conection**



Though voltage generates at the **both ends of terminal resistors in a current circuit**, it is not included in a voltage sensing circuit so it need not be considered. Each terminal resistor (r3 and r4) is quite small related to impedance in a voltage sensing circuit, **so it is possible to measure the current accurately without any consideration about resistance**

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Designing with Current Sense Resistors

3. **Power Rating**

Calculate the power dissipation under operating conditions ($I_{RMS}{}^2xR$). Allowing for transient or fault conditions and high ambient temperature if applicable, select the required power rating. For many current sense products, only the maximum temperature of the solder joints limits the power rating. Power rating is thus **a function of the PCB layout** design as well as of component selection (see point 4.).

4. **Layout**

Care must be taken when laying out a PCB if the stated performance of a sense resistor is to be achieved. **The current carrying tracks should be as wide as possible, using multiple layers connected by many vias near the component pad**. This also improves the heatsinking of the joints. The best way to make four-terminal connections to a two terminal through-hole resistor is to use different sides of the PCB for the current and voltage connections. **Failing this, current and voltage tracks should connect to opposite sides of the component pad**. In order to avoid interference from stray magnetic fields, the loop area contained by the sense resistor, the voltage sense tracks and the sense circuit input should be minimised. This means **keeping the sense circuitry as close as possible to the sense resistor and running the voltage sense tracks close to each other.**

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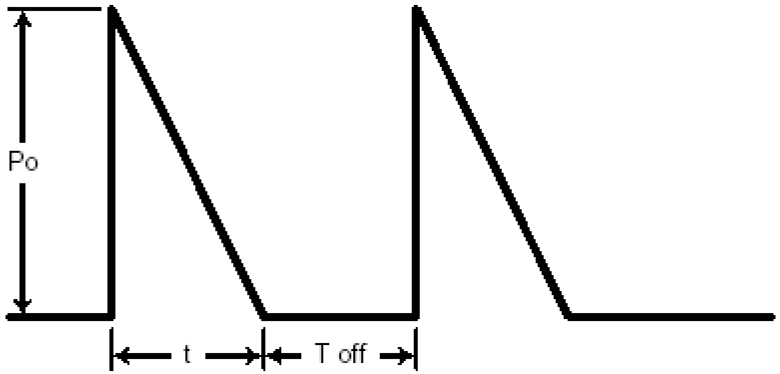
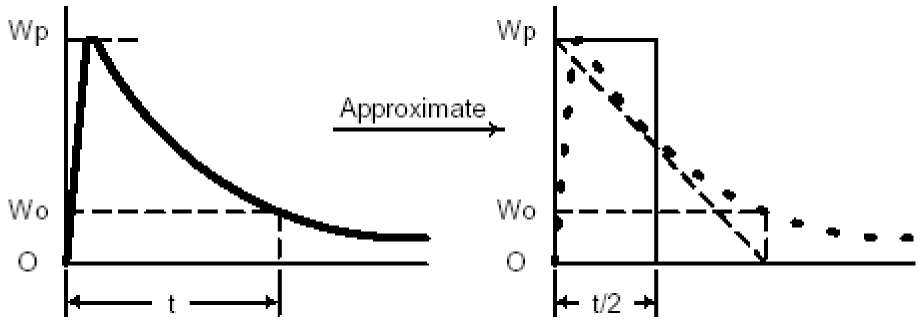
Power Rating for Discontinue Current

The peak power is defined as the maximum power dissipated at any point in time regardless of the waveform shape.

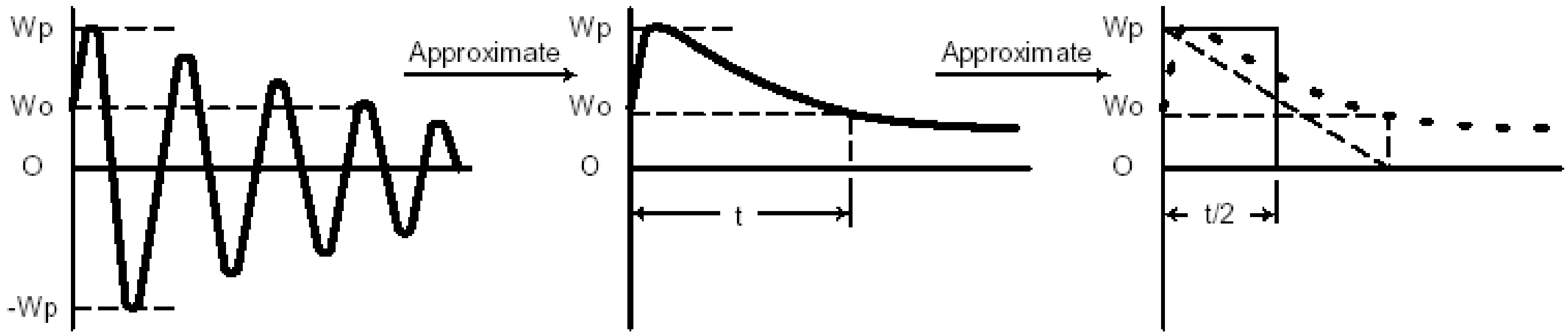


Wp:	Peak Power
Wo:	Rated Power
t:	Time to attenuate down to the rated power

Power Rating for Discontinue Current



The pulse waveform, if other than a square wave, must first be converted to an approximated square wave as shown on the left.



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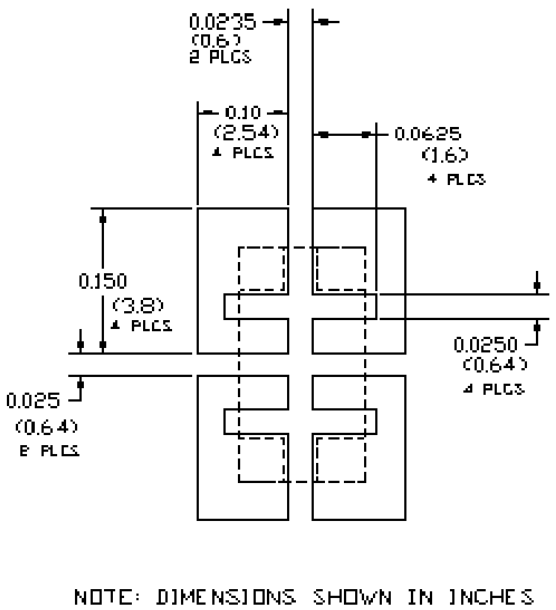
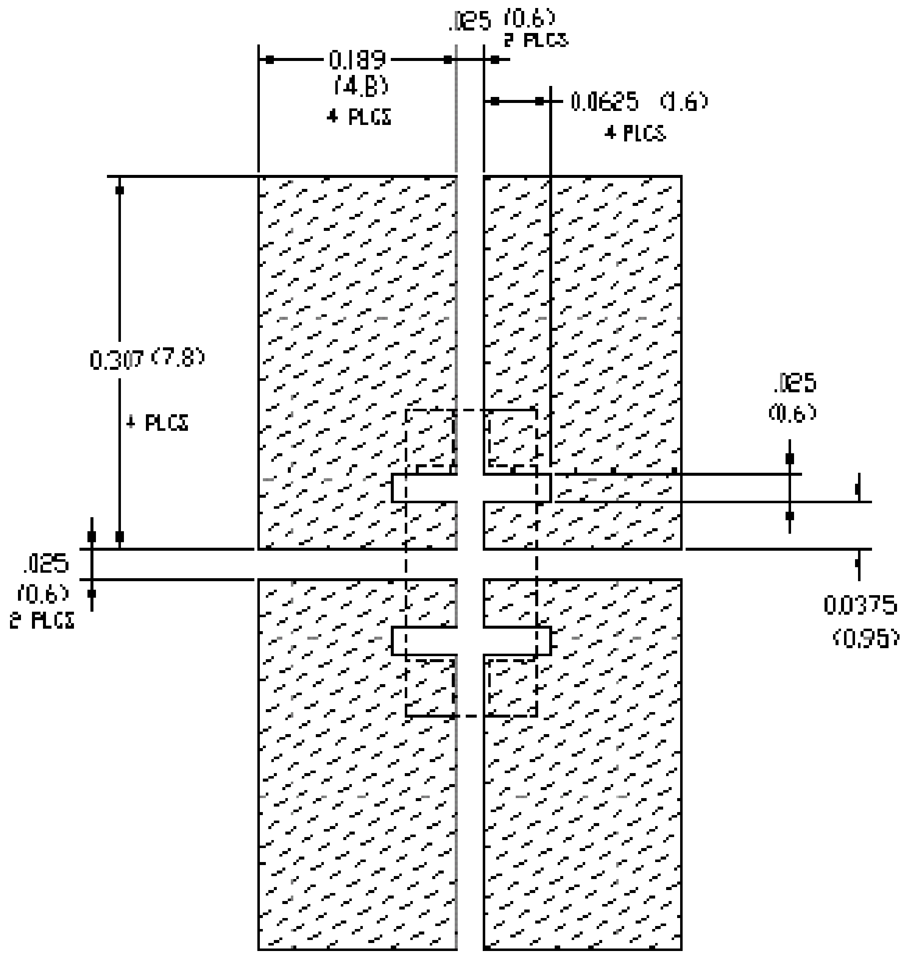
Power Rating Relation with PCB Layout





One Watt Operation **Two Watt Operation**

5. **Other Factors**

Where transient or AC currents involving high frequencies are to be sensed, the self-inductance of the resistor must be minimised. Wirewound or spiralled film parts should be avoided, in favour of bulk metal or low value chips. For example, **the RL series chip resistors have inductance values below 200pH**. When using a metallic element shunt with high heat dissipation and low sense voltage, consideration may need to be given to thermoelectric voltages. The junction between a metallic resistance element and metal terminations acts as a thermocouple, generating a voltage proportional to the temperature difference across it. A leaded metallic element sense resistor is therefore **like two thermocouples back to back**. This means that, if the temperature differences across both junctions are equal, the error voltage is cancelled out. This is achieved by making the design thermally symmetrical, that is, by presenting both terminals with similar heatsinking and by keeping any other heat sources thermally distant.

Cyntec's Current Sensing Resistor

- **Application**

  1. DC/DC Converter
  2. Switch Power Supplier
  3. Over Load Protection
  4. RF Power Control
  5. Motor Control

- **Process**

  1. Thick Film Printing(New)
  2. **Thin Film**
  3. **Metal Foil**
  4. **Metal Foil with Ceramic** patented)

- **Cyntec focus on**:

  1.NB , PC Vcore Power

  2.DC/DC Converter

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Cyntec's Current Sensing Map

Process	Metal Strip			Buck Metal		Thin Film		Thick Film			Wirewound		Molding
Power Rateing	<1W	1~2W	3~5W	1~2W	3W	<1W	1~2W	<1W	1~2W	3W	1~2W	3W	1~2W
Cyntec	V	V				V	V						
Vishay	WSL	WSL/WSR	WSR	VCS/CSM	CSM	L-NE/L-NS	L-NE/L-NS						
IRC		CSS							LR	LRF3W	WSM1/WSM2	WSM3	
KOA								SR73	SR73-3A				TSL1/SL1/CSR/TLR
Matshuita								ERJ	ERJ1T				
ROHM	PMR18	PMR						MCR	MCR100				
Note	Low TCR/Jigher Power			Low TCR		Small size		Low Cost					High Power

Cyntec's Major mOhm Products

Part No	Dimensions (mm^2)	R Range ($m\Omega$)	Power Rating (W)	Note
RL4527	11.7x 7.1	1~200	2	Metal foil with ceramic carrier
RL3264	3.2 x 6.4	1~500	1, 2	1~2 pure metal foil 3~100 metal foil with ceramic carrier 100~500 thin film with ceramic substrate
RL7520W	7.5 x 2.0	1~470	2	Thin Film with ceramic substrate
RL2550	2.5 x 5.0	1~500	3/4	Metal foil with ceramic carrier
RL1632	1.6 x 3.2	5~500	1/2	Metal foil with ceramic carrier
RL3720W	3.7 x 2.0	4~1,200	1	Thin Film with ceramic substrate
RL3720	3.7 x 2.0	4~2,200	1/2	Thin Film with ceramic substrate
RL1220	2.0 x 1.2	10~10,000	1/4	Thin Film with ceramic substrate
RL0510	1.0 x 0.5	75~4,700	1/8	Thin Film with ceramic substrate

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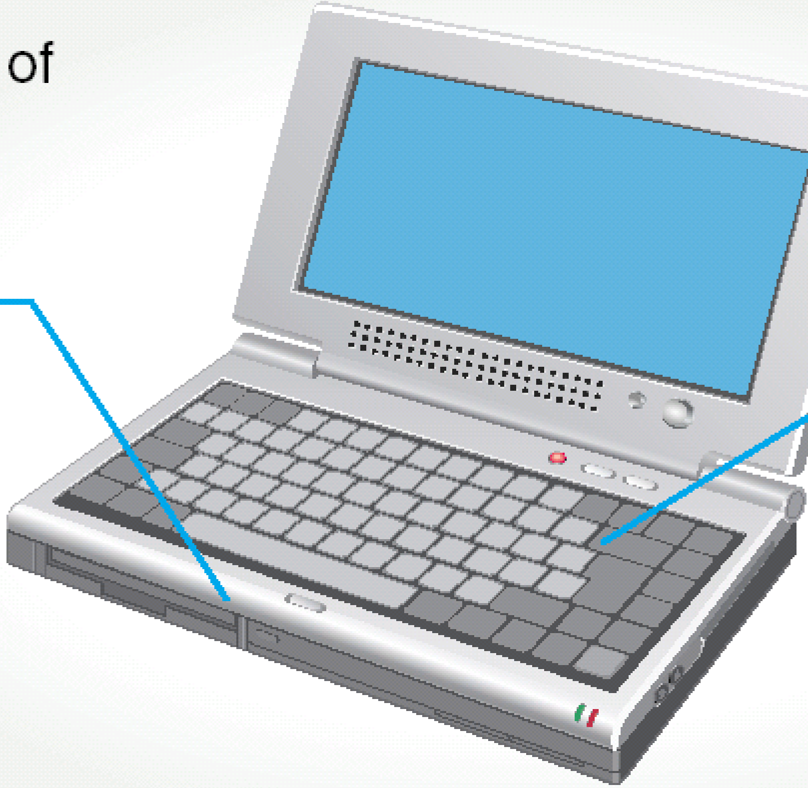
mOhm Resistor on Notebook PC

Notebook PC Use



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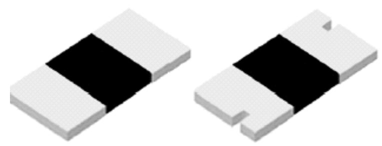
Current Sensor(mΩ) on Portable

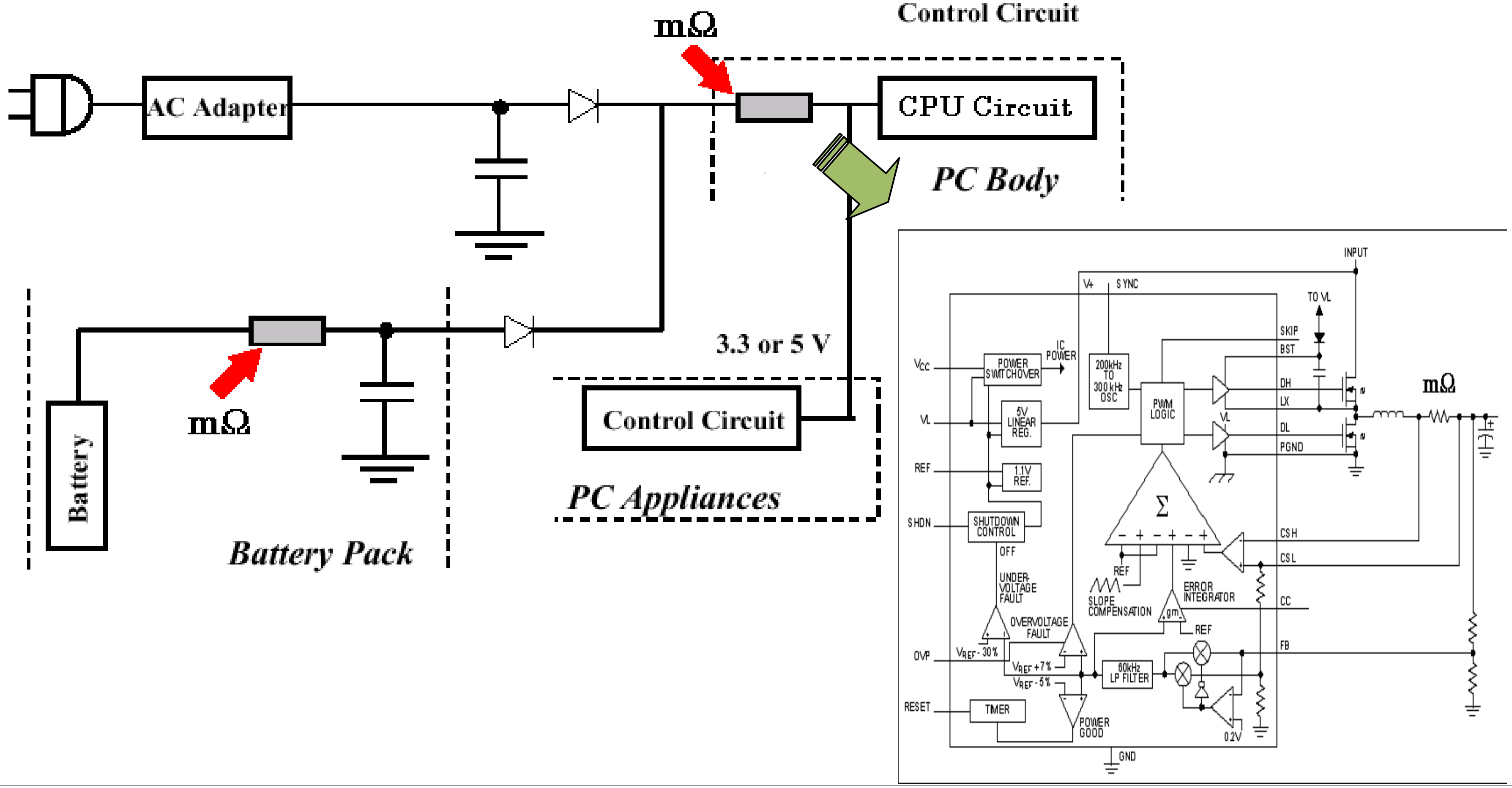
Notebook PC Power

Focus on DC power management

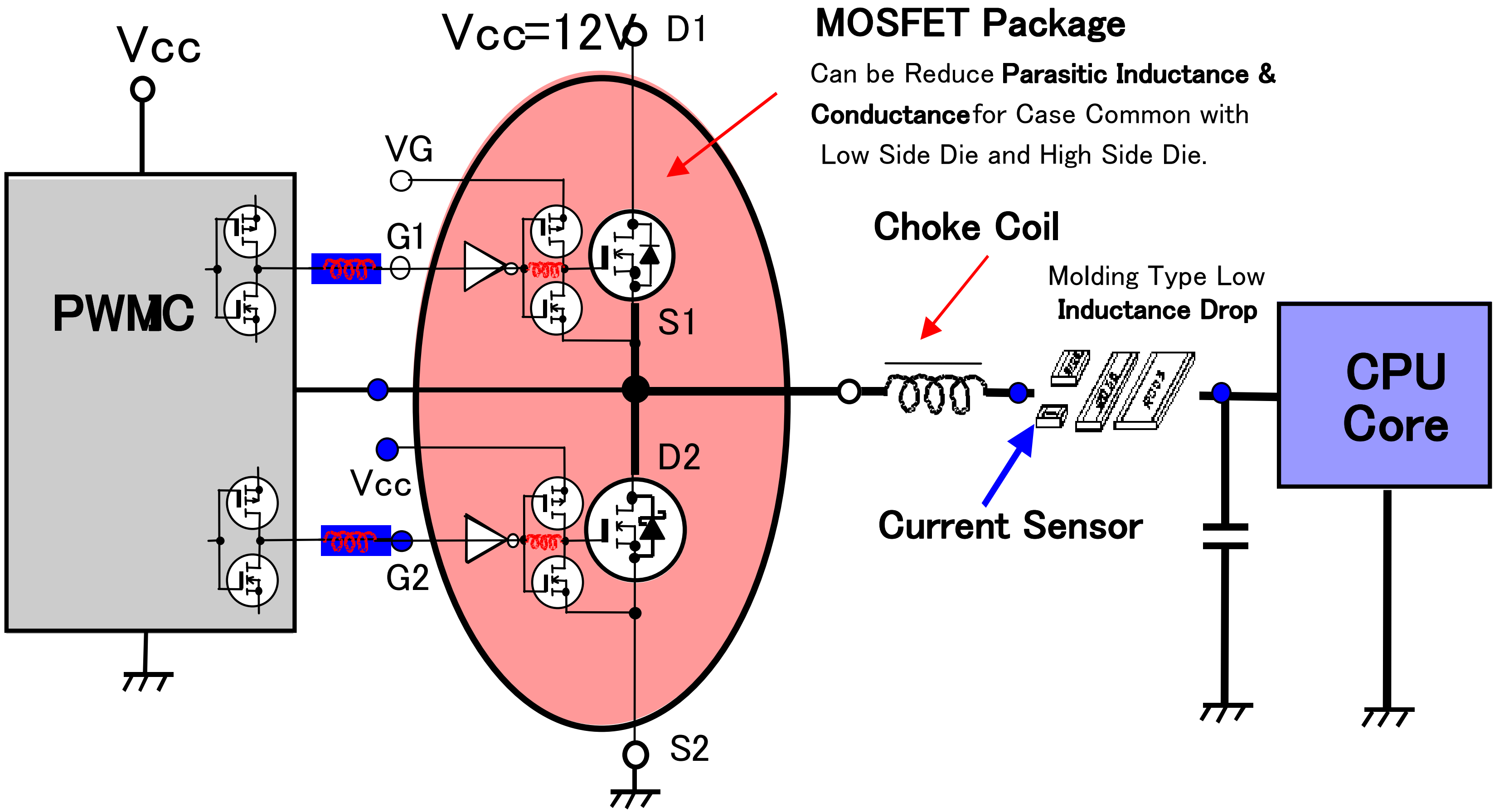
1.:N.B. PC, PDA, Mobile Phone Battery

2.:DC/DC Converter:Current detector Such as VRM





Current Sensing on Vcore Application



The Figure show the circuit of a DC/DC converter, The voltage across the current sensing resistor is fed back to control the output power, The resistor should

- Be low to reduce the power dissipation, Precise current-limiting capability
- Stand against repeated rush current, Overload protect when Capacitor short
- Be low self-inductance for high frequency applications, Precise voltage comparison

Current Sensing Method on Vcore

Efficiency, Accuracy and Cost of Various Current Sensing Methods

	Accuracy	**ΔEfficiency**	**Cost**
Discrete Output R Sensing	5-10%	4%	0.07
PCB Output R Sensing	20%	4%	0
Discrete Input R Sensing	5-10%	2%	0.07
PCB Input R Sensing	20%	2%	0
MOSFET Sensing	49%	0	0
Inductor Sensing	56%	0	0

Note: No attempt has been made in this table to estimate differences in IC cost.

using Fairchild's new third-generation controllers, the RC5052/RC5057.

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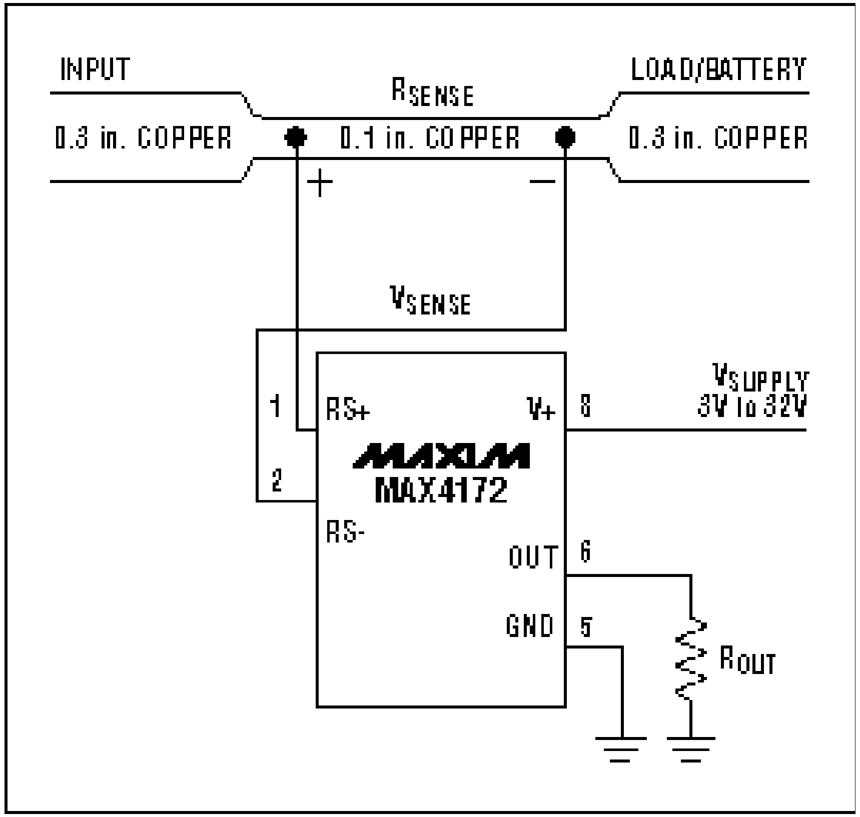
Used PCB Trace as Current sensor



Some People Using a PC-board trace as a sense resistor is an alternative method for applications where the cost of R_{SENSE} is an issue. **Maybe need to adjust the full-scale current value with a potentiometer because of inaccuracy in the copper resistance**. The resistance temperature coefficient of copper is fairly high (approximately **0.4%/°C**) in systems that undergo wide temperature variations.

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Current sensor requite on DC/DC Converter

- Very Low Ohmic Value
  - The ohmic value for minimizing power consumption at the current sensing resistor, should be below 25 milliohms**(Vcore <3mOhm)**
- Tight Tolerance
  - For maximizing the current supply within the limit of acceptable current, the tolerance of the resistor must **be 1% or tighter**
- Low T.C.R.
  - Since the maximum normal DC load current is in excess of **three amps**, in general, the maximum △ R due to self heating must be as low as 1,000ppm across the ambient temperature range of 0 ℃ to+60 ℃ , Thus, a low TCR is requite for current sensing. **(100~ 200 ppm for Vcore applaction)**
- Low Thermal EMF
  - For an accurate comparison between **the programmed current-limiting voltage (Typically, <100mV)** of the control IC and the detected voltage by the sensor resistor, the error due to thermal EMF of the sensor resistor must be minimized. Current level is programmed by the user by choosing ohmic value of the current sensing resistor.
- Resistor Value
  - For maximizing energy conversion efficiency of the DC/DC converter, the value of the sensing resistor is calculated according the worst-case low current-limiting threshold of the control IC and the peak inductor current by the equation:

$\mathbf{R_S = V_L / I_{peak}}$ R_S =Sense Resistor(Ohm), I_{peak}= Peak Inductor Current (Maximum DC Load Current) x 1.15, V_L = Worst-case-low current-limiting threshold voltage

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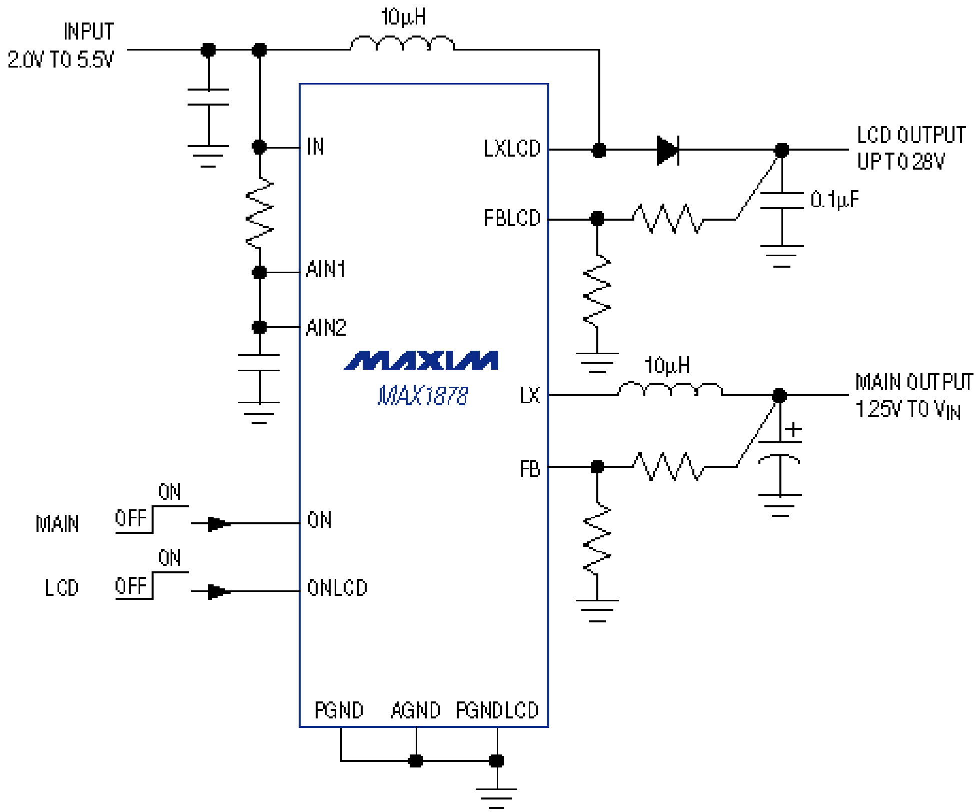
Dual output step-down DC/DC converter



- The Output terminal is monitored in order to compare the **worst-case low current-limiting** threshold voltage of the control IC with the level programmed by the user via sense resistor
- The sense resistor also functions as apart of **the smoothing circuit** to supply high linear DC current

Resistor Applications in Lithium-Ion Battery Chargers

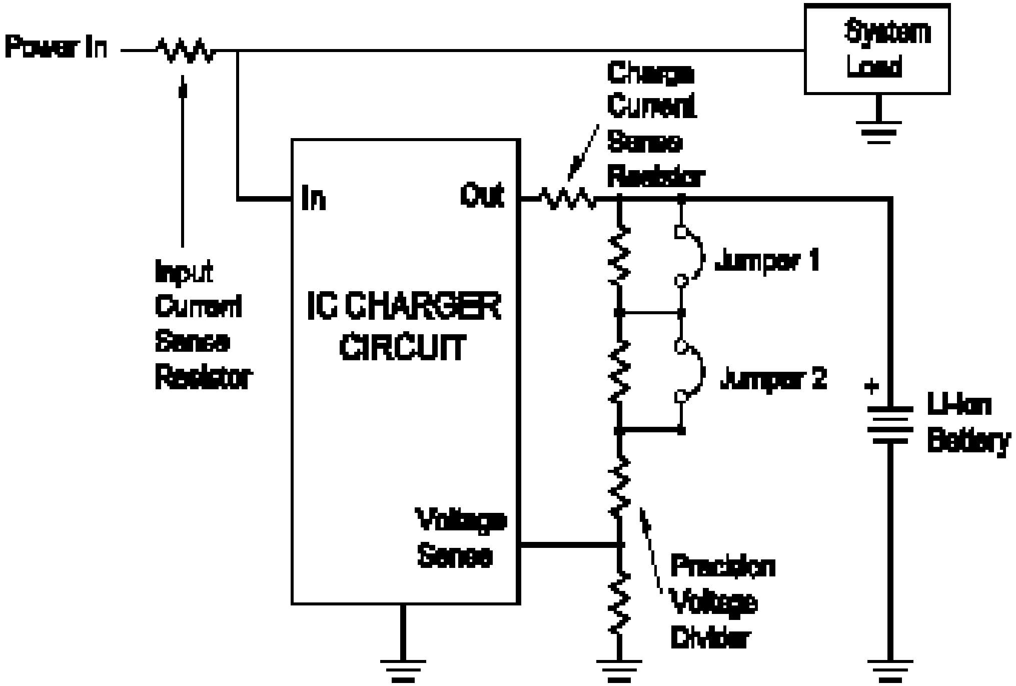
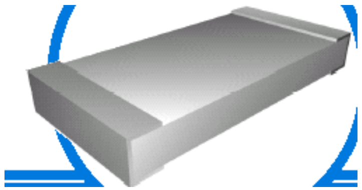


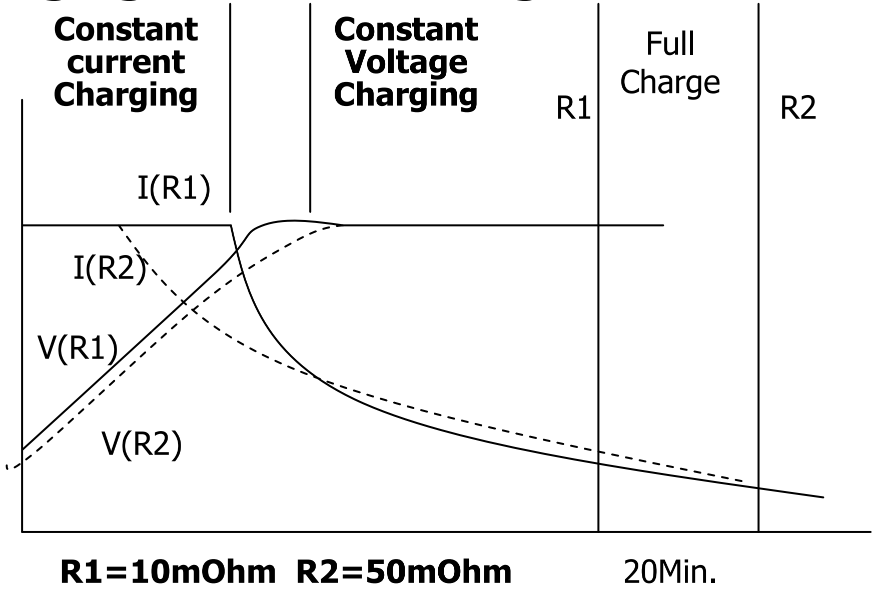
Figure 1



Portable, battery powered equipment is a rapidly expanding product area. The drive for more features and less frequent re-charging has led to lithium-ion becoming the preferred technology, with its superior energy density. The task of charging a lithium-ion battery is, however, more demanding than for earlier types. This has given rise to the development of charger controller IC's, which regulate the current and voltage within the tight limits required. A typical charging current is 500mA, so a 200mΩ resistor will give 100mV signal with negligible power dissipation. An RL1632-0R2, available to 1%, is a suitable choice..

Intelligent Lithium-Ion Rechargeable Battery

High Ohmic Values Increase The time for Charging and Causes large Power Losss



Intelligent Li-ion rechargeable batteries utilize current sensing resistor with ultralow ohm, low TCR, Tight tolerance, **high withstanding surge current** and low thermal EMF. The Li-ion battery had high energy density(1.5 times in volume and 2 times by weight compared to Ni-MH), High output voltage (.3~4V), and low soft discharge rate(10~12%) However, to assure the performance of intelligent Li-ion rechargeable batteries, three inherent difficulties must be taken into account

- **Heavy current discharge will cause degraded performance**, available energy will drop down to 90%, and sometimes 50% of nominal energy
- High internal impedance causes a potential drop, which makes it difficult to utilize the expected potential energy at high efficiency
- Requited **constant-current** and **constant-voltage** is difficult to control.

Current sensor requite on Li-ion Charger

- Very Low Ohmic Value
  - For minimizing energy loss, the requite ohmic value is below **100 milliohms**
- Tight Tolerance
  - To maintain the total accuracy of the intelligent Li-ion rechargeable batteries as close as +5%, -0.6% of total available power capacity, the tolerance of the sense resistor must **1%or tighter.**
- Low T.C.R.
  - Since the maximum normal operating current is generally **three to four amps**, the maximum due to self-heating must as low as 1,000ppm across the ambient temperature range of 0 ℃ to+60 ℃ , Thus, a low TCR is requite for current sensing.
- Low Thermal EMF
  - In standby mode, **a notebook PC requite 50~100mA to operate its DRAM and CPU, and a Handycam requites 5mA to operate its small memory**, Therefore, in the standby mode, the thermal EMF of sense resistor must be low compared to the terminal voltage generated by the current output.
- Resistor Value
  - For minimizing the **power loss** and **charging time** and **maximizing the efficiency of the potential energy**, the sensor resistor must be as close to zero as possible. The key factors to determine the resolution of the microcomputer are its semiconductor noise and offset voltage. Typical resistance values utilized in various microcomputers are **100,50,20 and 10 milliOhm**

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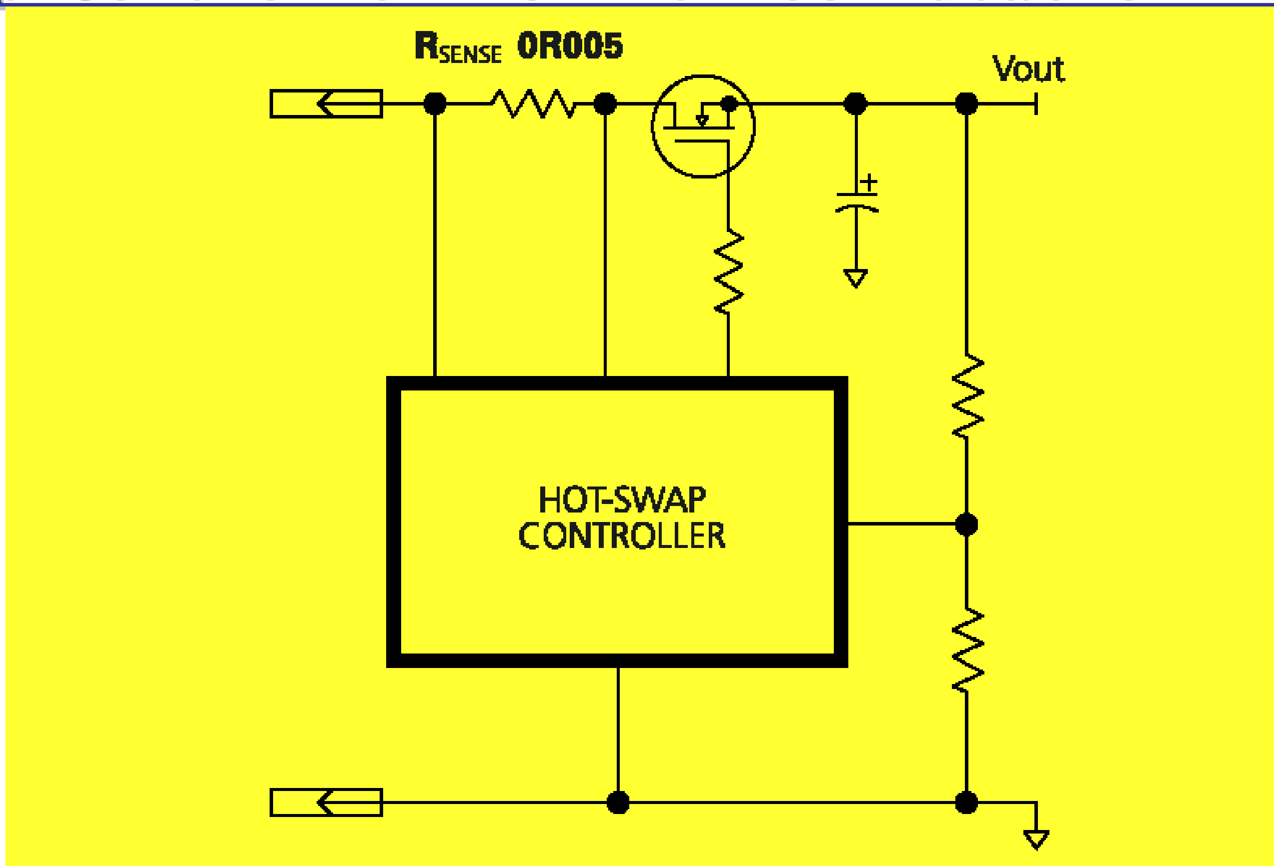
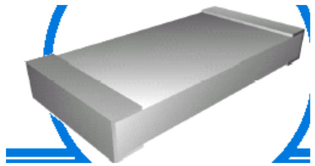
Hot-Swap Controller for Tel-commutation Line Card





Microprocessor-based boards require power supply rails of high integrity, even under extreme conditions such as removal from and insertion into a live backplane. This may be achieved using a hot-swap controller IC, which regulates the ramp-up of the supply rail on the plug-in card and protects against accidental shorts. This calls for sensing of the current, which may be several amps, depending on the requirements of the plug-in module. For example, a 5A current limit with a 5mΩ resistor gives a 25mV trip level and dissipates up to 125mW. An RL1220-R005 is ideal here, provided 1/5% tolerance and >100ppm/˚C TCR is acceptable.

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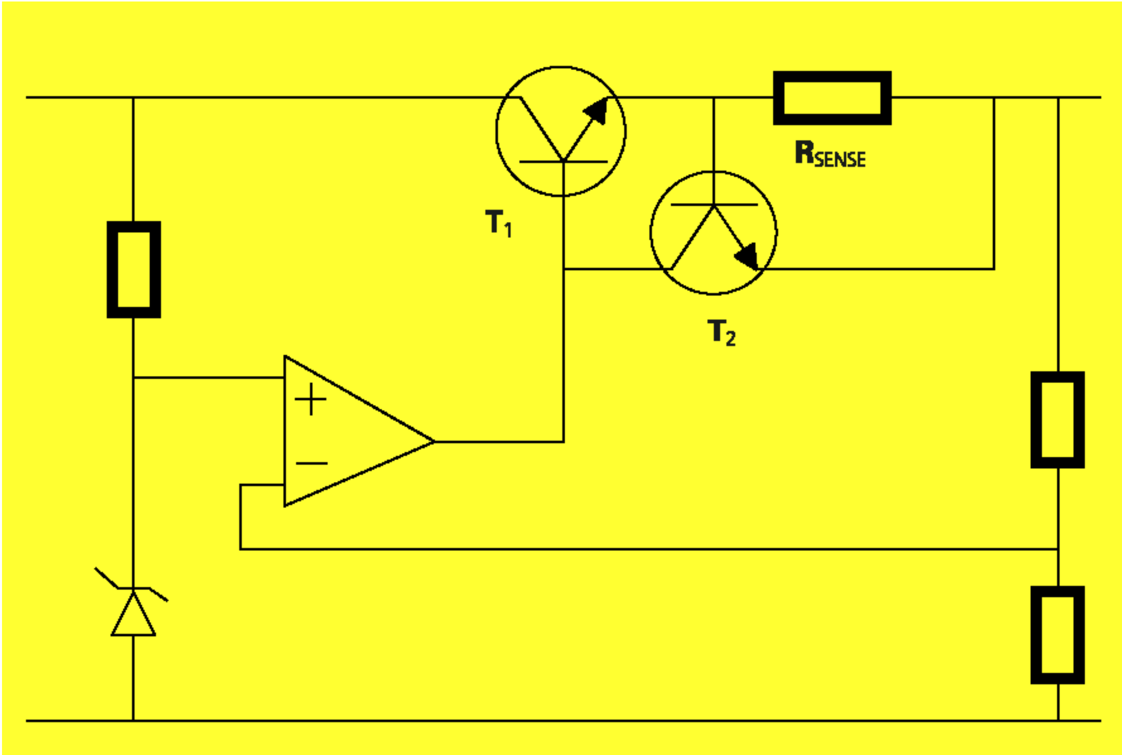
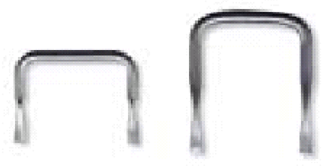
Switch Power Supply Current Limiting

The circuit below shows one example of a power supply application. It is a linear regulator with current foldback limiting. As the foldback limit is reached, the voltage across R_{SENSE} switches T_2 on, which diverts the base current of T_1. This overrides the voltage regulation, and the circuit operates in constant current mode.





A low cost solution for power supply applications is Dip type. This is a pluggable metal element resistor with a pitch between 5 and 20mm, and a maximum height of 25mm.

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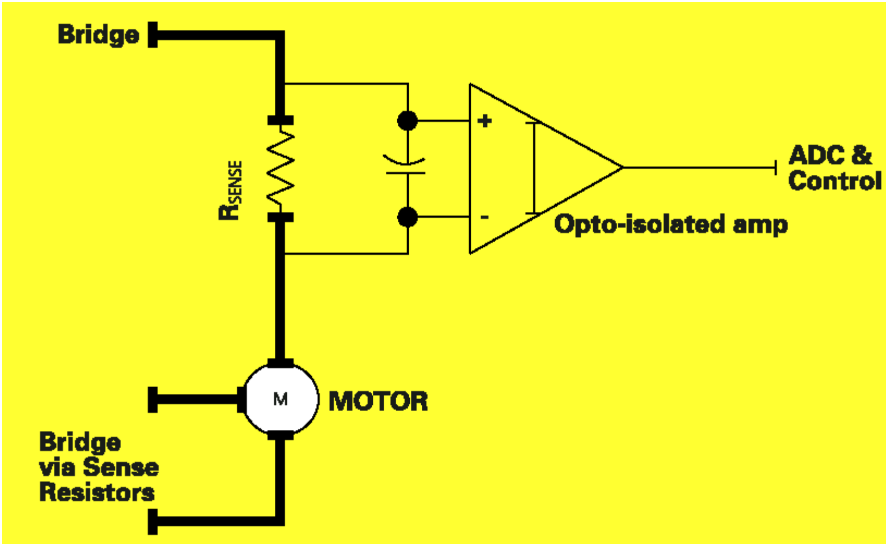
Motor Phase Current Sense

The availability of extremely low value sense resistors combined with opto-isolated amplifiers now presents a real alternative to using expensive Hall-effect sensors in the sub-60A range. This is of particular importance in the area of motor control, where isolation from the mains supply is essential. Opto-isolated resistive current sensing can also give benefits over Hall-effect sensors in terms of temperature stability, linearity and, with careful layout design, common mode rejection



The important attributes in this case are the availability of values below 10mΩ, up to 5W power rating with good surge withstand ability and low inductance. The ideal choice for RMS phase currents up to about 20A is a pluggable, formed tape element resistor available in 1, 3 and 5W ratings. The 1W type is also available in surface mountable form. For RMS phase currents up to 55A, the four-terminal Type is more suitable. Its rating is also 5W, but values extend down to 0.25mΩ at 1% tolerance. The Kelvin configuration with only the terminals plated gives this device the same TCR as the resistance alloy itself, which is 30ppm/°C.

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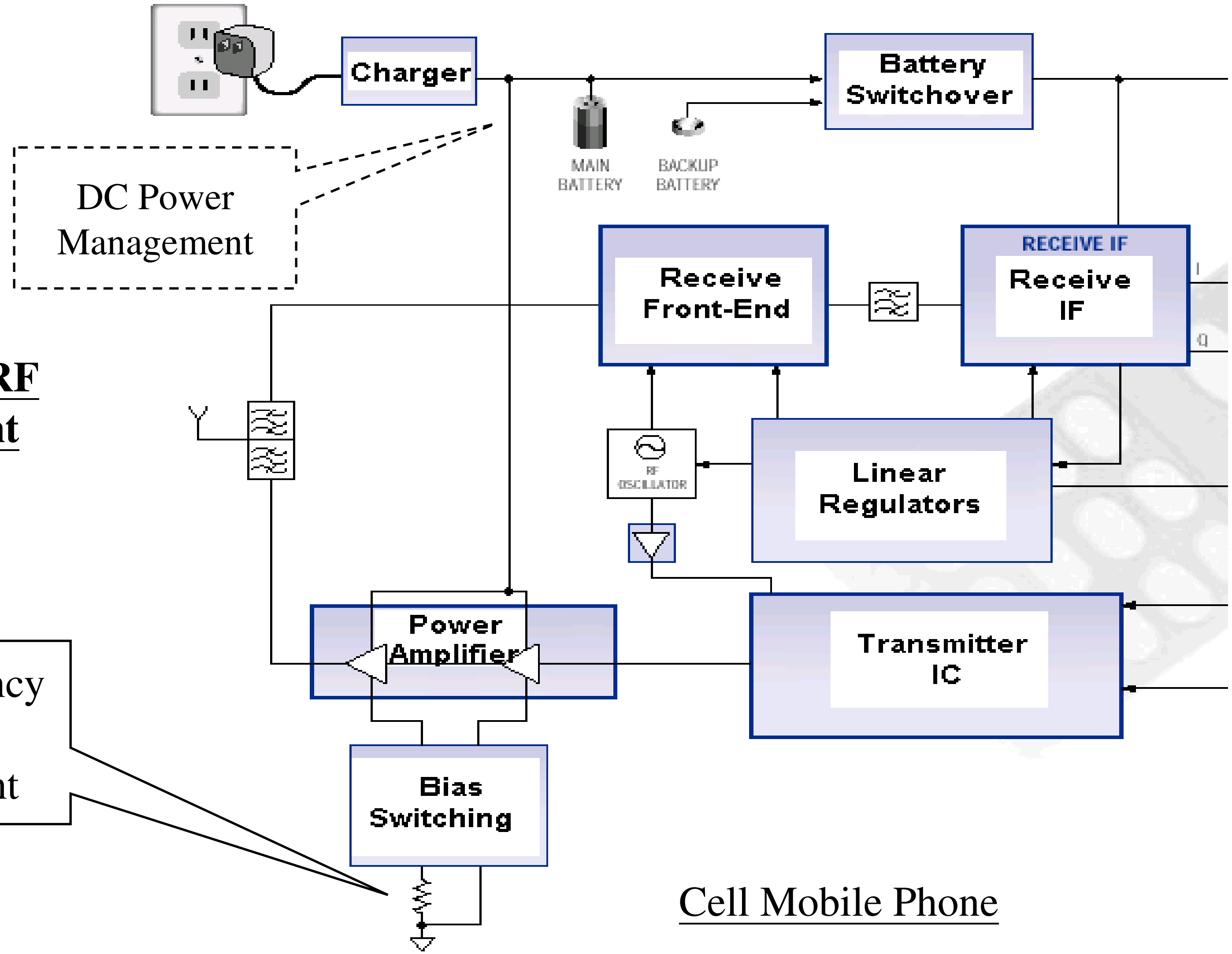
Current Sensor(mΩ) on Mobile

Mobile Phone



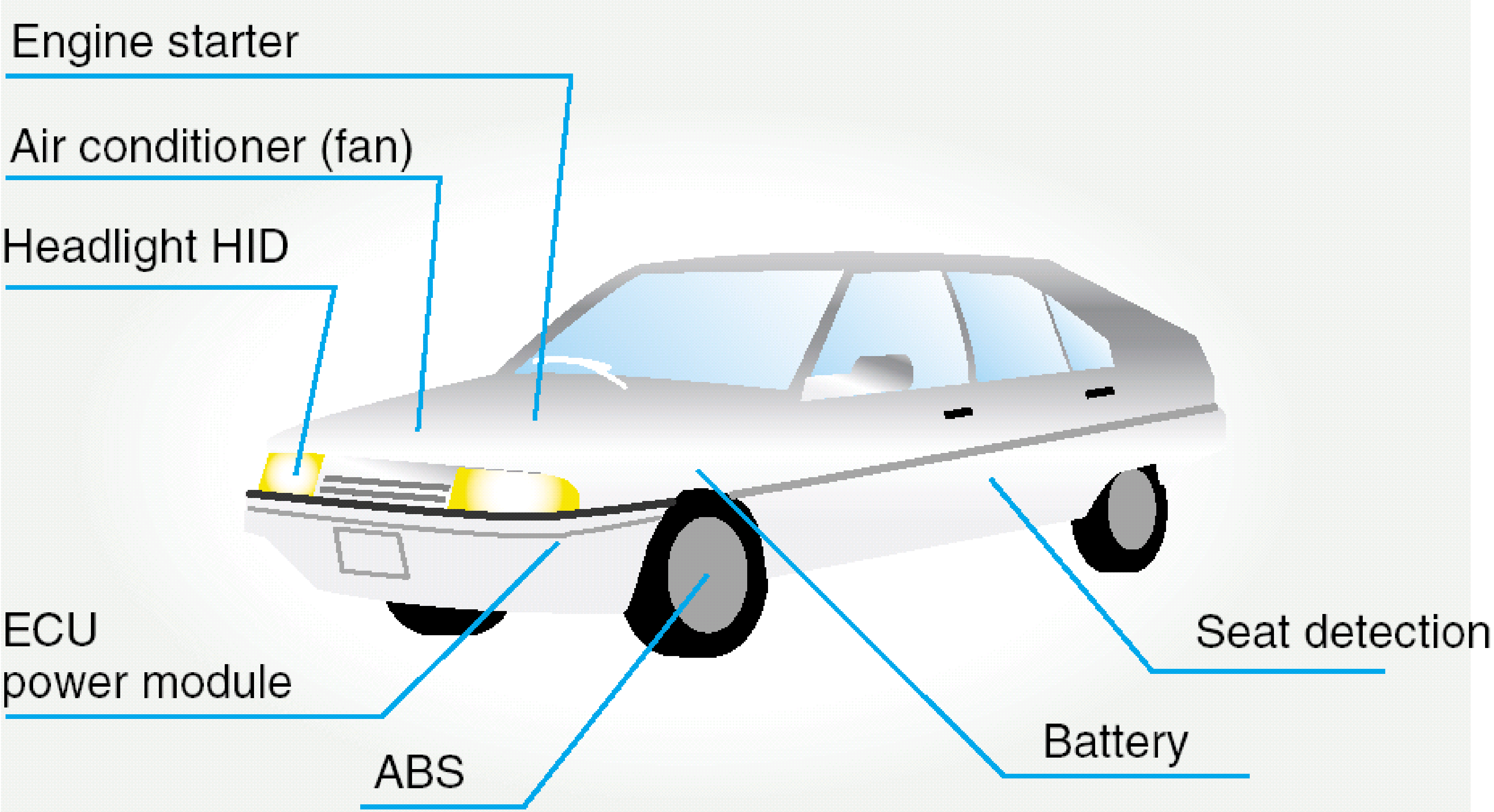
Current Sensor on RF Power Management

High Frequency Power Management

Cell Mobile Phone

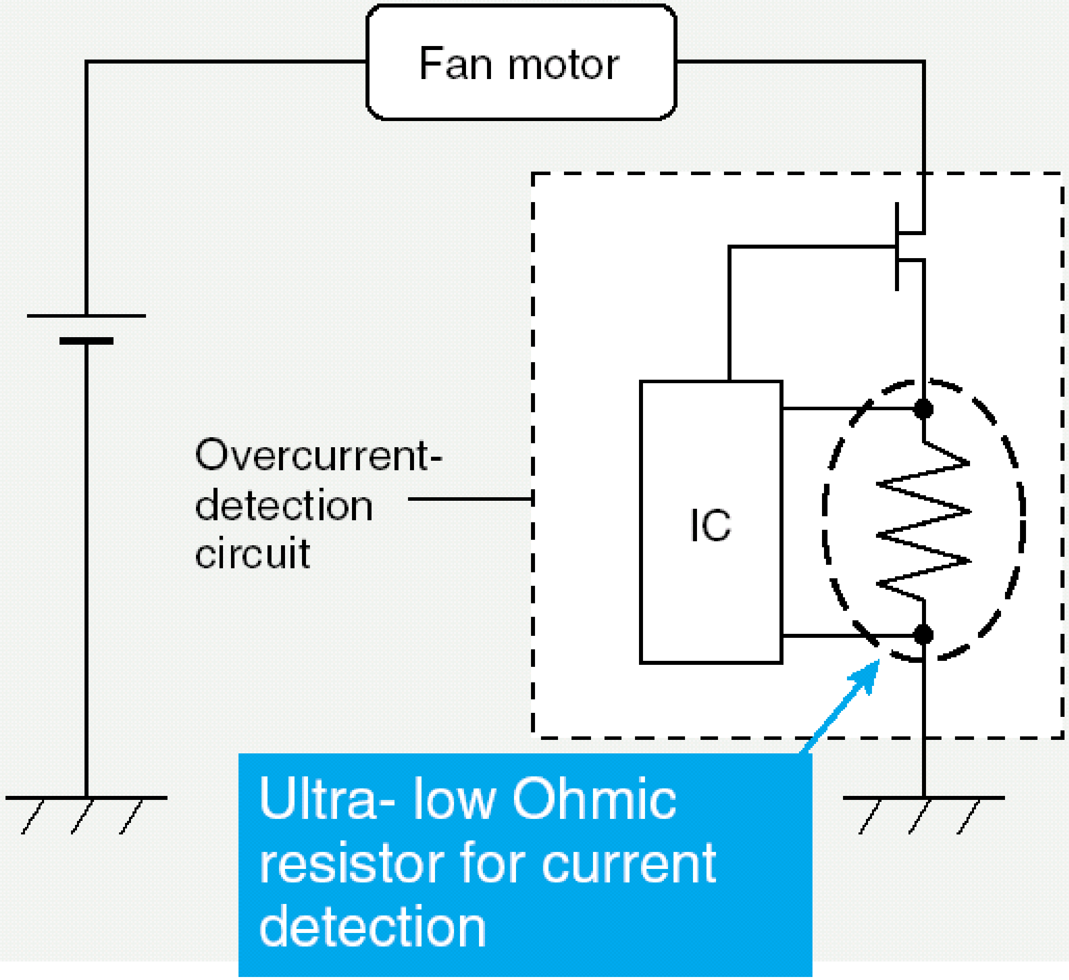
Current Sensor on Automotive

Automotive Use



Current on Car Air.-con.

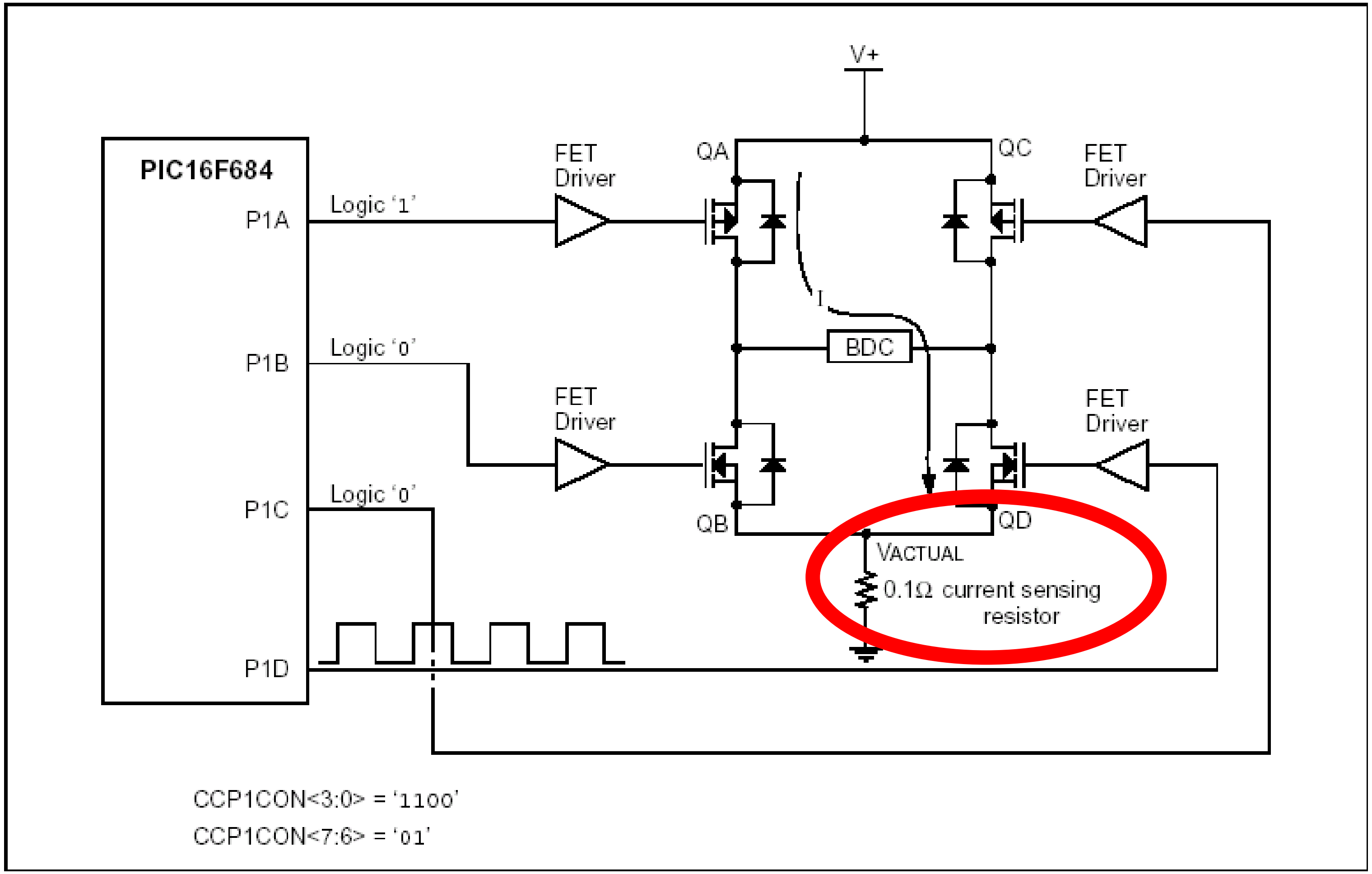
Application circuit example : Car air conditioner and fan motor control unit



Current Sensor for Auto Body Control

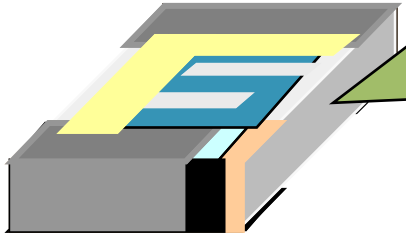
Low-Cost Bi-directional Brushed DC Motor Control Using the PIC16F684 for Power Windows

FIGURE 4: FULL-BRIDGE FORWARD WITH CURRENT-SENSING RESISTOR

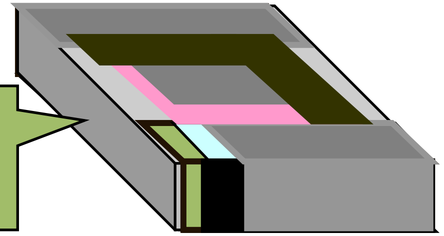


Thin/Thick Film Process

Thin Metal Film Chip Resistor		General Chip Resistor
Sputtering	Resistor	Printing
Etching & Laser cut	Resistance Adjustment	Sand blast or Laser cut
CVD or Printing	Over coat	Printing
Sputtering	Inner Electrode	Printing
Plating	Electrode Surface	Plating



Technology base
Thin Film
Similar method as Semiconductors



Technology base
Printing

Thin Film Tech.

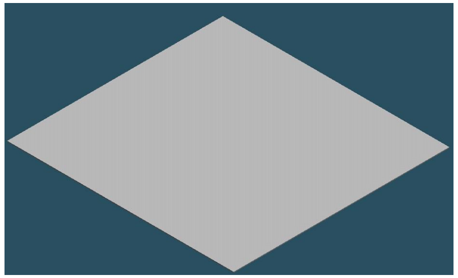
Thin Film Tech.

Thin Film Tech.

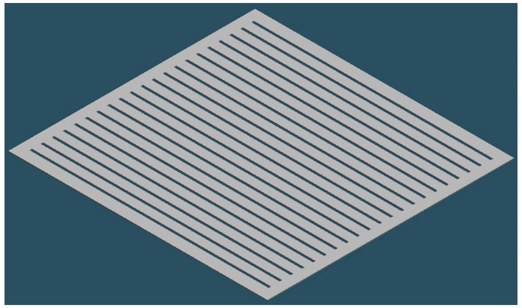
Thin Film Tech.

Easy method

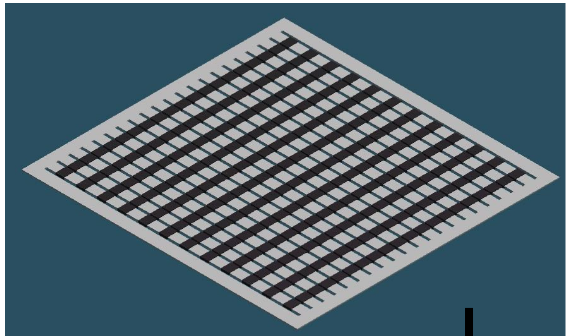
Metal Foil Current sensor Process



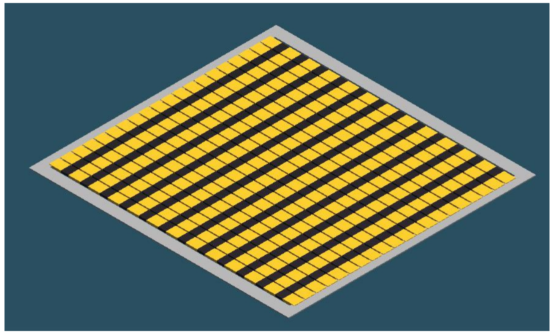
Patterning NiCu Alloy by Etching or Punching



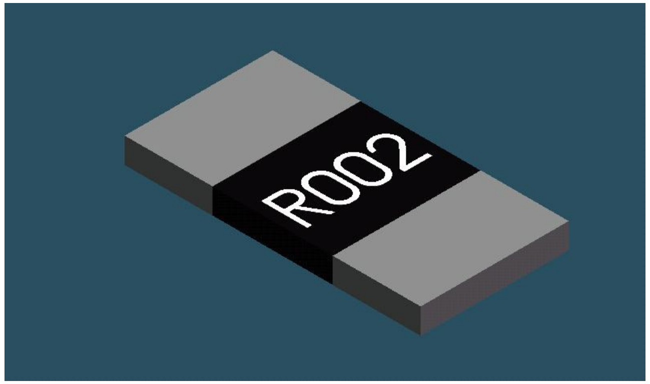
Making Passivation Layer & Defining R value by Lithography Process



Plating to make Pad



Punching to make individual chips



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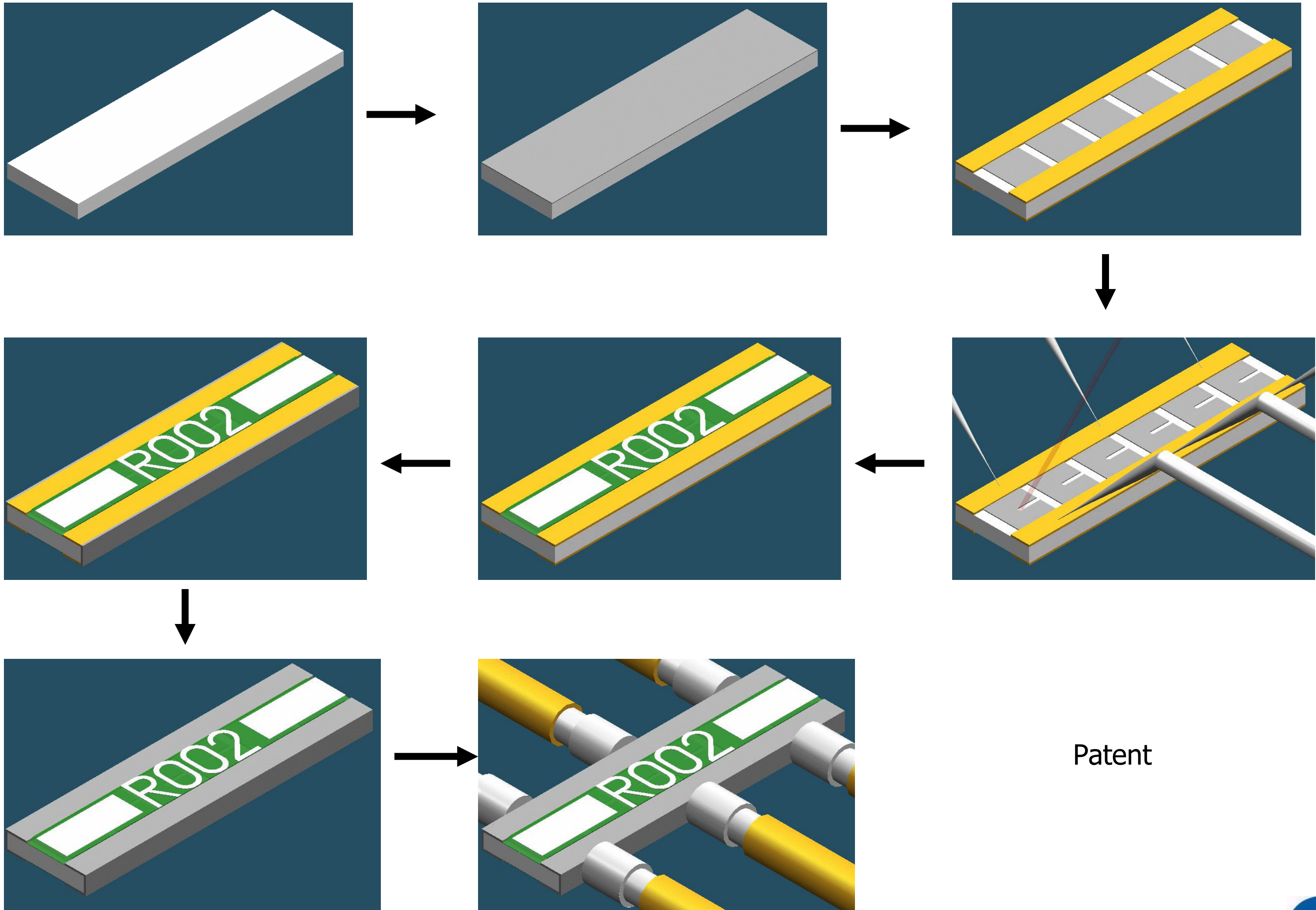
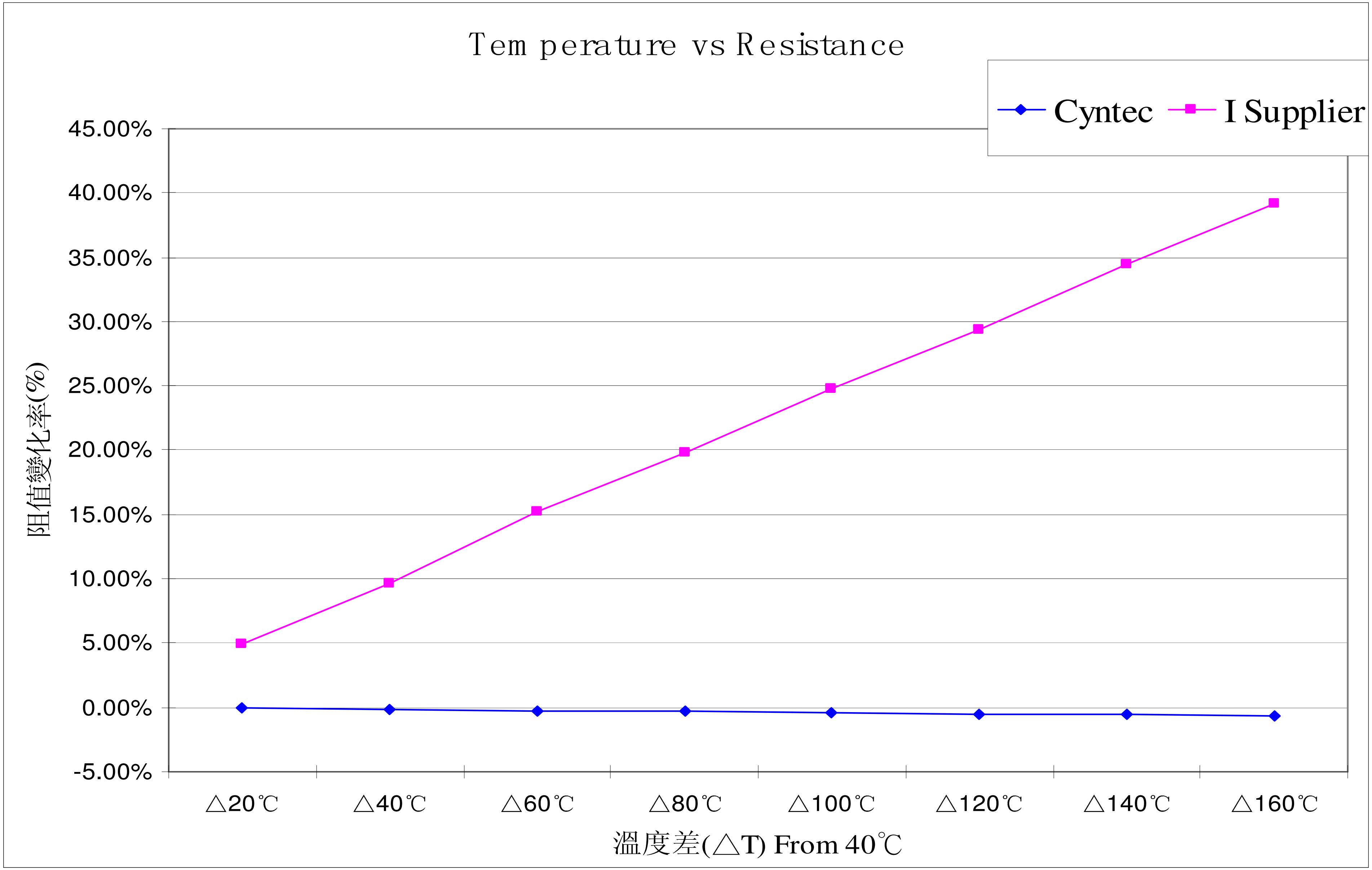
Metal Foil with Ceramic process



Patent

Comparison of Metal foil & Thick film printing Current Sensing Resistor (3 mΩ)



Why Metal Foil Bonded to Ceramic Substrate

- Keeping the properties of low TCR
- Rigid body for better SMT handling
- Easier for processing & increasing yield

Key Technology of Metal Foil with Ceramic Substrate

- Copper Bumping (Lithography & Plating)
- Bonding of Resistance Film & Ceramic Substrate
- Measuring

Conclusions

- Cyntec has developed a series of current sensing resistor for different field applications.
- New processing technologies : thick copper bumping plating & ceramic-metal bonding from developing the product mentioned above can be applied on RF or Power packaging.