CMicrotek

Leading Edge Current Measurement for Tomorrow's Products

CMicrotek µCP100™ / µCP120™

Current Probe

User's Guide

Version 0.3

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General Information

Introduction

The µCP100™ and µCP120™ are state of the art analog current probes for taking precise current measurements in modern ultra-low power products. The µCP100/µCP120 address all these issues facing designers of low-power electronics:

- With wide ranging current levels, a sense resistor sized to give enough voltage drop to measure microamps on a typical oscilloscope drops so much voltage the circuit stops operating when the current changes to the milliamp range.
- With voltage drops of a few millivolts across the sense resistor, the signal level can be less than the resolution of most oscilloscopes.
- With signals of just a few millivolts in amplitude, the accuracy of the measurement can be impacted by the accuracy of the oscilloscope.

The majority of the information in this document applies equally to the µCP100 and µCP120, "µCP1x0" will be used when referring to both products.

The µCP1x0 features a 20VDC input range to allow use in a variety of applications. The high end of the range makes the µCP1x0 suitable for use with 12V solar panels that may reach up to 17V under open-circuit and light load conditions. The µCP1x0 can also be used with voltages as low as a few millivolts, making it ideal for use with single 1.5V cell battery applications as well as "low voltage" energy harvesting power sources that can be in the 150mV range.

The µCP1x0 supports two measurement ranges using internal sense resistors along with support for an external sense resistor in the target system. The µCP1x0 also features a "Zoom In" view to enable more accurate measurements with mid-range and low-end scopes and a "Zoom Out" view for times when seeing the entire waveform is more important than precise measurements. These features combine to allow an engineer to focus on taking current measurements instead of changing out sense resistors as the current draw changes under different product use conditions.

The µCP1x0 is intended for use in applications where instantaneous current measurements are sufficient and power measurements over time are not required. These applications would include:

- Energy harvesting power sources ("low" and "high" voltage)
- Low power products with simple power management schemes
- Low power products without high-power wireless communications schemes like Wi-Fi or cellular
- Research in low-current power source and energy storage technologies

Features and Benefits

Features	Benefits
Wide input voltage range	Input voltages up to 20VDC for use with 12V lead-acid battery, solar cell or "high" voltage energy harvesting power sources. Input voltage range extends to ground for use with single cell 1.5V batteries and "low" voltage energy harvesting power sources.
0 to 40V output swing	Wide output range simplifies taking current measurements and allows use of lower resolution oscilloscopes.
Wide dynamic range	The 8,000:1 current range in normal mode allows for use on devices with wide ranging current draws between active and sleep modes.
Switch selectable current ranges	Two ranges to match the system measurement requirements without having to change sense resistor values.
Internal/external current sense resistor	The internal current sense resistor can be bypassed so that a sense resistor on the target system can be used, allowing the user to tailor the current range to their specific needs.
Switch selectable "normal" and zoom views	Zoom in amplifies the signal by 10X to allow use with oscilloscopes with 8-bit or 10-bit A/D converters without compromising measurement accuracy. Zoom out reduces the signal by 10X to increase the dynamic range to 20,000:1

Using the µCP1x0

The µCP1x0 Kit

The µCP1x0 probe is provided with everything needed to use it. The kit includes:

- µCP1x0 probe
- Target system harness
- Universal input 48VDC power supply and power cord
- BNC-BNC scope cable
- 6 micro-grippers for connecting to the target system

Connecting the µCP1x0

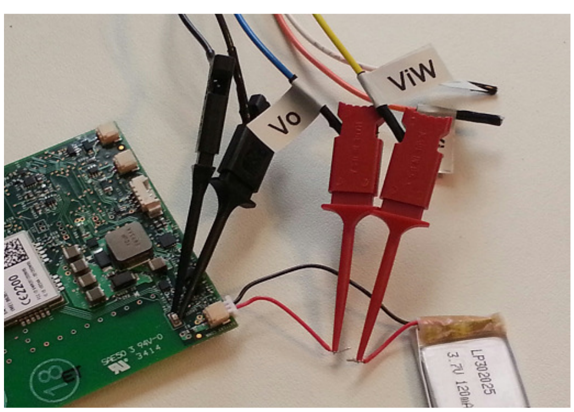
The µCP1x0 power supply should first be connected and then plugged into the power outlet. The oscilloscope must also be plugged into the power outlet and the BNC-BNC cable connected between the probe and oscilloscope. Set the scope for a 1X probe. With the target system turned off, the target system may then be connected to the probe. The ground wires to the target system should be connected first, followed by the voltage in and voltage out wires. This sequence should be reversed when disconnecting the probe from the target system and oscilloscope. Connecting the probe to a target system that is powered on should be avoided to prevent current surges or damaging the target system.

The µCP1x0 target system harness is color coded. The functions/colors are shown below. Both ground wires should be connected to the target system to minimize noise that could be interpreted as current fluctuations.

Function	Color	Label
Ground (2)	Black	-
Voltage out (see note)	Red	Vo
Voltage in – precision mode	White	ViP
Voltage in – wide range mode	Yellow	ViW
Voltage in – external sense resistor	Orange	ViX

Note – some early µCP100 target system harnesses used a blue wire for the voltage out.

The picture below shows the target system harness connected to a battery powered device. The voltage-in wire for wide range mode (yellow) is connected to the battery V+ wire, the voltage out wire (blue) connected to the battery V+ input to the device under test and the two ground wires connected to a ground test point on the circuit board.



The µCP1x0 may also be used with a precision volt-meter instead of an oscilloscope for steady-state current measurements. The same connection and safety considerations apply for use with an oscilloscope also apply for use with a volt-meter.

It should be noted that the µCP1x0's target interface is minimally protected against overvoltage conditions or ESD since typical protection devices can have higher leakage currents than the low current levels the probe is intended to measure. Because of this, particular attention should be paid to ESD considerations when working with the µCP1x0. Connecting the target system ground before the voltage in/out is very important for battery powered systems to ensure the input voltage doesn't damage the probe's front-end amplifier circuit.

Voltage/Current Conversion

Converting the voltage measurement from the scope to a current measurement is fairly straightforward with the µCP1x0. For the "normal" view in precision mode the current in nanoamps is equal to the voltage in millivolts, in wide-range mode the current in microamps is equal to the voltage in millivolts. The table below provides the conversion formula for both modes and the three zoom view levels.

	µCP100		**µCP120**	
	Precision mode (white wire)	Wide range mode (yellow wire)	Precision mode (white wire)	Wide range mode (yellow wire)
"Zoom in" (10:1) view				
Conversion formula	V * 0.0000001 = A mV * 0.1 = nA	V * 0.0001 = A mV * 0.1 = µA	V * 0.000001 = A mV = nA	V * 0.001 = A mV = µA
Output voltage	1mV = 0.1nA	1mV = 0.1uA	1mV = 1nA	1mV = 1uA
Normal (1:1) view				
Conversion formula	V * 0.000001 = A mV = nA	V * 0.001 = A mV = µA	V * 0.00001 = A mV * 10 = nA	V * 0.01 = A mV * 10 = µA
Output voltage	1mV = 1nA	1mV = 1uA	1mV = 10nA	1mV = 10uA
"Zoom out" (1:10) view				
Conversion formula	V * 0.00001 = A mV * 10 = nA	V * 0.01 = A mV * 10 = µA	V * 0.0001 = A mV * 100 = nA	V * 0.1 = A mV * 100 = µA
Output voltage	1mV = 10nA	1mV = 10uA	1mV = 100nA	1mV = 100uA

Examples using values for the µCP100:

- Normal view, wide range mode, 75mV output: 0.075V * 0.001 = 0.000075A or 75mV = 75uA
- Zoom in view, precision mode, 1.27V output: 1.27V * 0.0000001 = 0.000000127A or 1270mV * 0.1 = 127nA
- Zoom out view, wide range mode, 8.5V output: 8.5V * 0.01 = 0.085A or 8500mV * 10 = 85000uA

Selecting the Measurement Range

The µCP1x0 supports three measurement ranges. In Precision Mode currents from 4nA to 400uA can be measured. In Wide Range Mode currents from 4uA to 400mA can be measured. The External Resistor Mode allows the current range to be optimized for the target system (see the External Sense Resistor Considerations section for information on selecting the external sense resistor value).

The measurement range is selected via a three position switch next to the target system harness connector as shown above. The corresponding "voltage in" wire on the target harness must be connected to the target system (see table in the previous section). The target system should be turned off when changing measurement ranges to avoid potentially damaging the target system circuit board or the µCP1x0. To change measurement ranges, first turn-off the target system, disconnect the "voltage in" wire, change the switch setting and the connect the appropriate "voltage in" wire to the target.

Selecting the Zoom View Level

The µCP1x0 support three view zoom levels: normal 1:1 view, a 10:1 zoom-in and a 1:10 zoom-out. The view level is selected via a three position switch next to the BNC output connector as shown below. Since the least accurate measurement range for most oscilloscopes is at their lowest volts/division settings, the 10:1 zoom-in view is particularly helpful for measurements at the lower end of the µCP1x0's measurement ranges.

Measurement considerations

There are several things to keep in mind when setting up and using the µCP1x0.

- Most scopes default to a 10X probe, this should be changed to 1X for use with the µCP1x0.
- Depending on the target system design, the start-up surge current may be high enough that the voltage drop across the sense resistor can prevent the target system from powering up correctly. In this situation, a jumper wire can be used to connect the voltage-in and voltage-out to/from the µCP1x0 to allow the target system to power up and then removed for taking measurements.

Dynamic Range

The dynamic range of the µCP1x0 varies depending on the zoom view level and is primarily restricted by the 40 VDC maximum output of the probe. The table below shows the current range and dynamic range for the various zoom view levels for both nA and uA range measurements.

	µCP100		**µCP120**	
"Zoom in" (10:1) mode	**Precision mode**	**Wide range mode**	**Precision mode**	**Wide range mode**
Current range	5nA to 4uA	5uA to 4mA	50nA to 40uA	50uA to 40mA
Dynamic range (max/min ratio)	800:1		800:1	
Dynamic range (db)	58		58	
Normal (1:1) mode				
Current range	5nA to 40uA	5uA to 40mA	50nA to 400uA	50uA to 400mA
Dynamic range (max/min ratio)	8,000:1		8,000:1	
Dynamic range (db)	78		78	
"Zoom out" (1:10) mode				
Current range	5nA to 100uA	5uA to 100mA	50nA to 800uA	50uA to 800mA
Dynamic range (max/min ratio)	20,000:1		16,000:1	
Dynamic range (db)	86		84	

External Sense Resistor Considerations

The µCP1x0 supports using an external current sense resistor to allow tailoring the current range to the needs of a particular target system. With appropriately sized sense resistors, the µCP1x0 can measure current draws of several amps with sub-milliamp resolution.

Selecting the value for a current sense resistor requires compromise, particularly when measuring wide ranging currents. Higher value resistors allow for more accurate measurements of low current levels but are more susceptible to noise and with increased voltage drop at higher current levels will have more restricted dynamic range. Lower value resistors can provide for wider dynamic ranges due to their reduced voltage drop but at the expense of increased minimum measurable current level and more difficulty in measuring small current changes.

Specific considerations for selecting an external resistor value for use with the µCP1x0 include:

1. The input offset voltage of the front-end amplifier is 20µV typical, 35µV worst case. This is the minimum voltage drop across the sense resistor that can be detected and will determine the lowest current level that can be measured.
2. The voltage drop across the sense resistor for a certain current level must be multiplied by the gain of the probe to determine the output voltage. This gain factor varies based on the output zoom view level as follows:

	µCP100	**µCP120**
Zoom in view gain	2000	1333
Normal view gain	200	133.3
Zoom out view gain	20	13.33

3. To avoid exceeding the 40VDC output specification (or saturating the output amplifier), the maximum voltage drop across the sense resistor should be less than 40V divided by the highest gain factor listed above for the zoom view you anticipate using.
4. The resistor should be appropriately sized for the worst case power dissipation based on the expected maximum current and voltage drop across the resistor.
5. Common surface mount resistors with 1% or better accuracy generally make suitable sense resistors for low current applications. The temperature coefficient generally isn't critical, a 100 ppm/°C part should be more than adequate for most applications and provide less change in the output voltage over the temperature range than can be measured with most scopes. Wire wound resistors should be avoided as their inherent inductance may impact measurement accuracy.

The table below shows the sense resistor value needed for an output voltage of 1mV equal to various current levels. For these resistor values, with the µCP1x0 the voltage drop at maximum current will be 0.2VDC, for the µCP120 the voltage drop at maximum current will be 0.3VDC.

			µCP100		µCP120	
Output, 1mV =	**Resistor (ohms)**	**Minimum Current**	**Maximum Current**	**Conv. Formula**	**Maximum Current**	**Conv. Formula**
1nA	-	-	use Precision Mode		N/A	
5nA	1000	35nA	200uA	V * 0.000005 = A	300uA	V * 0.0000075 = A
10nA	500	70nA	400uA	V * 0.00001 = A	use Precision Mode	
25nA	200	180nA	1mA	V * 0.000025 = A	1.5mA	V * 0.0000375 = A
50nA	100	350nA	2mA	V * 0.00005 = A	3mA	V * 0.000075 = A
100nA	50	700nA	4mA	V * 0.0001 = A	6mA	V * 0.00015 = A
250nA	20	1.75uA	10mA	V * 0.00025 = A	15mA	V * 0.000375 = A
500nA	10	3.5uA	20mA	V * 0.0005 = A	30mA	V * 0.00075 = A
1uA	5	7uA	use Wide Range Mode		60mA	V * 0.0015 = A
2.5uA	2	17.5uA	100mA	V * 0.0025 = A	150mA	V * 0.00375 = A
5uA	1	35uA	200mA	V * 0.005 = A	300mA	V * 0.0075 = A
10uA	0.5	70uA	400mA	V * 0.01 = A	use Wide Range Mode	
25uA	0.2	175uA	1A	V * 0.025 = A	1.5A	V * 0.0375 = A
50uA	0.1	350uA	2A	V * 0.05 = A	3A	V * 0.075 = A
100uA	0.05	700uA	4A	V * 0.1 = A	6A	V * 0.15 = A
250uA	0.02	1.75mA	10A	V * 0.25 = A	15A	V * 0.375 = A
500uA	0.01	3.5mA	20A	V * 0.5 = A	30A	V * 0.75 = A

Oscilloscope Considerations

Most scope settings can be used with the µCP1x0 just like any scope probe. There are a couple of considerations when using the µCP1x0 :

- Most scopes default to a 10X probe, this should be changed to 1X for use with the µCP1x0.
- Triggering a scope on a current waveform can be difficult to do, particularly when trying to isolate the current waveform for a particular event. If there is a digital signal associated with an event it is much easier to use another channel on the scope to trigger on the digital signal. If there is not a digital signal that can be used for triggering, using a spare GPIO on a micro will allow you to trigger the scope under firmware control.

- Most oscilloscopes have very poor "vertical" accuracy at their lowest volts/division settings, in some cases the error can be as much or more than the voltage you are measuring. To ensure the best possible accuracy, use the combination of precision/wide-range mode and zoom view levels on the µCP1x0 to allow you to view the current waveform at the highest volts/division setting practical. Also, centering the 0 volt level vertically on the scope display will generally provide more accurate measurements than offsetting the voltage on the display. The major scope manufacturers usually provide in their manuals the information required to calculate the potential error based on the actual settings being used.

Safety Considerations

When used as intended in the development of low-current, low-voltage devices, the safety considerations are primarily related to the µCP1x0 itself and the target system. Particular attention should be paid to ESD considerations when working with the µCP1x0 to avoid damaging the probe. Other specific safety considerations are listed below.

Grounding

Care must be taken with the ground connections between the µCP1x0, the oscilloscope and the target system to ensure accurate measurements and avoid equipment damage. The target system ground will be connected to the oscilloscope's signal ground (and typically earth ground) through the µCP1x0.

Connecting & disconnecting the probe

Always follow the connection/disconnection sequence described in the "Connecting the µCP1x0" section above to avoid damaging the target system and the µCP1x0. The µCP1x0 should only be connected/disconnected when the target system is turned off. This is particularly important when taking current measurements on secondary power rails if the target system was not designed for that power rail to be turned on/off as this may damage the target system.

Isolation

If the oscilloscope is to be powered through an isolation transformer, the µCP1x0 power supply must also be powered through the same transformer with the oscilloscope and µCP1x0 earth grounds tied together. If the target system power supply is not floating (i.e. powered by a battery or some form of energy harvesting power source), the target system earth ground must also be tied to the oscilloscope and µCP1x0 power supply earth ground.

Probe ratings

The µCP1x0 may be safely operated with the input voltage up to 23VDC, exceeding this voltage may damage the probe. The µCP1x0 output is specified as 40VDC but may actually reach as high as 48VDC if the specified current ranges are exceeded.

Live circuits

Connecting the probe to a target system that is powered on should be avoided to prevent current surges.

ESD

The µCP1x0's target interface is minimally protected against ESD because typical protection devices have higher leakage currents than the low current levels the probe is intended to measure. Because of this, particular attention should be paid to ESD considerations when working with the µCP1x0.

Specifications

	µCP100		µCP120	
Input voltage range	0VDC to 20VDC [1]			
Output voltage range	0VDC to 40VDC [2]			
Bandwidth	550 Khz			
"Zoom in" (10:1) mode	Precision mode	Wide-range mode	Precision mode	Wide-range mode
Output voltage	1mV =0.1nA	1mV = 0.1uA	1mV = 1nA	1mV = 1uA
Current range	5nA to 4uA	5uA to 4mA	50nA to 40uA	50uA to 40mA
Dynamic range (max/min ratio)	800:1		800:1	
Dynamic range (db)	58		58	
Normal (1:1) mode	Precision mode	Wide-range mode	Precision mode	Wide-range mode
Output voltage	1mV = 1nA	1mV = 1uA	1mV = 10nA	1mV = 10uA
Current range	5nA to 40uA	5uA to 40mA	50nA to 400uA	50uA to 400mA
Dynamic range (max/min ratio)	8,000:1		8,000:1	
Dynamic range (db)	78		78	
"Zoom out" (1:10) mode	Precision mode	Wide-range mode	Precision mode	Wide-range mode
Output voltage	1mV = 10nA	1mV = 10uA	1mV = 100nA	1mV = 100uA
Current range	5nA to 100uA	5uA to 100mA	50nA to 800uA	50uA to 800mA
Dynamic range (max/min ratio)	20,000:1		16,000:1	
Dynamic range (db)	86		84	
Sense resistor voltage drop	Precision mode 7uV / nA	Wide-range mode 7uV / uA	Precision mode 750nV / nA	Wide-range mode 750nV / uA
Output voltage accuracy [3]	± 2.5%			
Sense resistor accuracy	± 1%			
Sense resistor temperature coefficient	± 100 ppm / °C			
Common mode noise rejection	130 dB (typical)			
Support for external sense resistor	Switch selection			
Interface to target board	Clip leads or 0.025" square post header [4]			
Power supply	48VDC, 94-264VAC 50/60Hz			
Enclosure	Aluminum 3.4" x 2.9" x 0.8"			

Notes:

1. The µCP1x0 may be safely operated with input voltage up to 23VDC. The specified accuracy is not guaranteed when the input voltage is above 20VDC.
2. The µCP1x0 output may actually reach as high as the 48VDC input voltage if the specified current ranges are exceeded. The specified accuracy is not guaranteed when the output voltage is above 40VDC.
3. Output voltage accuracy specified at normal (1:1) output, for "zoom out" and "zoom in" views accuracy is ± 5%. Measurement accuracy is highly dependent on the scope and settings used for waveform acquisition.
4. The target system harness is designed to connect to 0.025" square posts. This allows the µCP1x0 to be used with typical 0.1" pitch headers or any test grippers/grabbers with a 0.025" square post such as the E-Z-Hook XKM style micro grippers provided with the probe.

Voltage/Current Conversion Factors & Current Range Table

	µCP100		**µCP120**	
	Precision mode (white wire)	Wide range mode (yellow wire)	Precision mode (white wire)	Wide range mode (yellow wire)
"Zoom in" (10:1) view				
Conversion formula	V * 0.0000001 = A mV * 0.1 = nA	V * 0.0001 = A mV * 0.1 = µA	V * 0.000001 = A mV = nA	V * 0.001 = A mV = µA
Output voltage	1mV = 0.1nA	1mV = 0.1uA	1mV = 1nA	1mV = 1uA
Normal (1:1) view				
Conversion formula	V * 0.000001 = A mV = nA	V * 0.001 = A mV = µA	V * 0.00001 = A mV * 10 = nA	V * 0.01 = A mV * 10 = µA
Output voltage	1mV = 1nA	1mV = 1uA	1mV = 10nA	1mV = 10uA
"Zoom out" (1:10) view				
Conversion formula	V * 0.00001 = A mV * 10 = nA	V * 0.01 = A mV * 10 = µA	V * 0.0001 = A mV * 100 = nA	V * 0.1 = A mV * 100 = µA
Output voltage	1mV = 10nA	1mV = 10uA	1mV = 100nA	1mV = 100uA

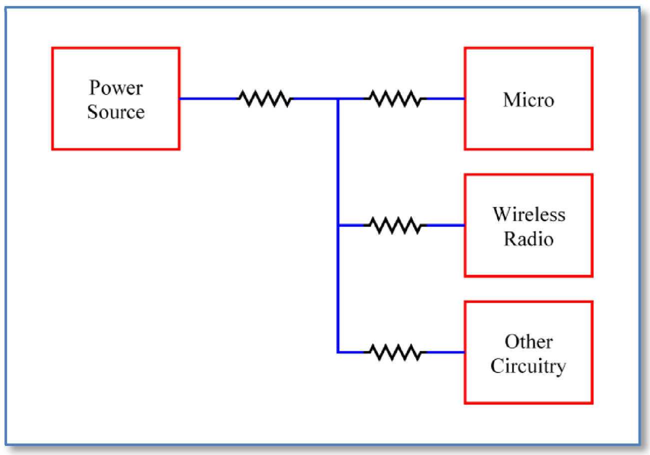
Examples using values for the µCP1x0:

- Normal view, wide range mode, 75mV output: 0.075V * 0.001 = 0.000075A or 75mV = 75uA
- Zoom in view, precision mode, 1.27V output: 1.27V * 0.0000001 = 0.000000127A or 1270mV * 0.1 = 127nA
- Zoom out view, wide range mode, 8.5V output: 8.5V * 0.01 = 0.085A or 8500mV * 10 = 85000uA

Design for Current Measurements

A little forethought during the hardware schematic design can make taking current measurements much simpler and provide more accurate measurements than working with a board designed without consideration for current measurements.

- The most important thing in designing a board to allow for current measurements is to isolate the power supply rail to the micro and any other high power circuitry like a wireless radio module using separate current sense resistors for each major circuit as show below (or headers with 0.025" square posts for use with the µCP1x0). It will also be important to be able to measure the current at the point of power entry to the board. This is usually good enough and isolating the power to each individual circuit just makes the board layout more difficult.



- If board space allows for it, place a 1x4 pin "Berg" header with the two middle pins in parallel with a current sense resistor and the end pins connected to ground. For normal operation, jumper across the header and then remove the jumper for taking current measurements. After development is completed it is easy to remove the jumper and current sense resistor in the board layout.
- When possible, it is a good idea to connect relevant digital signals to test pads or even a test header in order to provide scope triggers and context to current waveforms. It can be very difficult to trigger a scope on the current waveform for a specific event, particularly when a product has more than a few power states. I can also be very difficult to determine what the hardware is doing simply based on a current waveform.
- Consider routing spare GPIO pins to test pads or a test header to provide indication of certain events or conditions in the firmware. For instance, when using a wireless radio module and there are no digital signals that indicate when the radio is transmitting or receiving, using two GPIOs so the firmware can provide these indications can be very helpful when trying to capture the current waveforms for those events.

