App. Note Code: 5-F
Revision: 9

APPLICATION NOTE

Power Supplies

CAMPBELL SCIENTIFIC, INC.
815 W. 1800 N. • Logan, Utah 84321-1784 • (435) 753-2342 • FAX (435) 750-9540 • www.campbellsci.com

Power Supplies

Batteries, Solar Panels, AC Chargers

This application note describes power supplies available from Campbell Scientific, provides procedures for analyzing the power requirements of data acquisition systems, and includes examples of power consumption calculations. Specific equipment described includes alkaline and rechargeable batteries, charging sources, and regulators. The interaction of these components are outlined in Figure 1. In most applications, power supplies offered by Campbell Scientific will power a standard system for months without recharge. This information is intended for users who need to understand the specifics of their system due to use of peripherals, adverse environmental conditions, or use in high latitudes.

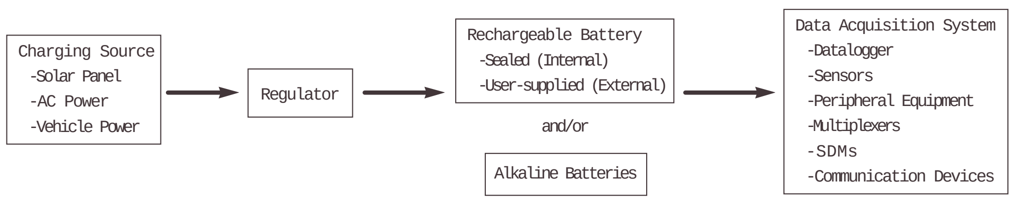


FIGURE 1. The interaction of a system's components.

Batteries

Campbell Scientific's equipment is powered with 12 Vdc batteries (either alkaline or sealed rechargeable).

NOTE

The datalogger batteries should not drop below 9.6 Vdc for the CR510, CR10(X), CR7, and CR9000(C), or below 11 Vdc for the CR23X and CR5000. You should program the datalogger to periodically measure, record, and transmit the battery voltage. Storing a daily minimum battery voltage is an excellent method of monitoring battery health.

Alkaline

Campbell Scientific's CR23X (with base option 10519) includes alkaline batteries as part of the integrated package. The BPALK power supply includes alkaline batteries for powering a CR10(X) or CR510 datalogger. The BPALK have eight D-cell batteries; the CR23X has ten.

These batteries are NOT rechargeable. Back-up power can be provided by a user-supplied sealed rechargeable battery. A blocking diode prevents the user-supplied battery from charging the alkaline batteries. The eight D-cell batteries have a nominal rating of 7.5 Ahr and the ten D-cells have a 10 Ahr rating. These amp hour ratings are at 20°C; the amp hour rating decreases with temperature. The table below depicts the relationship of temperature and battery service.

Typical Alkaline Battery Service and Temperature

Temperature (°C)	% of 20°C Service
20 - 50	100
15	98
10	94
5	90
0	86
-10	70
-20	50
-30	30

The above data are based on one "D" cell battery with a current drain of 50 mA. As the current drain decreases, the service improves.

CAUTION

Alkaline batteries may leak when used outside the temperature range of -25° to +50°C. Allowing the battery voltage to drop below 9.6 V (CR510, CR10(X), 21X, CR7, CR9000(C)) or 11 V (CR23X, CR5000), or mixing new and used batteries can also cause leakage.

Sealed Rechargeable

Campbell Scientific's CR23X (with base option 10518), CR5000 (with base option 10516), CR7, and CR9000(C) dataloggers include a sealed rechargeable battery as part of the integrated package. The nominal ratings of these batteries are 14 Ahrs for the CR9000, 7 Ahrs for the CR23X, CR5000 and CR9000C, and 2.5 Ahrs for the CR7. The PS100 power supply includes a sealed, rechargeable battery for powering a CR10(X) or CR510 datalogger. The PS100's battery has a 7 Ahr rating.

Also available from Campbell Scientific are the BP12 and BP24 battery packs which provide more power for high current drain systems. The BP12 and BP24 have nominal ratings of 12 and

24 Ahrs, respectively. These batteries typically require a CH100 charging regulator.

For Polar applications, we suggest using the Cyclon battery, manufactured by Hawker Energy Products. Testing has shown that these batteries have the best performance in extremely cold temperatures. Visit Hawker Energy's web site at www.hepi.com for more information.

All sealed rechargeable batteries are float-charge compatible and should be connected to a charging source (e.g., ac power, solar panel). The charging source powers the datalogger system while float-charging the batteries. The batteries then provide back-up power if the charging source is interrupted.

Cyclic Service Life of Rechargeable Batteries

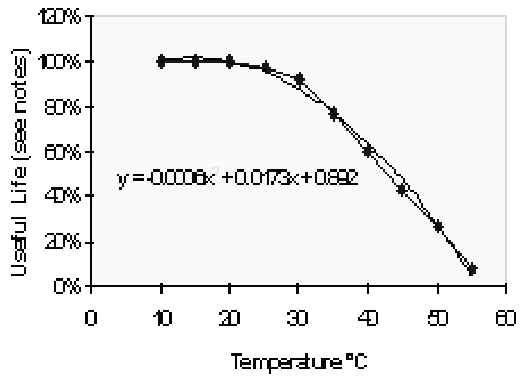
The industry definition of the "cyclic service life" of a battery is the period until it drops to 60% of its rated capacity. For a 7 Ahr battery, this is when after repeated recharging, the battery can only deliver 4.2 Ahrs. When choosing a battery, you should also consider the number of recharge cycles you can expect from the battery until it reaches the end of its cyclic service life.

Several factors affect the cyclic service life, including ambient temperature during charging and storage, number of discharge cycles, depth of discharge cycles, and charging voltage. Clearly, these are complex relationships.

The following may help you assess your batteries' service life:

1) **Temperature** – warmer temperatures decrease life because heat hastens chemical reactions that cause corrosion of the internal electrodes. The temperature effects are graphed and described on the following page.

815 W. 1800 N., Logan, UT 84321-1784 (435) 753-2342



Useful Life of Yuasa NP Batteries vs. Temperature

- 100% of useful life at an optimal 20°C, decreasing to . . .
- 90% of useful life at 30°C, then decreasing approximately linearly to . . .
- 10% of useful life at 55°C.

2) **Depth of discharge:**

- If constantly trickle-charged at a voltage of 13.5 to 13.8 Vdc at an ambient temperature of 20°C (~68°F), such that the battery voltage never drops below ~12.2 V, expect 5 to 6 years of useful life.
- If cycled down to ~11.6 V, expect ~1200 cycles.
- If cycled down to ~11.2 V, expect ~600 cycles.
- If cycled down to ~10.5 V, expect ~500 cycles.

NOTE

Campbell Scientific suggests you store the minimum and maximum battery voltages in your daily data. You can then analyze the data using CSI's Split software or another tool to count the number of times the voltage dropped below certain values.

Solar Panels and Required Battery Capacity

When using a solar panel, the batteries must have the capacity to power the system during periods of low light. The battery capacity's requirements vary with the latitude of the site. Below lists the recommended reserve time based on latitude.

Latitude of Installation Site	**Recommended Reserve Time**
0° to 30° (N or S)	144 to 168 hr
30° to 50° (N or S)	288 to 336 hr
50° to 60° (N or S)	432 hr
Polar Regions	8,760 hr

NOTE

Polar reserve time assumes yearly site visits. Because of long polar nights, riming, and snowfall, for many polar sites, you cannot count on any charging from the solar panels. Therefore, the reserve time should equal the time between visits.

Assuming your site isn't located in the polar regions, the following equation allows you to calculate your system's required battery capacity:

Required battery capacity =
(system's current drain)(reserve time)/(0.8)

The 0.8 value is to limit the battery depth of discharge to 80%. This assumes the worst case conditions. For more information, see Example section starting on page 13.

The following equation can be used to calculate the required battery capacity if your site is located at a polar region:

Required battery capacity =
2(system's current drain)(reserve time)

Regulators

A charging regulator must be used to connect rechargeable batteries with a charging source. The regulator controls the current flowing to the battery and prevents the battery current from flowing to the charging source.

The MSX10R, MSX20R, MSX64R, and MSX128R solar panels include a regulator and can be connected directly to an external rechargeable battery.

Unregulated solar panels (MSX10) and ac transformers must be connected to a Campbell Scientific regulator such as PS100, CR23X base, CR5000 base, CH100, or CR7 solar panel input.

Our regulators provide built-in temperature compensation to optimize battery performance.

Charging Sources

Charging circuitry, ac transformers, solar panels, and vehicle power are used in systems that have sealed rechargeable batteries. The charging sources must produce enough power to balance the power requirements of the system.

Charging Circuitry and ac Transformers

Charging circuitry and ac transformers charge sealed rechargeable batteries by using power from external ac power lines. Specifications are listed below:

	Input	**Isolated Output**
PS100	120 Vac, 60 Hz	20 Vdc @ 1.2 A max
CR7 with ENC 7L	100, 120, 220, or 240 Vac, 50 or 60 Hz	15-25 Vdc @ 400 mA
CR7 with ENC 7F	115 or 230 Vac, 50 or 60 Hz	15-25 Vdc @ 400 mA
CR23X	120 Vac, 60 Hz with 9591 Charger 90 to 264 Vac, 47 to 63 Hz with 14014 Charger	18 Vdc @ 1.11 A
CR5000	120 Vac, 60 Hz	18 Vdc @1.2 A
CR9000(C)	100-240 Vac, 50 or 60 Hz	17.5 Vdc @ 3.5 A max

Solar Panels

Solar panels charge batteries by converting sunlight into direct current. The panels can source current on cloudy days but not at night. Dirty panels, mountain shadows, inversions, and shading from snow, ice, and trees may reduce the solar panel's charging power.

Campbell Scientific offers six Solarex solar panel models on our price lists. The MSX10 and MSX20 are unregulated solar panels that must be connected to one of the regulators mentioned on the previous page. The MSX10R, MSX20R, MSX64R, and MSX128R solar panels include a regulator allowing them to be connected directly to a user-supplied external battery. The MSX128W consists of the MSX64R connected to unregulated 64-watt panel (part #13968); part number 13968 can be ordered as a retrofit.

NOTE

The MSX10R and MSX20R regulated solar panels have a 2 mA continuous current drain. The MSX64R and MSX128R draw <3 mA continuous current.

Solar panel specifications are listed below:

	MSX10/MSX10R	**MSX20/MSX20R**	**MSX64R**	**MSX128R**
Voltage @ Peak Power	16.8	16.8	17.5	17.5
Peak Power, Watts	10	20	64	128
Current @ Peak, Amps	0.59	1.19	3.66	7.32
Dimensions	17 x 11 x 1 in. (42.0 x 26.9 x 2.3 cm)	20 x 17 x 2 in. (50.1 x 42.2 x 5.0 cm)	44 x 20 x 2 in. (111.3 x 50.2 x 5.0 cm)	44 x 40 x 2 in. (111.3 x 100.4 x 5.0 cm)
Weight	3.3 lb (1.5 kg)	6.5 lb (3.0 kg)	15.9 lb (7.2 kg)	31.8 lb (14.4 kg)

NOTE

Specifications assume a 1 kilowatt per square meter illumination and a solar panel temperature of 25°C (77°F). Individual panels may vary up to 10%. The output panel voltage increases as the panel temperature decreases.

You can determine the best solar panel model for applications not located in a polar region by using this equation:

Solar panel current > ((system Ahr/day) x 1.2)/(hrs of light)

Where: **1.2** — accounts for solar panel system loss

hrs of light — the number of hours in the day that the sky is clear enough for the solar panel to source current. To be safe, we suggest you use the worst case condition, i.e., winter.

For more information, see Example section starting on page 13.

Use the following equation to determine the best solar panel model for sites located in a polar region:

solar panel current > ((system Ahr/day) x 2)

NOTE

For polar sites, the solar panel must be mounted vertically to take advantage of the low sun angle in the winter as well as maintaining a charge in the summer when the sun is higher in the sky. The panel is also mounted vertically to reduce the tendency for the panel to collect snow or rime up.

Vehicle Power

The CR23X and CR5000 can also use vehicle power to recharge their sealed rechargeable battery. A DCDC18R Boost Regulator is required to boost the vehicle's supply voltages to the 17 Vdc minimum required to charge the datalogger's battery.

Adapters

The A100 and A105 adapters connect to either the PS100 or CH100. The A100 adapter adds a null modem port for powering peripherals at non-datalogger sites such as an RF repeater. The A105 adapter increases the number of 12 V and ground terminals available.

Calculating Power Consumption of a System

The power consumption of a system is the sum of the datalogger, sensors, and peripheral equipment's (multiplexers, SDMs, and communication devices) average current drains. Examples of calculating a system's power consumption are provided on page 13 and 15.

Dataloggers

The average current drain can be calculated by determining the time spent in an active state (performing measurements, processing/storing data) versus the time spent in a "quiescent" state. This relationship is primarily affected by the datalogger's scan rate (see Figure 2) and the length of the datalogger program. The current drains of Campbell Scientific's dataloggers in both active and quiescent states are listed below.

815 W. 1800 N., Logan, UT 84321 (435) 753-2342

Typical Current Drain (mA)

Datalogger Model	Quiescent	Active
CR200 Series (Spread Spectrum Radio off)	~0.2	~3
CR10X	1.3	13 (processing) 46 (analog measurement)
CR10	0.7	13 (processing) 46 (analog measurement)
CR510	1.3	13 (processing) 46 (analog measurement)
CR23X	2.0	45 (processing) 70 (analog measurement)
CR7	3.5 - 6	~16 (processing) ~100 (analog measurement)
CR9000	30	750 to 1000 (processing) 750 to 1000 (analog measurement)
CR5000	0.4 (software power-off) 1.5 (sleep mode)	4.5 (at 1 Hz sample rate) 200 (at 5 kHz sample rate)

NOTE

The above current drains assume a temperature range of -25° to +50°C. Operation outside these limits increases the current drain. The CR9000 and CR7's power consumption varies according to the combination of modules and cards. A list of the current drains for the modules and cards is published in the CR9000 and CR7 manuals.

815 W. 1800 N., Logan, UT 84321-1784 (435) 753-2342

CR10X Current Drain

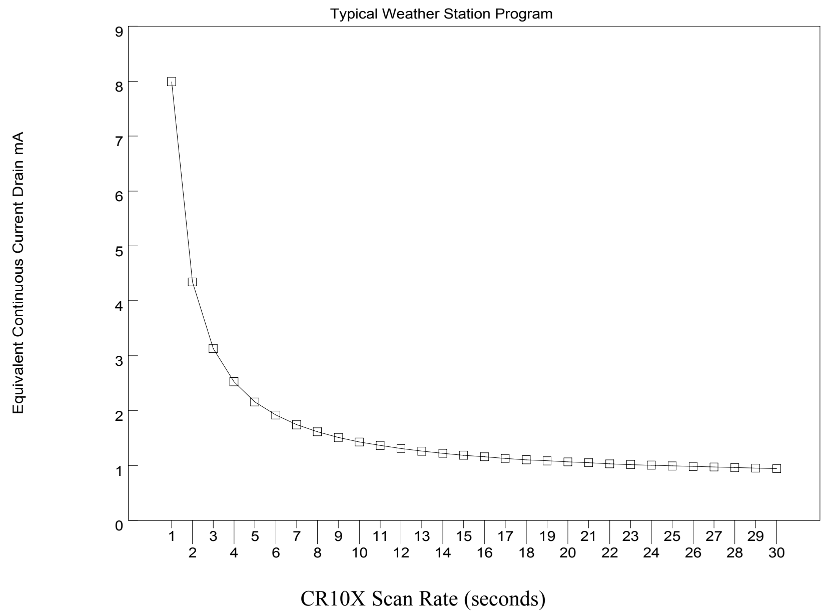


FIGURE 2. Short scan rates dramatically affect the current drain of a system.

Sensors

The current drain of a sensor is determined by its current drain during quiescent and active states, which is affected by the data-logger's scan rate. Most sensors supplied by Campbell Scientific have negligible power consumption. Below is a list of the current drains for the most commonly used sensors, as well as the current drain for sensors that have significant current drains. Further information is available in the sensor operator's manuals and brochures.

Typical Current Drain (mA)

Sensor	Quiescent	Active
Campbell Scientific Thermistors	negligible	negligible
Thermocouples	"	"
Potentiometers	"	"
Switch closures	"	"

CS500 Temperature and Relative Humidity Probe	"	2
HMP45C Temperature and Relative Humidity Probe	"	4
Barometric Pressure Sensor (Vaisala CS105)	"	4
SR50 Distance Sensor	2	250
CSAT3 Sonic Anemometer	negligible	200 @ 60 Hz measurement 100 @ 20 Hz measurement
DB1 Double-Bubbler	negligible	40

NOTE

Current drains assume a temperature range of -25° to +50°C.

Peripheral Equipment

Peripheral equipment includes multiplexers, SDMs, and communication devices. As with the datalogger, power consumption of multiplexers is determined by the percentage of time in active and quiescent states. This percentage is calculated from the datalogger's scan rate and program.

SDMs are generally in an active rather than a quiescent state and typically require an external rechargeable power supply.

Communication peripherals are typically active only during data transfer or while being interrogated by the base station computer. When a communication device is transmitting, the datalogger goes into a processing state. You should account for this when calculating your system's power consumption. Below is a list of some peripheral equipment's current drains. A more complete list is available in Campbell Scientific operator's manuals and brochures.

815 W. 1800 N., Logan, UT 84321-1784 (435) 753-2342

Typical Current Drain (mA)

Peripheral Equipment	Quiescent	Active
AM16/32 Multiplexer	<0.21	6
AM25T Multiplexer	0.5	1
Redwing CDMA	20	120
COM210 Phone Modem	0.12	160
COM310 Voice Synthesizer Modem	0.1	180
HDR GOES Satellite Transmitter	1	350 (during GPS acquisition) <4000 (during transmission)
RAD Modem and SC932A Interface	2.2	10 to 15
RF310-RF313 Radios	<65 mA	<2000 (transmit 5 W RF Power) <1000 (transmit 12 W RF Power)
RF310M RF Modem	1.4	30
SAT Argos Satellite Transmitter	<0.09	15 (<700 transmitting)
SDM-AO4	10.5	continuous
RF400 and RF410	<1 (power saving mode)	24 (receiving), <75 (transmitting)
RF415	<1 (power saving mode)	36 (receiving), 75 (transmitting)
SDM-CD16AC	6.0	45/LED lit
SDM-INT8	0.4	6.5
SDM-IO16	0.6	3
SDM-SIO4	0.7	29
SDM-SW8A	3	6
SM4M/SM16M Storage Module	<0.2	30-40 (processing) 10 (communications mode) 15 (data storage)

NOTE

Current drains assume a temperature range of -25° to +50°C.

Typical Weather Station Example

System's Current Drain

Suppose the weather station uses a CR10X with a thirty second scan rate. The average current drain is:

	Duration (sec)	**Current Drain (mA)**
Analog Measurement:	0.2	46
Processing:	0.03	13
Quiescent:	29.77	1.3

$$\text{Datalogger average current drain} = \frac{(0.2\text{ sec})(46\text{ mA}) + (0.03\text{ sec})(13\text{ mA}) + (29.77\text{ sec})(1.3\text{ mA})}{30\text{ sec}} = 1.61\text{ mA}$$

If the station is called once a day (1440 min) for five minutes via a telephone line (COM210 modem), then the average current drain of the COM210 is:

COM210 Modem	**Duration (min)**	**Current Drain (mA)**
Active:	5	160(COM210) + 13(CR10X) = 173
Quiescent:	1435	0.12

$$\text{COM210 Modem average current drain} = \frac{(5\text{ min})(173\text{ mA}) + (1435\text{ min})(0.12\text{ mA})}{1440\text{ min}} = 0.72\text{ mA}$$

Assuming the meteorological sensors require negligible power, the average current drain of this weather station system is:

System's average
current drain = 1.61 mA + 0.72 mA = 2.33 mA or 0.00233 A

815 W. 1800 N., Logan, UT 84321-1784 (435) 753-2342

Theoretical Alkaline Battery Life

This weather station can be powered with the BPALK power supply which has an amp hour rating of 7.5. The alkaline batteries will theoretically last:

(7.5 Ahr)/(0.00233 A) = 3219 hours or about 134 days

NOTE

Because temperature and other factors can affect battery service, you should monitor the battery voltage to determine the actual battery replacement schedule.

Using Rechargeable Battery and Solar Panel

If we choose to use a solar panel and rechargeable battery to power the station, the rechargeable battery must be able to power the weather station during periods of low light. If the weather station is at a latitude of 40° North, the recommended reserve time listed on page 4 is 336 hours. According to the equation listed on page 5, the required battery capacity is:

Required battery capacity = (0.00233 A)(336 hr)/(0.8) = 0.98 Ahr

Because the PS100's rechargeable battery has a 7.0 Ahr capacity, it sources sufficient current for this weather station.

We can determine the best solar panel model for the weather station by using the equation on page 7. First we need to calculate the station's average amp hours per day:

Ahr/day = (0.00233 A) x (24 hr/day) = 0.0559 Ahr/day

Assuming the solar panels source current for five hours per day, the panels must produce:

((.0559 Ahr/day) x 1.2)/5 hr = 0.0134 A

Because the MSX10 and MSX10R's current at peak is 0.59 A, they can easily provide sufficient current for this system.

Example of a Weather Station Using RF Telemetry

System's Current Drain

An example of a high current drain system is when the previous weather station is called every five minutes (300 sec) using an RF310 radio and RF310M modem. The RF's average current drain is:

RF System	**Duration (sec)**	**Current Drain (mA)**
Active:	10	2000(RF310) + 30(RF310M) + 13(CR10X) = 2043
Quiescent:	290	65(RF310) + 1.4(RF310M) = 66.4

$$\text{RF system's average current drain} = \frac{(10\ \text{sec})(2043\ \text{mA}) + (290\ \text{sec})(66.4\ \text{mA})}{(300\ \text{sec})} = 132.29\ \text{mA}$$

Since the datalogger has a current drain of 1.61 mA, the average current drain of the system is:

1.61 mA + 132.29 mA = 134.3 mA or 0.1343 A

Using Rechargeable Battery and Solar Panel

The current drain of the RF system requires the use of a rechargeable battery instead of alkaline batteries. If you choose a solar panel for the charging source, the rechargeable battery must be able to power the station during periods of low light. If the station is at a latitude of 40° North, the recommended reserve time listed on page 4 is 336 hours. According to the equation listed on page 5, the required battery capacity is:

Required battery capacity = (0.1343 A)(336 hr)/(0.8) = 56 Ahr

Therefore this station requires more battery capacity than what the PS100, BP12, or BP24 can source. In this situation, a user-supplied marine or RV battery or ac power should be used.

CAUTION

Disconnect the batteries included with the CR23X or CR7 when using an external battery. Two rechargeable batteries that have different Ahr ratings should not be connected in parallel.

The best solar panel model for this example can be calculated using the equation on page 7. First we need to calculate the station's average amp hours per day:

Ahr/day = (0.1343 A) x (24 hr/day) = 3.2232 Ahr/day

Assuming the solar panel sources current for five hours per day, the panel must produce:

((3.2232 Ahr/day) x 1.2)/(5 hr) = 0.7736 A

Because the MSX20R's current at peak is 1.19 A, it can easily provide sufficient current for this system.