Soaring Aviation Electrical

"Best Practices" Series

Circuit Examples & Minimizing Lost Volts

[Part 3 of 3]

John DeRosa OHM Ω

Updated: January 21, 2025

PLEASE NOTE

This document may have been updated with new information, changes, and corrections.

Be sure to visit my presentation web site and download the latest version of this document. It could make an important difference to your work!

http://aviation.derosaweb.net/presentations

Thank you, John

Disclaimers

- I am **not** an FAA licensed A&P or IA
- I am **not** an approved avionics technician
- You should know the difference between Experimental & Standard airworthiness certification, and what you can and cannot do to your glider
- Work closely with an IA to get your work properly inspected and signed off in your glider's log book
- Proceed at your own risk.

Chapters

Part 1

1.  Reference Information
2.  Your Tool Box
3.  Wires and Wiring
4.  Making Connections
5.  Other Things of Note

Part 2

6.  Power Management

Part 3

7.  **Examples of Battery Bus Sys.**

8.  **Minimizing Lost Volts**

9.  **Providing USB Power**

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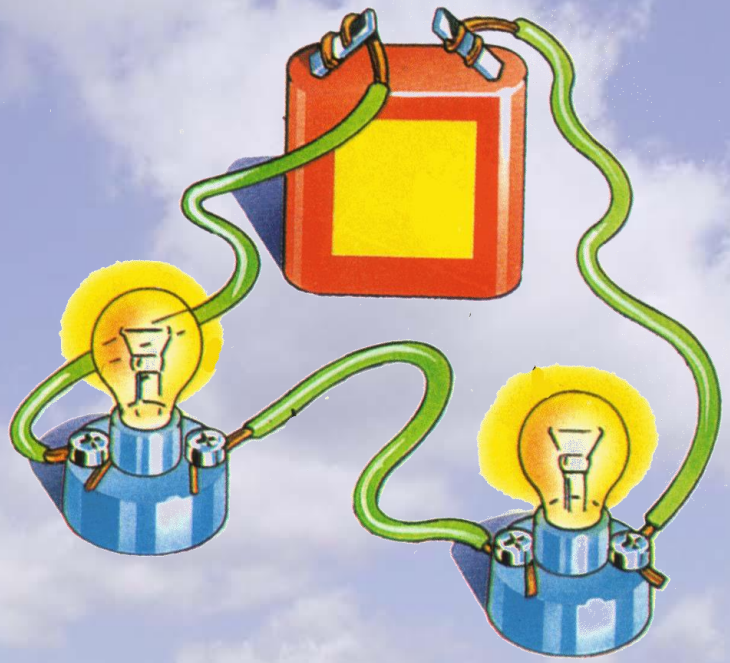
- Proceed at your own risk
- **'Nuff said, let's get started…**

Chapter 7
Examples of Battery Bus Systems



Examples of Battery Bus Systems

Single and Dual Battery Bus Systems

My General Comments

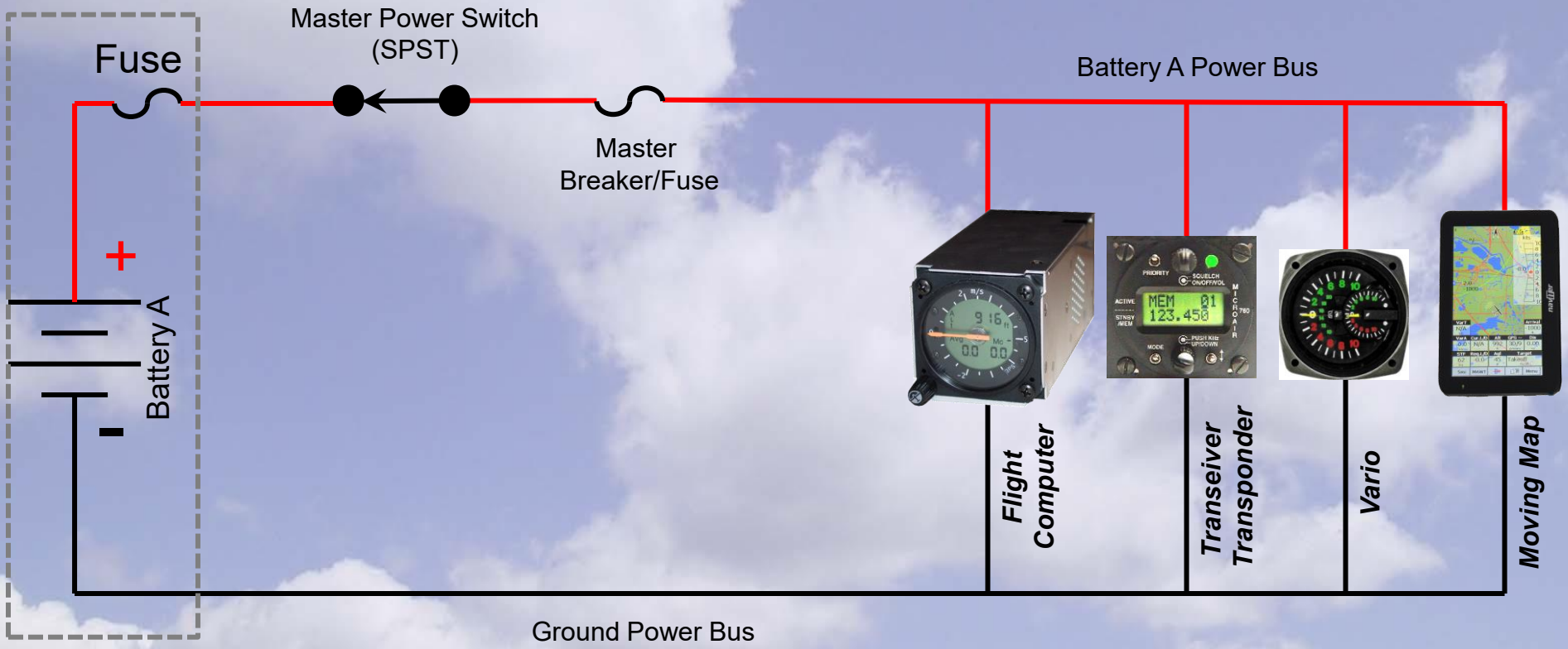
1) *All batteries **MUST HAVE A FUSE** connected directly to their positive terminal. It is your **FIRST LINE OF DEFENCE** to prevent major electrical problems while in flight.*
2) *All systems must have master switch(es) easily accessible to the pilot.*
3) *Breakers are preferred, rather than fuses, between the battery and the main power bus as breakers are easily switched off.*
4) *All fuses and breakers should be 5A or greater - see Chapter 8 for reasoning.*
5) *Separate fuses/breakers for each device are not needed. A single fuse/breaker per a collection of similar devices is (communications, navigation) is an option.*
6) *Each individual device should have a way to turn off it's power while in flight.*

Examples of Battery Circuitry

Basic Single Battery Bus Systems

Sample Power Bus Systems

Single Battery Switching
Minimum Configuration

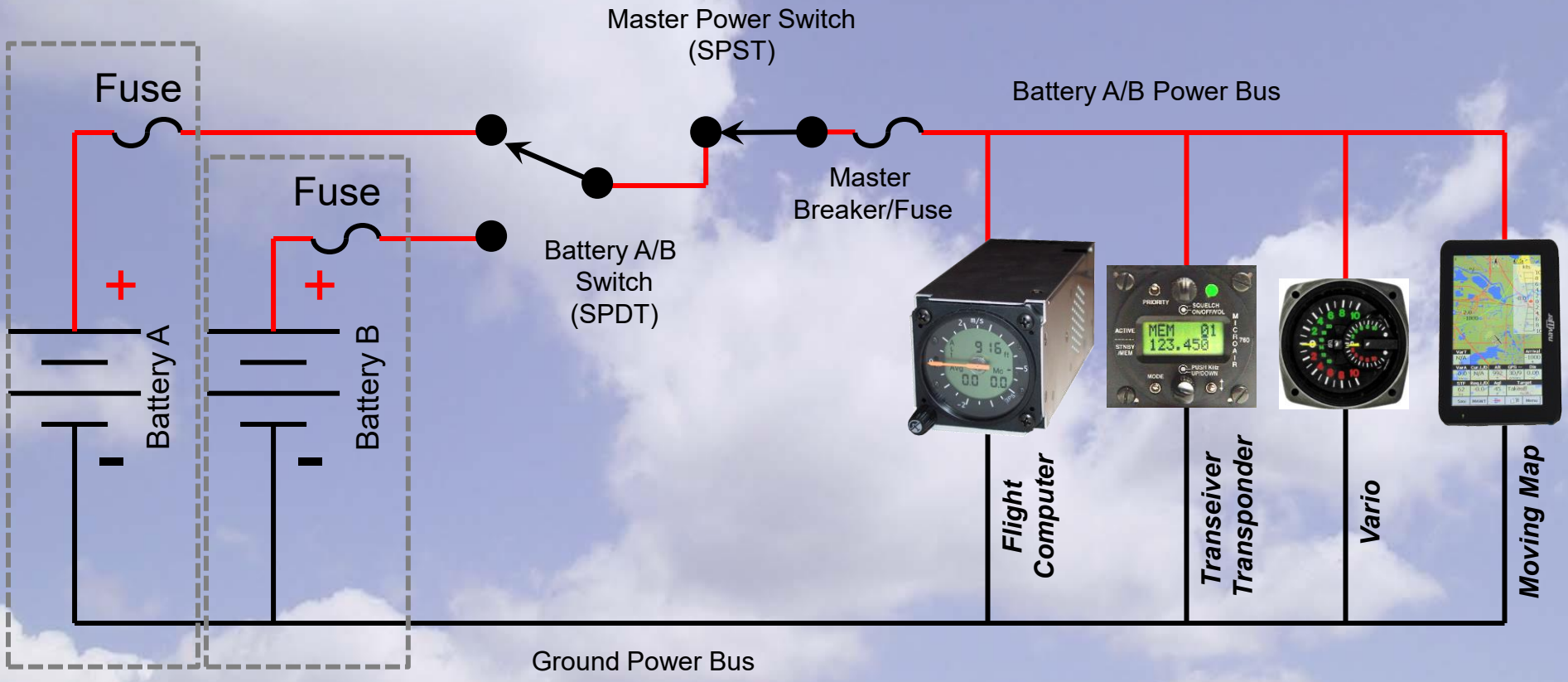


Examples of Battery Bus Systems

Better Two (2) Battery Bus Systems

Sample Power Distribution Circuits

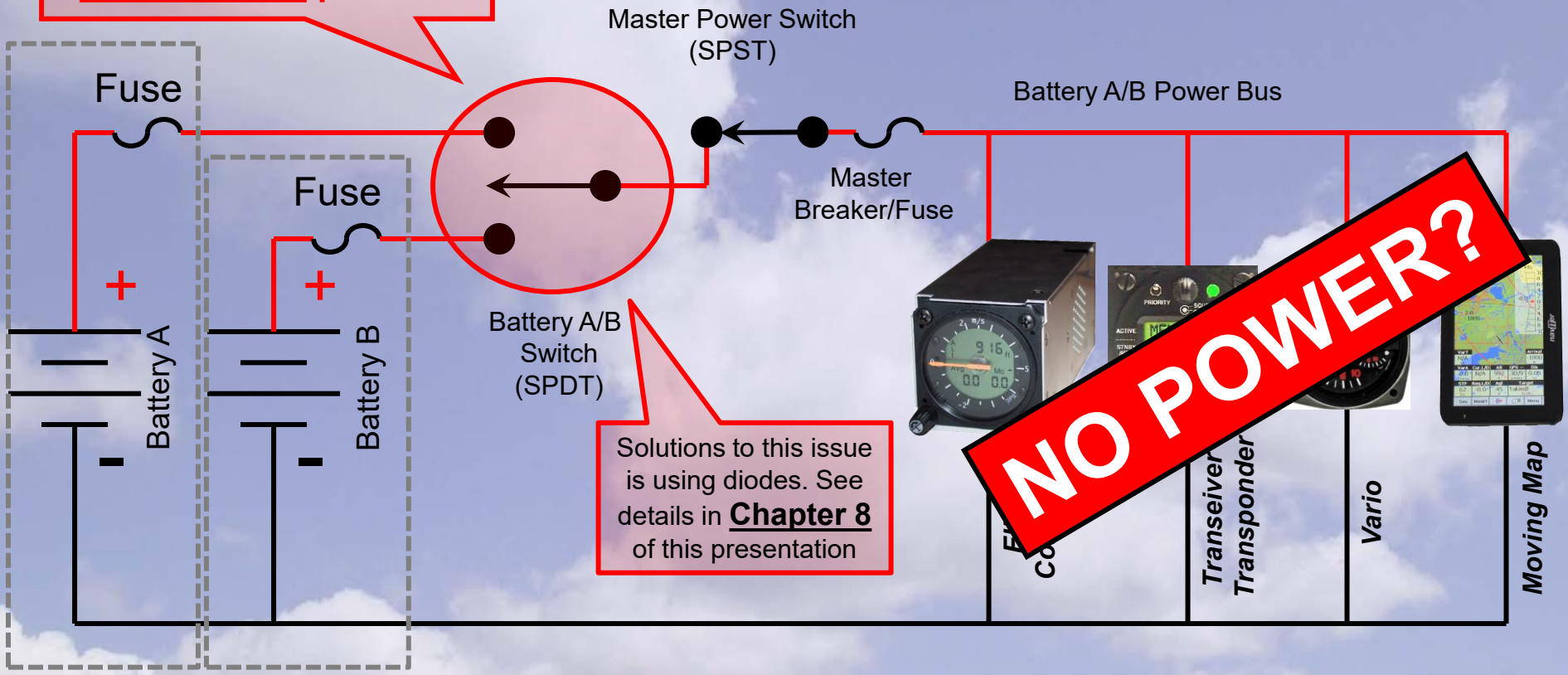
Simple Dual Battery Switching



Sample Power Distribution Circuits

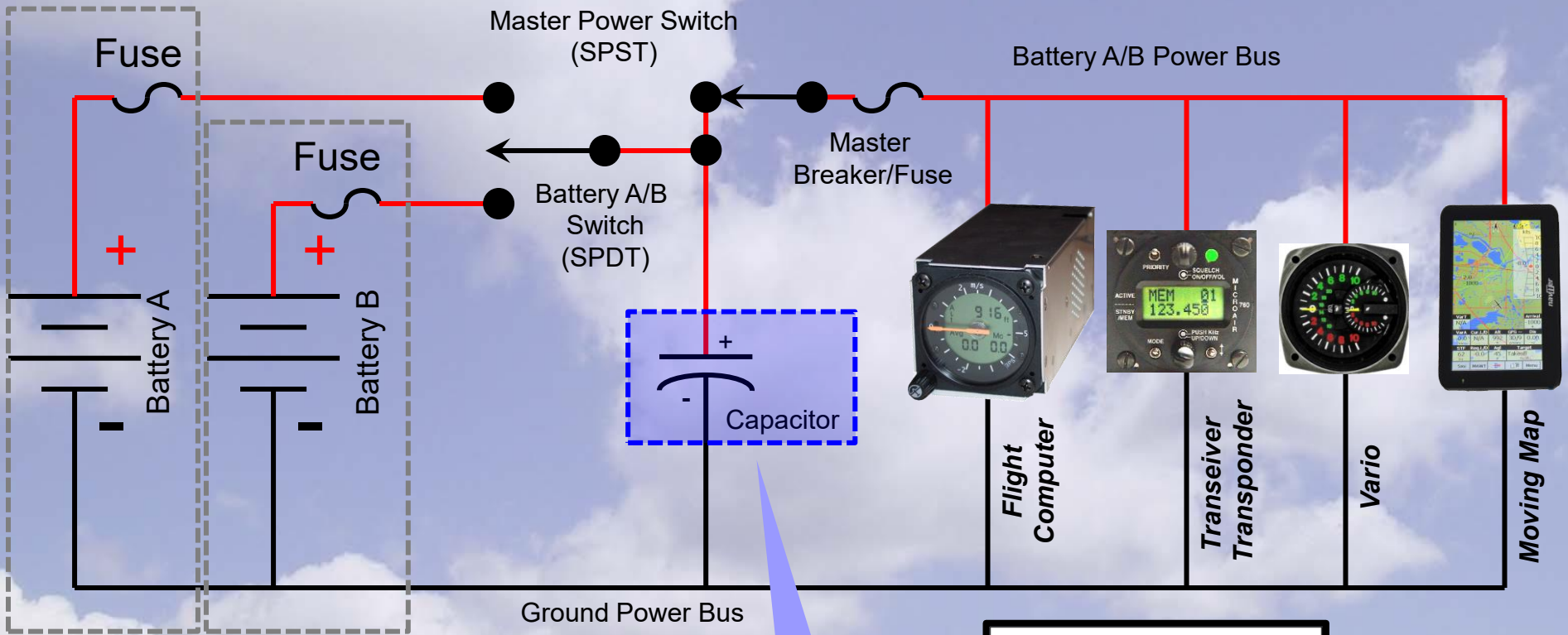
Switch is momentarily in the half-way disconnected position

Problem - Dual Battery Switching



Sample Power Distribution Circuits

Capacitor Solution for Dual Battery Switching

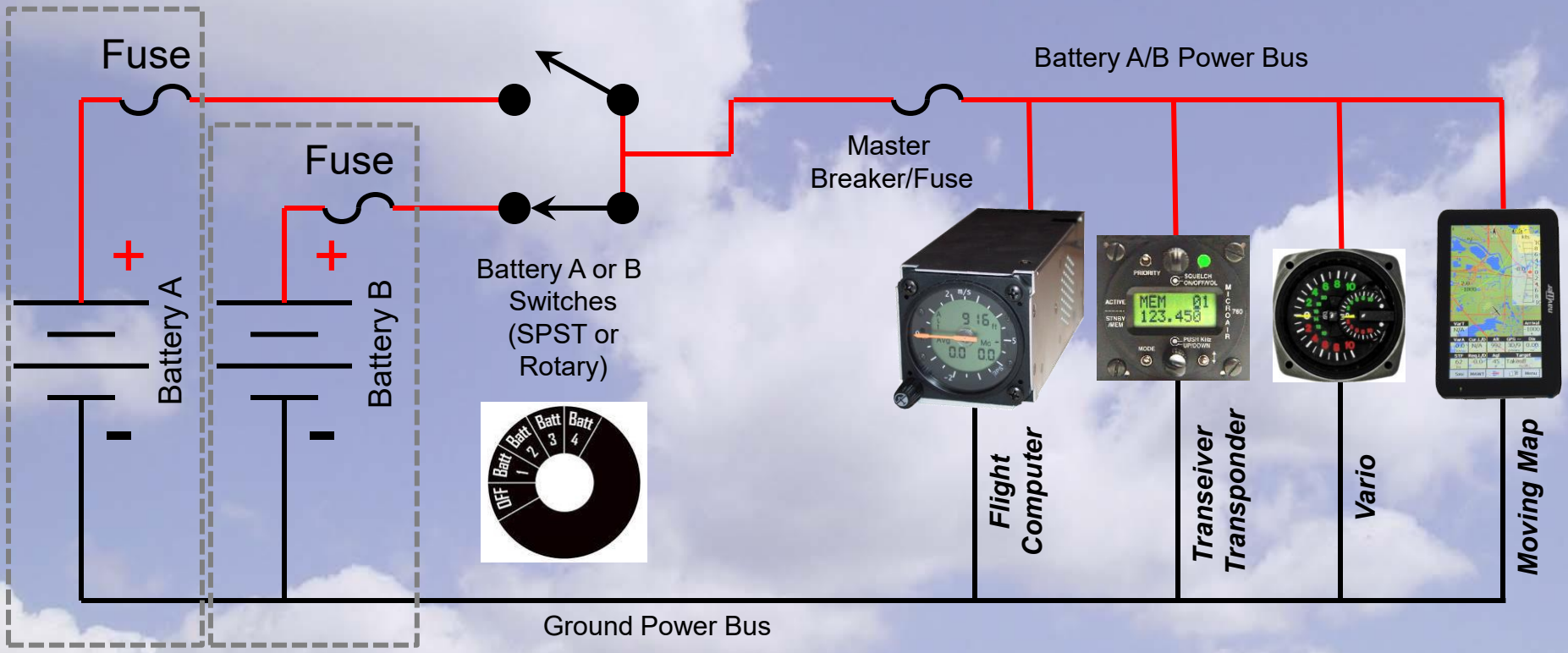


During switching the electrolytic capacitor will hold a charge for a short period of time and should prevent the instruments from loosing power. The value should be very large (100,000uf or larger) and rated at 20Vdc or higher. Watch the polarity!

← Note the negative polarity symbol on the capacitor

Sample Power Distribution Circuits

Dual Battery Switching/Bridging

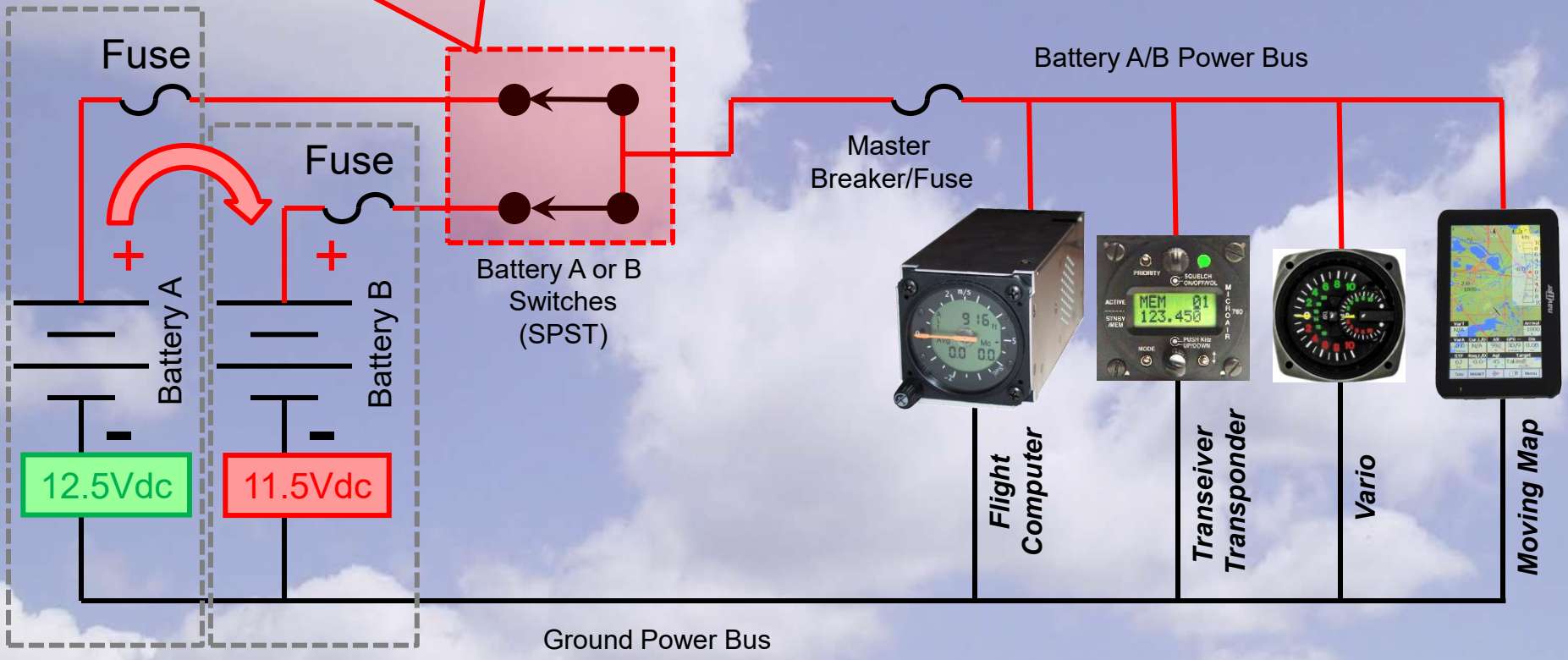


- Having two switches allows either battery to power the power bus. And allows a smooth transition from one battery to the other by momentarily connecting both batteries to the bus.

Sample Power Distribution Circuits

PROBLEM - Dual Battery Bridging

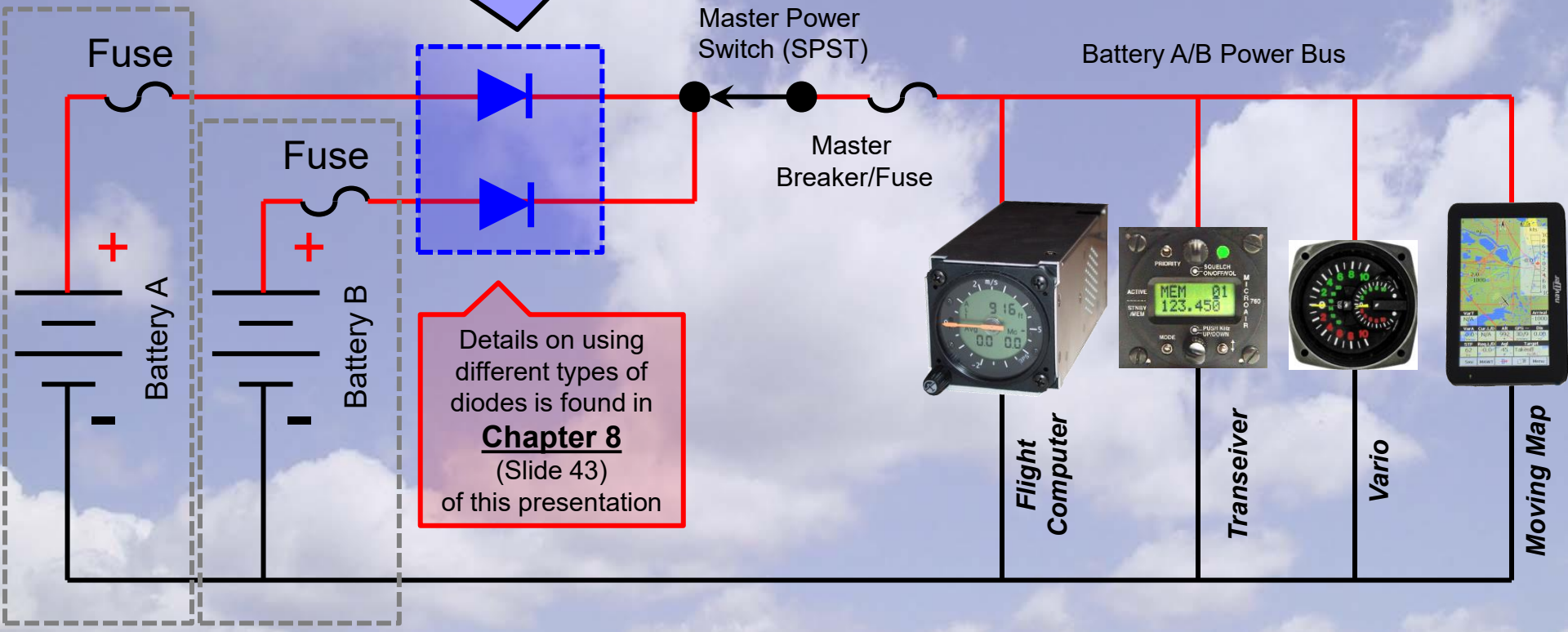
When both switches are closed the batteries are "bridged" and can cross-charge one another if they are at a different state of charge. This may cause a current surge, blown fuses, battery damage, or worse.



Sample Power Distribution Circuits

Dual Battery Bridging

The diodes prevent current surges by not allowing the batteries to cross-charge each other while still allowing either battery (the one with the most charge) to supply power to all the instruments



Details on using different types of diodes is found in **Chapter 8** (Slide 43) of this presentation

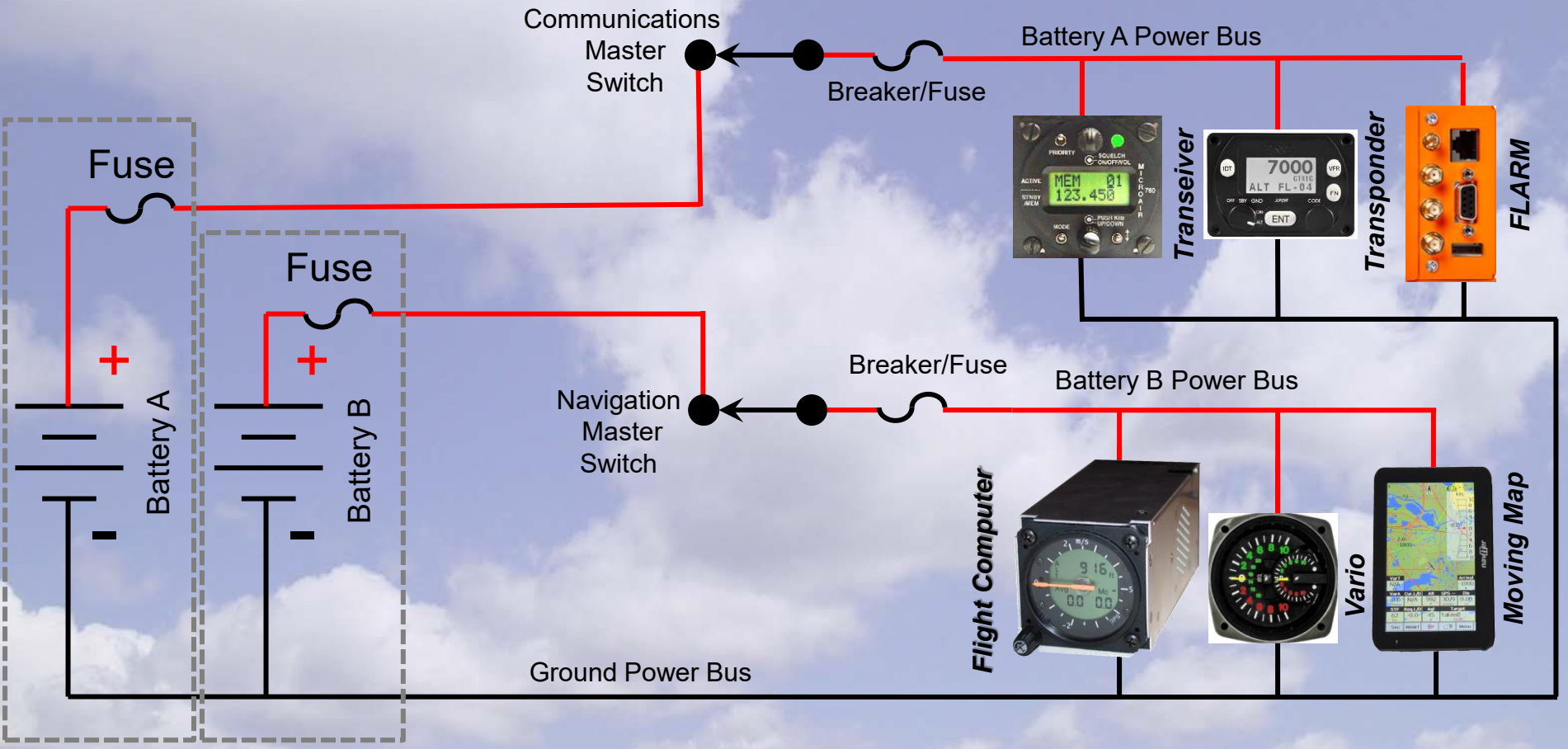
Examples of Battery Circuitry

Advanced Two (2) Battery Bus Systems

Sample Power Distribution Circuits

Separate Buses For Communications & Navigation

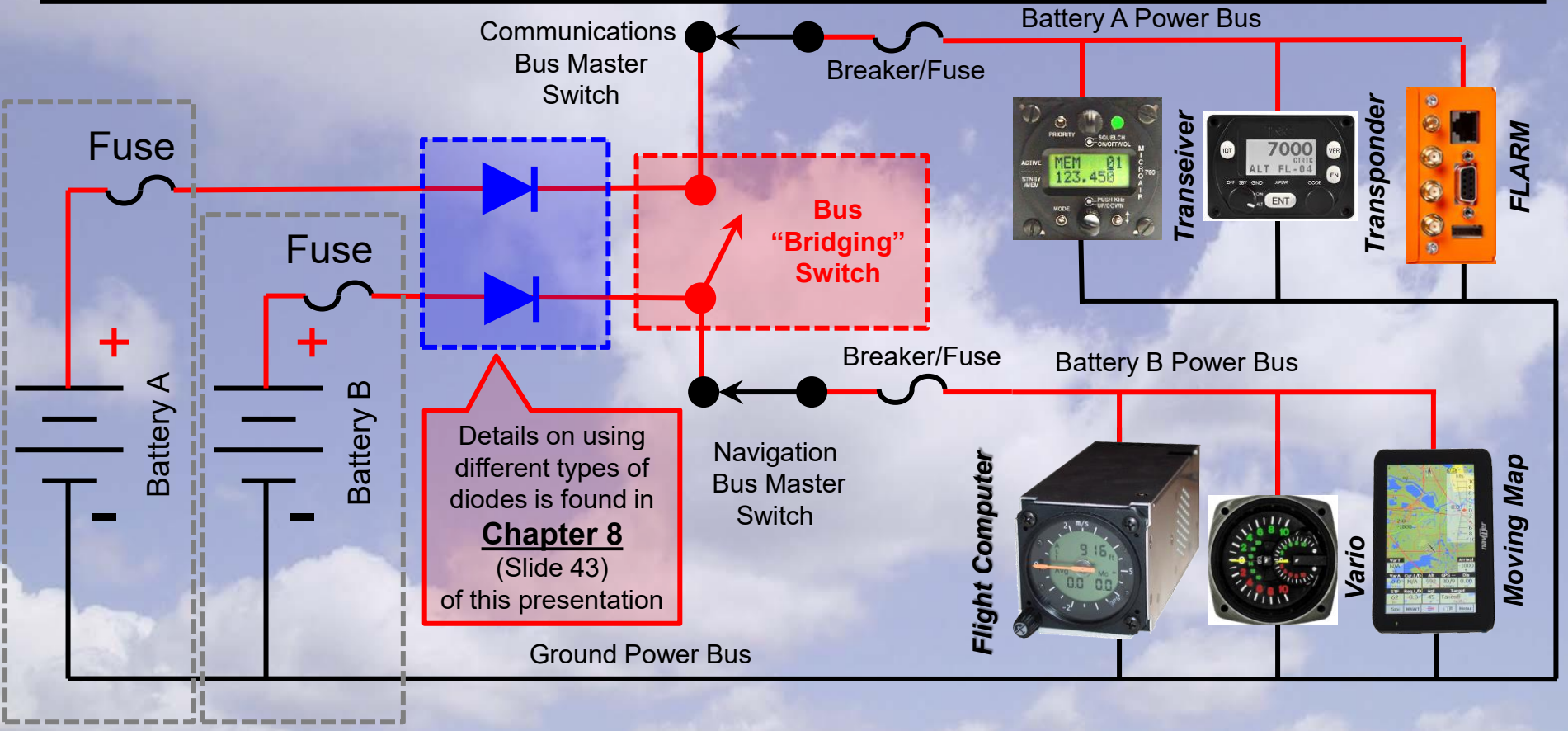
- Splitting a single power bus into two buses for 1) Communications and 2) Navigation equipment has the advantage of allowing different battery densities (amp-hours) for heavily utilized and critical avionics.



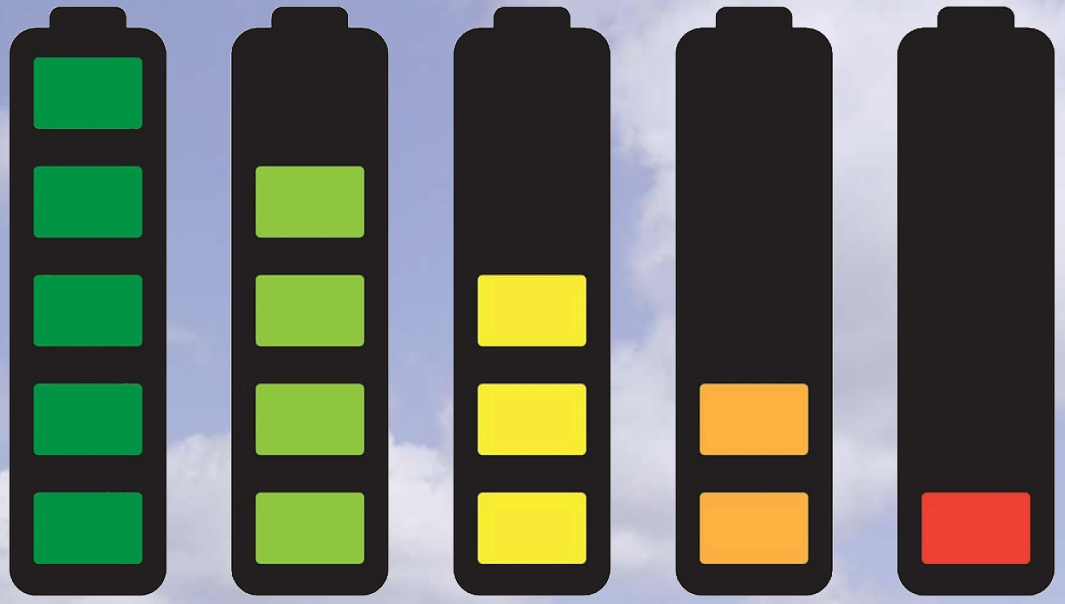
Sample Power Distribution Circuits

Dual Battery with Split Bus Bridging

- Bridging of the Communication and Navigation buses has the advantage of allowing for either battery to power either bus.
- This can be useful if one battery is “dead” allowing the pilot to choose which avionics is the most critical at this moment.
- While bridging the buses the battery with the highest voltage provides 100% of the power for both buses.



Chapter 8
Minimizing Lost Volts



Sections

A. With Battery Type
B. With Wire Sizing
C. With Fuses & Breakers

Losing Volts & What to Do About It!

- Glider avionics need as much voltage as possible to their avionics because they don't have generators or alternators.
- As the battery voltage goes down, the amps required goes up;
  - Power (watts) requirements stays the same for a given device;
    - Power (W) = Voltage (V) times Amps (A)
  - As the voltage drops, current increases to maintain the power required
  - Higher current requirements may require larger wiring, or battery, or both
- Glider power systems can lose volts in many insidious ways. This means that devices may fail during long flights to operate poorly or not operate at all.
- Where do we "lose" volts & what can we do about it?
  - Battery Types (discharge "droop")
  - Too Small Wire gauge (resistance per foot)
  - To Small of Breaker/Fuse (resistive load)
  - Poor Connections & Grounding (corrosion resistance)
  - Cross Current Diode Types (voltage drop)

Section A

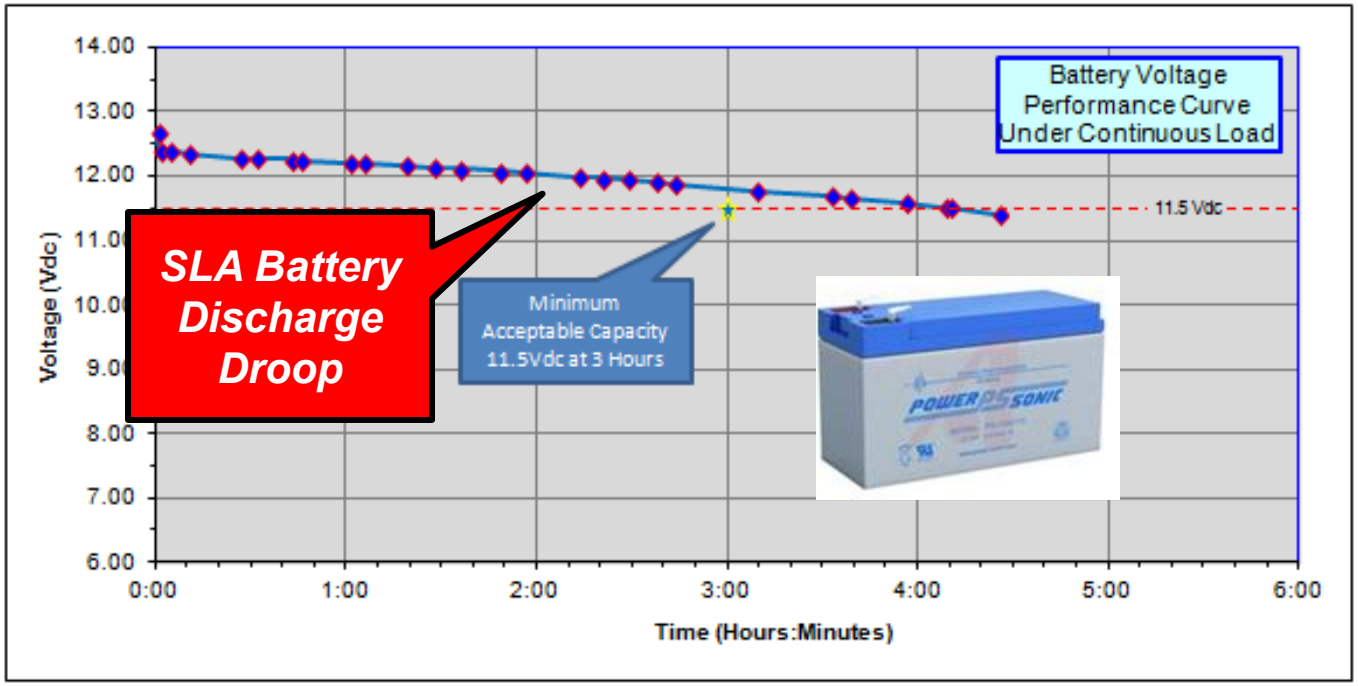
Loosing Volts With Battery Type

Battery Load Testing - SLA

For more testing details see *SOARING* Feb 2012 or http://aviation.derosaweb.net/presentations

Testing Description December 21, 2012 - Battery 1/06 - #1 - Load 12ohm = 1A nominal load

Time (HH:MM)	Voltage (Vdc)	Duration (HH:MM)
08:39	12.68	0:00
08:40	12.40	0:01
08:43	12.40	0:04
08:49	12.35	0:10
09:05	12.29	0:26
09:10	12.28	0:31
09:21	12.26	0:42
09:24	12.25	0:45
09:40	12.21	1:01
09:44	12.20	1:05
09:57	12.17	1:18
10:06	12.14	1:27
10:14	12.11	1:35
10:27	12.08	1:48
10:35	12.05	1:56
10:52	11.99	2:13
10:59	11.97	2:20
11:07	11.94	2:28
11:16	11.91	2:37
11:22	11.89	2:43
11:48	11.78	3:09
12:11	11.69	3:32
12:17	11.66	3:38
12:35	11.58	3:56
12:47	11.52	4:08
12:49	11.50	4:10
13:04	11.41	4:25



Enter data in the yellow cells only

How to Use this Spreadsheet

Hint: For ease of identification, uniquely mark each battery, i.e. the date it was purchased.

1) Note the date, battery type, unique identifier and other details in row 3.
2) Save-as the spreadsheet and indicate the battery type, unique identifier and test date in the filename.
3) Delete the contents of the yellow colored cells (select the contents and hit "delete").
4) Fully charge the battery. Connect a resistive load to the battery and a voltmeter.
5) Take a voltage reading and note the time the reading was taken.
6) Enter the voltage reading in column D.
7) Enter the clock time of your voltage reading in column C in HH:MM 24-hour format (i.e. 9AM = 09:00, 9PM = 21:00).
8) Repeat steps 5 through 7 every 10-15 mintues until the voltage of the battery drops to approximately 11.5Vdc or lowe
(NOTE: 11.5Vdc is a reasonable minimum voltage for avionics use - refer to your avionics owner's manuals).
9) Save the spreadsheet and print it for your records.

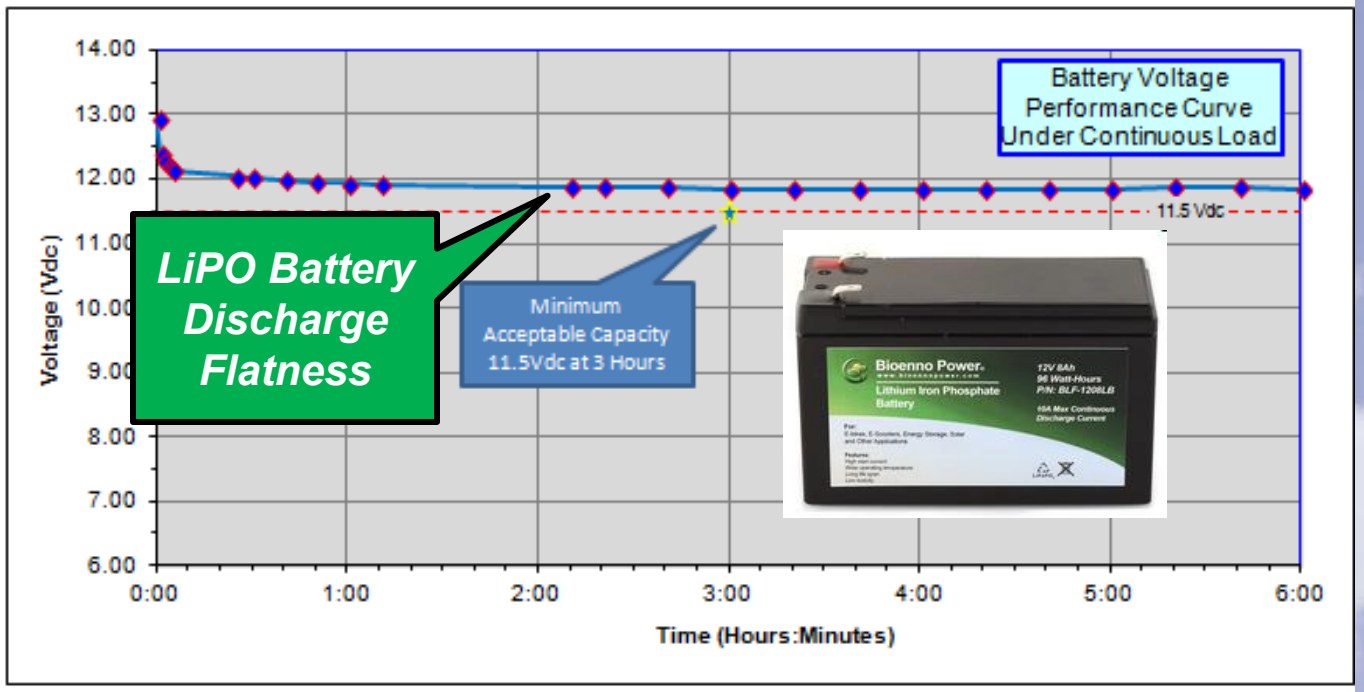
WARNING Do not leave the battery connected to a load for an extended period of time. This can damage the battery.

Battery Load Testing - LiFePO4

For more testing details see *SOARING* Feb 2012 or http://aviation.derosaweb.net/presentations

Testing Description 2/1/15 - N101RP Lithium #1 - labeled Jan, 2015 12Ω resistive load =1A nominal load

Time (HH:MM)	Voltage (Vdc)	Duration (HH:MM)
00:00	12.93	0:00
00:01	12.37	0:01
00:02	12.26	0:02
00:03	12.20	0:03
00:04	12.15	0:04
00:05	12.14	0:05
00:25	12.04	0:25
00:30	12.03	0:30
00:40	11.97	0:40
00:50	11.95	0:50
01:00	11.93	1:00
01:10	11.90	1:10
02:10	11.89	2:10
02:20	11.89	2:20
02:40	11.86	2:40
03:00	11.85	3:00
03:20	11.84	3:20
03:40	11.83	3:40
04:00	11.83	4:00
04:20	11.83	4:20
04:40	11.83	4:40
05:00	11.85	5:00
05:20	11.88	5:20
05:40	11.86	5:40
06:00	11.85	6:00
06:20	11.78	6:20
06:30	11.74	6:30
06:40	11.55	6:40
06:50		6:50
07:00		7:00
07:10		7:10
07:20		7:20
07:30		7:30
07:40		7:40
07:50		7:50
08:00		8:00
08:10		8:10
08:20		8:20
08:30		8:30



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8) Repeat steps 5 through 7 every 10-15 mintues until the voltage of the battery drops to approximately 11.5Vdc or low
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9) Save the spreadsheet and print it for your records.

WARNING Do not leave the battery connected to a load for an extended period of time. This can damage the battery.

Section B

Loosing Volts With Wire Sizing

Importance of Wire Size

Energy Source

Power Wiring

14ga wire

12ga wire

10ga wire

EVIL Wire Resistance!!

Devices

Incandescent Lights

Microwave

Electric Stove

As the Device's Power (W) increases the wire's resistance and gauge becomes important

Increased wire gauge means less resistance, less lost volts and more power!

Importance of Wire Size

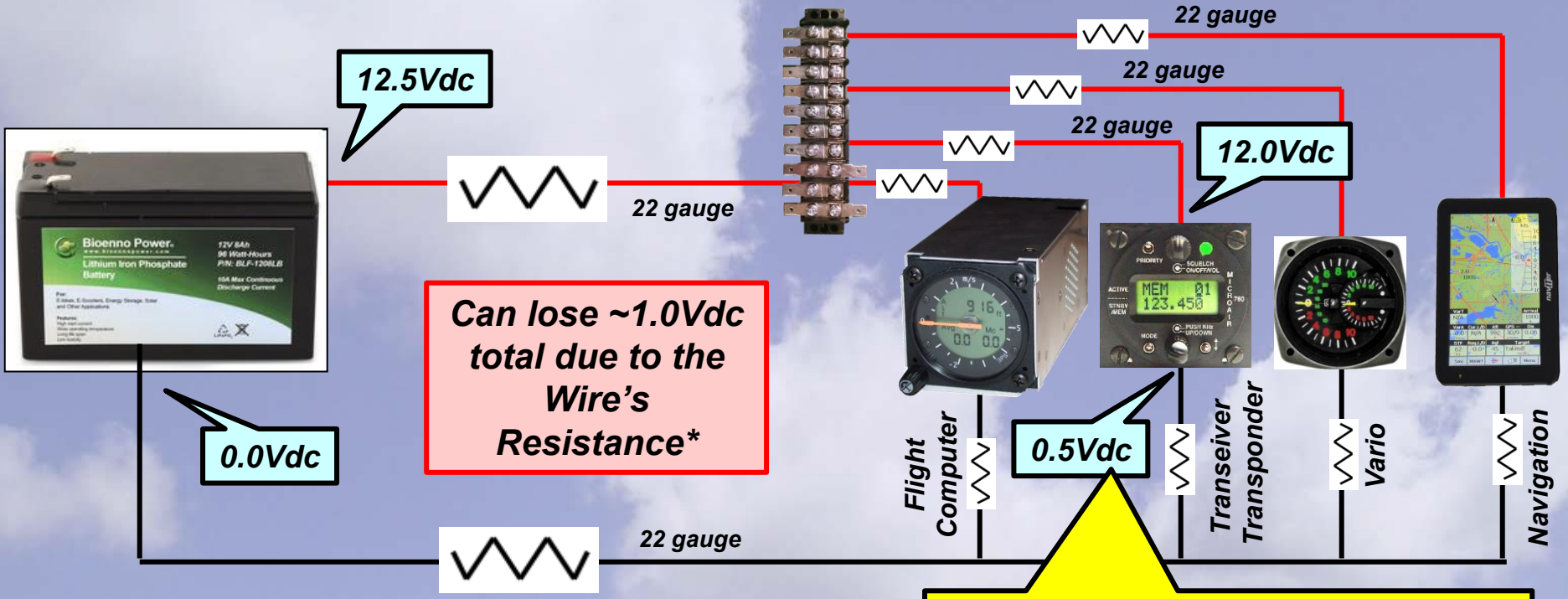
Energy Source ***Power Wiring*** ***Devices***

Wire Gauge Too Small

Too small of gauge wire increases resistance and looses battery's energy as lost heat (and lost volts)

Device's current requirements can be thought of as it's own "Resistance"

Loosing Volts – 22ga Example

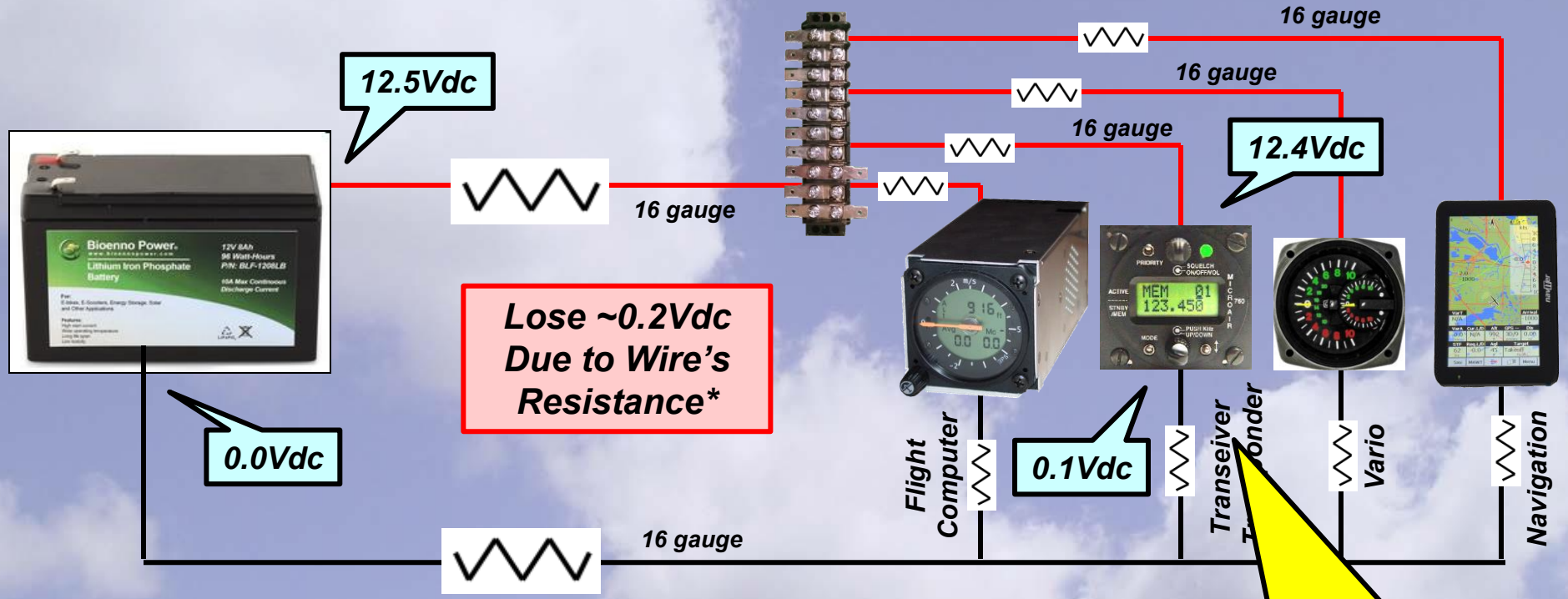


Too small gauge wire increases resistance and looses battery's energy as lost heat (and lost volts)

In this example the instruments have only 11.5Vdc across their terminals.

*Assumes 22ga, 20 feet of wire total, 12.5Vdc Battery, 1A Load
http://www.calculator.net/voltage-drop-calculator.html

Loosing Volts – 16ga Example



- Voltage drops get worse as you increase the amount of current instruments are drawing, especially;
  - Transceivers keyed and transmitting
  - Transponders being interrogated (transmitting)
  - Sunlight readable brighter displays

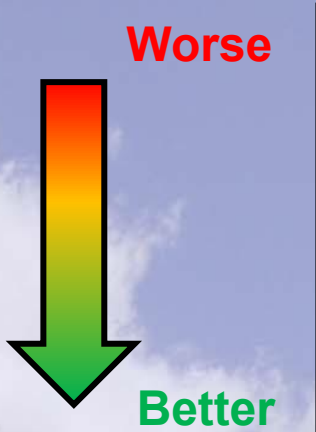
In this example the instruments have 12.3Vdc across their terminals.

*Assumes 16ga, 20 feet total, 12.5Vdc Battery, 1A load
http://www.calculator.net/voltage-drop-calculator.html

Loosing Volts - Wire Size

- How Wire Gauge Impacts Voltage Drop*
  - 24 gauge = ~1.0 volt lost
  - 20 gauge = ~0.5 volt lost
  - 18 gauge = ~0.3 volt lost
  - 16 gauge = ~0.2 volt lost
  - 14 gauge = ~0.1 volt lost
  - 12 gauge = ~0.06 volt lost

Worse



Better

*Assumes 20 feet of wire total, 12.5Vdc Battery, 1A Load
http://www.calculator.net/voltage-drop-calculator.html

Resistance of Wires

From FAA AC43-13-1B (Table 11-9)

TABLE 11-9. Current carrying capacity and resistance of copper wire.

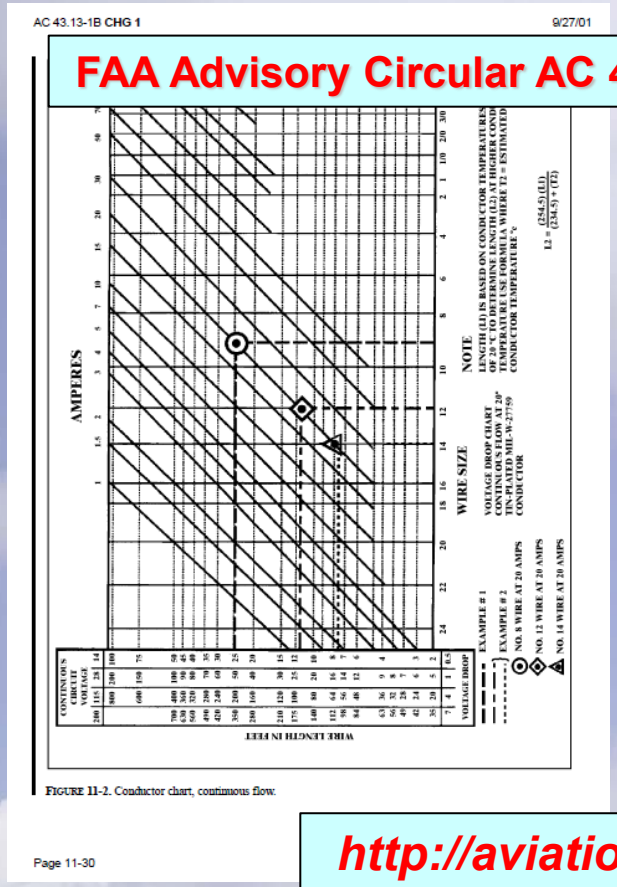
Wire Size	Continuous duty current (amps)-Wires in bundles, groups, harnesses, or conduits. (See Note #1) Wire Conductor Temperature Rating			Max. resistance ohms/1000ft@20 °C tin plated conductor (See Note #2)	Nominal conductor area - circ.mils
	105 °C	150 °C	200 °C		
24	Small 2.5	4	5	28.40 Worse	475
22	3	5	6	16.20	755
20	4	7	9	9.88	1,216
18	6	9	12	6.23	1,900
16	7	11	14	4.81	2,426
14	10	14	18	3.06	3,831
12	13	19	25	2.02	5,874
10	17	26	32	1.26	9,354
8	38	57	71	0.70	16,983
6	50	76	97	0.44	26,818
4	68	103	133	0.28	42,615
2	95	141	179	0.18	66,500
1	113	166	210	0.15	81,700
0	128	192	243	0.12	104,500
00	147	222	285	0.09	133,000
000	172	262	335	0.07	166,500
0000	Large 204	310	395	0.06 Better	210,900

Note #1: Rating is for 70°C ambient, 33 or more wires in the bundle for sizes 24 through 10, and 9 wires for size 8 and larger, with no more than 20 percent of harness current carrying capacity being used, at an operating altitude of 60,000 feet. For rating of wires under other conditions or configurations see paragraph 11-69.

Note #2: For resistance of silver or nickel-plated conductors see wire specifications.

Selecting Correct Wire Gauge

As per the FAA Advisory Circular AC 43-13-1b


AC 43.13-1B CHG 1 9/27/01

AMPERES

WIRE SIZE

WIRE LENGTH IN FEET

NOTE

EXAMPLE # 1

EXAMPLE # 2

NO. 8 WIRE AT 20 AMPS

NO. 12 WIRE AT 20 AMPS

NO. 14 WIRE AT 20 AMPS

FIGURE 11-2. Conductor chart, continuous flow.

Page 11-30

FAA Advisory Circular AC 43-13-1b, Chapter 11, Section 5, "Electrical Wire Rating"

To Learn More ➔ Read *"Selecting Wire"*
by Thomas Inman
in *Avionics News*, July 2020 Issue

http://aviation.derosaweb.net/presentations/documents/Avionics_News_Selecting_Wire_July_2020.pdf

“Suggested” Wire Gauges

Must Comply with FAA Advisory Circular AC 43-13-1b

- **12 to 14 gauge** - Main power lead from battery to power bus
- **16 to 20 gauge** - Power leads from power bus to individual devices
- **20 to 22 gauge** - Speaker wiring
- **22 to 26 gauge -** Control wires such as push-to-talk, air brake warning switches, flap switches, etc.
- **Hint:** Leave extra length (slack) in the cables for future changes and modifications

Glider Power Wiring Quote for the Day

“It ain’t the current load that’s gonna’ get ya’ on that long flight. It’s the voltage drop!”

(More on this Subject Later Slides)

Section C

Loosing Volts With Fuses & Breakers

Fuses

Breakers

Circuit Protection Requirements

Reference
FAA Circular
AC 42-13-1B
Chapter 11
Table 11-3

FAA Suggests 5 amps as the minimum for Breaker & Fuse Sizing

Using small amperage breakers and fuses less than 5A will cause a loss of voltage at your avionics increasing the current draw.

TABLE 11-3. DC wire and circuit protector chart.

Wire AN gauge copper	Circuit breaker amp.	Fuse amp.
22	5	5
20	7.5	5
18	10	10
16	15	10
	20	15
	30	20
	40	30
	50	50
	80	70
	100	70
	125	100
		150
0		150

Basis of chart:

(1) Wire bundles in 135 °F. ambient and altitudes up to 30,000 feet.
(2) Wire bundles of 15 or more wires, with wires carrying no more than 20 percent of the total current carrying capacity of the bundle as given in Specification MIL-W-5088 (ASG).
(3) Protectors in 75 to 85 °F. ambient.
(4) Copper wire Specification MIL-W-5088.
(5) Circuit breakers to Specification MIL-C-5809 or equivalent.
(6) Fuses to Specification MIL-F-15160 or equivalent.

Loosing Volts - Fuses

Example: Common Eaton/Bussman AGC Fuse

Specification Source: http://www.cooperindustries.com/content/dam/public/bussmann/Electronics/Resources/product-datasheets/Bus_Elx_DS_OC-2543_AGC_Series.pdf

Fuse Size (Model)	Typical DC Cold Resistance	Typical Voltage Drop (at 1A load)
1 amp (AGC-1-R)	0.190Ω	0.190 Vdc
2 amp (AGC-2-R)	0.078Ω	0.078 Vdc
3 amp (AGC-3-R)	0.045Ω	0.045 Vdc
4 amp (AGC-4-R)	0.030Ω	0.030 Vdc
5 amp (AGC-5-R)	0.024Ω	0.024 Vdc
10 amp (AGC-10-R)	0.008Ω	0.008 Vdc

Avoid Smaller

OK to Use

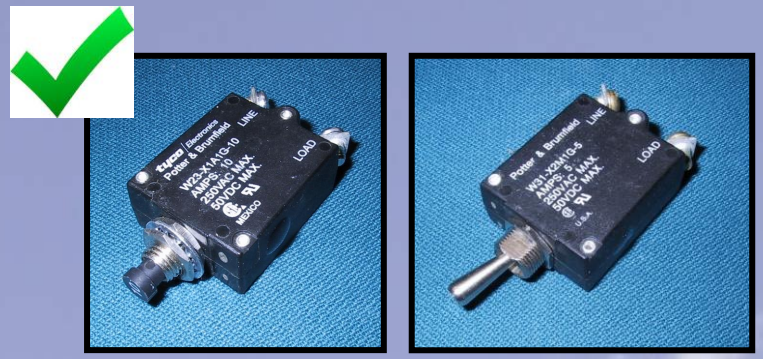
Loosing Volts - Breakers

Klixon 7277/7274 Breakers Voltage Drop

Rating	Max. Voltage Drop
½	2.00Vdc
¾	1.45Vdc
1	1.10Vdc
1½	0.75Vdc
2	0.70Vdc
2½	0.50Vdc
3	0.33Vdc
4	0.30Vdc
5	0.25Vdc
7½	0.20Vdc
10	0.15Vdc
15	0.15Vdc
20	0.15Vdc

Do Not Use

OK to Use



Tyco W23 & W31 Breakers Voltage Drop

Rating	Max. Voltage Drop	Resistance
1	0.61 Vdc	0.61
5	0.15 Vdc	0.03
10	0.1 Vdc	0.01
15	0.09 Vdc	0.006
20	0.08 Vdc	0.004
30	0.09 Vdc	0.003
40	0.08 Vdc	0.002
50	0.1 Vdc	0.002

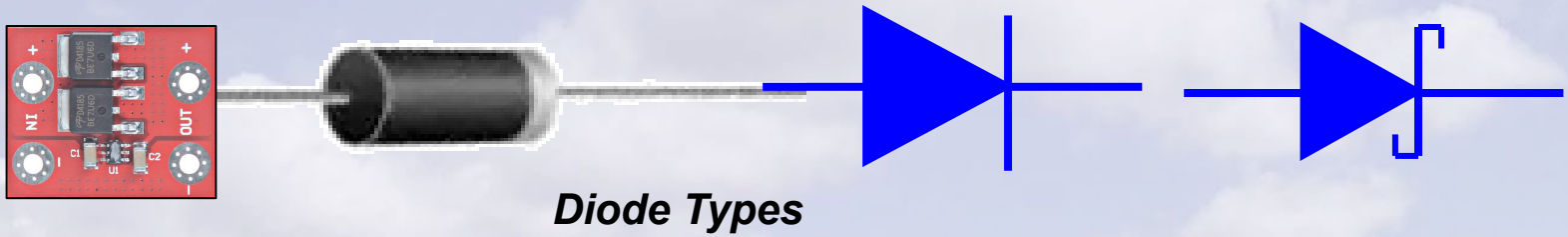
Loosing Volts - Breakers

All Electronic Breakers

Source: http://www.bridgingworlds.com/

- **Pros**
  - **0.1Vdc Voltage Drop**
  - **Over Current**
  - **Under & Over Voltage**
- **Cons**
  - **Large**
  - **Expensive $$$**

Chapter 8
Using Diodes
To Prevent Battery Cross Charging

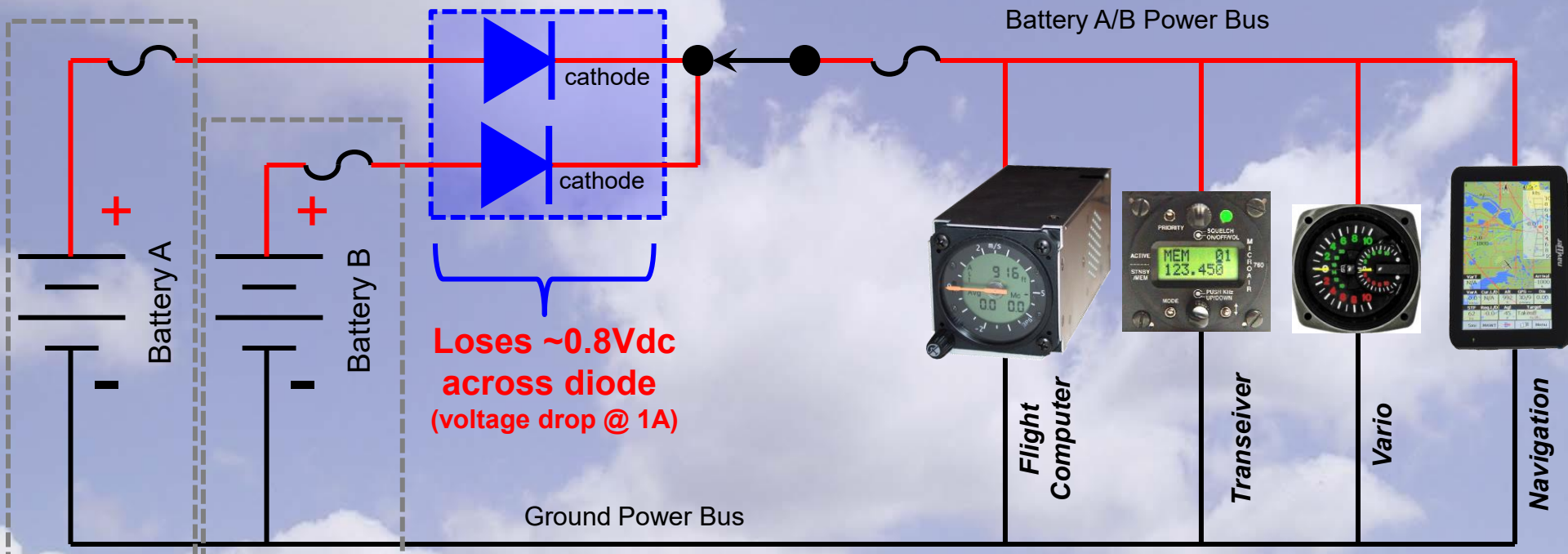


Diode Types

Sample Power Distribution Circuits

Prevent Dual Battery Cross Charging

Silicon Diodes – 1N4001



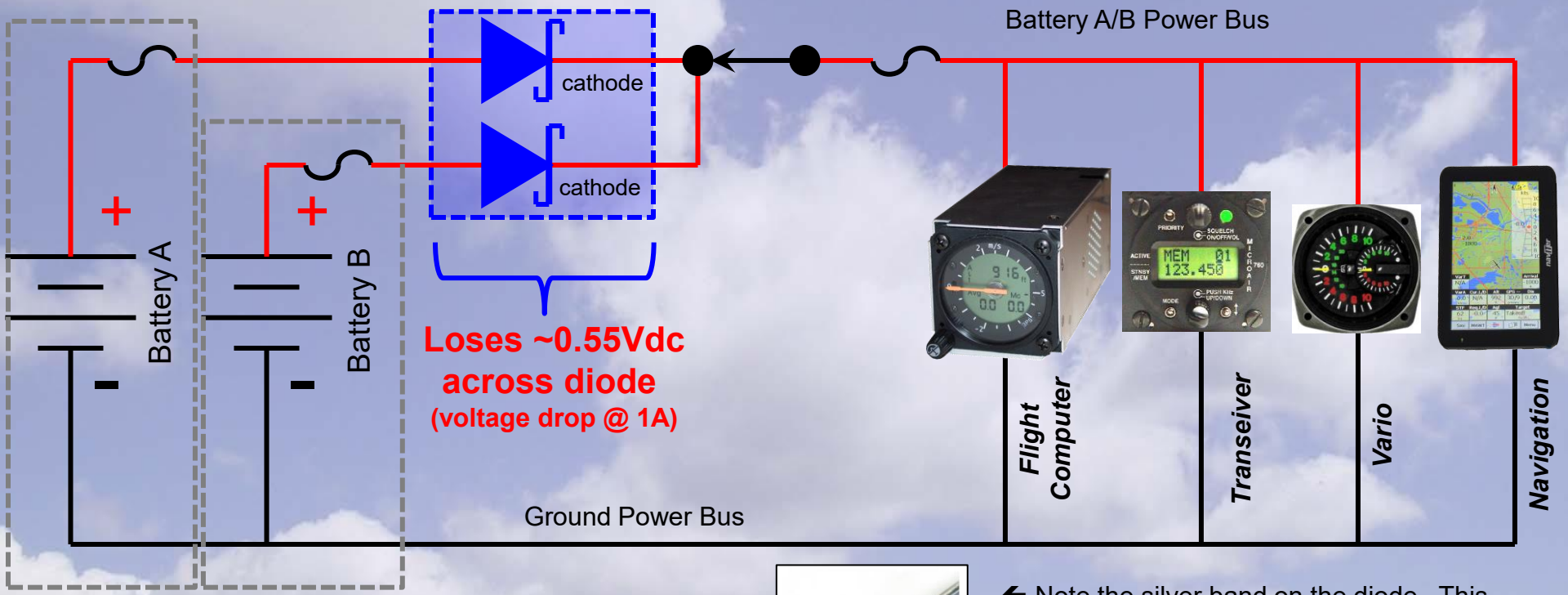
Source: Search eBay for "1N4001 Diode"
Cost: $0.20 per diode

← Note the silver band on the diode. This represents the cathode end which helps indicate the direction of current flow. The cathode silver band should be at the correct end of the diode as shown above.

Sample Power Distribution Circuits

Prevent Dual Battery Cross Charging

Schottky 5A Diodes - 1N5824 (5A 21V)

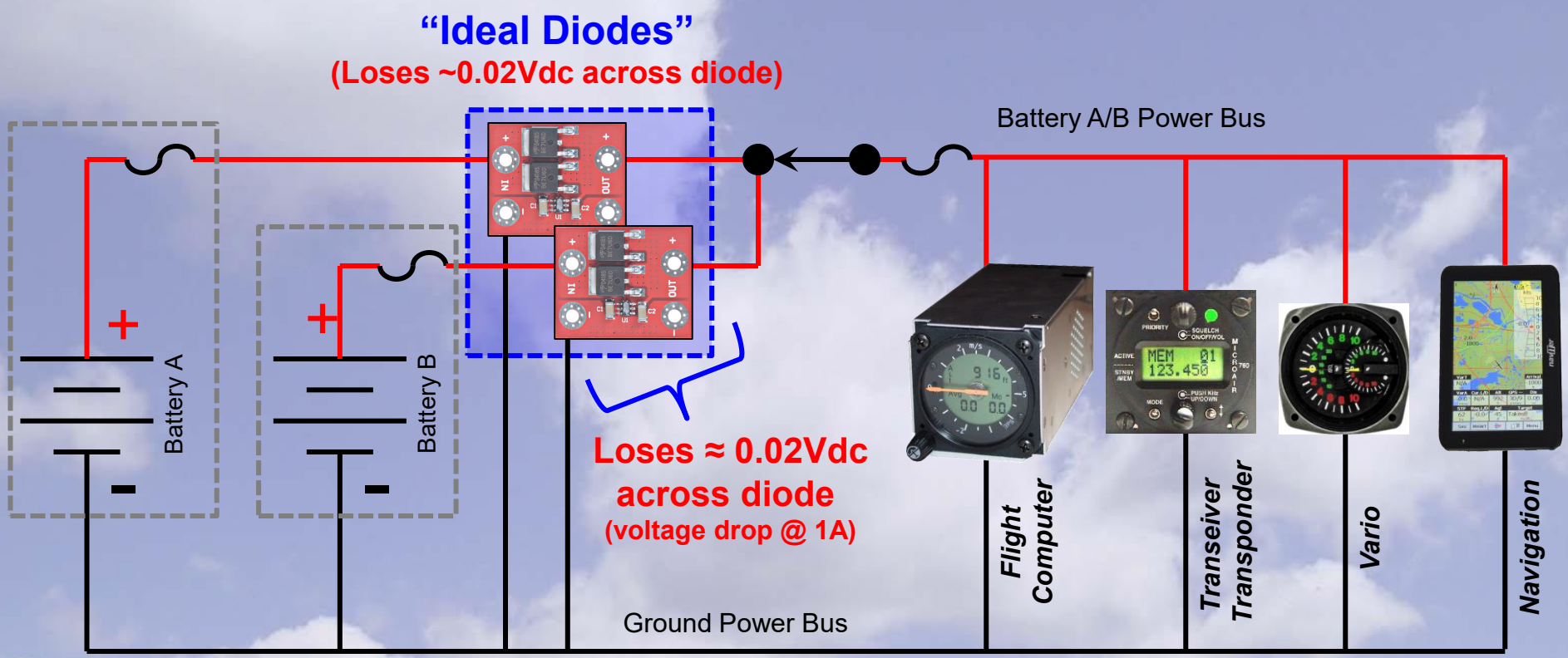


Source: Search eBay for "1N5824 Diode"
Cost: ~$1.00 per diode

← Note the silver band on the diode. This represents the cathode end which helps indicate the direction of current flow. The cathode silver band should be at the correct end of the diode as shown above.

Sample Power Distribution Circuits

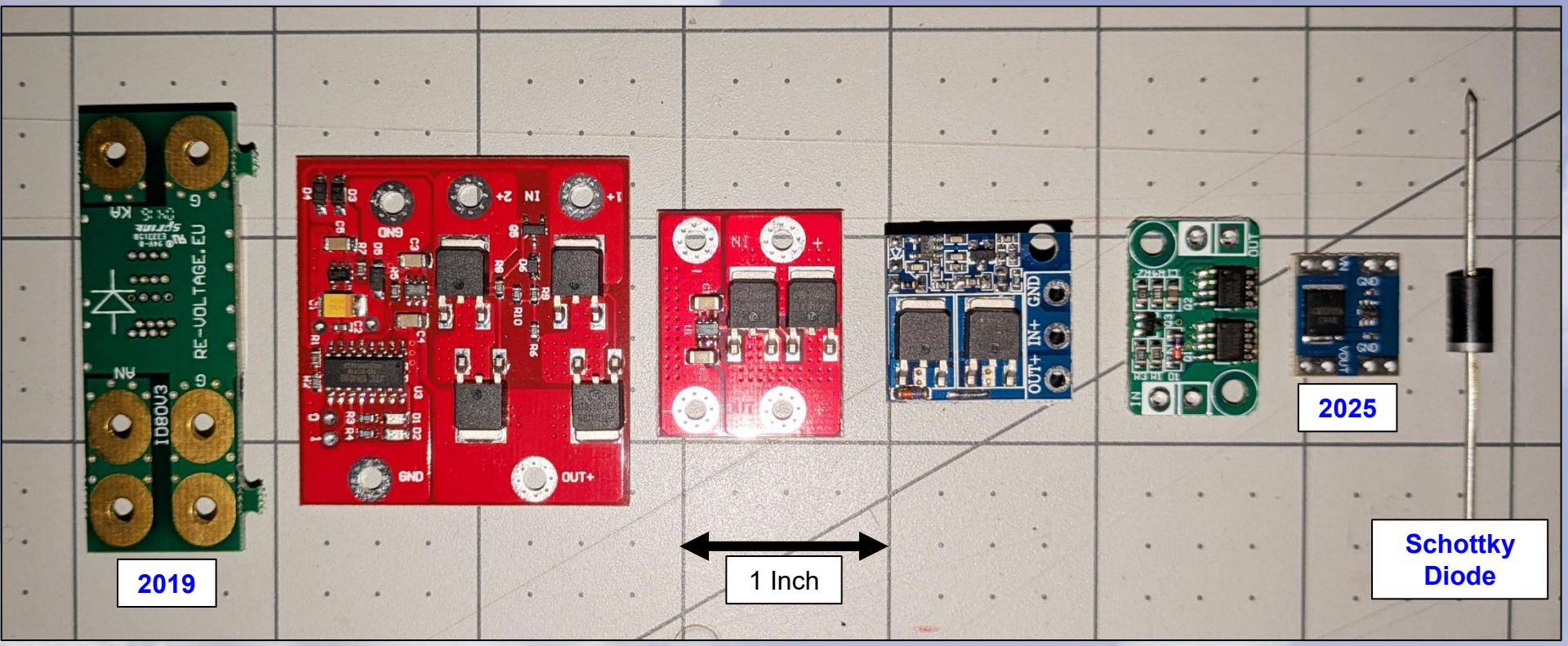
Prevent Dual Battery Cross Charging



Source: eBay - Search for "Ideal Diode"
Cost: $3 to $20 per diode

Sample Power Distribution Circuits

Ideal Diode Typical Voltage Drop
≈ 0.02Vdc @ 1A Load

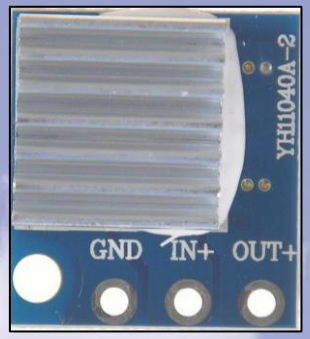


Source: eBay - Search for "Ideal Diode"
Cost: $3 to $20 per diode

Sample Power Distribution Circuits

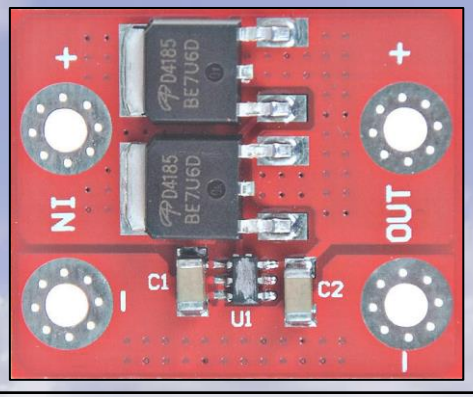
Idea Diode – Various Styles & Voltage Drops

Voltage Drop = 0.029Vdc

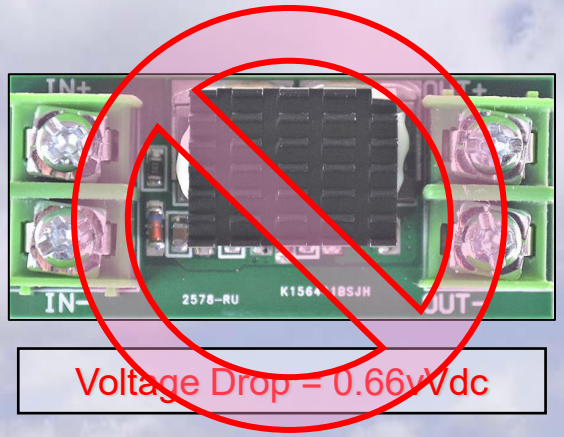


Voltage Drop = 0.005Vdc

Measured Voltage Drop Across Terminals from 12Vdc Source at 1A Load



Voltage Drop = 0.018Vdc

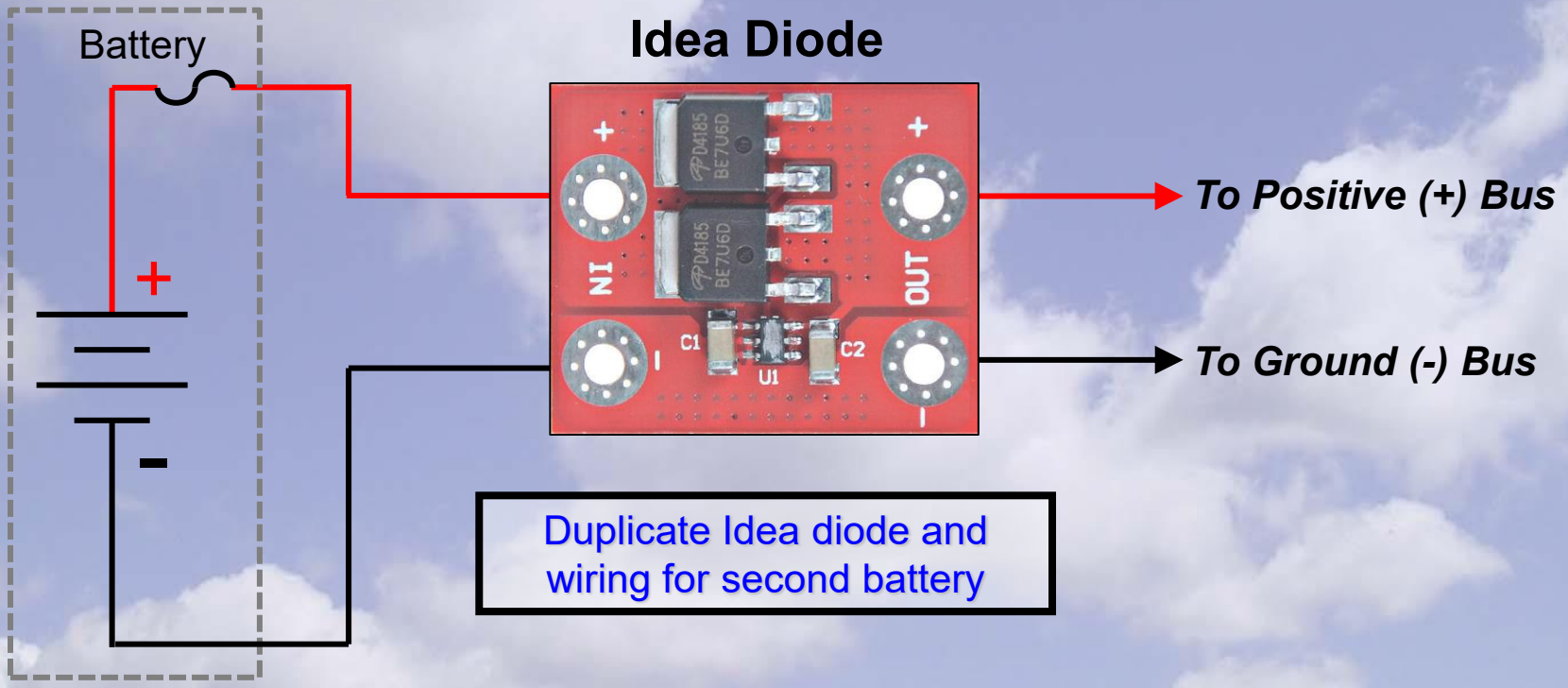


Voltage Drop = 0.66vVdc

Source: Search eBay for "Ideal Diode" Price: $6 to $25 per diode (2 devices required)

Sample Power Distribution Circuits

Idea Diode
Simple Example Wiring Diagram



Duplicate Idea diode and wiring for second battery

Loosing Volts – Diodes Recap

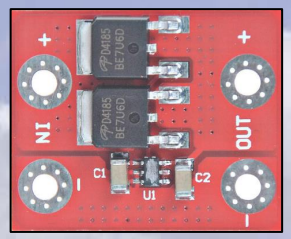
Diodes should be used when cross connecting two batteries …

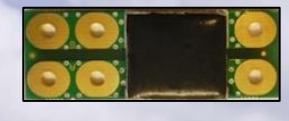
Pro – Prevents high amperage cross-charging

Con - Can lose volts across its terminals

Silicon Diodes – Loses ~0.8Vdc*

Schottky Diodes – Loses ~0.4Vdc*





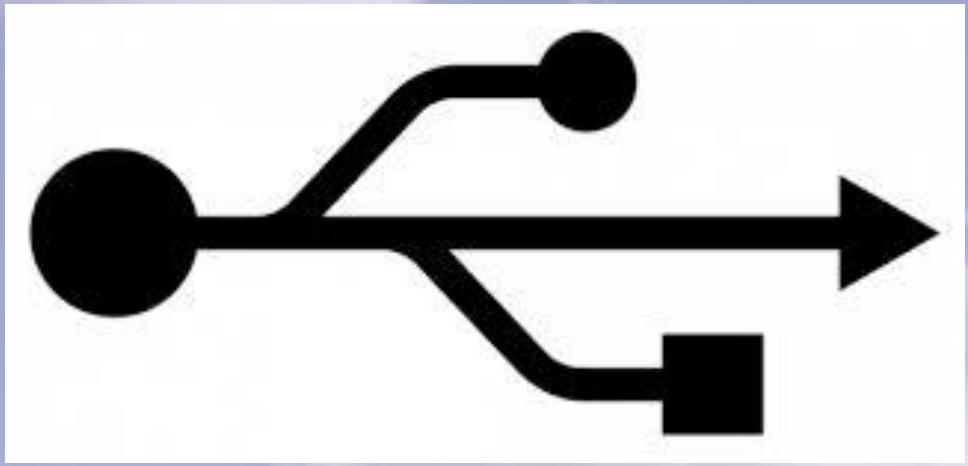
"Ideal" Diodes – Loses ~0.02Vdc*

***Voltage drop across diode at 1A current flow**

Loosing Volts - Recap

- **Wiring**
  - **Problem:** Can lose ~1.0Vdc due to resistance of small gauge wiring
  - **Solution:** Use Larger Gauge Wiring
- **Circuit Protection**
  - **Problem:** Can lose ~1.0Vdc due to small amp rated fuses and breakers
  - **Solution:** Use 5A and Larger Rated Fuses and Breakers
- **Batteries**
  - **Problem:** Discharge voltage droop causing more current to flow which, in turn, causes more voltage drop in the wiring
  - **Solution:** Use Lithium Batteries (flat discharge profile)
- **Diodes**
  - **Problem:** Can lose up to 0.8Vdc
  - **Solution:** Use Schottky or “Ideal” Diodes
- **Connections**
  - **Problem:** Poor connections causing resistance
  - **Solutions:** Use the best products, best crimping practices, eliminate corrosion, and minimize the number of electrical connections

Chapter 9
Proving USB Power



Proving USB Power

It has become an important ingredient in our cockpits to provide reliable USB (Universal Serial Bus) power to be used by our removable electronics devices such as cell phones, flight loggers, tablets, etc.

There are VERY IMPORTANT considerations when adding a USB outlet to your cockpit. The most important of which is providing clean power without interfering with other critical avionics onboard your glider.

Providing USB Power

Commonly Found Types of USB connections

Output Power Jack

Input Power Plugs

Output/Input Power Jack/Plug

Proving USB Power

USB charging adapters come in many forms (see later slide) but they all convert 12Vdc input voltage (and sometimes other voltages) to 5Vdc used by all USB powered devices.

Again, the fatal flaw of many chargers, especially the commonly sold cheap units, is causing RF noise (due to the use of "switching" power supplies) which can easily cause interference in your avionics instrumentation.

TESTING ➔ Be sure to test a USB charger before permanent installation. Temporarily connect the charger to 12Vdc and then to a USB powered device.
Then make several test flights. Just because it charges a device does **not** mean that it will not cause interference.

Providing USB Power

These USB chargers are made by the aviation industry and should be interference free*.

As you might imagine they cost $200-$400 each

Garmin

Stratus

True Blue

Electronics International

*** NOTE: I have tested none of these chargers**

Electrical Parts Sources

http://aircraftspruce.com

http://www.hi-line.com

http://wagaero.com

http://wingsandwheels

http://www.wicksaircraft.com

http://craggyaero.com

http://cumulus-soaring.com

http://www.steinair.com

http://www.airsuppliers.com

http://waytekwire.com

See My Other Presentations

- Transceiver Troubleshooting
- Oxygen Systems
- Working with Glider Air Lines
- Sailplane Wiring
- Trailer Wiring & LED Lights
- Pilot Relief Systems
- Battery Testing
- Open Glider Network (OGN)
- Spar Alignment Tool
- L'Hotellier Fittings
- Carbon Fiber Panels
- IGC Filename Decoding
- Blanik L-23 Strut Work
- Landout Survival Kits
- Removing Painted Lettering
- Emergency Location Devices

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