Extending ProMark 3 RTK Radio Range

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Thesis:

A simple modification for the ProMark3.RTK factory base radio which allows:

- ☞ placing the transmitter on a high pole, effectively quadrupling range: Urban ranges increases from 1,400 feet to 3,800 feet
- ☞ powering the GPS and radio from an external power source
- ☞ charging the PM3 base battery during operation, insuring the base is always operating at full output power

Warnings (Please Read Carefully):

1. **These modifications are 'totally NOT factory approved.' If you implement any of the changes in this document, you will void the factory warranty on your radio. Your only remedy may be purchasing a new radio.**
2. It is possible to mis-wire your radio cable so 12 volts is fed back into your ProMark3 receiver's Vcc connection (+5Vdc). If you do this, your ProMark3 GPS receiver will be toast.
3. **If you use a pole longer than 12 feet, you risk electrocution and death from overhead power lines.** If you don't have any common you should not consider making the described modifications. If you make these modifications, you should insure that the modified radios are not used near power lines!

In simple terms:

There is a clear risk of electrocution and death from radios placed on tall poles.

Any electronic technician should be able to successfully follow the instructions in this paper. In any case, I (Mark Silver) am not responsible for any trouble that you cause!

Background:

The ProMark3 GPS receiver was initially released by Thales Navigation. Thales Navigation was later renamed 'Magellan Professional' and in late 2009 was renamed Ashtech LLC, while products continue to be flagged as 'Magellan Professional'. Your ProMark 3 GPS may be branded Thales, Magellan Professional or (in the future) something different. I have referred to the company and product as Ashtech throughout this document.

The Ashtech ProMark3 RTK GPS receiver is a single frequency, dual constellation (GPS & SBAS ranging) RTK solution. The system is delivered from the factory with radios that connect to the back of the ProMark 3 receiver and are powered by the receiver's internal batteries.

No doubt there was considerable thought in the selection of the radio for the ProMark 3 RTK application. Tradeoffs include:

License Free		FCC License Required
450 MHz	900 MHz	2.4 GHz
Low Power		High Power
Runs on Internal Batteries		External Batteries Required
No Extra Batteries	Long Battery Life	Short Battery Life
Short Range (< ½ mile)		Long Range (> 6 miles)
Low Cost (<$1000)		High Cost (>$4,000)
Small Size and Weight		Heavy Radios with big heat sinks
TrimTalk compatibility		Proprietary modulation schema

The physics of radio coverage preclude an ultimate solution: "License free, internal batteries, long battery life, long range, Pacific Crest compatibility and $200 total cost."

Ashtech chose the Adeunis (http://www.adeunis-rf.com/) ARF53 data modem. This radio is a 50 channel, ½ watt, 900 MHz frequency hopping spread-spectrum UHF radio that runs on 4.5 volts. (If you are not in North America, the radios and frequencies are slightly different.)

We (Igage) sell an excellent Pacific Crest radio alternative that provides long range and TrimTalk compatibility. The price is nearly $5,600! You can read about it here: http://www.igage.com/mp/pm3/PacCrestRadiosforPM3.htm.

Considering the price of an alternative, I think that the factory radios are great solutions!

The range of the ARF53 radios is under 1,400 feet in urban environments. Of course (at least in the Western United States) we would like to be able to breakdown a 1 mile square section dependably. The ARF53's don't satisfy this requirement when placed 6 feet off the ground (the best we can do with the delivered cables.)

Documentation for the factory modem can be found with the following links:

Web Page: http://www.adeunis-rf.com/en/products/2-data-modem/27-arf53.html

Manual: http://www.adeunis-rf.com/files/produit/ARF53/EN/ARF53-Modem-data-915MHz-user-guide-V6.pdf

Is an Adeunis Repeater in Our Future?

New firmware was recently released for the ARF53 radio which supports repeater operation: http://www.adeunis-rf.com/files/produit/ARF53/EN/ARF53-repeater-technical-note-A2.pdf

Since the repeater operation implements a mesh network it would be possible to deploy several linked repeaters which could enable extremely long distance communication hauls.

I have heard no rumblings of support for repeater operation. If you think it would be worth pursuing, let your dealer know so they can rattle the product manager's chain.

Changing the Frequency Hop Sequence:

The ARF53 radios use the 33 cm band (902 to 928 MHz) UHF radio band. This ISM (Industrial, Scientific and Medical) band (see http://en.wikipedia.org/wiki/ISM_band) has a secondary allocation to Amateur Radio Service and is also used by a lot (Google '900 MHZ Radio Modem' and checkout the 452,000 matches) of other uses like:

> Amateur Radio Television, Walkie-Talkies, Ricochet Internet modems, Motorola Canopy radios, XBee 900 MHz modems and **most notably consumer 900 Mhz Cordless Phones**.

(I have verified that ProMark3 receivers will not receive corrections if a 900 MHz cordless phone is in nearby operation.)

If you are located in a country that licenses GSM-900 cellular then the North American radios won't work at all for you as they will directly compete and be completely overpowered by cell phone infrastructure. Alternative frequency range radios should be supplied in your market. **(For this reason, users in South America should not consider purchasing PM3 RTK from North American dealers!)**

A 'Radio Configuration' tool on the utility menu allows the end user to choose between one of 50 preset starting frequencies. (The 'Utility: Radio Configuration' tool sets the 'Start Channel Number' for the hopping table register S201=xx.)

When you choose a channel number, you are NOT choosing a single operating frequency, but instead you are selecting a pseudorandom channel hopping sequence known to both the transmitter and receiver.

Frequency Hopping Spread Spectrum signals (FHSS) are very resistant to narrowband interference and allow successful operation with other nearby and

possibly overpowering transmissions. You can read more about FHSS at http://en.wikipedia.org/wiki/Frequency-hopping_spread_spectrum.

One consequence of the frequency hopping is if you listen to any of the frequencies in the hop table with a scanner (I use and recommend the Yaesu FT60) you will hear broken squelch on **all** of the frequencies listed in the channel table because the radio is using all of the frequencies, hopping from channel to channel.

Click on this link [http://www.maqprogps.com/ms/PM3_RTK_Radios/SquelchBreak.wav] to hear what the radios sound like on a scanner.

Here is a copy of the starting frequency table from the radio user's guide:

Channel S200	Frequency (MHz)	Channel S200	Frequency (MHz)
Low Sub Band		High Sub Band	
0	902.75	**25**	915.25
1	903.25	**26**	915.75
2	903.75	**27**	916.25
3	904.25	**28**	916.75
4	904.75	**29**	917.25
5	905.25	**30**	917.75
6	905.75	**31**	918.25
7	906.25	**32**	918.75
8	906.75	**33**	919.25
9	907.25	**34**	919.75
10	907.75	**35**	920.25
11	908.25	**36**	920.75
12	908.75	**37**	921.25
13	909.25	**38**	921.75
14	909.75	**39**	922.25
15	910.25	**40**	922.75
16	910.75	**41**	923.25
17	911.25	**42**	923.75
18	911.75	**43**	924.25
19	912.25	**44**	924.75
20	912.75	**45**	925.25
21	913.25	**46**	925.75
22	913.75	**47**	926.25
23	914.25	**48**	926.75
24	914.75	**49**	927.25

Changing the initial frequency for two RTK-pairs operating nearby each other allows them to NOT interfere with each other.

Debugging the PM3 Radio Link

The ProMark 3 receivers can be a bit challenging if the radios don't work. There are not many things you can do to verify the link. The green LED's can be very difficult to see outdoors.

Luckily, you can fully test the radio power and serial connections by running the 'Utilities: Configure Radio' tool. If the tool reports 'North American Radio Detected' then you can be sure the radios are working.

From experience, I have found that most radio problems are due to the DGPS setting being set to NONE instead of UHF.

If your radios are not working:

1st check the DGPS settings on the Rover, insure UHF is selected.

2nd run the Radio Configuration tool on both the base and rover. Insure that both base and rover radios are detected and that both channels are the same.

3rd make sure that the base position is correct. If you seed the base with a location that is more than a ½ arc second distant from the true location, the rover may never switch from DGPS to FLOAT.

Checking Out the Factory Radio Configuration

If you connect a PC terminal to the radio and power the radio appropriately you can read the configuration settings that the Ashtech 'Utilities: Radio Configuration' sets the ARF53 to.

Here is the 'AT/V' dump:

```
Sending AT/V:
   A   d   e   u   n   i   s       R   F       v   e   r   s   a          Adeunis RF versa
   t   i   l   e       m   o   d   e   m       I   I       9   1          tile modem II 91
   5       M   H   z       5   0   0   m   W       V   0   0   .          5 MHz 500mW V00.
   5   0  ^M  ^J                                                          50..
```

Interpretation: Versatile Modem II, 915 MHz ½ watt Version 0.5

Here is the 'AT/S' dump:

```
Sending AT/S
   S   2   0   0   =   0   0       2   5       1   9       4   4          S200=00 25 19 44
       1   2       3   7       0   5       3   9       0   9               12 37 05 39 09
   3   4       ^M  ^J                                                     34 ..
                       2   3       4   8       0   2       2   7               23 48 02 27
       1   3       3   8       1   7       4   2       0   7               13 38 17 42 07
   3   2       ^M  ^J                                                     32 ..
                       1   5       4   0       2   2       4   7               15 40 22 47
       1   8       4   3       0   1       2   6       1   2               18 43 01 26 12
   3   3       ^M  ^J                                                     33 ..
                       1   4       3   9       0   6       3   1               14 39 06 31
       1   0       3   5       0   4       2   9       2   1               10 35 04 29 21
   4   6       ^M  ^J                                                     46 ..
                       0   3       2   8       1   6       4   1               03 28 16 41
       2   4       4   9       2   0       4   5       1   1               24 49 20 45 11
   3   6       ^M  ^J                                                     36 ..
   S   2   0   1   =   0   0  ^M  ^J                                      S201=00..
   S   2   0   2   =   0  ^M  ^J                                          S202=0..
   S   2   1   0   =   4  ^M  ^J                                          S210=4..
   S   2   1   1   =   8  ^M  ^J                                          S211=8..
   S   2   1   2   =   1  ^M  ^J                                          S212=1..
   S   2   1   3   =   1  ^M  ^J                                          S213=1..
   S   2   1   4   =   0   0   8  ^M  ^J                                  S214=008..
   S   2   1   5   =   0  ^M  ^J                                          S215=0..
   S   2   1   6   =   2  ^M  ^J                                          S216=2..
   S   2   1   9   =   3  ^M  ^J                                          S219=3..
   S   2   2   0   =   2  ^M  ^J                                          S220=2..
   S   2   2   1   =   0  ^M  ^J                                          S221=0..
   S   2   3   0   =   -   2   8       d   B   m   ;   0   0   5          S230=-28 dBm;005
   0  ^M  ^J                                                              0..
   S   2   3   1   =   0   0   3  ^M  ^J                                  S231=003..
```

```
S   2   3   2   =   0   ^M   ^J                                   S232=0..
S   2   5   2   =   0   0    0    0   ^M   ^J                     S252=0000..
S   2   5   6   =   0   0    0    0   ^M   ^J                     S256=0000..
```

Interpretation:

(Details of these settings are in the ARF53 User's Guide)

S200 is the hopping table channel order, S220=2 sets the protocol to 'hopping all bands' which includes all of the high and low band frequencies. S202=0 sets 10KHz narrow band. (Narrow band operation has longer range than wide band operation, but limits the data transmission rate to 10,000 bits per second, which is just what we need for 9,600 baud.)

S210=4 sets 9,600 baud, S211=8 sets 8-data bits, S212=1 sets no parity, S213=1 sets 1 stop bit. S215 sets RS-232 interface (as opposed to RS-485).

S252 and S255 set the reception and transmission address. (Both these values would need to be changed for repeater operation.)

Expected Range

My testing and RF characterizations lead me to believe that the ARF53 radios have a 1,400 foot urban non-line-of-sight range and a 7-20 mile **RF** Line-of-Sight range.

In town with buildings and trees in the propagation path and the radios 6 feet off the ground, you won't do much better than 1,400 feet. If you can set your base on top of a very high hill, you could have coverage out to the fixing range of a ProMark3.RTK system (about 6 miles). **I have personally used unmodified radios at distances exceeding 3 miles by placing the base on a high hill.**

You may have noticed that I claim a 7 mile range with RF line-of-sight. This does not imply that radios will work with a visual line of sight. **You need a RF line of sight.**

What is RF line-of-sight? French Physicist Augustin-Jean Fresnel, 1788-1827 (http://en.wikipedia.org/wiki/Augustin-Jean_Fresnel) figured all of this out for us. Checkout this Wikipedia link for Fresnel Zone information: http://en.wikipedia.org/wiki/Fresnel_zone (Even if you are using Pacific Crest high power radios you should read about Fresnel Zones. They are the reason your radio range is not what you want.)

To greatly simplify Fresnel Zone theory: the radio beam is not a narrow laser-like beam that propagates from the transmitter to the receiver. The beam is actually football shaped, narrow at the path ends and tall in the middle of the path. At 1 mile range you need both antennas about 23 feet off the ground or above the highest obstruction along the path to only loose 40% of the signal to obstructions. (In other words, 60% of the radio energy is contained in a 46' diameter circle at the midpoint of the path.) At 2 miles you need 33 feet of antenna height!

Because the receivers in the RF53's are quite sensitive, they work with less than optimum Fresnel Zone clearance. But we can not over emphasize the importance of having our antennas as high as possible. Antenna elevation rules in the expected range equations. More power is more better, but at 900 MHz high power just can't make up for obstructions in the Fresnel Zone.

The best solution is to raise the base radio antenna as high as possible above the ground. (For safety and convenience reasons, we can't raise our rover antenna higher than 6 feet.)

But how can we raise the ProMark 3 RTK radio antennas high above the ground? The cable is only 4 feet long!

Move Your Base to Higher Ground

Works great when possible.

Modem near PM3, Move Antenna Higher with More Antenna Cable

Another method would be to add a coaxial cable between the antenna and the RF connection on the transmitters. Unfortunately, coaxial line losses at 900 MHz just plain suck (about ½ power loss in 14 feet of RG58 at 900 MHz!) Any benefit that we might achieve by raising the antenna will be more than lost in driving the coax extension.

Better Antennas

We might replace the 1/4 wavelength end-fed dipole antennas with a more directional antenna:

A 5/8ths wavelength end fed dipole might be a good solution; however it would require an antenna matcher at the feed point. This won't provide a good match over the entire hopping frequency range and will significantly increase the cost.

A multi-element Yagi beam antenna. While large gain is possible, we would need to have the base and rover antennas pointing directly towards each other throughout the survey day.

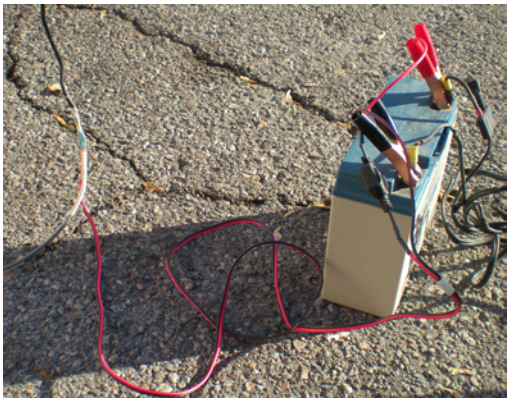
Adding more gain to the antennas will eventually result in an effective radiated power that exceeds the FCC limits for unlicensed operation.

Raise the Radio Modem

I think the most successful method is simply raising the entire radio as high as possible. To do this we can extend the power, TXD and RXD connections to the radio (I added 30 feet of extension cable).

We have to add a decoupling capacitor near the radio to supply burst power at the end of the long extension cable (a 1,500 uF 35V electrolytic capacitor is just fine)

In addition it is possible to add connections to charge the PM3 GPS receiver from a 6 to 18 volt DC power source. This will insure that your base battery never runs down and the transmitted power won't drop during the day.

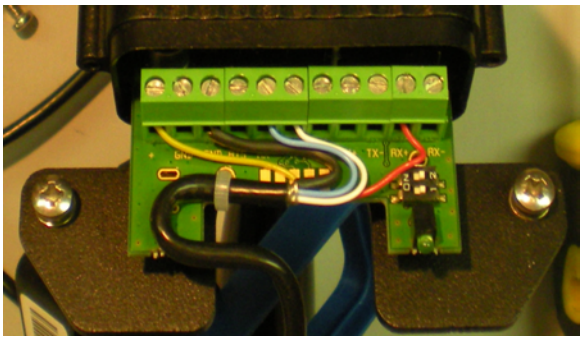


I also added a diode to prevent reverse connection to an external battery and a 10-fuse just in case something evil happens to the cables.

Using the modifications described below and moving the base radio 20 feet above ground level I can dependably extend the range to over 3,800 feet in the urban landscape around our office. In relatively open (Salt Flat) conditions the range is over 3 miles!

The Modifications

Here is a picture of the unmodified radio connections as shipped from the factory:



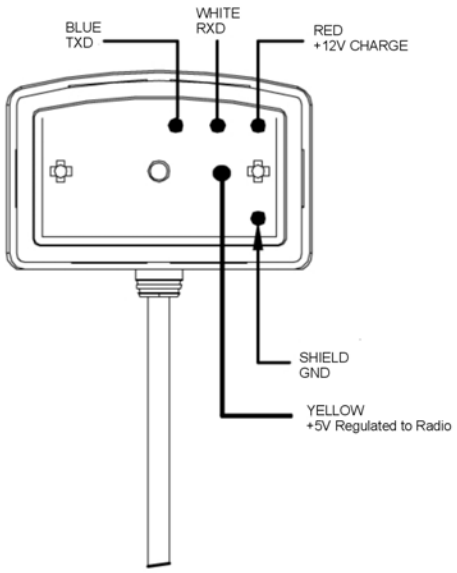
These are the factory connections to the radio (as shown above):

Radio Connector	Assignment
1 (left)	Yellow, +5V Regulated from PM3
2	-open- Ground
3	Shield (black shrink) Ground
4	-open- (rts)
5	Blue (RXD on modem, TXD on PM3)
6	White (TXD on modem, RXD on PM3)

7	-open-(cts)
8	-open- (tx+)
9	-open- (tx1)
10	Red (+12 to PM3) (rx+ used as placeholder)
11 (right)	-open- (rx-)

Pins 2 and 3 are electrically connected on the PCB. Pin 10 is only used as a holding location for the Red wire. The Red wire connects to the charging input on the ProMark 3 receiver.

The D-shaped connector that is used to connect the radio modem to the PM3 has these pin assignments:

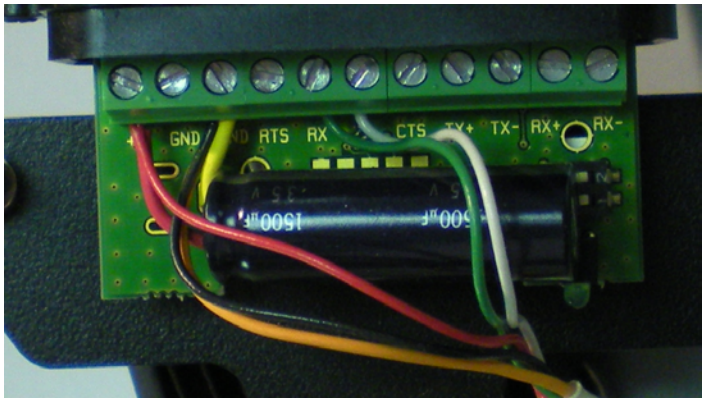


PM3.RTK Radio Cable Connections (2009-11-23 MSilver)

(Note that this radio cable which is shipped with the radio is completely different than the serial cable #730523 which is available as an accessory, PN 730523 has different color coding and does not have the +5V regulated supply connection.)

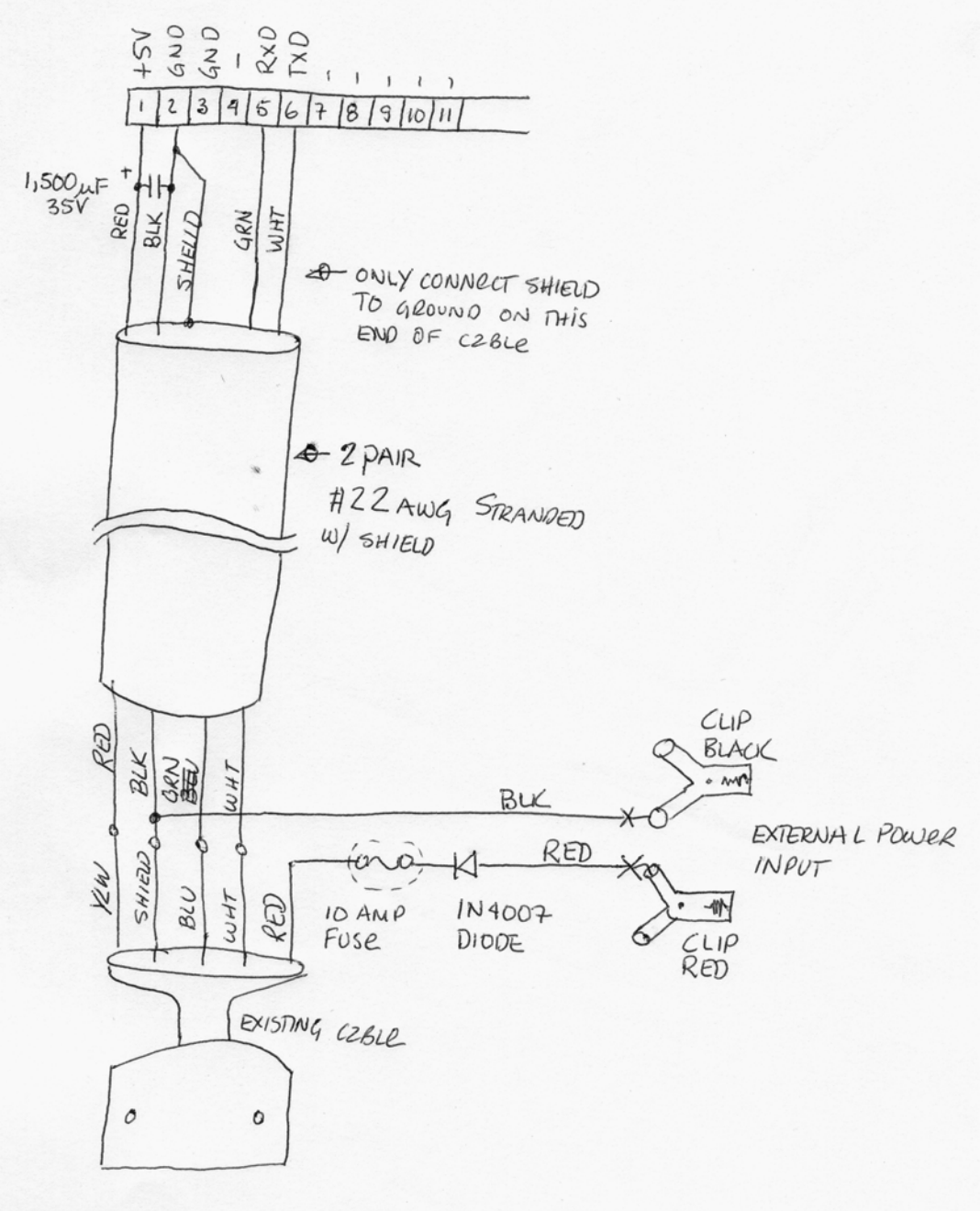
Modifications

This picture shows the modem terminals with the bypass capacitor after modifications:



I used glue filled heat shrink over the end of the cable to insure that it can't be pulled through the strain relief instead of wire-tying the cable to the PCB.

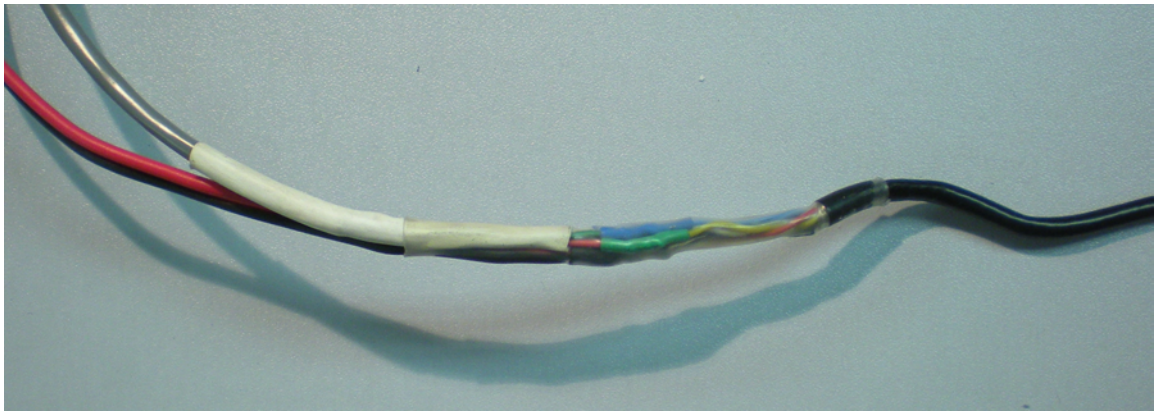
Here is a schematic showing the modified radio connections:



Note the 1,500 uF electrolytic capacitor which must be installed inside the modem enclosure. You MUST add this capacitor near the modem or the radio won't have enough power to transmit!

I used 22 AWG stranded, 2 pair, shielded cable. I recommend connecting the shield to ground only at the modem end of the cable. With this cable you can extended the radio at least 100' from the PM3, however 30 feet should be enough get you into plenty of trouble.

Here is a picture of how I made the connections on the battery/PM3 end of the cable with glue filled heat shrink:



If you are going to be spending a lot of time working in the rain (not likely in the Utah desert,) you can fill the shrink with RTV before you heat it.

That is the entire modification. It takes about 1 ½ hours to get it done correctly and tested (always test the modems before you hack into them). The parts are all available at Radio Shack for under $25 so anyone in the US should be able to get the parts they need.