6 SOLAR POWER and POWER CONTROL

The TDR systems described herein have been successfully powered from solar panels charging deep cycle lead acid batteries. Systems typically consist of a notebook computer, Tektronix cable tester, one or more multiplexers and attached TDR probes; all powered by 12 VDC from the lead acid batteries which are in turn charged by the solar panels. The cable tester is usually equipped with the TR-302 power control module so that the TACQ program can turn off power to the cable tester between data acquisition periods. The notebook computer’s power conservation features should be enabled (this is usually done in BIOS setup) to allow the computer to turn off LCD backlighting, turn off the hard disk, and slow the clock speed while the program is not acquiring data; yet keep the CPU active so that the program can correctly time the next acquisition interval. The TACQ program is written such that it does not write to the screen between data acquisition intervals. The lack of screen activity allows the computer’s power conservation features to cut in. The TACQ program also sets all multiplexers to channel 1 between data acquisition periods. Since channel 1 has the lowest power consumption (6 mA), this ensures the lowest possible multiplexer power consumption between data acquisition periods.

6.1 Power Requirements

Because the TDR system uses more power when data are actually being acquired than when the system is quiescent (waiting until the next data acquisition interval); design of the solar power subsystem is influenced by the number of probes in the TDR system, by the automatic data acquisition interval, and by the kind of data acquired. The kind of data acquired determines the time needed to acquire and store data from each probe. For instance, saving only water contents takes slightly less time than saving both wave forms and water contents, even though a wave form must be measured in both cases, because much more data is written to disk if wave forms are saved. Saving bulk electrical conductivity data takes even more time because four separate wave forms are acquired for each probe. The number of probes determines the number of multiplexers and the period of time needed for one data acquisition cycle. The acquisition interval determines the number of acquisition cycles in a day. The time required for one acquisition cycle, multiplied by the number of acquisition cycles in a day, determines the time during which the system is active. For the remaining time in a 24 h period the system is inactive or quiescent. If we know the power requirement during the active period and the power requirement during the quiescent period, plus the length of these periods, we can determine the power requirement for a 24 h period.

6.1.1 Multiplexer Power Requirements

During data acquisition, the power use by the multiplexers ranges from 6 mA for channel 1 to 101 mA for channel 16 at 12 VDC (Table 6-1, column 2). In multiplexing systems with up to 16 multiplexers, only two multiplexers are active at one time; the primary multiplexer and one second level multiplexer (See Fig. 1-2). In a 16 multiplexer system, multiplexing 240 probes, there are 15 second level multiplexers and 1 primary multiplexer. The 15 secondary multiplexers use the first 15 channels of the primary multiplexer. Peak current on the primary multiplexer will thus be 78 mA, while peak current on any second level multiplexer will be 101 mA. Current on the non-active multiplexers at any one time will be 6 × 14 = 84 mA. Thus, peak current on this system will be 101 + 78 + 84 = 264 mA. The third column in Table 6-1 gives the mean current for probes 1 through n where n is the channel number for the last channel used on a given multiplexer. [The mean current calculation assumed that each channel takes the same amount of time for data acquisition.] For the 16 multiplexer system, average current during the acquisition period will be 51 + 54 + 14 × 6 = 189 mA. Average current during the quiescent period will be 16 × 6 = 96 mA.

It is possible to connect a 17th multiplexer to the system if this multiplexer does not share the address of the primary multiplexer. Since the 17th multiplexer must share an address with one of the second level multiplexers, there will be a period during data acquisition when two second level multiplexers are switching. However, only one of these will be connected to the cable tester through the primary multiplexer at any one time. A 17 multiplexer system can multiplex up to 256 probes, but its power requirements are slightly different. During the quiescent period the current draw is 17 × 6 = 102 mA. The average current draw for 14/16 of the data acquisition period is 54 + 54 + 15 × 6 = 198 mA. The average current draw for 2/16 of the data acquisition (time when both the second level multiplexers sharing an address are on) is 54 + 54 + 54 + 14 × 6 = 246 mA. The average current draw for the entire data acquisition period is 198 × 14/16 + 246 × 2/16 = 204 mA.

Table 6-1. Current draw when switched to different input channels.

	Current (mA)	
Channel No.	**For Chan. No.**	**Mean to Chan. No.**
1	6	6
2	31	18
3	31	22
4	55	31
5	31	31
6	55	35
7	54	37
8	78	42
9	31	41
10	55	42
11	54	44
12	78	46
13	54	47
14	78	49
15	78	51
16	101	54

For smaller systems, current use during an acquisition period depends on the number of second level multiplexers (this determines the number of channels used on the primary multiplexer), and the number of channels used on those multiplexers. Peak and average current use can be estimated by referring to Table 6-1 for the mean current needed for the number of channels to be used and duplicating the calculations given above. For example, consider a system with 1 primary multiplexer, and 6 secondary multiplexers all of which have 16 probes attached. From the second and third columns of Table 6-1 we see that the primary multiplexer will use a peak current of 55 mA and a mean current of 35 mA over the course of the data acquisition period (6 channels used). The active secondary multiplexer will use a peak current of 101 mA and a mean current of 54 mA during the data acquisition period (assuming 16 channels used). Peak current to the multiplexers will be $55 + 101 + 5 \times 6 = 186$ mA. Average current during the data acquisition period will be $35 + 54 + 5 \times 6 = 119$ mA. Average current during the quiescent period will be $7 \times 6 = 42$ mA.

6.1.2 Computer and Cable Tester Power Requirements

A typical monochrome subnotebook computer uses about 500 mA at 12 VDC during data acquisition. Between acquisition periods the same computer will use about 300 mA (with hard disk and LCD backlight power management enabled). Current used by the Tektronix 1502B/C cable testers is about 1000 mA at 12 VDC. Average current draw during data acquisition will be the sum of 500 mA for the subnotebook computer plus 1000 mA for the cable tester plus the average current draw of the multiplexers (see previous paragraph). Between data acquisition periods the current draw will be the sum of 300 mA for the subnotebook, plus 5 mA for the cable tester (quiescent current of the TR-302 power control module), plus the number of multiplexers times 6 (6 mA quiescent current per multiplexer). For example, a system using 7 multiplexers would use $300 + 5 + (7 \times 6) = 347$ mA between data acquisition periods.

6.2 Length of Data Acquisition Period

The length of the data acquisition period depends on the number of probes being read, whether or not the travel times and water contents are to be found, and whether or not data for bulk electrical conductivity (BEC) calculations is to be acquired. The fastest acquisition will occur if the user has chosen to store only wave forms. Next fastest is if both wave forms and water contents are stored; and slowest is if wave forms, water contents, and BEC data are acquired and stored. It is virtually impossible to predict how quickly any given computer will be able to acquire data, but some examples are given here as quidelines.

Acquire 72 wave forms and convert to water content, saving both wave forms & water contents, 19200 baud:

386SX at 16 MHz, no math coprocessor:	19 min.	15.83 s/probe.
386SX at 16 MHz, with 387SX math coprocessor:	12 min.	10.00 s/probe.
Pentium at 133 MHz:	6 min, 18 s.	5.25 s/probe.
486 SLC at 33 MHz:	10 min, 49 s.	9.01 s/probe.

As above but with baud rate at 9600:

486 SLC at 33 MHz	11 min, 7 s.	9.26 s/probe.

Acquire 72 wave forms and save, 19200 baud:

486 SLC at 33 MHz	7 min, 25 s.	6.18 s/probe.

Acquire 72 wave forms and save only travel times, Ka and water contents:

486 SLC at 33 MHz	10 min, 16 s.	8.56 s/probe.

Acquire 72 wave forms and convert to water content, save both wave forms & water contents, acquire and save BEC data, 19200 baud:

Pentium at 133 MHz:	18 min, 41 s.	15.57 s/probe.
486 SLC at 33 MHz:	24 min, 12 s.	20.17 s/probe.

There are 3600 s per hour or 86400 s per day. Knowing the acquisition interval in seconds, we can divide it into 86400 to find the number of acquisition periods in a day. Using the data given above we can estimate the length of each acquisition period by multiplying the number of probes to be measured by the appropriate time needed for each probe (estimated from the above data considering the computer and baud rate to be used). Multiplying the number of acquisition periods by the length of each acquisition period gives the data acquisition time during a 24 h period. The remaining time is the quiescent time. Multiplying the data acquisition time (in hours) by the average current draw during data acquisition (in Amps) gives the Amp hours (Ah) needed for data acquisition. Multiplying the quiescent time by the current draw during the quiescent period gives the remaining Ah needed. Adding the Ah needed during acquisition to the Ah needed during the quiescent time gives the total Ah requirement. Multiply this by 1.2 to compensate for system losses (battery charging and discharging losses, resistive heat losses, etc.) to find the Ah per day needed from the solar panels. Note that Amp hours are not power. There is an assumed system voltage of 12 VDC. Power is measured in Watts (Joules/s). Wattage can be calculated using the formula: Watts = volts × Amps. Also, energy is power times time. The Joule is the standard unit of energy. Another unit for energy is the Watt hour (Wh). We can calculate the daily energy requirements by multiplying the Ah requirement by the system voltage to get Watt hours (Wh).

6.3 Power Available from the Sun

Solar panels provide optimum power output only during a few hours of the day when the sun is high in the sky. These are called the peak hours. For a given location, the average number of peak hours available in a day varies with the season of the year, with latitude, with altitude, and to some extent with climate. The average number of peak hours can also be influenced by solar panel mounting, sun tracking, and concentrators. Systems that track the sun can extend the number of peak hours. Concentrators change the peak hour relationship by effectively increasing the surface area of the panel. The National Renewable Energy Laboratory (NREL) has made available on the world-wide-web solar radiation data for many stations throughout the U.S. Data are available for flat plate and for concentrating collectors, and are available for one-axis and two-axis tracking systems as well as for systems mounted in fixed positions. Most solar systems used for remote data collection will utilize fixed mounting. The data are available at the URL http://rredc.nrel.gov/solar/. An example of average daily solar radiation available in December to a flat panel tilted at latitude plus 15 degrees is shown in Fig. 6-1. Note that the NREL data are in kWh/m^2/day, not in peak hours. The units of kWh/m^2/day are more defensible since they are standard units and peak hours are not. The concept of peak hours becomes confusing when concentrators are used. Also, note that this is solar energy available to the solar cells on the panel; not the electrical energy available from the panel. The panel electrical output will depend on the panel's overall conversion efficiency.

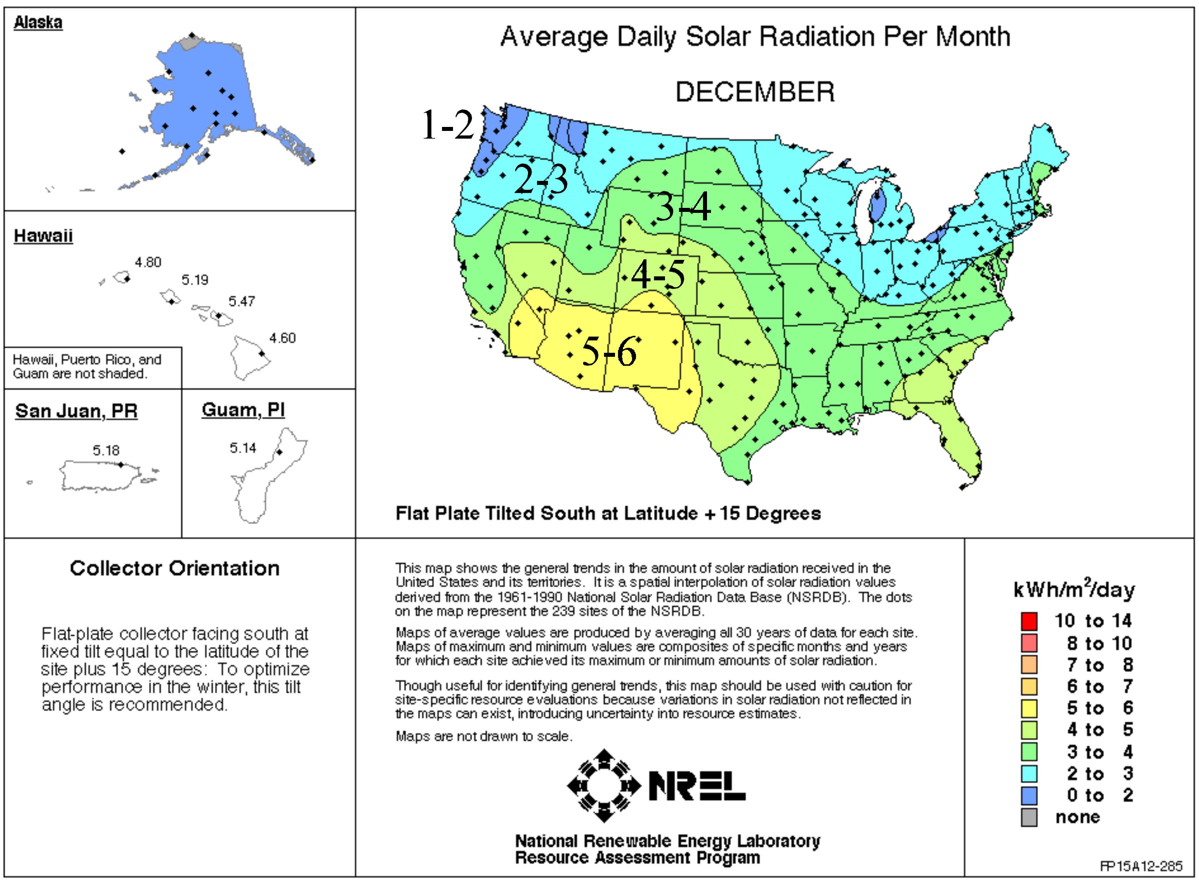

Figure 6-1 Solar radiation data from NREL.

6.4 Power Available from a Solar Panel

To find what power may be obtained from a solar panel we must know the panel's overall conversion efficiency and its surface area. Most solar cells have a conversion efficiency of about 13%; but solar panels, made of many cells, have lower efficiencies due to unused panel surface.

The overall conversion efficiency of a panel may be calculated from the panel rating, its size, and knowledge of the test conditions that prevailed when the panel rating was established. For example, a Solarex VLX-53 solar panel is rated at 53 Watts, determined under an illuminance of 1000 W/m^2, and has dimensions of 0.938 m by 0.501 m or an area of 0.469 m^2. Divide the rating in Watts by the surface area to get the rating in W/m^2 = 112.9 W/m^2. Divide the rating in W/m^2 by the illuminance in W/m^2 and multiply by 100 to get the efficiency in percent = 11.3%. The solar cells have a conversion efficiency of about 13% and the panels have only a slightly lower conversion efficiency because the solar cells cover most of the panel surface.

To use the data in Fig. 6-1 we can use the overall panel conversion efficiency to convert the daily solar radiation to power output by the panel. For example, in Amarillo, Texas the average daily solar radiation in December for a fixed panel tilted at latitude plus 15 degrees is about 4.9 kWh/m^2/day. The Solarex panels would put out $0.113 \times 4900 = 554$ Wh/m^2. Since the panel has an area of only 0.469 m^2, a single panel would put out 260 Wh. Using the relationship W=vA, or Watts equal volts times Amps, we can convert the Wh number to an Amp hour or Ah number by dividing by the system voltage: 260/12 = 21.6 Ah.

6.5 Sizing a Solar Power System

As an example of how to configure a solar system, assume a TDR system consisting of 96 probes on six second-level multiplexers, which are in turn connected to one first level multiplexer. Also assume a notebook computer with the 486 SLC 33 MHz chip, and data acquisition every hour. Finally, assume that power to the cable tester is turned off when data is not being acquired. It takes 9.01 s/probe to acquire wave forms and water contents and save both to disk. For 96 probes it takes $96 \times 9.01 \times 24 = 20{,}760$ s = 5.77 h to acquire the data. From Table 6-1 we see that the average current of the first level multiplexer (using the first 6 channels) is 35 mA during data acquisition. Also from Table 6-1 we see that the average current for one of the second level multiplexers is 54 mA during data acquisition, while the average current for the other five is $5 \times 6 = 30$ mA. The total average multiplexer power use during data acquisition is 119 mA. The total current for multiplexers in the quiescent period is $7 \times 6 = 42$ mA.

Power Consumption for a 24-h Period:

Multiplexer during data acquisition = 5.77 h × 119/(1000 mA/A) = **0.69 Ah**
Multiplexer in the quiescent period = (24 - 5.77) × 42/1000 = **0.77 Ah**
Computer during data acquisition = 5.77 × 500/1000 = **2.88 Ah**
Computer in the quiescent time = (24 - 5.77) × 300/1000 = **18.23 Ah**
Cable tester during data acquisition = 5.77 × 1000/1000 = **5.7 Ah**
Cable tester in the quiescent period = (24 - 5.77) × 5/1000 = **0.09 Ah**
Total power consumption in a day = 0.69 + 0.77 + 2.88 + 18.23 + 5.7 + 0.09 = **28.67 Ah**

Multiplying this by 1.2 to account for losses due to charge/discharge we have a **34.4 Ah** daily power requirement. As seen in the last paragraph, in Amarillo, power from two 53-Watt solar panels should more than meet this need. These calculations show that using a low-power external timer to turn on the computer at acquisition times could save the majority of the total power used.

The solar power system is not complete without battery storage. The above calculations assume an average of 4.1 kWh/m^2/day solar energy available. There may be cloudy periods during which the energy available is much less than this for several days. In a conservative design battery, capacity must be large enough to keep the system running for several days - up to 10 days in critical applications. Multiplying our 34.4 Ah daily power requirement by 10 we see we need at least a 344 Ah battery. To protect against discharging the battery too much we divide by 0.6 to get a 573 Ah battery capacity. This may be provided by a battery bank of one or more deep cycle lead acid batteries. To protect the battery bank from overcharging, a charge controller must be used between the solar panel(s) and battery bank.

The design example just provided used some simplifying assumptions. For example, it was assumed that the worst case for available solar radiation would be in December and that the panel should be tilted at latitude plus 15 degrees to enhance wintertime radiation capture. In some locations the worst case design might use data from another period of the year when local climate produces cloudy conditions that minimize solar irradiance. For more complex systems a good starting place is “Stand-Alone Photovoltaic Systems: A Handbook of Recommended Design Practices”, Sandia National Laboratories, no. SAND87-7023. Available from NTIS, U.S. Dept. Of Commerce, 5285 Port Royal Rd., Springfield, VA 22161. Also helpful is the freeware computer program PVsize, available from the Energy Efficiency and Renewable Energy Clearinghouse (EREC), P.O. Box 3048, Merrifield VA 22116, tel. 800.363.3732 or by browser at http://erecbbs.nciinc.com, or through their BBS at 800.363.3732.

6.6 Cable Tester Power Control with the TR-302 Power Control Module

Considerable power savings may be attained by switching off power to the Tektronix cable tester when it is not in use. This may be accomplished by designating a pin of the computer's parallel port to signal power on (logic high) and power off (logic low) to the optional TR-302 power control module installed in the cable tester (1502B only). The Campbell Scientific model TR-302 installs in the space at the rear of the cable tester normally reserved for the removable battery pack. The pin used is normally pin 9 and this is the pin used in the TR-2200 cable set. But any pin from 2 to 9 may be used provided it is not designated for other use, and the user is willing to build a cable or rewire the TR-2200. See the documentation for program TACQ.EXE for details on designating the pin number. The TR-302 is connected to the computer, and to 12 VDC power, using cable TR-2200A of the TR-2200 cable set. A polarized connector on the TR-2200A ensures correct connection. The TR-302 is clearly marked for wires carrying 12 VDC power, ground, and the control signal from the parallel port. Be sure that a common ground exists for the computer and cable tester. See section 6.9 for alternative hardware for controlling 12 VDC power.

Program TACQ.EXE controls the power automatically. Power is on when the user is at the main menu of the program or in software setup; but is turned off when the program is in the automatic data acquisition mode until measurements start. When measurements begin, the computer provides a 5 VDC signal to turn on power. The computer waits for a short period (user designated in software setup, but usually 5 s) to allow the cable tester to self-initialize before beginning RS-232 communications. When measurements are finished the computer sets the pin low, turning off power to the cable tester until the next acquisition interval. We recommend that this feature be used for systems that rely solely on battery power and/or solar power. If adequate power is available, we recommend that this feature not be used since switching the cable tester on and off carries the risk of cumulative damage to its electronic circuitry.

6.7 Cable Tester Power Control with the TR-304 AC Power Control Module

With a cable tester powered from an AC line, it sometimes happens that the wave form becomes noisy because of noise in the AC power. If the cable tester has an internal battery, the TR-304 AC Power Control Module may be used to switch off AC power during the data acquisition period, switching AC power back on to recharge the battery when data acquisition is finished. Unless the duty cycle of data acquisition approaches 100% this is a good solution to the noise problem. It is especially useful when the Tektronix 1502C cable tester is used, since this cable tester has no opening in its case for the TR-302 Power Control Module, precluding the easy use of regulated and isolated DC power. The TACQ software allows a pin of the parallel port to be dedicated to controlling the TR-304. If pin 9 is not used to control a TR-302 module, then pin 9 may be used; otherwise pin 5 is usually available as well. If the TR-2200 cable set is used, then the TR-2200A stub cable (with optional TR-2201 extension cable) may be plugged into the TR-304 AC module. In this case, pin 9 should be specified to control AC power, since pin 9 is the parallel port pin that is wired to the TR-2200A stub cable.

Note that the action of the TR-304 AC module is the opposite of that of the TR-302 module. During data acquisition the TR-302 turns on DC power to the cable tester; while for the TR-304, AC power to the cable tester is turned off during data acquisition. All three AC power wires are disconnected when power is off; the power, common, and ground wires. It is necessary to disconnect the ground wire because the noise is often on the ground. Noise problems of this sort are usually found in outdoor applications where AC power grounding is not the best.

6.8 Connect External 12 VDC Power to the 1502C TDR Cable Tester

The Tektronix model 1502C TDR cable tester was originally conceived as a commercial varient of the model 1502B, which was a military specification unit. Unlike the 1502B, it did not have a recess in the back of the case for a removable NiCd battery pack. It did have an option for an internal lead acid battery (12 VDC) and the uppermost power supply PCB has a four-pin in-line header for connecting the battery. The two outside pins are for ground and connect to the chassis; while the two inside pins are for +12 VDC. After the 1502B was discontinued, Tektronix revised the options for the 1502C and made available an option with the case recess and banana plug connectors to accomodate the removable NiCd battery pack. If bought with this option, the 1502C may be used, as was the 1502B, with the Campbell Scientific, Inc. (CSI) model TR302 power supply module to turn 12 VDC power on and off to the cable tester. This section is intended to help those who have a 1502C without the removable battery pack option (the majority of 1502Cs in service) to wire that cable tester for external 12 VDC power and to control that power. Note that these modifications may invalidate the manufacturer’s warranty.

The most straightforward modification is to run a two wire cable through a hole in the back of the case (Fig. 6-2). Put a polarized connector on the cable to help avoid reversing the polarity. The cable must be long enough that the case can be removed from the chassis with the connector on the end of the cable (Fig. 6-3). Some care is required when replacing the case to avoid crimping the cable between the case and chassis. The cable should be terminated in a four position female in-line connector (0.1 inch spacing) with the two outer sockets connected to ground, while the two inner sockets are connected to +12 VDC (Fig. 6-4). The terminated cable may be plugged into the in-line header on the power supply PCB (Fig. 6-5). Before applying power, check that the ground side of the polarized connector has a closed path to the chassis; and check that the +12 VDC side of the polarized connector has a closed path to both of the inside pins on the power supply PCB, and no path to the chassis.

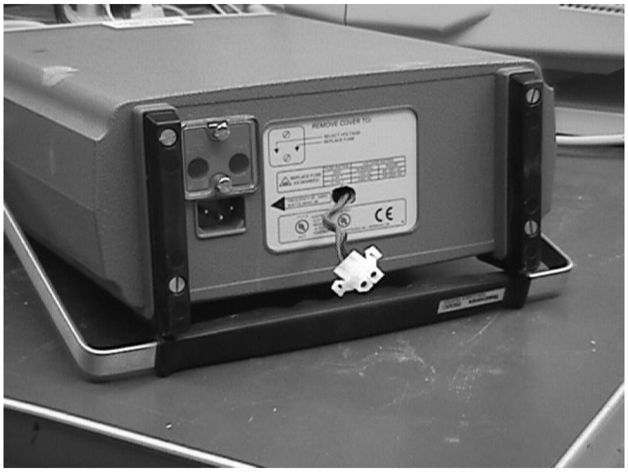

Figure 6-2 DC power cord, with polarized nylon connector, emerging from a hole drilled in the back of the case for a Tektronix 1502C TDR cable tester.

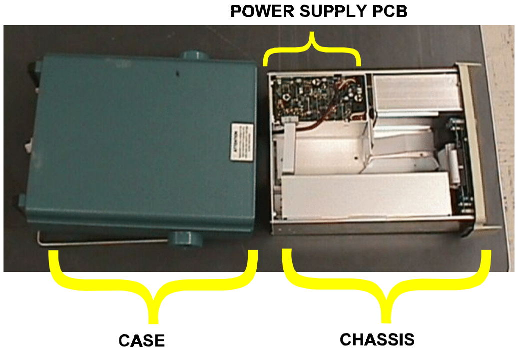

Figure 6-3 Tektronix 1502C TDR cable tester with case (at left) removed far enough to allow access to the power supply printed circuit board.

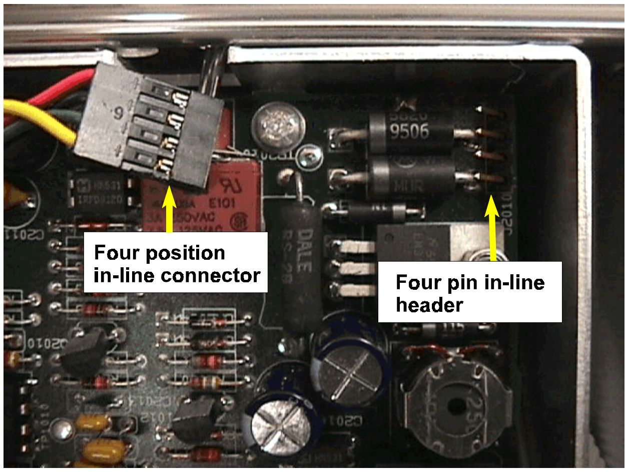

Figure 6-4 Close up view of power supply printed circuit board in model 1502C cable tester. The four position connector will be placed on to the header to complete the connection of an external 12 VDC power source.

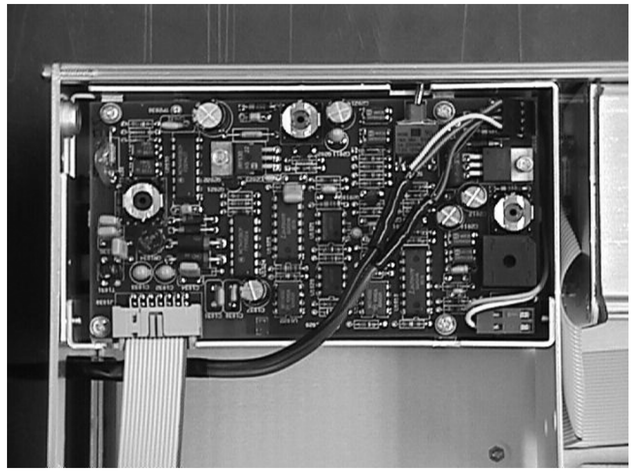

Figure 6-5 View of power supply circuit board in model 1502C cable tester with external power connected to four pin in-line connector. The two outer pins are connected to the ground side of the two-conductor cable.

The 12 VDC power supply should source enough current to allow the cable tester to power up without a low voltage fault. The Tektronix cable testers check for a low voltage condition at power-on. If the supply will not source enough current to prevent a dip in voltage at power-on then the cable tester will detect the dip as an out-of-range voltage and will not come on. For this reason, some AC-DC inverters will not allow the cable tester to reliably turn on. Because lead acid batteries source current very well, even a small 12 VDC lead acid battery will reliably turn on these cable testers.

6.9 Control 12 VDC Power to the 1502C TDR Cable Tester

If the CSI model TR302 power supply module cannot be used, we can control power with a simple Darlington transistor pair driving a relay and triggered by a TTL level signal (Figs. 6-6 and 6-7). Pin 9 of the computer's parallel port can be used to provide the TTL signal at the I/O pad (Fig. 6-6). Cabling can be similar to that used for the TR302. The three wires needed in the cable carry +12 VDC, ground, and the TTL signal, respectively. Spacing for the I/O, GRND, and +12 circuit pads is 0.2 inch (Fig. 6-6), which is compatible with many screw terminal strips. If a Wieland type 8213S/3WOB horizontal socket is used here, then the 3 pole Wieland 8213B/3 screw terminal plug may be used to terminate the cable carrying I/O, ground, and +12 VDC. This is compatible with the plug used with the TR302. Note that the circuit shown in Figures 6-6 and 6-7 is not optically isolated, has no fuse, is not diode protected against reverse polarity connections, and is not protected against transients with a MOV. The specified relay could probably be replaced with one rated for less current and voltage, but has proven reliable. The circuit draws from 30 to 40 mA at 12 VDC. A much lower power circuit could be designed using a small solid state relay and an optoisolator.

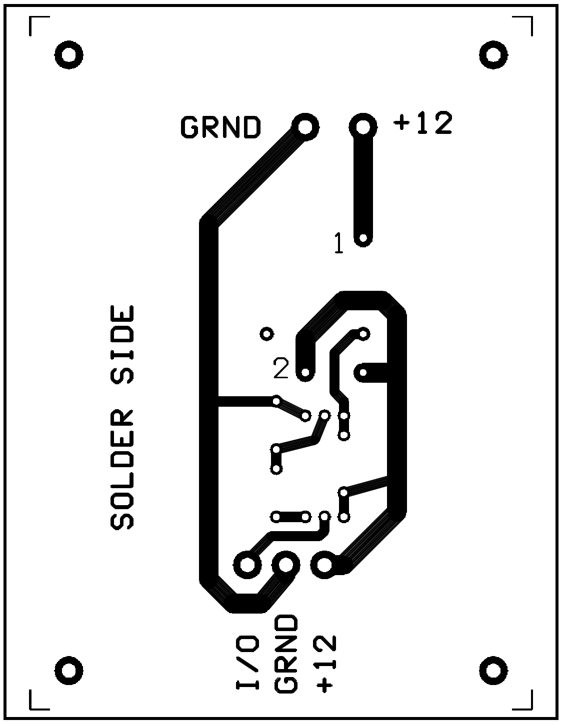

Figure 6-6 Solder side of circuit board for controlling power to the 1502C cable tester. The ground and +12 VDC pads at the top of the figure should be connected to the power supply PCB of the cable tester as described in the text. The I/O, ground, and +12 VDC pads at the bottom are for connection to pin 9 of the parallel port, the ground (negative side of the battery), and +12 VDC side of the battery, respectively.

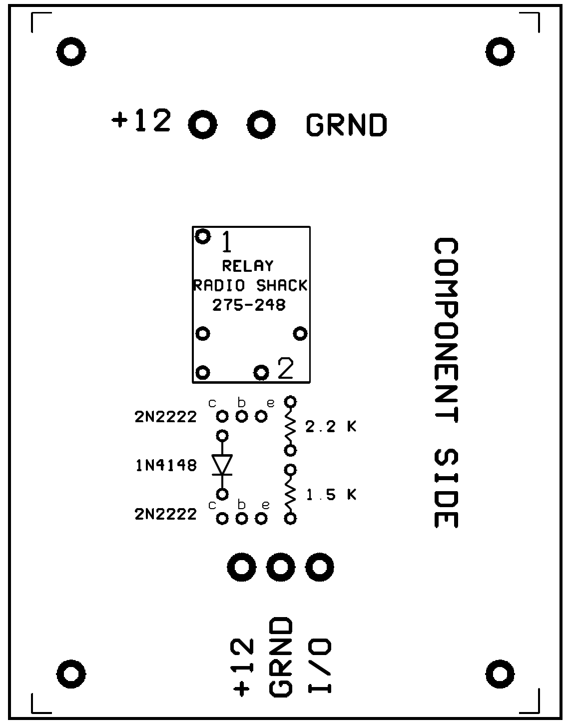

Figure 6-7 Component side of circuit board for controlling power to 1502C cable tester. The 2N2222 transistors are common NPN transistors. The 1N4148 is a common switching diode. The Radio Schack relay is made to be powered from 12 VDC. The normally open circuit in the relay is from pin 1 to pin 2. The coil resistance is about 400 ohms, and the contacts are rated at 10 A at 120 VAC.

Figures 6-6 and 6-7 are only approximately to scale. The apexes of the corner marks should be 2.6 inches apart horizontally, and 3.6 inches apart vertically. The circuit is single-sided and can be built using only the traces and pads shown in Fig. 6-6. The Gerber file for Fig. 6-6 is 1502CT-1.001, the aperture file is 1502CT-A.001, and the numerical control drill file is 1502CT-D.001. All three files may be downloaded from http://www.cprl.ars.usda.gov/programs