[5.6] Build your own GraphLink cable (Hess's BCC Serial Link)

A GraphLink cable provides a serial interface between the calculator and a personal computer. This gives you the capability to download programs to the calculator, to back up your calculator's memory on the PC, and to transfer variables between the calculator and the computer. The original TI cable was gray in color, and so was called the gray cable. TI has since released another version, called the 'black cable', which is less expensive, has a higher transfer rate, and seems to be more reliable. The black cable is reasonably priced at $20US, and is readily available, at least in the US.

Even so, there are some good reasons to build your own cable. One reason is education: to learn how such a cable works, and to gain insight into the GraphLink communications protocol. If you live outside the US, TI's cable may not be as readily available, or the cost may be excessive. Finally, if you are an electronic experimenter, you probably already have all the parts you need to build the cable.

Several users have developed alternatives to TI's GraphLink cables. As an example, I have chosen a design by Frank Mori Hess, for several reasons. Frank calls his design the BCC, which is an acronym for 'black-compatible cable', because it is compatible with TI's black cable. The BCC works with TI's GraphLink software; other cable designs require custom third-party software. The BCC is built with inexpensive, non-critical, readily available parts. I have built both BCC versions, and they work quite well. The BCC works only with IBM-compatible personal computers, not with the Apple Macintosh.

You should not attempt to build the BCC unless you have some electronics experience. The BCC is extremely simple, and no users have reported any damage to either the calculator or the PC from a properly constructed BCC. Still, there is always the risk of damage, particularly if the cable is incorrectly assembled. Neither Frank nor I accept any responsiblity for any damage that may result.

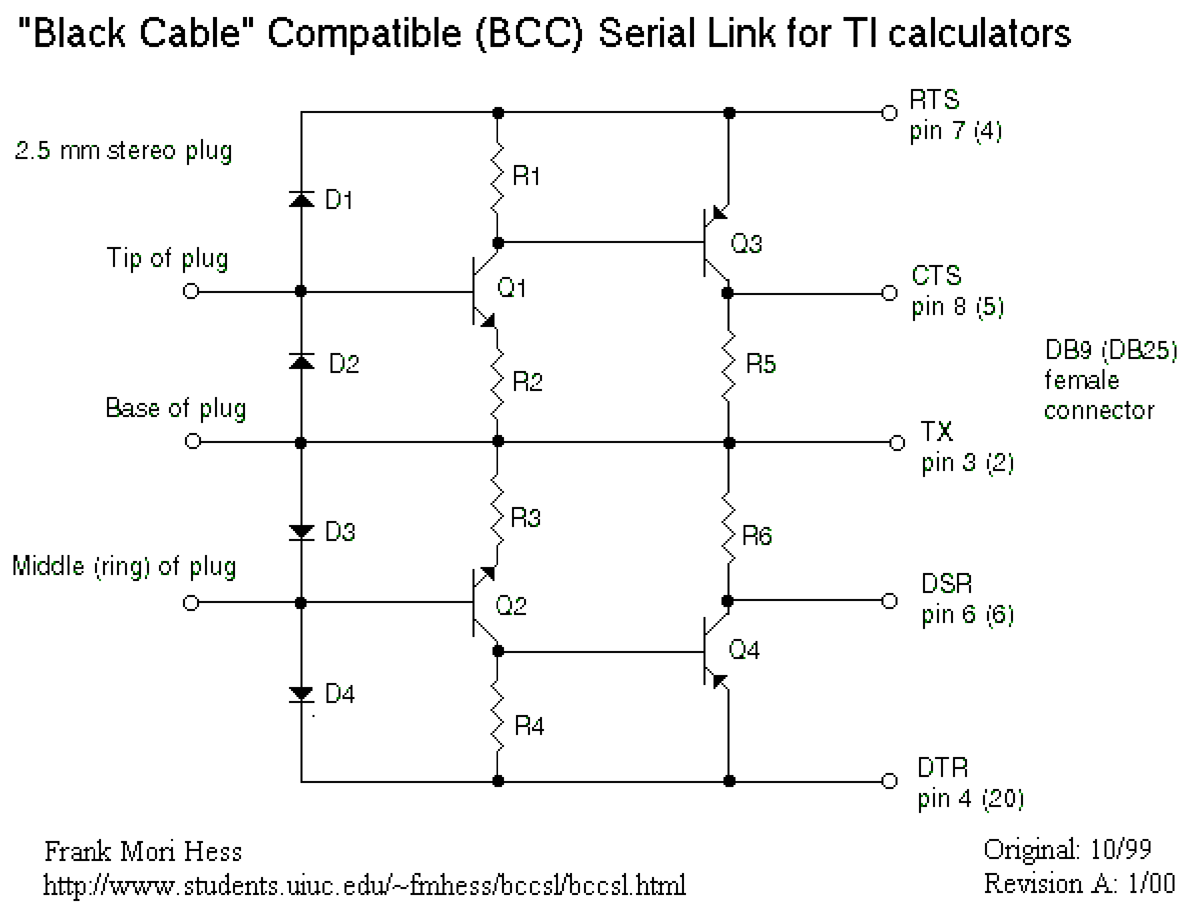
Almost all of the information for this tip is taken from Frank's excellent web site:

http://www.students.uiuc.edu/~fmhess/bccs/bccsl.html

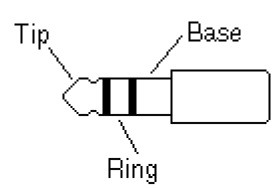
and is reproduced here with his permission. You can email Frank at *fmhess@uiuc.edu*

The original BCC

Frank designed two versions of the BCC cable, the 'original' and the 'deluxe'. The original cable works well, but the deluxe cable draws less current and will probably work better with PCs which do not implement true RS-232 signal voltage levels. The deluxe cable adds two transistors to the design, and changes the resistance values. The balance of this section describes the original cable, and the following section describes the deluxe cable.



The schematic for the original cable is shown above. The connection to the computer may be either a DB9 or a DB25 connector; the DB25 pin numbers are shown in parentheses. The GraphLink plug which connects to the calculator is a 3-conductor (stereo) 2.5 mm connector. The three conductors are named like this:



The parts list for the original cable:

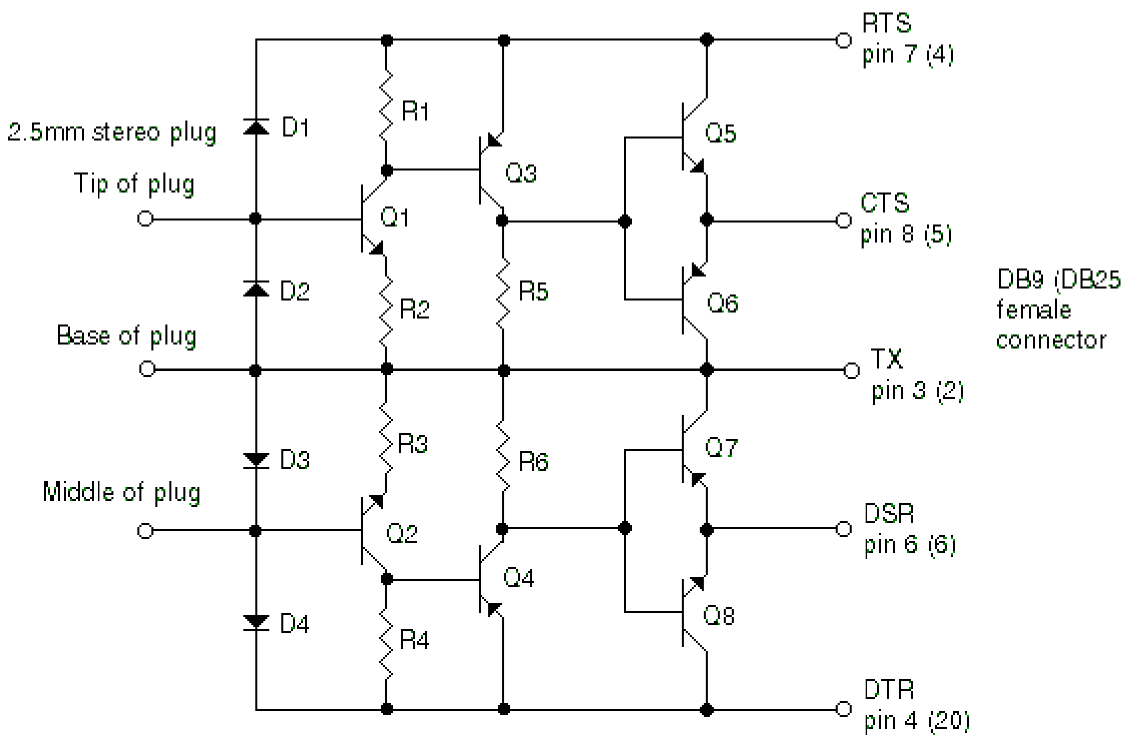
Designator	Value	Comments
D1, D2, D3, D4	1N914	May also be 1N4148, 1N4004. Not critical.
Q1, Q2	2N4401	May also be 2N3904, or any NPN transistor with at least 25V collector-emitter voltage rating
Q3, Q4	2N3906	Any PNP transistor with at least 25V collector-emitter voltage rating
R1, R2, R3, R4	20kohm, 1/8W, 10%	Any type of resistor will work, also any value from 18K to 24K
R5, R6	7.5kohm, 1/8W, 10%	Any type of resistor will work, also any value from 5.6K to 9.1K
Miscellaneous	Printed-circuit board (PCB) Enclosure 2.5mm stereo plug (or jack) DB9 or DB25 female connector Hook-up wire	

The diodes, resistors, transistors, DB-9 connector and are commonly available from many sources, including Radio Shack, Digikey (www.digikey.com) and Mouser Electronics (www.mouser.com). Mouser carries a very nice 2.5mm jack (161-3307, $1.47) which I use. As an alternative to this jack, you could also make a hard-wired pigtail, connected to the BCC printed circuit board, by cutting off one end of the calculator-to-calculator link cable which comes with the calculator. You can also buy this cable from TI at their on-line store; look under 'Graphing Calculators'.

The Deluxe BCC

The deluxe BCC is quite similar to the original BCC. A push-pull output stage is added and the resistor values are changed, so that the circuit draws less current (meaning longer calculator battery life), and the signal levels at the serial port outputs are increased. The increased level provides better compatibility with some PC serial ports, which do not really comply with the ±12V RS-232 standard.

BCC–Deluxe Serial Link for TI Calculators



Frank Mori Hess
http://www.students.uiuc.edu/~fmhess/bccsl/bccsl.html

Original: 5/2001

The parts list for the deluxe cable:

Designator	Value	Comments
D1, D2, D3, D4	1N914	May also be 1N4148, 1N4004. Not critical.
Q1, Q2, Q5, Q8	2N4401	May also be 2N3904, or any NPN transistor with at least 25V collector-emitter voltage rating
Q3, Q4, Q6, Q7	2N3906	Any PNP transistor with at least 25V collector-emitter voltage rating
R1, R2, R3, R4	100kohm, 1/8W, 10%	Any type or wattage of resistor will work, also any value from 82K to 120K
R5, R6	40kohm, 1/8W, 10%	Any type or wattage of resistor will work, also any value from 36K to 43K
Miscellaneous	Printed-circuit board (PCB) Enclosure 2.5mm stereo plug (or jack) DB9 or DB25 female connector Hook-up wire	

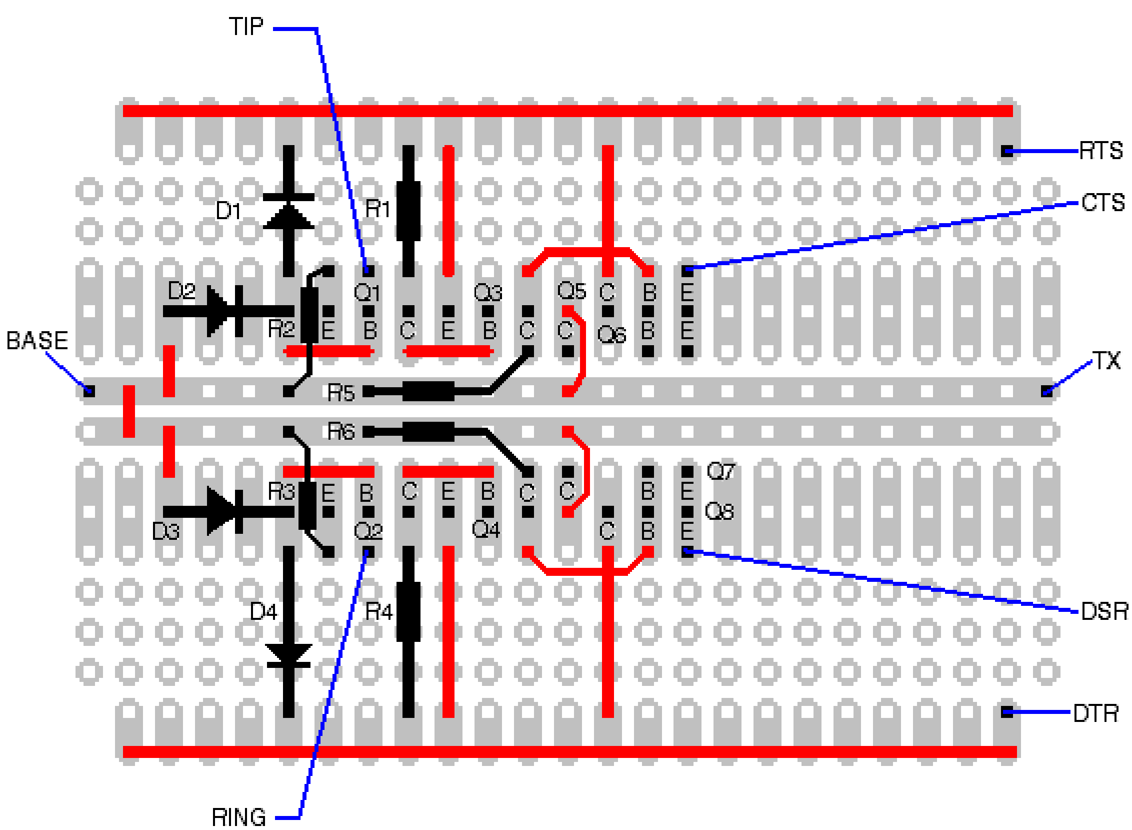
You can build the deluxe cable with standard parts from Radio Shack, as shown in this table:

RadioShack parts list for BCC deluxe

Designator	Value	RadioShack part number	Total cost US$
D1, D2, D3, D4	1N914/1N4148	276-1122 (pack of 10)	1.19
Q1, Q2, Q5, Q8	2N4401	276-2058	1.96
Q3, Q4, Q6, Q7	PN2907	276-2023	2.36
R1, R2, R3, R4	100kohm, 1/8W, 10%	276-1347 (pack of 5)	0.49
R5, R6	47kohm, 1/8W, 10%	276-1342 (pack of 5)	0.49
Printed-circuit board (PCB)		276-150	1.19
DB9 female connector		276-1538C	1.29
Enclosure	4" x 2" x 1"	270-1802	2.29
Stand-offs	10 mm	276-1381	2.19
4-40 machine screws		64-3011	1.49
4-40 hex nuts		64-3018	1.49
3/32" female jack		274-245	1.99
Hook-up wire	4-conductor 24GA solid phone cable, 1 foot	278-1310	0.15
		Total cost:	18.57

All of these parts should be in stock at any RadioShack, but your particular RadioShack may have to order some of them. Also, prices may vary slightly from store to store. The 4-40 machine screws and nuts are used to mount the DB9 connector to the enclosure. The individual wires of the phone cable are used for jumper wires on the PCB. Considering that the component cost is about $19, and you can buy the TI cable for $20, you aren't saving much money. However, much of the cost is in the enclosure and mounting hardware. You can save some money by using creative alternatives.

This figure shows one possible component layout on the 276-150 PCB:



Components are shown in black, jumper wires in red, and off-board connections are blue. Note that the PCB is not vertically symmetrical; the two rows of single pads are near the top. This layout shows the component side of the board. All components are mounted on this side, but it will be easier to mount some of the jumpers on the reverse side (called the solder side). The two long jumper wires at the top and bottom of the PCB are bare wire, and need only be soldered at the pads where other jumpers or parts are connected. You must use 1/8W resistors for this layout, because 1/4W resistors are probably too big. Note that the collector leads for Q6 and Q7 are separated from the other leads. Also note that the two center traces are connected with a short jumper, so that both are connected to the base and TX. The general assembly procedure is:

1. Lightly polish the copper pads with very fine steel wool or sandpaper, or ScotchBrite. This removes the oxidation and results in better, faster solder joints.
2. Install all jumpers except the Q6 and Q7 collector jumpers. On the component side, install the emitter jumpers for Q3 and Q4, and the base jumpers for Q5 and Q8. Install the remaining jumpers on the solder side of the PCB.
3. Install the diodes.
4. Install Q1, Q2, Q3 and Q4. Pay close attention to the emitter/base/collector lead order, and mount the transistors as close as possible to the PCB, so that they will clear the enclosure sides.
5. Install the resistors.
6. Install Q5, Q6, Q7 and Q8.
7. Install the collector jumpers for Q6 and Q7, on the component side of the PCB.
8. Install the wires for the the off-board connections for the 3/32" jack and the DB9 connector.
9. Assemble the components into the enclosure.
10. Check your work for solder bridges, which are particularly likely with RadioShack PCBs, because the pads and holes are so large.
11. Test the cable.

Circuit description

The GraphLink cable has three conductors. Two of the conductors are data lines, which connect to the tip and the ring of the 2.5mm plug. The third conductor connects to the calculator ground through the base conductor of the plug. Each data line sends and receives data. One data line is used to transmit a '0' bit, and the other transmits a '1' bit. The data lines are asserted low but float high, about +5V above the calculator ground. So, if either the calculator or the PC asserts a data line, both ends of the line are pulled low. Both data lines have a pull-down resistor of about 10Kohm in the calculator, so the transmitting circuit must sink about 0.5mA. For the moment, assume that the two calculators (a 'transmitter' and a 'receiver') are connected with the GraphLink, then these steps are used to transmit a data bit:

1. Initially both data lines are floating high. This is the idle state.
2. The transmitter asserts one of the data lines low, to transmit a bit.
3. The receiver asserts the other data line to indicate it has received the bit.
4. The transmitter stops asserting low.
5. The receiver stops asserting low.
6. Both calculators are back in the idle state, and the next bit may be transmitted.

Note that precise timing is not required, because this is an asynchronous data link.

Since the GraphLink is designed for communications between two calculators, the purpose of the GraphLink cable circuit is to use the computer's serial port to emulate a calculator. This is accomplished with five of the serial port pins. The RX and TX lines do not receive and transmit data, as is usually the case with RS-232 communications. Instead, the TX line is perpetually set to its low voltage state, and sinks current from the cable circuit. The RX line is not used at all. The RTS and DTR lines are used to transmit data from the PC, and the CTS and DSR lines receive data from the calculator. Since the upper and lower halves of each BCC link circuit are identical, we need only describe the upper half.

This table describes the four conditions the BCC circuit must apply.

Case	Calculator asserting Low?	State of RTS line	Result at data line (Plug tip and CTS)
#1	No	HIGH (Positive voltage with respect to serial port ground	HIGH (plug tip 5V with respect to calculator ground, CTS positive with respect to serial port ground).
#2	No	LOW (Negative voltage with respect to serial port ground)	LOW (plug tip 0V with respect to calculator ground, CTS negative with respect to serial port ground.)
#3	Yes	HIGH	LOW
#4	Yes	LOW	LOW

In cases 3 and 4, the calculator is either transmitting a data bit or acknowledging receipt of a bit, so, regardless of the state of the RTS line, the CTS line must be low so that the PC reads the low level. In cases 1 and 2, the calculator is either in the idle state, or the 'other' data line is asserted low, so the plug tip and CTS must follow the RTS line state. The BCC circuit implements these cases as follows.

Case 1:
RTS is at about +12V relative to serial port ground. The plug tip is at about 5V, relative to calculator ground, so Q1's base is at about -7V relative to the serial port ground. This turns Q1 on which in turn turns Q3 on, so the CTS line is only below RTS by Q3's Vce drop, or, essentially, at RTS, so CTS is high.

Case 2:
RTS and TX are at the same voltage, so neither Q1 nor Q3 can turn on. D1 pulls the plug tip low, and pull-down resistor R5 pulls CTS low.

Case 3:
The plug tip is low, so neither Q1 nor Q3 turn on. R5 pulls CTS low.

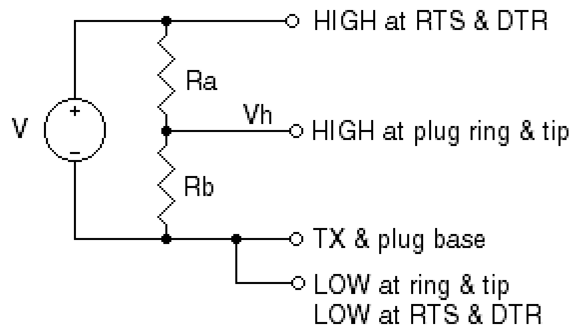
Case 4:
Neither Q1 nor Q3 can turn on. R5 pulls CTS low.

The deluxe BCC operates in much the same way, except that Q5 and Q6 form a push-pull output stage to drive the CTS line.

Testing the cable

The simplest way to test the BCC is to plug it into you calculator and computer, and try it. Download and install the GraphLink software from the TI website. From the *Link* menu, select the proper serial port and choose the *Windows only (black cable)* option from the *Cable type* submenu. If you can successfully complete the *Get Screen* operation from the *Link* menu, then the cable works. If the *Get Screen* operation fails, immediately unplug the BCC from the calculator and the computer. While both the computer serial port and calculator I/O port are fairly robust, you minimize the chance of damage, to either one, by unplugging everything. If the operation fails, read the rest of this section, and see the *Troubleshooting* section below.

You can also test the BCC before you connect it to the calculator and computer, with this simple test circuit, a voltmeter and some test leads:



The voltage source V may be a power supply or even a 9V battery. The two resistor Ra and Rb set voltage Vh, and simulate the 10K source impedance of the calculator data lines. For a desired source impedance Rs and output voltage Vh, use these equations to find Ra and Rb:

$$Ra = \frac{Rs \cdot V}{Vh} \qquad Rb = \frac{Rs \cdot V}{V - Vh}$$

which are found as the solutions to

$$Rs = \frac{Ra \cdot Rb}{Ra + Rb} \qquad Vh = V\frac{Rb}{Ra + Rb}$$

For example, if we use a 9V battery, and want a 5V output voltage with 10K source impedance, then Rs = 10K, V = 9 and Vh = 5, and we find Ra = 18K and Rb = 22.5K. The nearest standard 5% tolerance values are 18K and 22K, which results in an output voltage of 4.95V and a source impedance of 9.9K, which is close enough. It is simpler and just as effective to use two 20K resistors for Ra and Rb.

The 'tip' and 'ring' sections of the circuit are tested separately, following cases 1 to 4 as described above. The tables below show the correct results, as well as my measured results when using a 9V battery. Note that V+ is the positive terminal of the battery (or power supply), and V- is the negative terminal.

Test results for 'tip' circuit

Case	Calculator asserting low?	State of RTS line	Result at data line (Plug tip and CTS)
#1	No (Connect tip to Vh)	High (Connect RTS to V+)	tip: HIGH, Vh CTS: HIGH; about 9.3V
#2	No (Connect tip to Vh)	Low (Connect RTS to V-)	tip: LOW, about 0.6V CTS: LOW, about 0V
#3	Yes (Connect tip to Tx)	High (Connect RTS to V+)	tip: LOW, about 0V CTS: LOW, about 0V
#4	Yes (Connect tip to Tx)	Low (Connect RTS to V-)	tip: LOW, about 0V CTS: LOW, about 0V

Test results for 'ring' circuit

Case	Calculator asserting low?	State of RTS line	Result at data line (Plug tip and CTS)
#1	No (Connect ring to Vh)	High (Connect DTR to V+)	ring: HIGH; Vh DSR: HIGH; about 9.3V
#2	No (Connect ring to Vh)	Low (Connect DTR to V-)	ring: LOW, about 0.6V DSR: LOW, about 0V
#3	Yes (Connect ring to Tx)	High (Connect DTR to V+)	ring: LOW, about 0V DSR: LOW, about 0V
#4	Yes (Connect ring to Tx)	Low (Connect DTR to V-)	ring: LOW, about 0V DSR: LOW, about 0V

Troubleshooting

If the BCC cable does not work, first verify that:

1. You are using the latest version of the TI GraphLink software.
2. You have selected the Black Cable option in the GraphLink software.
3. You have selected the correct serial port for your computer.
4. You have reasonably fresh batteries in the calculator.
5. Both the GraphLink and serial port connections are secure. On the TI-89, in particular, the GraphLink cable connector must be *firmly* pushed into the calculator connector.

If all this seems correct, check the BCC circuit itself. Most circuit flaws are caused by mis-wiring. In particular:

1. Verify that the diode polarities are correct.
2. Verify that the transistor connections (base, emitter and collector) are correct.
3. Verify that the plug, tip and base connections are correct.
4. Verify that the serial port connections (RTS, CTS, TX, DSR and DTR) are correct, *for the connector you are using - either the 9- or 25-pin.*
5. Verify that all component connections are correct. Use a voltmeter with a continuity function (beeper). For example, verify that RTS is connected to D1, R1 and Q3's emitter. Verify that the plug base connects to D2, D3, R2, R3, R5, R6 and TX, and so on.
6. Verify that the correct resistor values are in the right places.

7. Check the schematic and verify that you have, in fact, built the circuit shown.

Some circuit flaws are caused by soldering problems:

1. Carefully check the circuit for shorts (unintentional solder bridges between pads or leads).
2. Check all solder connections for cold joints. A good solder joint has a shiny, smooth appearance. A cold joint has a dull, rough appearance. A cold joint may be mechanically solid but may not be a functional electrical connection.

If all this fails to get the BCC working, have someone else check your work. This is helpful even if (particularly if!) the person has no electronics experience. Sometimes, just explaining the circuit to someone else will make a mistake obvious.

It is remotely possible, but unlikely, that failed parts cause the BCC fault. Transistors and diodes can be damaged or destroyed outright by the heat from excessive soldering times. Again, the most likely cause of failure is mis-wiring.

Comments

The serial port input lines (CTS and DSR) have a relatively low impedance of about 5Kohm. The are *not* high-impedance inputs.

If either of the data lines (plug or ring) are asserted low, calculator operation may become sluggish because the calculator thinks that communications is in progress. It appears that the GraphLink software does not set the DTR and RTS lines high on all computers when the software is started. This may prevent the calculator from being put into 'receive' mode, and it may also prevent sending programs using the SEND button in the GraphLink windows. This can usually be fixed by executing *Recieve* or *Get Screen* from the GraphLink menu.

If you use the GraphLink software to develop CBL or CBR programs, you may want to build the switch-box circuit (described in tip [5.7] below) into your BCC.

(Credit to Frank Mori Hess for the cable designs and documentation)