A Repeater for the NCE Radio System

By Mark Schutzer January 6, 2005

Introduction:

This is a follow on to my earlier write up that described a diversity receiver for the NCE radio system. In this write up I will describe how to make a repeater, or slave transceiver for the radio system. A lot of this is based on the diversity receiver and I would encourage you to read the diversity write up prior to reading this document. This write up really should be considered as part two, as it talks about the modifications to turn the diversity receiver into a slave transceiver.

The repeater (or slave) can be used to implement bi-directional diversity, or it can be used to extend the range of the radio system. As will be described later in the document it does work and noticeably improves the performance of the radio system.

And while this is not for everyone maybe this will give you a bit of a background on how a repeater can work. And even if you don't want build your own I know that NCE is working on their repeater and it will probably be available in the not to distant future.

What I wrote in the earlier write up bears repeating here…

Before I go any further I should say that these are modifications that I made to my system, they are quite involved and require surface mount assembly skills and quite a bit of knowledge concerning electronic circuit design. This is not intended to be a simple how to guide and this is definitely not for everyone. If you read through the rest of this write up and it all makes sense to you, then feel free to proceed at your own risk. And needless to say none of this is endorsed by NCE and will likely affect your warranty.

With that said if you want to learn a bit more about what I did feel free to continue reading …

How it works:

Rather than starting completely over I would refer the reader to my earlier write up on the diversity receiver. In that document I discussed how a RF Monolithics DR3000[1] module was used to make a diversity receiver. The explanation that follows will discuss the changes to make the diversity receiver also transmit.

Since it's no longer just a diversity receiver I'm going to start referring to it as a slave transceiver, or slave for short. Please refer to the schematics on the following pages when reading the following description.

If you recall the DR3000 module contains the same TR1000[2,3] transceiver module that is used in the NCE radio base station. For the diversity receiver the module was only used in receive mode, now it will also be used in transmit mode, just as on the NCE base station. When in receive mode it will still function as a diversity receiver, when in the transmit mode it will send data with the same timing as the base station.

For the diversity receiver design a RS-485 link was used send the receive data back over to the base station. For that design the RS-485 link was set up to function in one direction only, that is passing the receive data from the slave back to the radio base station. To make the slave also transmit the RS-485 link must be made to switch directions and pass data to the slave when it is time to transmit.

The transmit enable signal in the base station is used as a source for this timing. An inverting FET driver (Q4) provides the direction control signal for the RS-485 transceiver (U2) in the base station. Another FET inverter (Q3) feeds the opposite polarity of this signal over to the slave on pin 6 of the RJ-12 connector. On the slave side pin 6 of the RJ-12 connector is fed to the direction control of the RS-485 transceiver (U1) and to the transmit enable line (CTR1) of the DR3000 module. This line is terminated with a 1k pull up resistor that has been added to the DR3000 module.

On the base station the transmit data has been fed over to the transmit data pin (U2, pin 4) of the RS-485 transceiver. On the slave side the corresponding RS-485 receive data pin (U1, pin 1) has been connected to the transmit input of the DR3000 module.

The diagram on the next page shows the relationships between all these signals.

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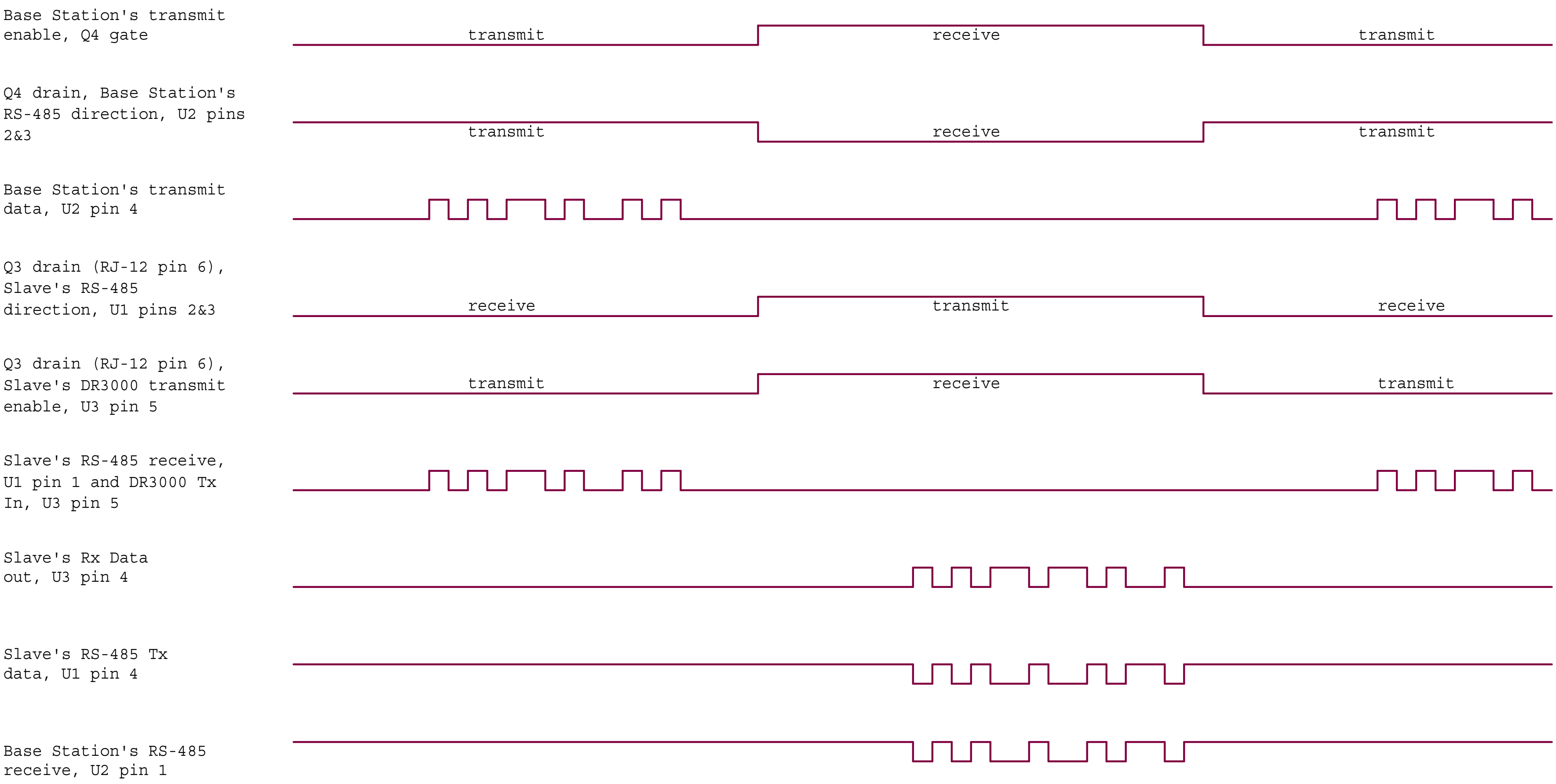
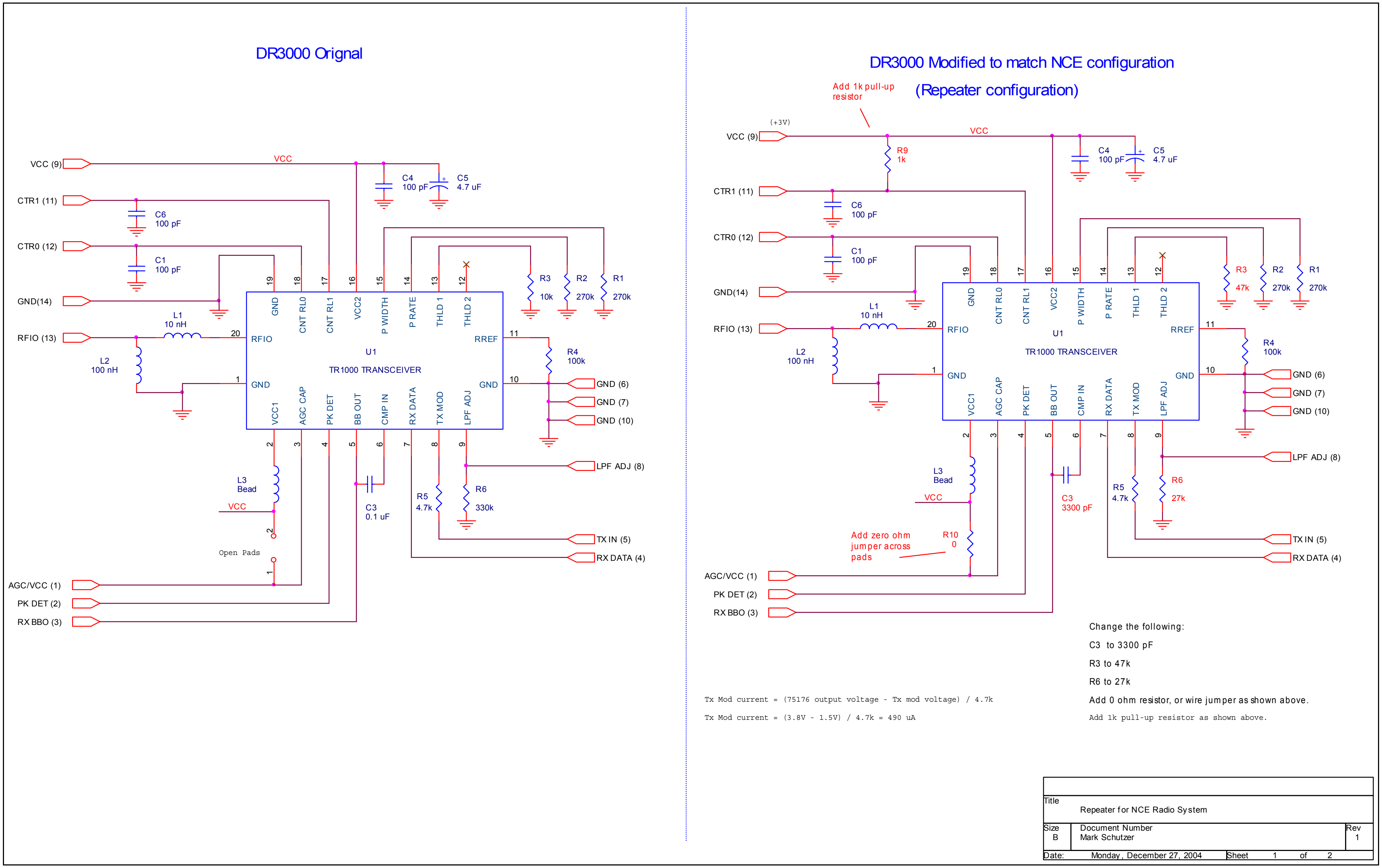
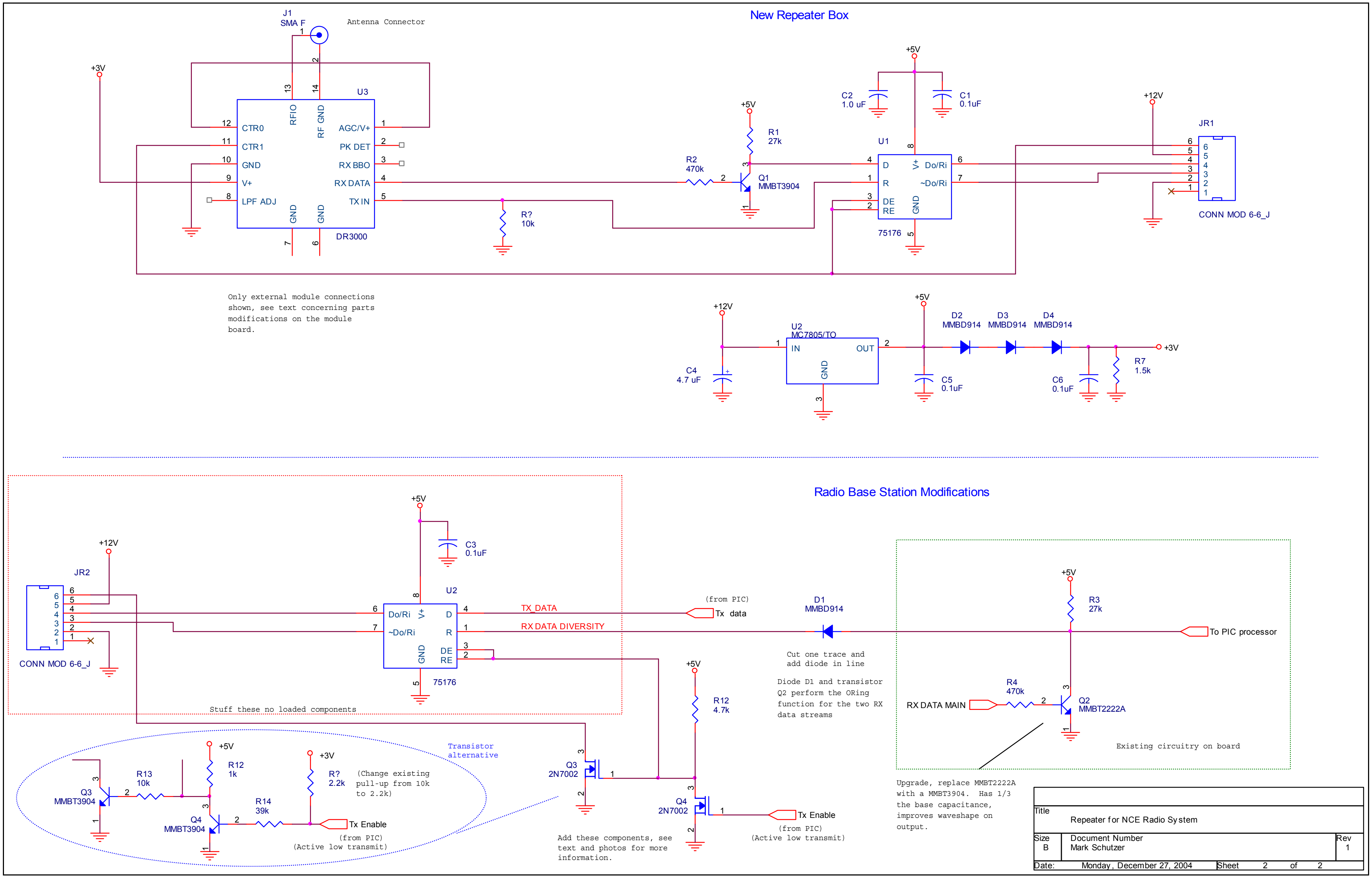
[1] Datasheet for the DR3000 available at: http://www.rfm.com/products/data/dr3000.pdf
[2] Datasheet available for the TR1000 at: http://www.rfm.com/products/data/tr1000.pdf
[3] Application notes available at: http://www.rfm.com/products/tr_des24.pdf

RS-485 Signal Diagram




DR3000 Orignal
VCC (9)
VCC
C4 100 pF
C5 4.7 uF
CTR1 (11)
C6 100 pF
CTR0 (12)
C1 100 pF
GND(14)
RFIO (13)
L1 10 nH
L2 100 nH
U1
TR1000 TRANSCEIVER
GND
CNT RL0
CNT RL1
VCC2
P WIDTH
P RATE
THLD 1
THLD 2
RFIO
RREF
GND
VCC1
AGC CAP
PK DET
BB OUT
CMP IN
RX DATA
TX MOD
LPF ADJ
R3 10k
R2 270k
R1 270k
R4 100k
GND (6)
GND (7)
GND (10)
LPF ADJ (8)
L3 Bead
VCC
C3 0.1 uF
R5 4.7k
R6 330k
TX IN (5)
RX DATA (4)
Open Pads
AGC/VCC (1)
PK DET (2)
RX BBO (3)
DR3000 Modified to match NCE configuration
(Repeater configuration)
Add 1k pull-up resistor
(+3V)
VCC (9)
VCC
R9 1k
C4 100 pF
C5 4.7 uF
CTR1 (11)
C6 100 pF
CTR0 (12)
C1 100 pF
GND(14)
RFIO (13)
L1 10 nH
L2 100 nH
U1
TR1000 TRANSCEIVER
R3 47k
R2 270k
R1 270k
R4 100k
GND (6)
GND (7)
GND (10)
LPF ADJ (8)
L3 Bead
VCC
C3 3300 pF
R5 4.7k
R6 27k
TX IN (5)
RX DATA (4)
Add zero ohm jumper across pads
R10 0
AGC/VCC (1)
PK DET (2)
RX BBO (3)
Change the following:
C3 to 3300 pF
R3 to 47k
R6 to 27k
Add 0 ohm resistor, or wire jumper as shown above.
Add 1k pull-up resistor as shown above.
Tx Mod current = (75176 output voltage - Tx mod voltage) / 4.7k
Tx Mod current = (3.8V - 1.5V) / 4.7k = 490 uA
Title
Repeater for NCE Radio System
Size B
Document Number
Mark Schutzer
Rev 1
Date: Monday, December 27, 2004
Sheet 1 of 2


New Repeater Box
J1
SMA F
Antenna Connector
U3
DR3000
CTR0
CTR1
GND
V+
LPF ADJ
RFIO
RF GND
AGC/V+
PK DET
RX BBO
RX DATA
TX IN
+3V
+5V
+12V
R1
27k
R2
470k
Q1
MMBT3904
R?
10k
C2
1.0 uF
C1
0.1uF
U1
75176
D
R
DE
RE
V+
Do/Ri
~Do/Ri
GND
JR1
CONN MOD 6-6_J
Only external module connections shown, see text concerning parts modifications on the module board.
U2
MC7805/TO
IN
OUT
C4
4.7 uF
C5
0.1uF
D2
MMBD914
D3
MMBD914
D4
MMBD914
C6
0.1uF
R7
1.5k
Radio Base Station Modifications
JR2
CONN MOD 6-6_J
C3
0.1uF
TX_DATA
RX DATA DIVERSITY
(from PIC)
Tx data
D1
MMBD914
To PIC processor
R3
27k
Cut one trace and add diode in line
Diode D1 and transistor Q2 perform the ORing function for the two RX data streams
RX DATA MAIN
R4
470k
Q2
MMBT2222A
Existing circuitry on board
Stuff these no loaded components
R12
4.7k
Q3
2N7002
Q4
2N7002
Tx Enable
(from PIC)
(Active low transmit)
Add these components, see text and photos for more information.
Transistor alternative
Q3
MMBT3904
R13
10k
R12
1k
Q4
MMBT3904
R14
39k
R?
2.2k
(Change existing pull-up from 10k to 2.2k)
Tx Enable
(from PIC)
(Active low transmit)
Upgrade, replace MMBT2222A with a MMBT3904. Has 1/3 the base capacitance, improves waveshape on output.
Title
Repeater for NCE Radio System
Size
B
Document Number
Mark Schutzer
Rev
1
Date: Monday, December 27, 2004
Sheet 2 of 2

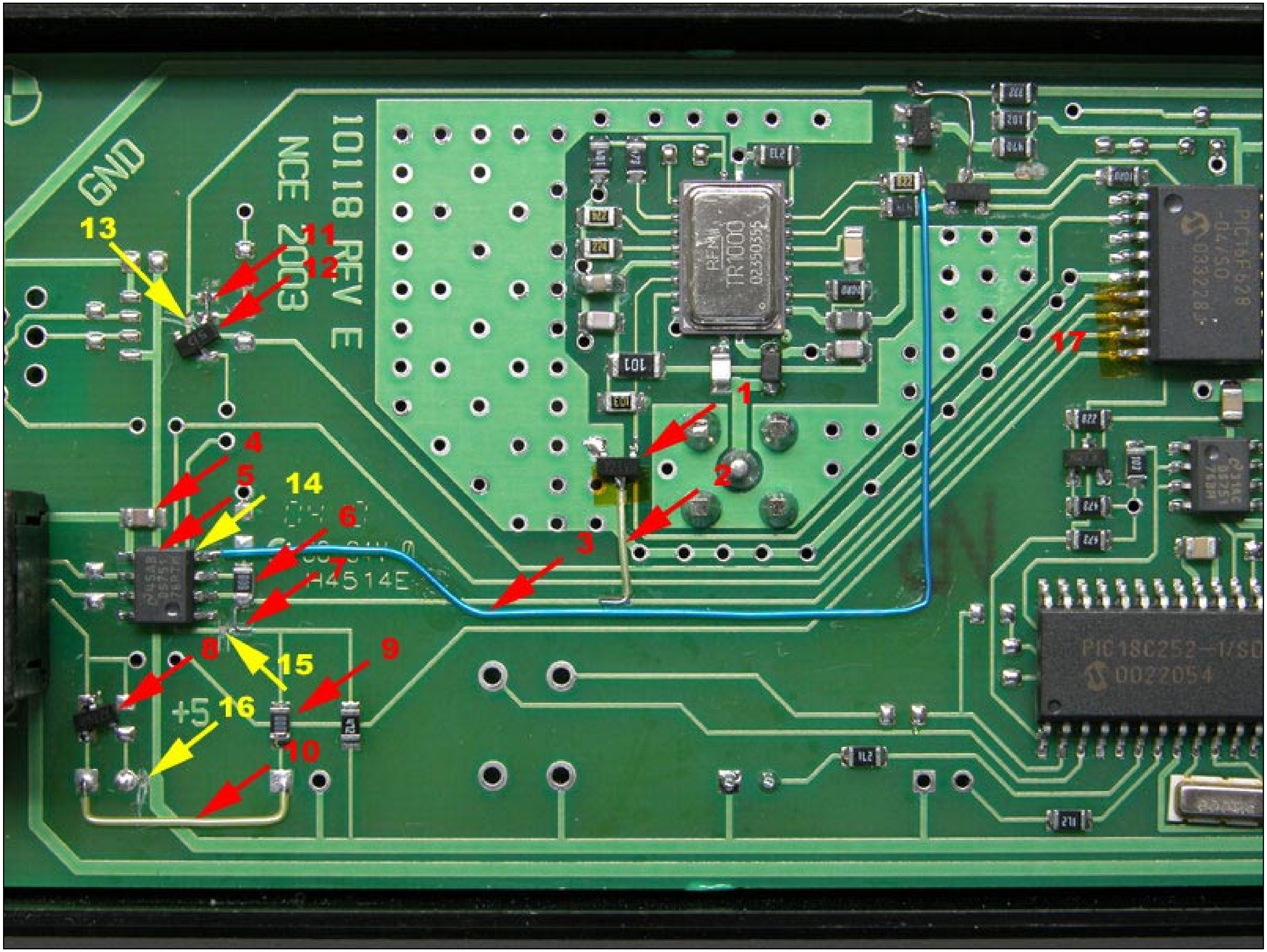
Implementation

On the next few pages I will show you some pictures of both the slave transceiver and the modified base station.

For the base station side I have included some annotations in the photo that show the modifications to the board. Please note that there are some zero ohm resistors and trace jumps in the photo that don't show up on the schematic. I tried to make use of many of the existing traces and pads on the base station so that the modifications would be as "clean" as possible given the changes. If you look at the photo and trace the connections on the schematic you will see that the implementation is the same.

The photo on the next page shows the base station modifications, here are the annotations for the photo:

Number	Description
1	FET Q4 (2N7002), scrape solder mask from narrow trace and install as shown. Insulate under drain pin.
2	Jumper connecting Q4 drain to U2 pin 2. Scrape solder mask from narrow trace running to pin 2 of U2
3	Jumper wire from base station Tx data to U2 pin 4.
4	Capacitor C3 (0.1 uF) added on existing pads
5	RS-485 transceiver DS75176 (U2) added on existing pads
6	Zero ohm jumper, size 0805 connecting U2 pins 2 and 3 together
7	Jumper wire connecting to intermediate trace. Scrape solder mask from narrow trace before installing
8	FET Q3 (2N7002), remove 4.7k resistor from right hand pads, install FET as shown
9	Zero ohm jumper to connect trace over to open via hole
10	Jumper wire between open vias, connects Q3 gate to U2 pins 2 and 3 (through zero ohm resistor)
11	Jumper to facilitate installation of D1
12	Diode D1, receive data Or'ing diode
13	Trace cut to open line to allow D1 to bridge gap
14	Trace cut behind U2 pin 4, Cut before installing U2, isolate pin 4 pad from the trace that connects over to pin 1
15	Trace cut
16	Trace cut, Isolate via hole from +5 volts, add wire in hole and jumper to the ground plane on the bottom side of the board
17	Lift four pins on PIC processor as shown, place insulating material under pins as shown

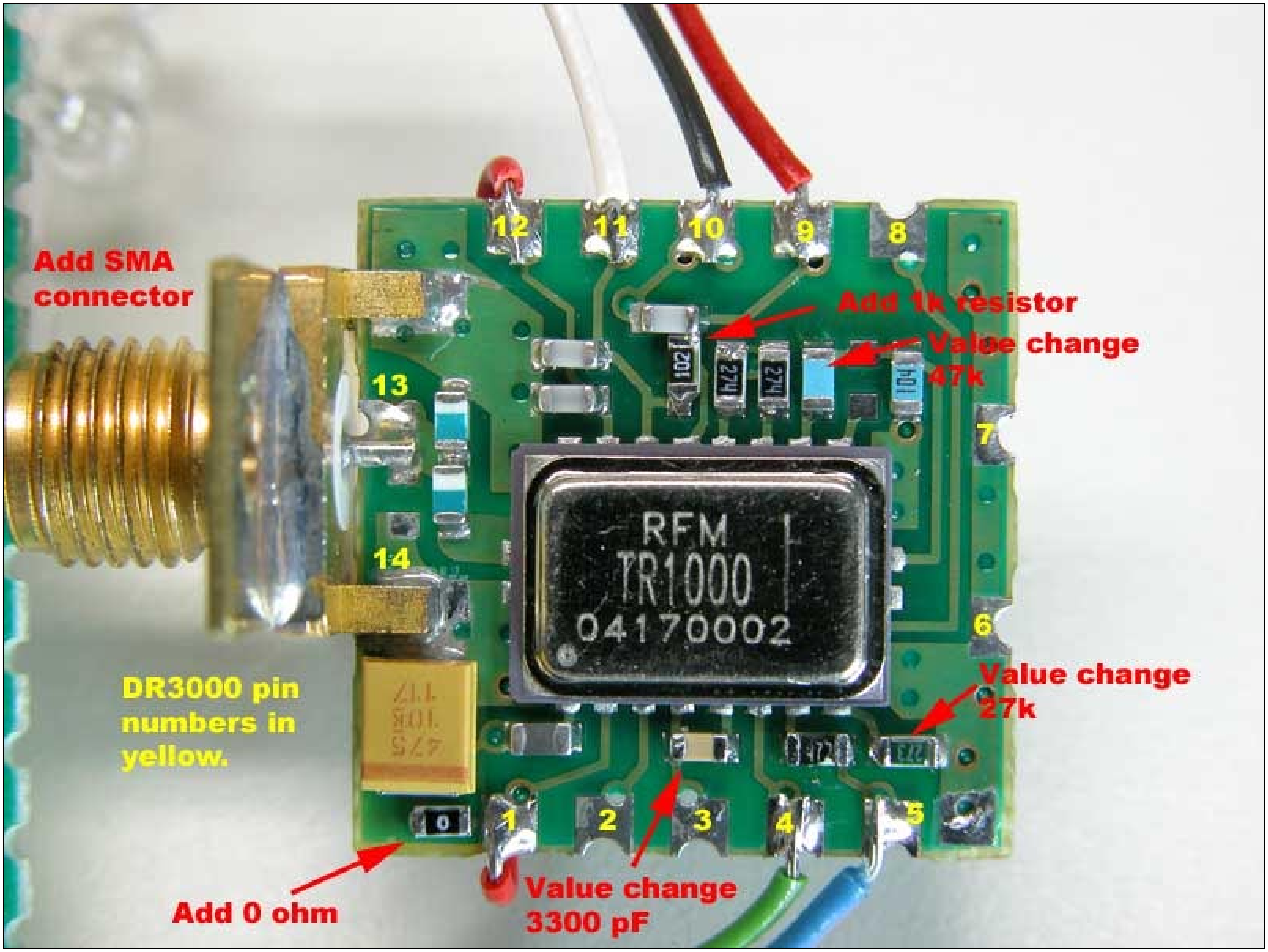

GND
10118 REV E
NCE 2003
TR1000
PIC16F628
PIC18C252-I/SO
+5
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17

The base station contains spare circuit board pads for two extra RS-485 transceiver links. I added my parts on the lower set of pads and bridged the receive data OR'ing diode (D1) across two of the IC pads from the upper pad set. My modifications could easily be expanded upon to support two separate slave transceivers. If this is anticipated D1 should be located elsewhere to keep the upper set of pads free for the second RS-485 link.

The schematic of the base station modification also shows an alternate implementation of the direction switching using the surface mount version of 2N3904 transistors instead of the FET's. I also built this version as a test and it does work, but it requires more rework and draws more current than the FET equivalent. I recommend using the 2N7002 FETs as it a better solution. By the way the 2N7002 is the same part that is used for the function output drivers on a lot of the NCE decoders.

Another improvement that can be made to the base station involves the inverting transistor driver that is coming off of the receive data line of the TR1000 (shown as Q2 in my schematic). The receive data output of the TR1000 can only drive a very high resistance line, that is why the 470k resistor (R4) is in series with the base of the transistor Q2. The base capacitance of the MMBT2222 is quite high (25 pF to 30 pF) and the waveshape of the receive data is significantly distorted by the low pass filter formed by R4 and the 30 pF of base capacitance. Another general purpose transistor, a MMBT3904 has the equivalent gain but one third of base capacitance at 8 pF. Swapping a MMBT3904 for the MMBT2222 transistor raises the corner frequency of the low pass filter so that it doesn't distort the receive data signal.

The picture on the following page shows the modifications that I made to the DR3000 radio transceiver module. The annotations highlight the changes to the basic board and I've also identified all the module pin numbers to help you relate the photo back to the schematic. All of the added or changed parts on the module are 0603 size (.060" x .030").



Add SMA connector
Add 1k resistor
Value change 47k
RFM
TR1000
04170002
Value change 27k
DR3000 pin numbers in yellow.
Add 0 ohm
Value change 3300 pF

While the modifications to the base station and DR3000 module are fairly easy to illustrate in photos it's not quite that easy for the rest of the circuitry contained in the slave transceiver. The power supply and the RS-485 transceiver circuitry was built up freehand on a "surfboard" adapter board and a small piece of perforated board. The layout is not critical but care should be taken to keep the bypass capacitors close to the RS-485 transceiver.

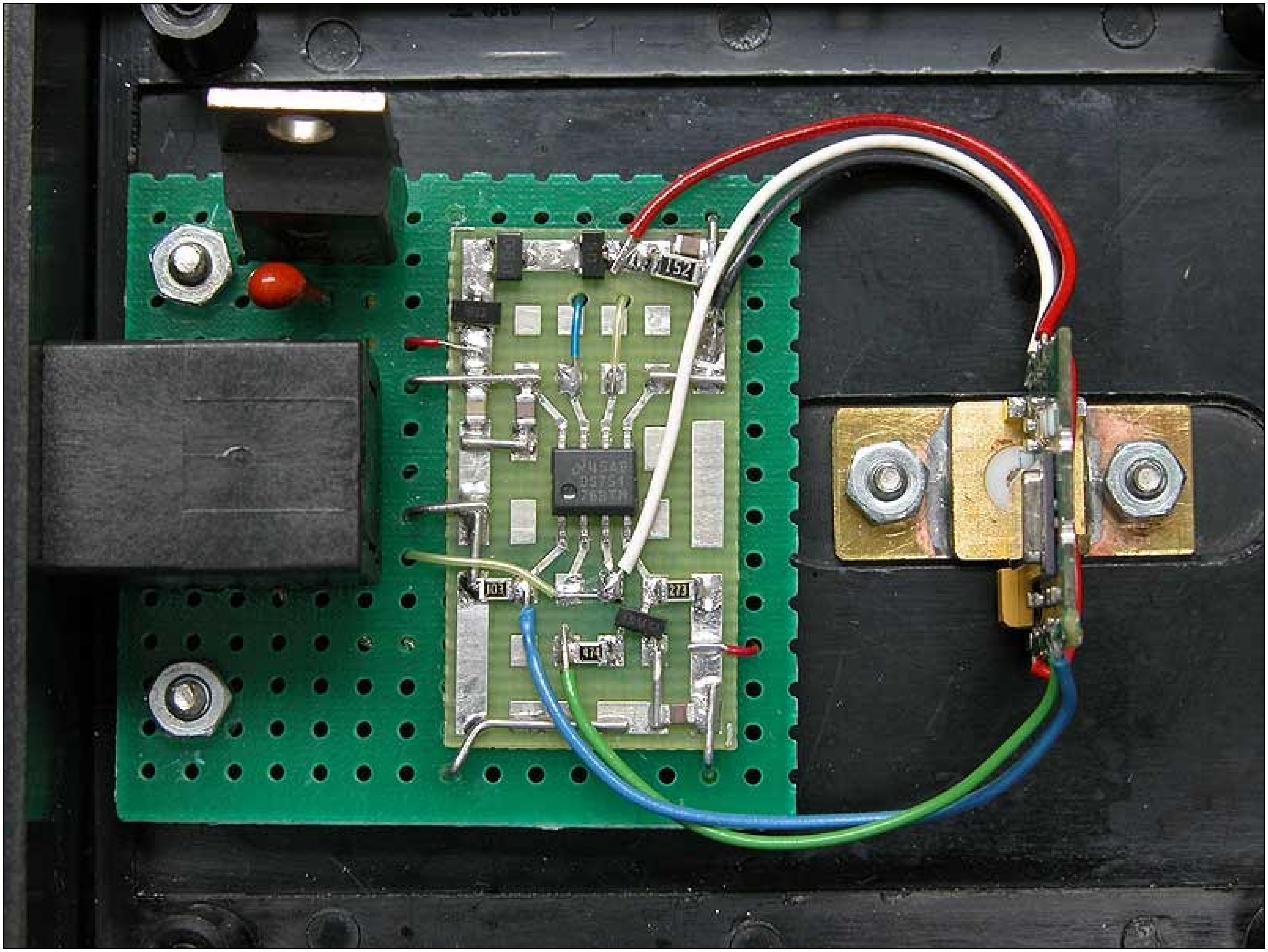
For reference the photos on the next couple of pages show how I constructed this circuitry, and also how I mounted everything in a small plastic enclosure that is roughly the same size as the NCE base station. I haven't tried to annotate the photos as the readers construction technique may likely vary. This is the part of the project that requires some decent assembly skills and the ability to read a schematic. One could also construct this part of the slave using the equivalent through hole versions of the parts at the cost of additional physical space.

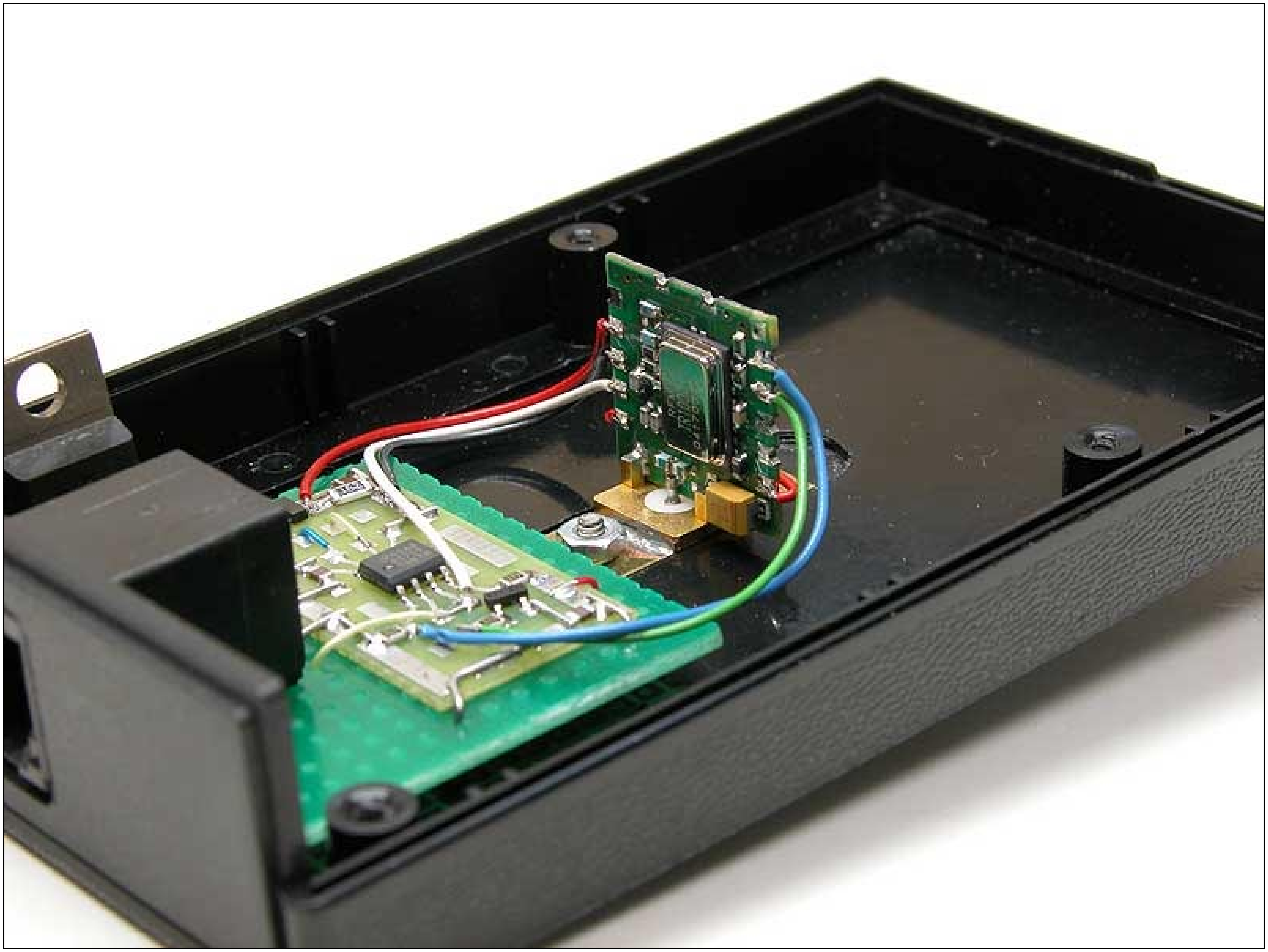
As I mentioned in the diversity receiver write up all of the circuitry components used in the slave also reside in the base station. It would be relatively simple to start with a spare base station and with a few cuts and jumps you could turn it into a slave transceiver. The five volt regulator is already on the base station, as is a simple transistor regulator to supply three volts to the TR1000. The RS-485 transceiver is also present but it connects the processor to the cab bus. These connections would have to be opened up, and the RS-485 transceiver would have to be connected over to the inputs and outputs of the TR1000.

Testing

I used an oscilloscope and verified that all the signals were at the correct levels and that signals were behaving as I thought they should. While a scope is really needed to diagnose problems it's not really needed to verify that everything is working.

Some very simple tests can be done to verify that the slave is working correctly. First connect the base station without the slave and verify the radio still works normally. Next plug in the slave and connect an antenna to it. Verify that the radio still works. Then remove the antennas from both the base station and the slave, move the cab a few feet away and the radio link should be down. Now only connect the antenna to the slave and verify that radio link comes back up. With only the slave antenna connected all of the data is being passed to the cab through the slave's radio transceiver. This step verifies the operation of the slave and the integrity of the connections between the base station and slave.





Performance

I was pleasantly surprised by the performance of the radio system when running with the slave transceiver. I was concerned that there might be problems with the cabs receiving both signals at the same time. As the base station and the slave are on slightly different frequencies the signals will be different RF phases when they arrive at the cab. This has the potential to create different signal strength levels at the cabs as the two signals may add, or may subtract depending on their phasing. As it turns out this is not a problem, probably due the simple carrier detection used in the TR1000 part.

When most readers think of the slave transceiver they probably think about the potential to extend the range of the radio system. By connecting the slave to a long cable the radio system range can be extended by the length of the cable. If you have a big layout you can strategically place the base station and slave in different locations to give you the best coverage. I made up a cable that was about 40 feet long and took the slave outside of my layout room. I then mapped out the extended coverage with the slave in place. Just to verify things I unplugged the slave and the extended range went away. It really works just as it should; you get two radio hotspots centered around the base station and the slave.

Since the data between the base station and the slave is running over a RS-485 link the cable between them should be able to go hundreds of feet. With long cables the limiting issue will probably be the direction control signal running on pin 6 of the cable. With long cables the pull up resistor on slave side of this line may need to be lowered and a small shunt capacitor may also be helpful. (The time constant of the pull up resistor and the shunt capacitor should be less than one microsecond to minimize effects to the switch timing.)

The slave can also be used to implement diversity across the radio link. Diversity simply means that there is more than one radio path. By providing multiple radio paths diversity can help eliminate the localized signal nulls that can occur with 900 MHz radio signals. For diversity to be effective the base station and the slave antennas should be separated by at least a radio wavelength, for the 916.5 MHz frequency this distance works out to be 13 inches or more.

As my layout room is only 9’ x 13’ I don’t have any range limitation issues but I still can place a cab in some orientations where the link light flickers off more than on. I originally built the diversity receiver to help with these null areas, but that only addressed one direction, from the cab to the base station. While that helped some it was less than I had hoped for as the radio needs good two way communication to work well.

With the slave providing diversity in the other direction the results are much better than I had expected. All of my signal null areas have gone away and the radio link behaves almost as well as being plugged into the bus. With the better link the display updates quickly and keystrokes always seem to be recognized the first time. It now works so well that I'm doing my decoder programming over the radio link. I really didn't expect all that much of a difference, but the diversity seems to have greatly improved the overall quality of the link. I can now walk around the room, hold the cab in any orientation, even behind me without a hint of a drop out. And those occasional "stuck on" whistles are a thing of the past.

Summary

While this isn't a project for everyone, the slave transceiver can improve the radio performance in a couple of ways. It can be used as a repeater to extend the overall range of the system, or it can be used to implement diversity. With diversity implemented the quality and performance of the radio link is greatly improved.

I hope this write up helps everyone to understand a bit more about my modifications to the radio. And if this is beyond your ability, don't worry, NCE is working on their repeater and it should be available before too long.