

Receiver Diversity for the NCE Radio system

By Mark Schutzer

Introduction:

This write up describes the modifications I made to my radio base station to allow it to operate with two different radio receivers at the same time. This multiple receiver technique is also known as receiver diversity and is commonly used to reduce the localized signal nulls that are common in the near microwave radio band where the NCE radio operates. Signal nulls in the 900 MHz frequency band tend to be very localized, that's why you usually only have to move the cab antenna a few inches one way or the other to get out of a weak signal null. Now imagine if you have two receivers that are spaced 12 inches apart or so, while one location may be in a signal null for one receiver, it is very likely that it will not be in a null for the other receiver. If you can pick the signal from the best receiver you can improve the cab to base station data path.

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. I had originally tried to keep this write up simple, but I found I couldn't adequately explain the subject without getting into all the technical details. 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:

Before I get in to the explanation of how the diversity receiver works I need to give you a little background on how the radio transceiver works in the NCE system. The radio system transmits and receives signals using a 916.5 MHz carrier operating in the unlicensed frequency band. Both the base station and the cabs share the same carrier frequency by alternating when they are transmitting and receiving.

The base station acts as the master controller by regularly transmitting data to the radio cabs. After each data burst is completed the base station switches into the receive mode and listens for a response from a radio cab. While I don't know all the details of the protocol it is probably a polling protocol where the base station asks each cab if they have anything to transmit. The base station will wait for a certain amount of time for a response from a cab and then proceed to transmit another data burst. The exact specifics of the data protocol don't really matter for this explanation, the point to understand is that the base station is continually alternating back and forth between transmit and receive modes. The cabs are also alternating following the lead of base station.

Because a single carrier frequency is utilized the same physical radio circuitry can be used in both the base station and the cabs. The NCE radio system is based on the use of a TR1000 low power transceiver part made by RF Monolithics¹. This part combines SAW filter technology with a novel use sequenced amplifiers to provide for a low cost and compact transceiver. See the footnotes links to more information on the TR1000 transceiver².

To minimize cost and complexity the TR1000 transceiver utilizes a form of very simple data transmission called on and off keying. When the transmit carrier is on a binary one is transmitted to the receiver, and when the transmit carrier is off the receiver interprets the data as a binary zero. When in the transmit mode the transmit data modulates³ the RF signal on and off to represent ones and zeros. On the receive side the receiver looks for the presence or absence of signal to decide whether to output a one or a zero.

¹ Datasheet available for the TR1000 at: <http://www.rfm.com/products/data/tr1000.pdf>

² Application notes available at: http://www.rfm.com/products/tr_des24.pdf

³ The data transmission rate to and from the cabs is 9600 bits/sec, but the data rate over the radio is actually 19,200 bits/sec due to Manchester encoding that is required by the simple receiver implementation.

The key point to understand is that presence of a RF signal at the receiver input represents a one, and lack of a RF signal represents a zero.

Now lets look at what this means under poor signal conditions such as those caused by obstructions or antenna nulls. Weak or poor signals will cause ones to be interpreted as zeros at the receiver causing bit errors. The transmission of zeros will not be affected by poor signal strength as the RF signal is off when a zero is transmitted.

Now on to the point of receiver diversity and how it helps. Diversity simply means that you have more than one receiver and antenna looking at the signal coming from the transmitter. As antenna signal nulls are very localized at 916 MHz, moving the antenna a few inches one way or another can make a big difference in the signal strength. Imagine now if you have two receive antennas that are spaced a foot or more apart, it is very unlikely that both receivers will suffer signal nulls at the same time. The theory is that one or the other will always be seeing a good signal.

The simple data modulation format makes it very easy to combine the output data from two different receivers. If the data from the base station receiver is a one OR if the data from diversity receiver is a one then the data output should be one. If the data from both receivers is zero then the output should be zero. A simple OR gate can be used to combine the two receive data streams.

In actual implementation the receive data is routed through an inverting buffer to enable it to drive the processor input. Since the signal combining must take place after the buffer, the logic sense will be inverted, and a NOR gate will be used. More on this later...

RF Monolithics also makes what they call a transceiver module that includes the TR1000 part and all the supporting components. They sell this part under the number DR3000⁴ and refer to it as a transceiver module, its single piece price is \$40 dollars. As I do this stuff for a living I was able to get a couple of samples from the local RFM representative. Here's a picture of the DR3000 module, you can immediately see the similarity between the module and the NCE circuitry.

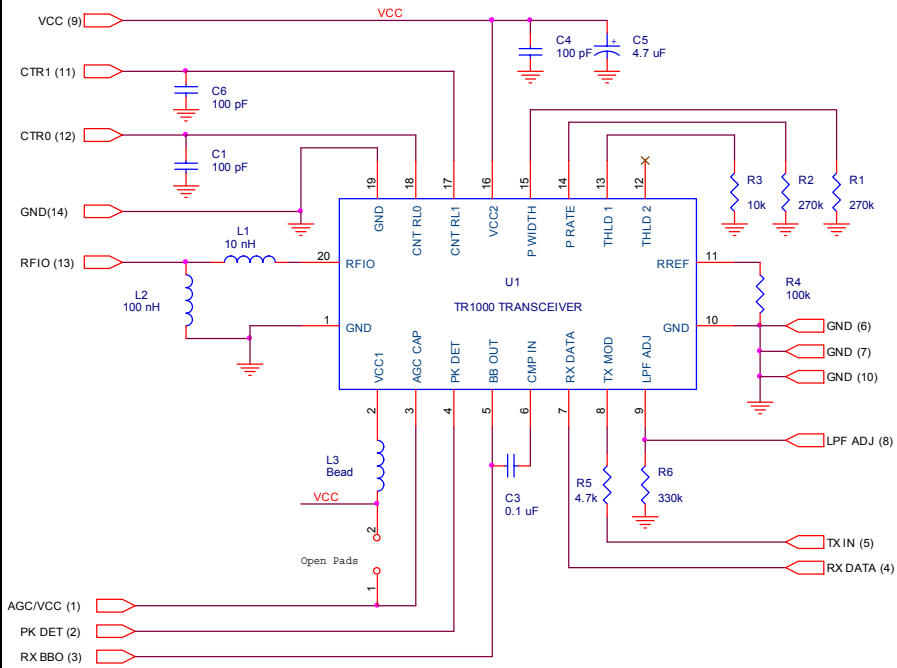


By changing a few chip components this module can be made to be the same as the NCE implementation.

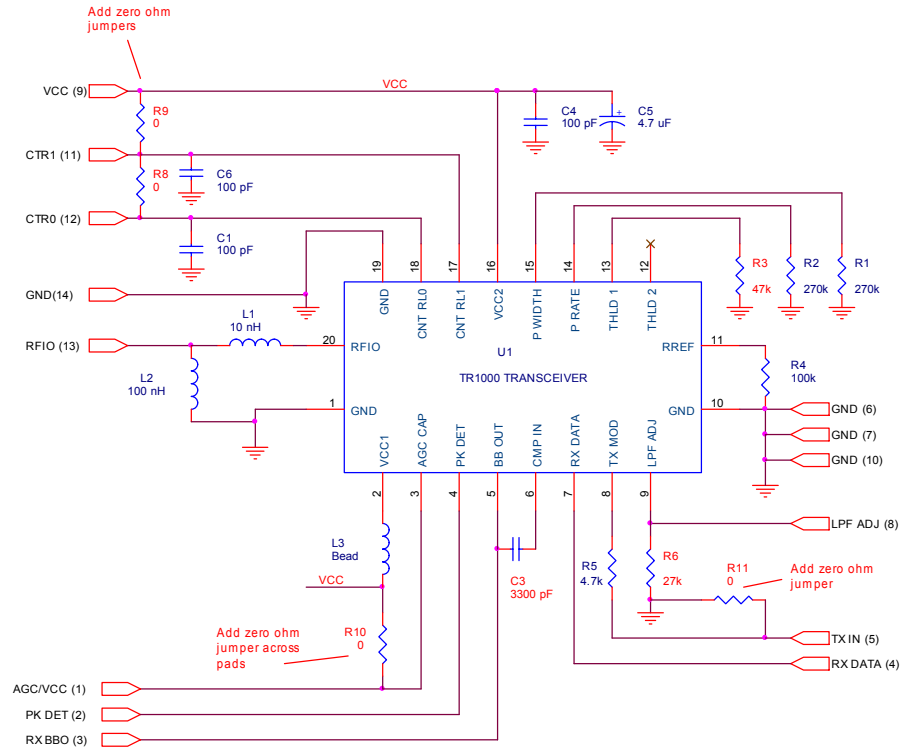
The following page shows a schematic of the original DR3000 module, and the changes required to make it a receiver that is compatible with the NCE configuration.

⁴ Datasheet for the DR3000 available at: <http://www.rfm.com/products/data/dr3000.pdf>

DR3000 Original



DR3000 Modified to match NCE configuration



Change the following:

C3 to 3300 pF

R3 to 47k

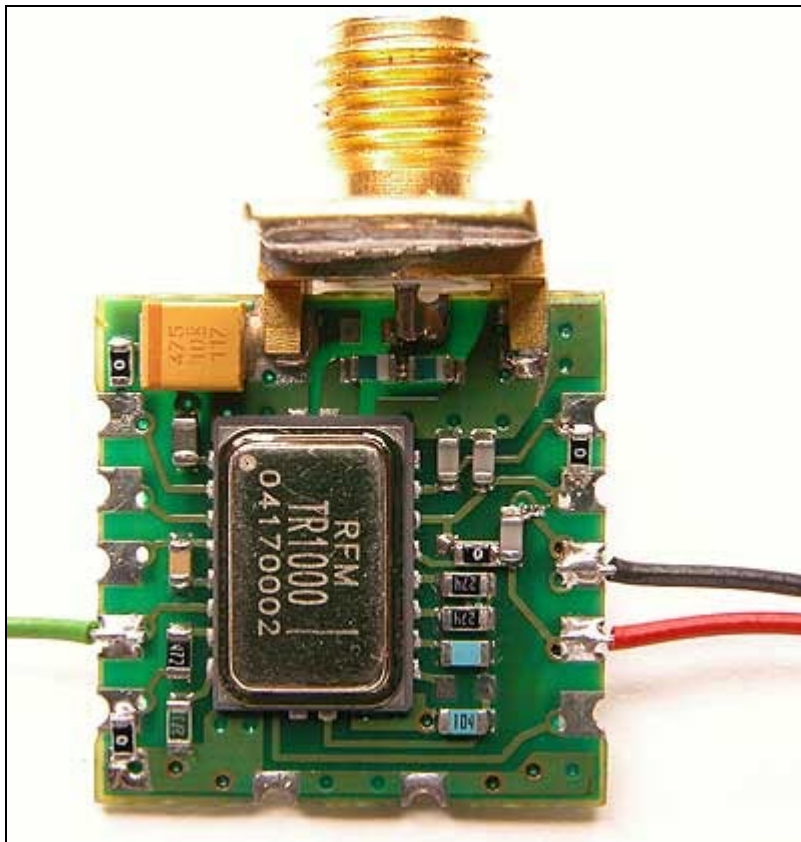
R6 to 27k

Add 0 ohm resistors, or wire jumpers as shown above.

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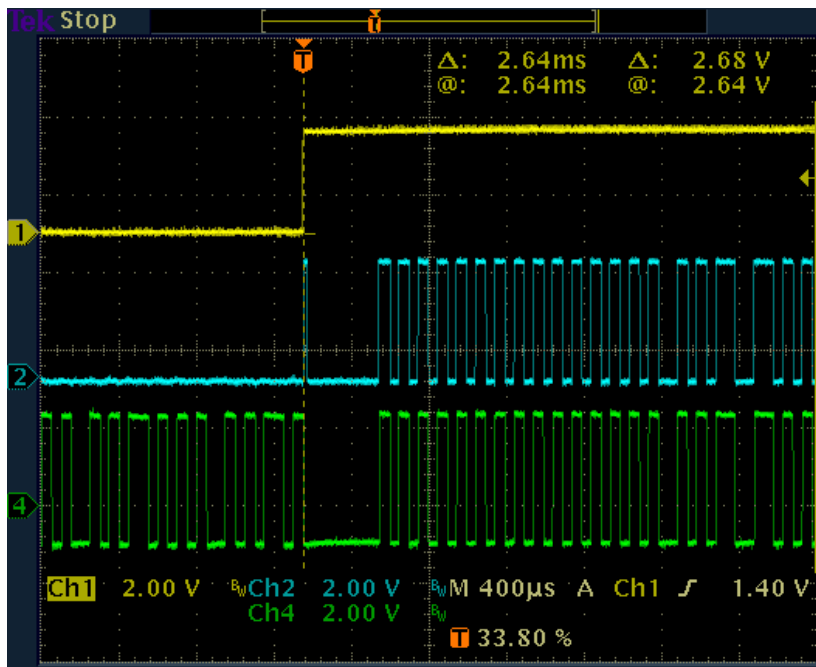
The right side of the schematic above shows all the required changes in red. The zero ohm resistors are additions and configure the module to work in receive only mode. Wire jumpers can also be used in place of the zero ohm resistors. All of these components are 0603 (.060" x .030") sized parts and can be obtained from Digikey Electronics.

Here is a photo of the modified DR3000 module:



A board launch female SMA connector has also been soldered to the board to serve as the antenna connection.

Before I talk about how to get the diversity receiver output combined with the base station I want to talk a bit more about what will be seen by the diversity receiver. This is much easier to explain with a picture, so here is the receive data output as seen on an oscilloscope.



Trace 1 is the transmit enable on the radio base station, when it is low the transmitter is enabled, when it is high the receiver is enabled.

Trace 2 is the receive data coming out of the receiver on the radio base station. The transitioning to the right of the trigger point shows a data burst coming in from a cab.

Trace 4 is the receive data output of the diversity receiver module. As the diversity receiver is always in receive mode it sees data bursts from both the base station and the cabs. The data transitions to the left of the trigger point (yellow vertical line) represent a data burst from the base station, the transitions to the right is the data burst from the cab.

Notice that both the base station receiver and the diversity receiver see the identical data burst from the cab.

The next question to ask is what about that extra data burst coming from the base station transmission. Well it turns out that you don't have to worry about it as the processor in the base station ignores the receive data line while it is in the transmit mode. I confirmed this by temporarily disconnecting the base station's receive data line, wiring the receive data line from the diversity receiver in its place. The performance of the radio link is unaffected by the extra base station data bursts.

Please reference the schematic and photos on the next pages when reading the following paragraphs.

Up to this point when I have been speaking of the receive data line I have been discussing this signal right at the output of the respective TR1000 part. This output is only capable of driving a very high impedance load ($500k \parallel 10pf$) and as such it must be buffered to provide a useable output.

A simple inverting transistor buffer is used in the base station to provide an interface to the processor (shown as Q2, R3, and R4 in the lower half of schematic). This same buffer needs to be added to the diversity receiver to both invert and buffer the signal (Q1, R1, and R2). Using the same buffer also assures that signal delays (which are significant due to the high impedances involved) are matched between the two buffer outputs.

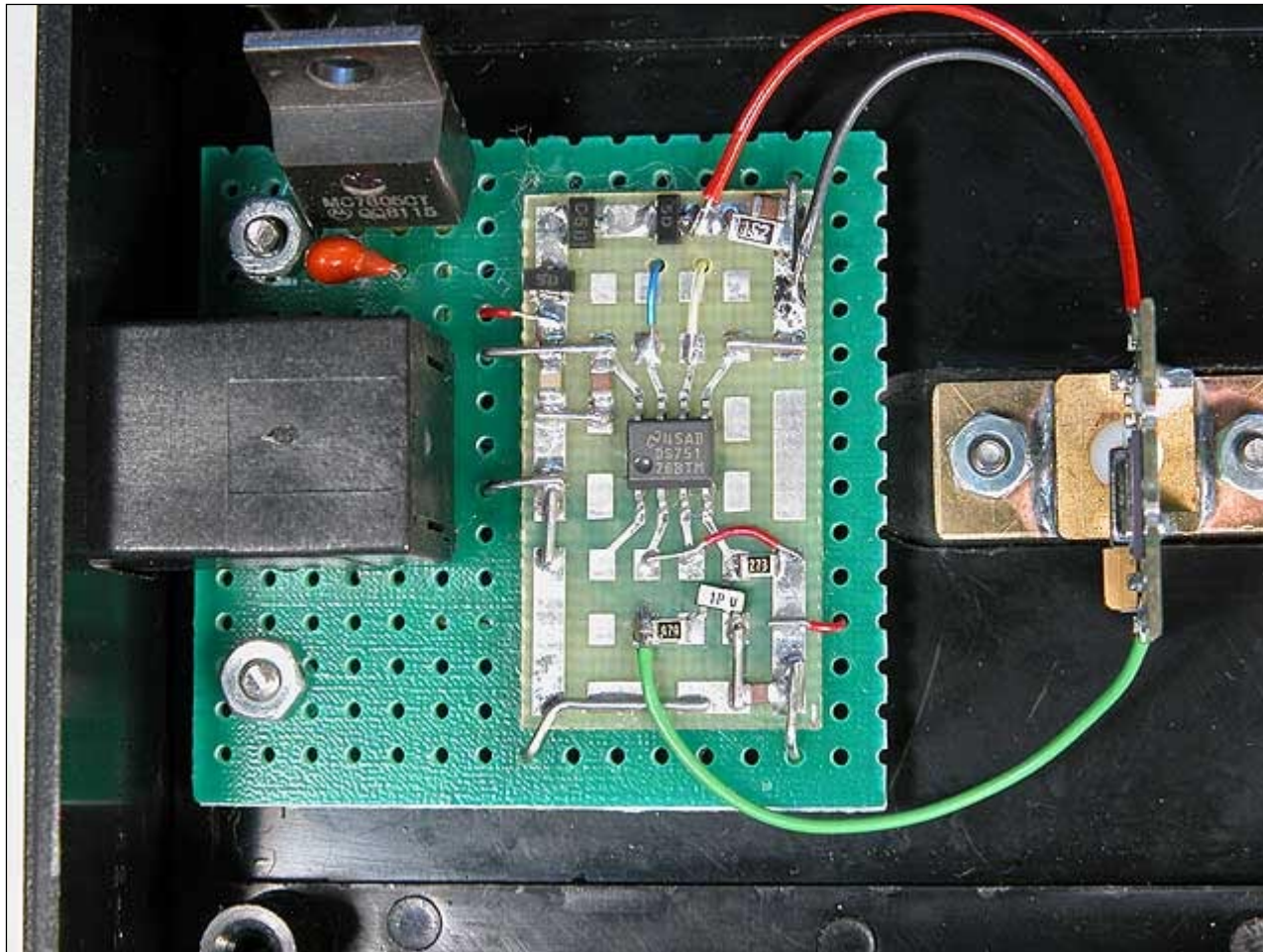
Now that the receive data signal is buffered it matches the signal in the base station, but it is still a signal that is located at the diversity receiver. While this signal is suitable to run a few inches on a printed circuit board its impedance and noise susceptibility preclude the running of a long wire over to the base station.

I used a pair of RS-485 transceiver chips (DS75176) to get the receive data signal back to the base station. The RS-485 part in the diversity receiver is configured to act as a driver, while the RS-485 part added in the base station is set up as a receiver. The RS-485 driver provides a low impedance differential signal that can successfully be run the distance between the diversity receiver and the base station⁵. These are in fact the same parts that the NCE system uses to send and receive its signals over the cab bus. The decision to use the RS-485 parts was easy as there are spare circuit board pads in the base station that are all ready laid out for the RS-485 transceiver parts. There are also spare pads where a RJ-12 jack can be added. More on this later.

The diversity receiver requires two different supply voltages, +5 volts for the RS-485 transceiver, and approximately +3 volts for the DR3000 radio module. The spare circuit board pads for the RJ-12 jack in base station connect +12 volts and ground to the jack just as they do for the cab bus. Taking advantage of this I used this +12 volt source to power the diversity receiver. A 7805 regulator and three dropping diodes provide the two voltage sources.

⁵ The roughly 50 nS of delay introduced by the driver and receiver is insignificant when compared to the bit time of 52 μ S.

On the diversity receiver side I just wired the circuitry up on a piece of perforated board and tacked the RS-485 transceiver on one of the little surf-board adapters. For the data connector I added a RJ-12 whose wiring matched that of the spare connector location on the base station. The connections are standard cab bus pin outs and the connecting cable is straight RJ-12 plug terminated cable, just as with the standard cab bus cables. See the photo below:



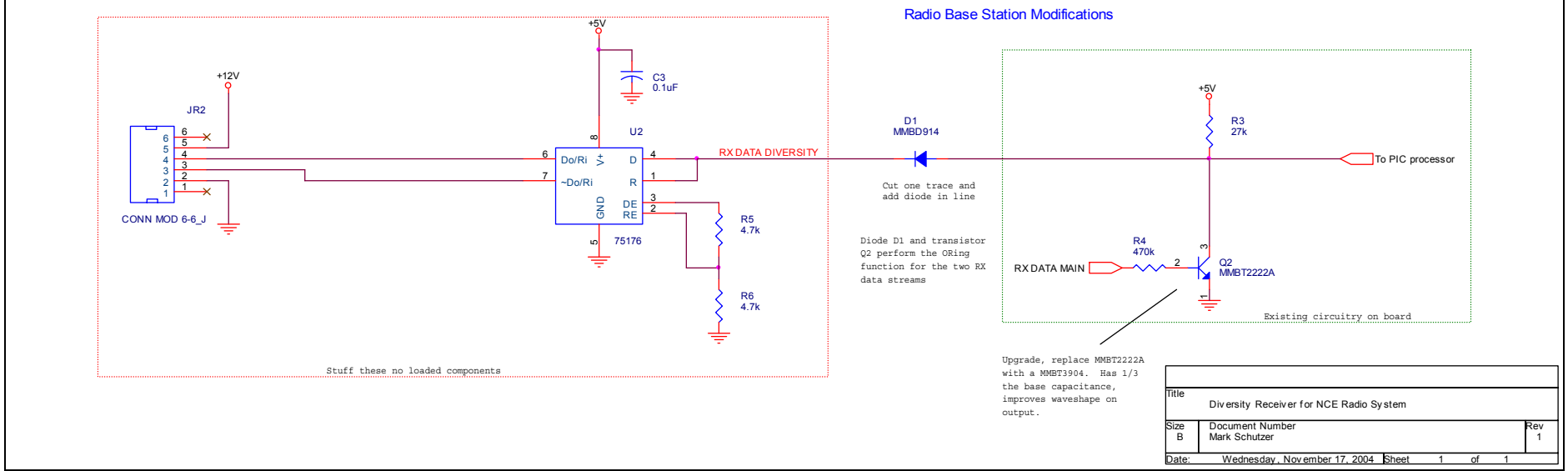
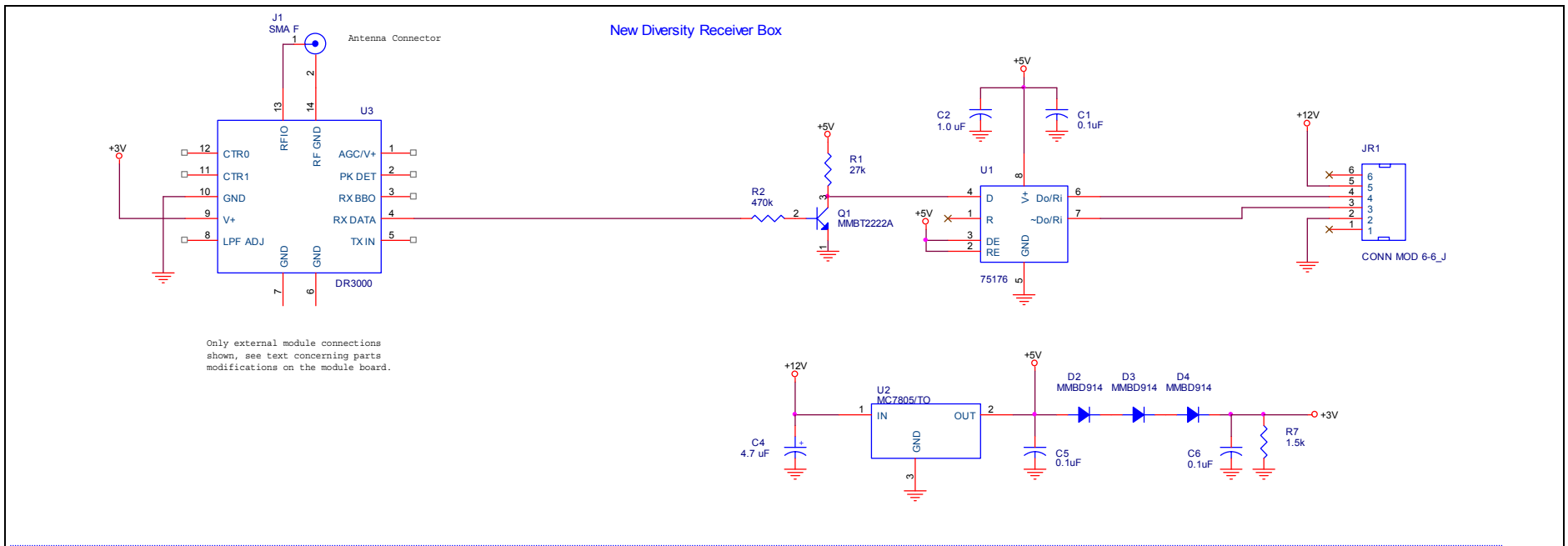
Completed diversity receiver.

DR3000 module shown on right side of photo (mounted on the SMA antenna connector).

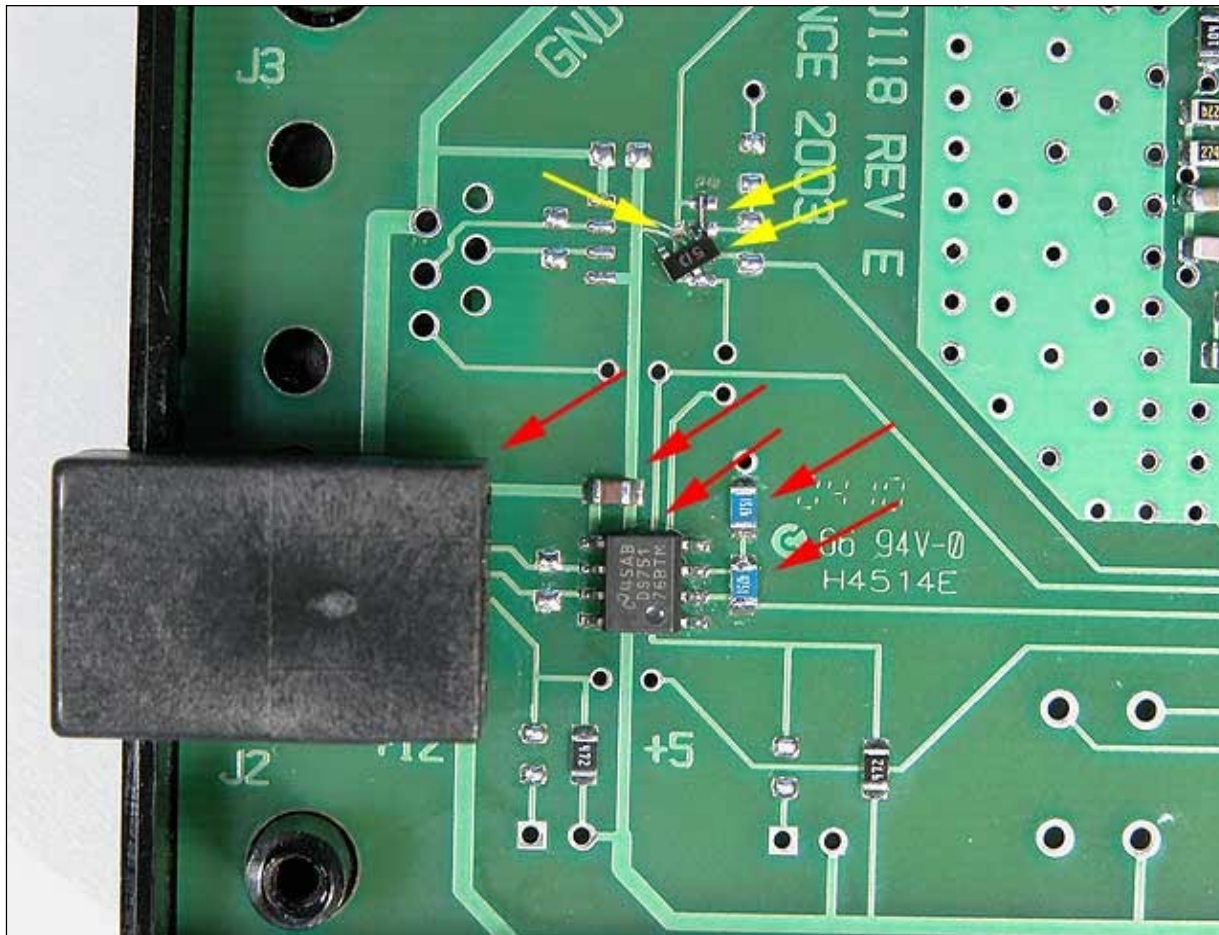
RS-485 driver, voltage regulator, and connector shown on the left.



Another view of completed diversity receiver in box



The base station modifications are shown on the bottom half of the schematic on the preceding page. The dashed red area on the left side shows the parts that need to be added to the board. These parts just need to be soldered in as the board is already laid out to accept them. The photo below shows the parts to be added to the base station.



The red arrows show the parts that need to be added on the pre-existing solder pads. The red arrows also correspond with the parts in the dashed red portion of the schematic.

The dashed green area of the schematic shows the receive data buffer that's already on the base station board.

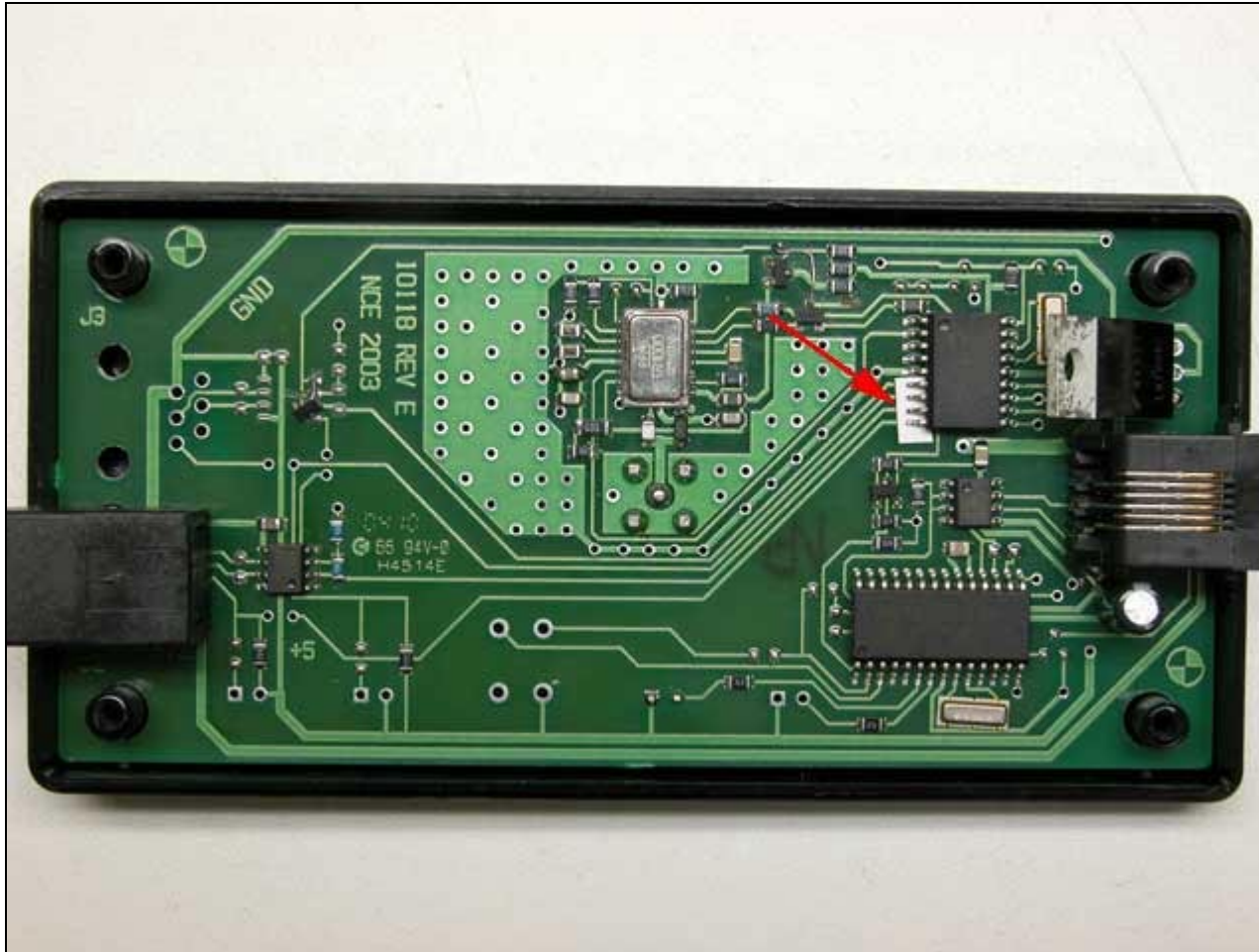
Diode D1 and the buffer transistor Q2 form a simple NOR logic function that combines the two receive data streams together.

This is where the logical ORing of the receive data takes place although its actual implementation uses a NOR function due to the inversion caused by the buffers.

The yellow arrows show D1 and the trace cut associated with it.

Since there are no specific pads for D1 (labeled 5D on part) I just tacked it to couple of spare IC pads that were available. The vertical trace that runs under the middle of D1 connects back to the collector lead of Q2.

There is one more modification of the base station that is also required. As the RS-485 solder pads on the board were clearly for future use, some of these pads and traces connect back to the processor on the board. These traces need to be isolated from the processor. The following photo shows four pins that I lifted on one of the processors. I placed a white piece of paper under the pins so that they would stand out for the photo. This photo also clearly shows how the four traces feed over to the area of the added RS-485 interface chip.



All that's left to do is to make a new hole in the case for extra RJ-12 jack. I milled the hole in the case, but you also create the hole with a bit filing.

The connection between the base station and the diversity receiver is a straight one to one cable, just like on the cab bus. In fact the signal assignments are the same as the standard cab bus. Another nice feature of the RS-485 receiver is that it goes to a fail safe condition when there is no input. What this means is that when the cable from the diversity receiver is unplugged the output of the RS-485 receiver in the base station will be high, and diode D1 will be reversed biased. In other words when you unplug the diversity receiver the base station ignores this input and functions just as always has, as a single stand alone receiver.

Other ideas:

I did not include a LED indicator on the diversity receiver as its use is somewhat limited. As the diversity receiver sees both the base station and cab transmissions the LED would always be blinking even if the cab was out of range. As there are far more polling transmissions from the base station the LED would see mostly these data bursts. Because of this I decided to skip the LED. If you want to add an LED the simplest way would be to add an additional transistor driver that is fed off the collector of the buffer transistor Q2.

While I built up the diversity receiver from a DR3000 module you could also start with a spare base station. All of the right radio transceiver components are already on the board, and by cutting one trace you can modify the transceiver to operate in receive only mode. The receive data buffer and one RS-485 transceiver is also already on the base station. You could easily cut the existing traces running to the cab bus RS-485 transceiver and jumper the data pin over to the output of the buffer.

I had another thought for an area of improvement in the antenna system. As the base station is normally mounted with the antenna in a vertical position the antenna radiates and receives signal that are vertically polarized. When you hold your cab with the antenna vertical the cab is also vertically polarized. If the cab is held with the antenna horizontal it's working with a horizontal polarization. If the two antennas are cross polarized, that is one vertical, and one horizontal the signal attenuation can be in excess of 20 dB. That's why the cab works better if the antenna is held vertical. Well I don't know about you but holding the cab with the antenna vertical isn't a natural position, I tend to hold the cab such that the antenna is about 30 degrees off of horizontal. In this position you only get half ($\text{SIN } 30^\circ$) the signal strength when compared to the vertical orientation. As everyone holds a cab differently and the antenna orientation changes the signal strength is affected.

Well there's a solution to this that's commonly used in RFID tags where the tag is at a random orientation with respect to the scanning transceiver. RFID tags use a circular polarized patch antenna that receives both vertical and horizontally polarized signals equally well.

It seems to me that a circular polarized patch antenna would be idea for this application also. The circular polarized antenna would go on the base station to make it insensitive to the orientation of the cab antenna.

There only one catch, while these patch antennas are common at 2.4 GHz I haven't yet been able to find a suitably cheap and small antenna that operates in the 902-928 MHz band where the NCE system resides.

Performance:

I guess I really should say something about the radio performance with the diversity receiver in the system. Well in terms of absolute distance covered by the radio the performance is about the same as it is without a diversity receiver. The diversity receiver improves the cab to base station data path but does nothing for the base station to cab data path. The cabs still must see the data poll from the base station before they respond, when they don't see the poll due to distance, they don't respond back.

As my layout room is small (14' x 19') the radio system works just fine without the diversity receiver. With the diversity receiver the nulls tend to be fewer and the radio seems to work better when you place your body between the cab and the receiver. At some point I would like to take this setup to a bigger club layout where the performance change can be better determined.

Closing:

Well I guess that brings me to the end; I wasn't really planning on writing this much it sort of just started growing and growing. While these modifications are definitely not for everyone I hope that this write up has brought you some insight into the radio hardware used in NCE system. On the next page I've included one final photo showing the diversity receiver in operation.



Diversity Receiver in operation on the layout