Universal protection and remote control circuit for solid state amplifiers

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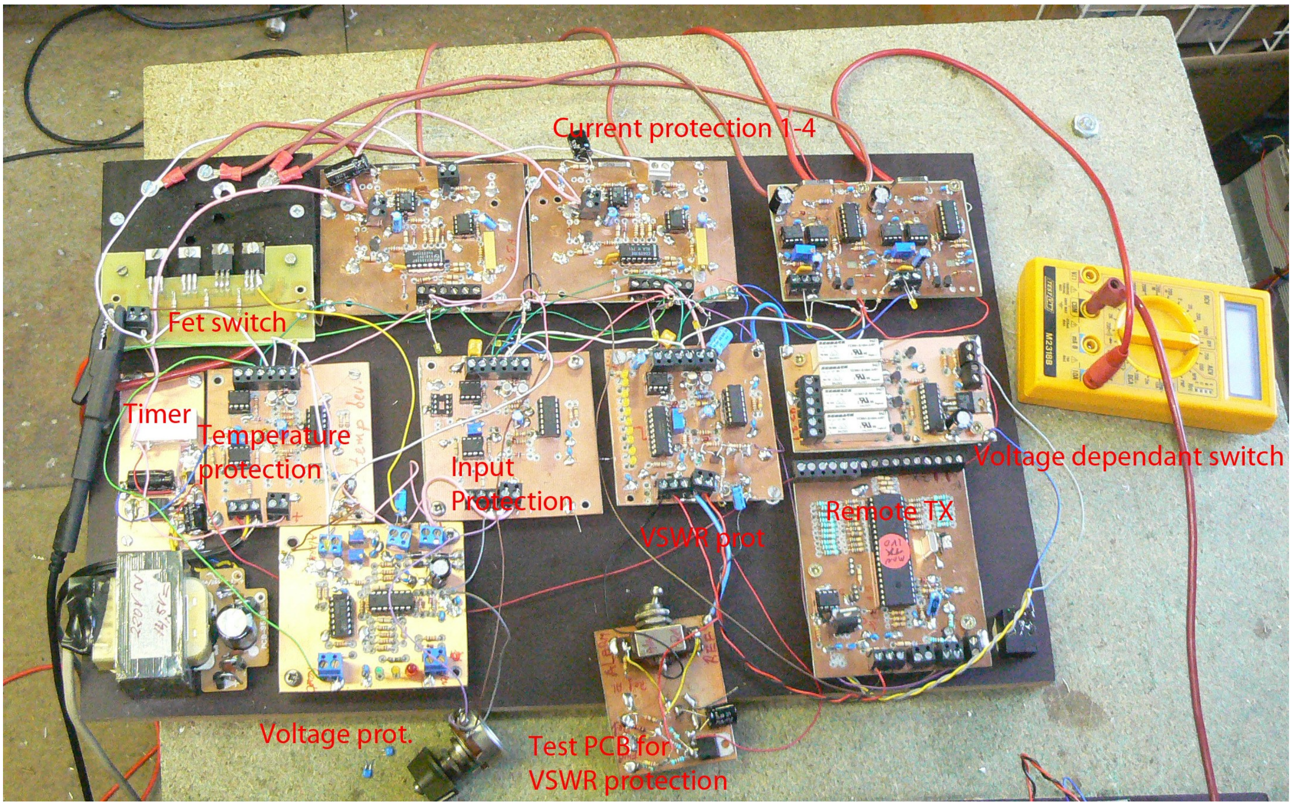
1. Introduction

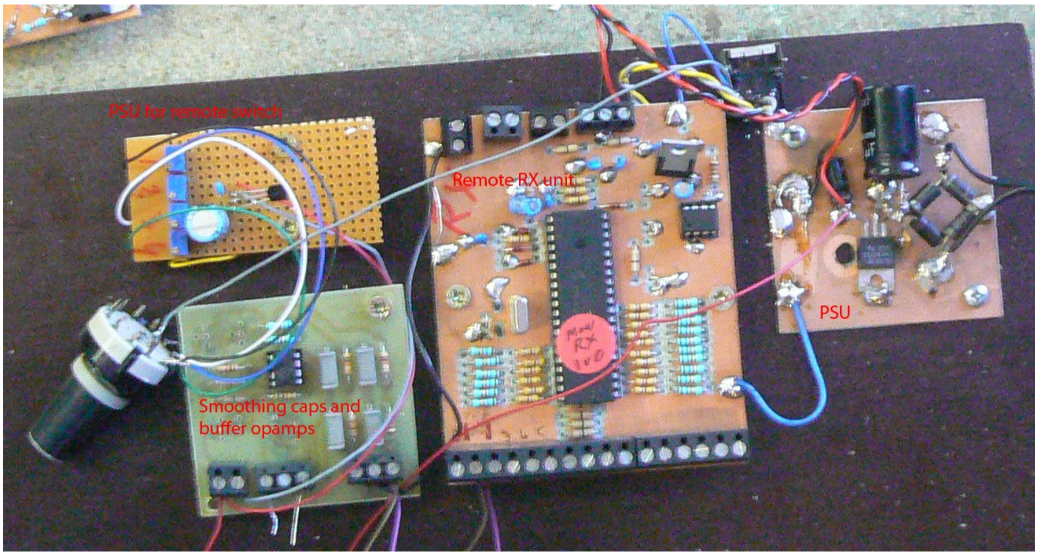
Over the last few years solid state amplifiers have become more and more common in amateur radio use. Especially in SHF applications, were the generated power is moderate, the solid state amp becomes very attractive for amateurs. The availability of “surplus” amplifiers in the 200W region made EME on 13cms very interesting and popular for us. Many stations use the same solid state amplifiers. The “DB-hungry” among us use 2 (or 4) of them in parallel.
Although with the introduction of the ldmos fet, these semiconductors became more and more resistant to mistakes and system faults. The price to replace these fets is still much higher than an “ordinary” tube. This increases the need for a good protection circuitry.
Another good thing for solid state amplifiers is that these can be mounted at the feed point of your dish, in this way eliminating feeder losses. The feeder losses increase rapidly with an increasing frequency. Maybe the protection circuit could also help in monitoring the remotely mounted amplifier. But how to monitor such an remote amplifier? It requires a lot of cables going back to the shack. And.....how to switch this amplifier on?
What protections are needed? Current protection for every stage separately! How many stages? The circuit presented here goes up to 4 stages but is easily extended to 8 or even more stages. Of course VSWR protection and overdrive protection. What about voltage protection? Some of our switch mode power supplies seem to be rather unreliable. Also a temperature protection is included.
All these problems are hopefully solved with the circuits here presented.



1: Prototype testing of the SSPA protection at PA3CSG

2. Design considerations

It has to be a universal circuit! It should be suitable for (almost) any solid state amplifier using about any supply voltage. Also the used components should be easy to obtain.
It should also be possible to tailor the protection circuit to your needs. If you never have to worry about over driving your amplifiers because you don't have enough drive, you should not be forced to build an overdrive protection. If you only need 3 stages current protection, you should only build 3 stages! If your power supply is rock solid and there is absolutely no need to worry about the supply voltage going crazy, you should not be forced to build the voltage protection part.
If you don't need the remote monitoring thing, well there should be no need to build it. For this reason this is on a separate board. On the other hand what you don't need now, you might need later!
The alignment of the protection circuits should be easy to do. Nothing more than a digital voltmeter should be necessary to align. Because of this, the choice has been made for certain “absolute” reading sensors.
It should act very fast! For this reason, protection circuits should quickly switch off. A normal “mechanical” relay is far to slow so fets have to be used to switch off the supply of the amps. This involves a very high current switch of more than 50 amps. After the supply is cut off a coax relay should switch off the drive power. The coax relay uses the same supply voltage as the amplifiers and will switch the drive power to an appropriate dummy load preventing the amplifiers to be driven while the supply voltage is off.
The diminishing size of components and the loss of eyesight due to the increasing age is rather logarithmic than linear so the choice has been made to use normal “wired” components. Only the MAX4080 is an SMD type IC.

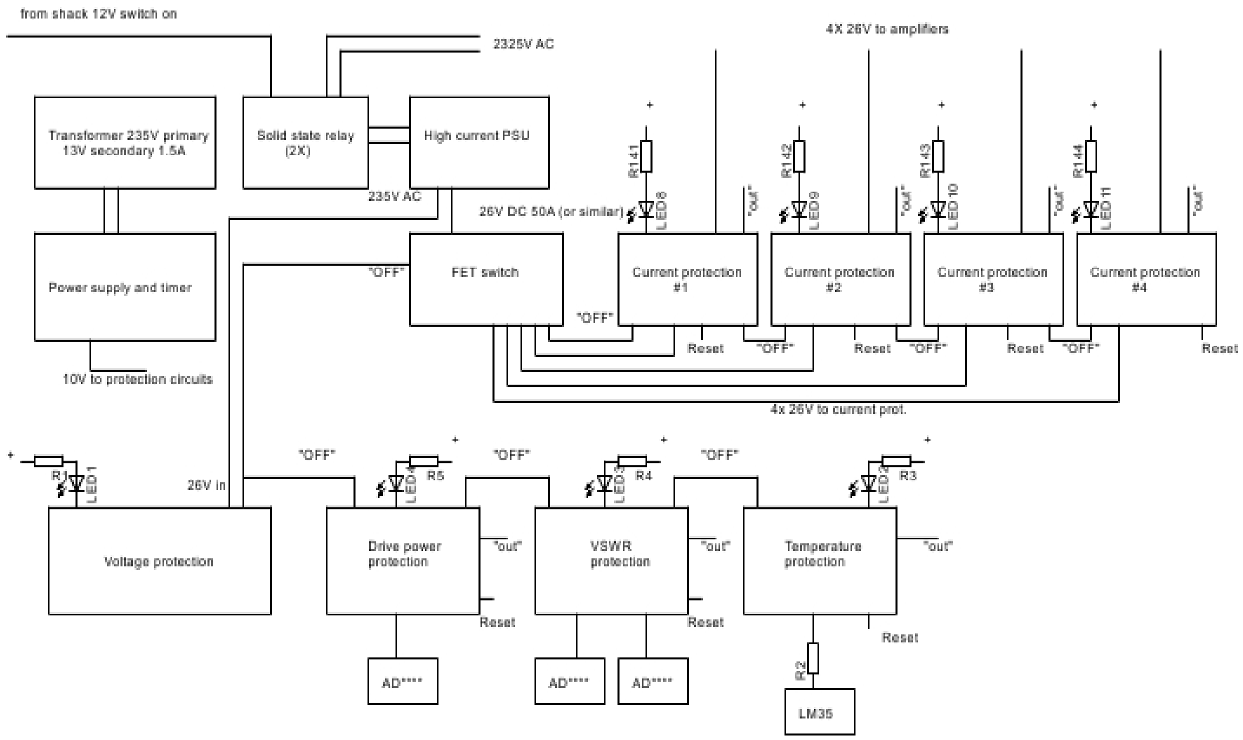


2: The remote receiver

3. The block diagram

Below is the block diagram of the SSPA protection circuit. Not in the schematic is the coax relay which switches the RF input to an dummy load. It is connected to the output of the fet switch and is normally activated. When the voltage of the amplifier is removed (in case of an alarm) the coax relay will switch its drive to a load. Each stage has 2 open collector switches. One can be used to switch a led (or the remote TX) the other to switch off the PSU of the SSPA. All “OFF” circuits can be connected, also all “RESET” ports can be connected together. One “RESET” connection has to go to a push-button switch which grounds the reset line in order to reset the alarm circuitry. If this RESET button should be in the shack or outside with the amp is your own choice. A nice walk to the tower could help you realize what went wrong.

A 12V signal is used to switch the high current PSU on. It should be clear how the system is hooked up.



3: The block diagram

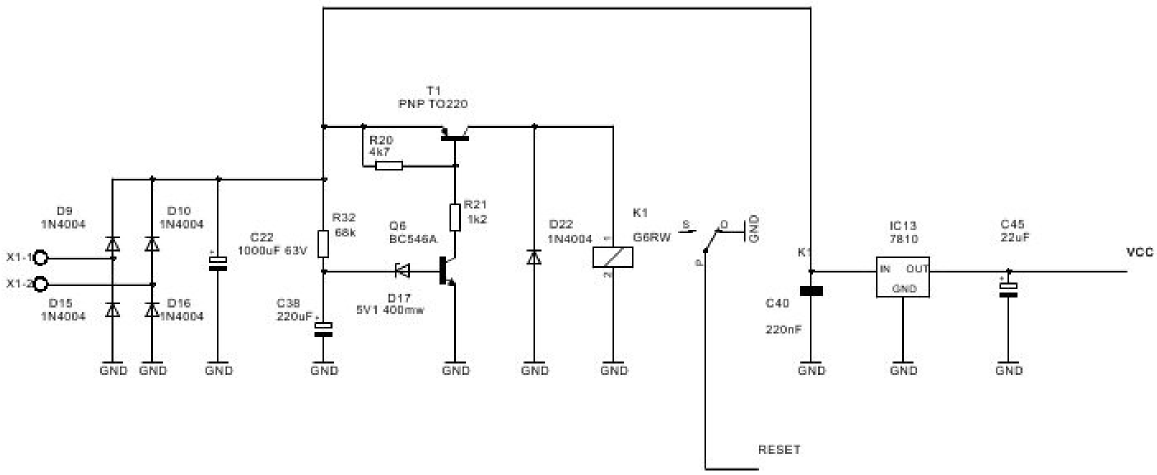
4. The power supply and the delay circuit

This fairly simple circuit consists out of a normal full wave rectifier and a small timer circuit. The timer circuit is only there because the modern switch mode power supplies need some time to get going. It switches the RESET line to ground when powering up. Otherwise the voltage protection would already set off an alarm.

In case your SMPS is slower (or quicker) than mine. You might want to change the values C38 and R32 to suit it for your needs.

Testing

This should be fairly simple to test. After switching on the mains it will take 2-3 seconds to hear the relay “click” .



4: Timer and PSU

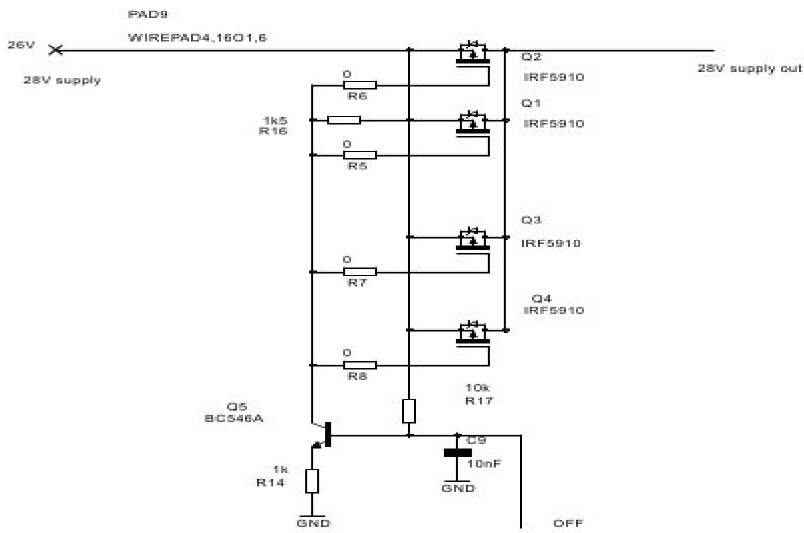
5. The fet switch

The fet switch serves as a high speed “off” switch. It has been tested at 26V and 55A. Because of the low Rds it doesn't get hot. The fets do need an extra cooling plate or can be mounted on the chassis of the amplifier.

The 26V via R17 makes the base of Q5 conduct. This pulls the gates of the 4 IRF5910 to ground so the drain source will conduct and the amplifier(s) will get their supply voltage.

In case of an alarm the base of Q5 will be grounded through the open collector circuit of the alarm circuit. The fet switches off.

On the PCB board the tracks carrying the high current have to be made suitable for the high current by soldering a thick copper wire on these tracks. Otherwise the heat dissipated by the PCB is too high. Two 2mm thick wires (or a copper braid) soldered on the track could carry the current and prevent damage to the PCB. The heat sink for the fets can serve as a distributor for “outgoing”current. Just tap a 4mm hole in the heat sink for each current protection stage to be used after the fet switch.



5: The fet switch

Testing

After building the fet-switch you can supply any high current power supply to the source of the fets. The output should be available at the drain. By grounding the “OFF” the output voltage drops to 0V

6. The current protection

MAX4080 and LM393

The heart of the current protection is the MAX4080. This IC is especially designed to sense current. It comes basically in three versions. These only differ in gain. The choice here has been made to use the MAX4080T version which has a gain of 20. This IC can handle up to 76V input voltage and therefore is extremely suitable for measuring current for solid state amps. Amps operating at 50V can be used with this IC. This is the only SMD IC used. It has to be mounted on the bottom side of the PCB.

The current is measured across a 10 milli Ohm resistor. The low value of this resistor will result in a low voltage drop. The measured voltage is amplified 20 times, so for each ampere the IC is providing an output of 200mV. For other applications different types of the MAX4080 maybe used. The “F” version has a gain of 5 and the “S” version has a gain of 60. The data sheet gives plenty of examples how to use the different models in combination with other values of shunt resistors. These should be exchangeable but this has never been tested by me.

So the 200mV/A output of the MAX4080F fed to a comparator, one half of a LM393. This (standard) op amp compares the output of the MAX4080 with a pre set voltage on pin 3 of this IC. If the output of the MAX4080 goes above the pre set voltage pin 4 will go low. In SSB operation this should act fairly quick and even in a peak, the amplifier should be shut down. This requires a set – reset flip-flop. The following circuit is used in all protection circuits but is only described in detail here.

The NAND set-reset flip-flop and the LM358 buffer.

NAND gates can be used as a set – reset flip-flop. The two inputs of the gates are “cross coupled” with the outputs. The remaining inputs are kept high via a 10 K resistor. These remaining inputs form the set and reset inputs of the flip-flop. If you want to figure out yourself how it works the truth table for a NAND gate is below:

Input A	Input B	
1	1	0
0	0	1
1	0	1
0	1	1

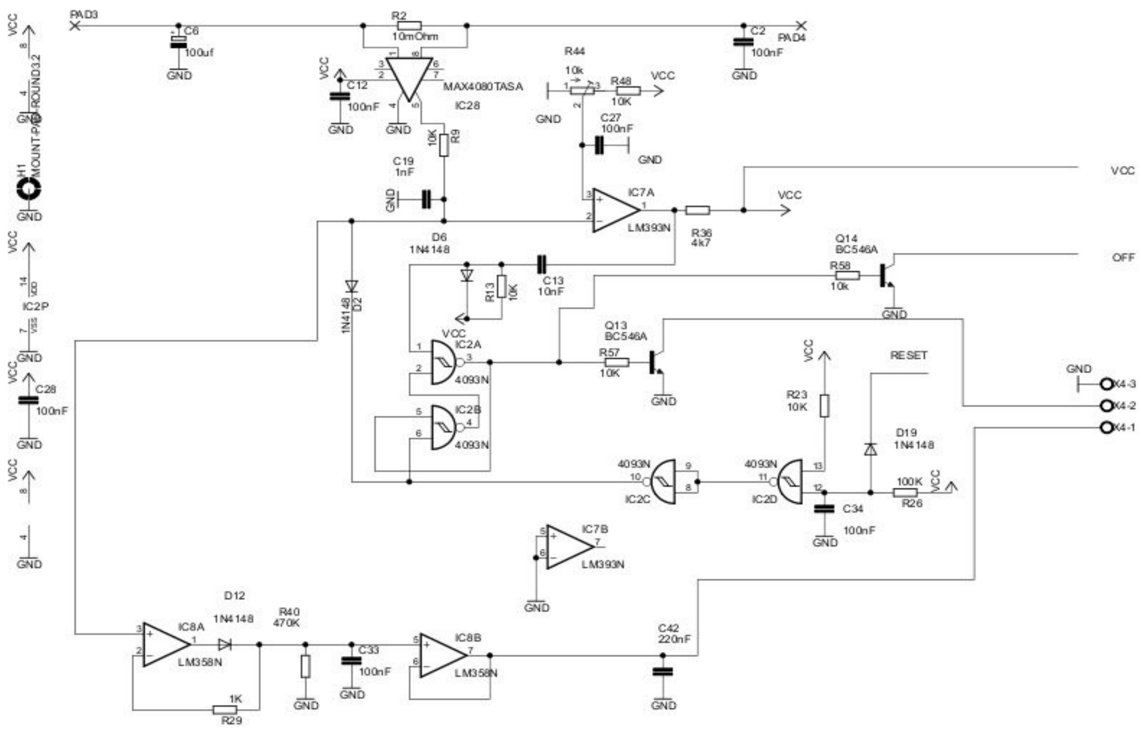
Table 1: Truth table of a NAND gate

The described situation is stable as both outputs of the CD4093 keep the inputs at the desired level. If (in case of an alarm) pin 1 of the HEF4093 is pulled low by op amp (set) IC7A the situation will change. Pin 3 of the 4093 will go high and Q13 and 14 will be conducting. So the alarm will hold itself because of the set function. It will only change to on by pulling pin 12, IC2D, to ground (reset).

The transistor Q13 can be used to switch on a small led so you will see which of the stages has gone into alarm. Q14 is used to pull Q5 in the fet-switch circuit low as a result of that the voltage supply of the complete amplifier is shut off.

The output of the MAX4080 is supplied to pin 3 of IC8A, a LM358, this provides a simple x 1 amplifier to buffer the output of the MAX4080. As the LM358 has 2 opamps, the same process is repeated with IC8b. Therefore the connector X-4-1 can serve as a current measurement point. 2V output represents a current of 10 amps.

6: Current protection



Testing

Place all components on the board but do not put the IC's in their sockets. Apply 10V to the circuit and check current. Almost no current should flow. Verify the Vcc on the pin 14 of the HEF4093. Do this also for pins 8 of the LM393 and LM358. Switch off supply voltage.

Plug the HEF4093 in its socket. Connect a led to X-4-2 in combination with an appropriate resistor to the VCC and re-apply power. The led should not light. With a small piece of wire ground pin 1 of the HEF4093 the led should light and stay on. Grounding the reset via diode D19 should turn the led “off”. This verifies the working of the set reset flip-flop.

Next is to set the trip level of the protection circuit. If your amplifier will draw 10 A than set R44 is such a way that there is a voltage of 2V on pin 3 of IC7A. Use a digital voltmeter to do this. For other currents please change the voltage on pin 3.

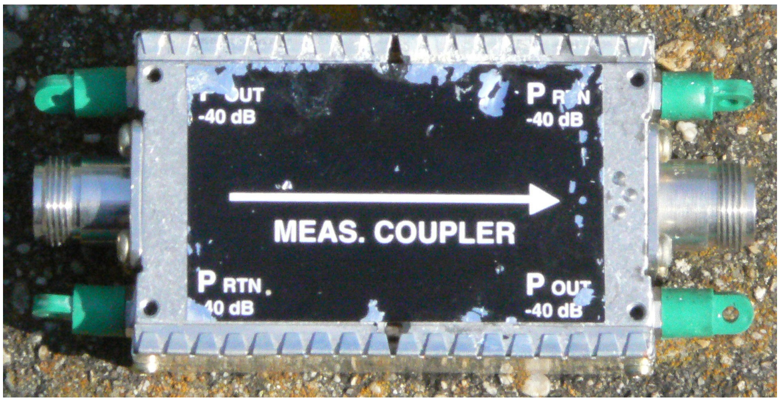
Now we are ready to “smoke-test” your protection circuit. You need a high current power supply for this and a loading resistor or some different kind of load. W1GHZ describes a load circuit on his web page. In schools you can also find high current variable resistors to test your circuit. These resistors are “idiot-proof”. (2 times 7 amp resistors took the full load, 26V 55A. I must admit they did smell a bit after the test.) Connect the PSU to PAD3 and the load resistor to PAD4 and ground. Make sure that the ground of the high current PSU is also connected to the ground of the board. Measure current and change the load of you circuit. When the current comes above the set threshold the alarm led should light. Reset the circuit and test again but only load it to halve of the threshold level. In this example this should be 5V. Verify that there is 2,5V on the X-4-1 connector. This verifies the working of the buffer op amp IC8. Please note that the component numbers given here apply to the circuit here above. The board contains 4 current protection circuits and thus numbers will vary. But all 4 protection circuits are exactly the same.

7. The overdrive protection

The overdrive (and VSWR) protection rely on absolute power sensors build around the Analog Devices log converters using the AD8307 and the AD8313 or any other device giving a certain voltage per dB. A search on the web gives you plenty of information. In this case I used the detectors described by DL2MAJ published in the papers of the Weinheim 2002 meeting. This one uses the AD8313 and gives an output of 40mV/dB. In combination with an appropriate coupler we can measure any input or output power. The German AATIS sells printed circuit boards for this

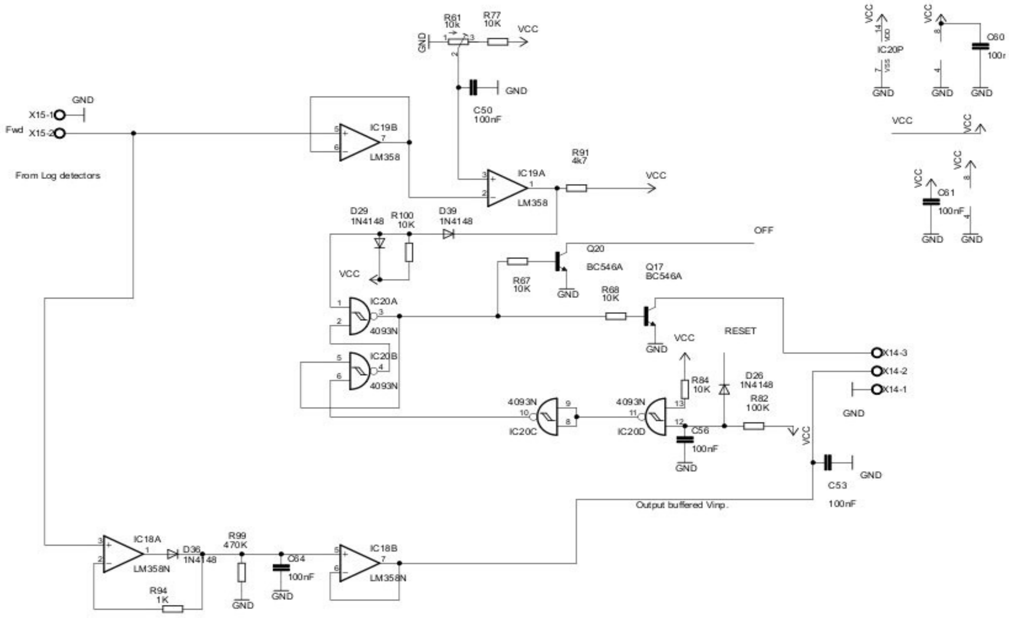
A 0 dbm level produces around 3.6V output in the detector. So choose your coupler in such way that on full output the level doesn't go above the 0 dBm output. This should give you a safety margin. Some nice coupler to work with is the Ericsson coupler as pictured below. It has a high coupling on the lower frequencies, is equipped with 2 forward and 2 reflected ports. It has a very high directivity which makes it suitable for VSWR measurements. And it's coupling can be adapted to ones need.

The rest of the circuit is very easy. The input coming from the log detector goes to a buffer amplifier IC19B. The other half of the op amp is used as a comparator. In case, the input voltage on pin 2 of the op amp goes higher than the reference level set with R61 on pin 3, the output pin 1 should go low and triggers the flip-flop build around IC20. A buffer amp for the output of the log detector is available in IC18. But this is all the same as described in the "current protection" section.



7: Ericsson coupler

8: Overdrive protection



8. The VSWR protection

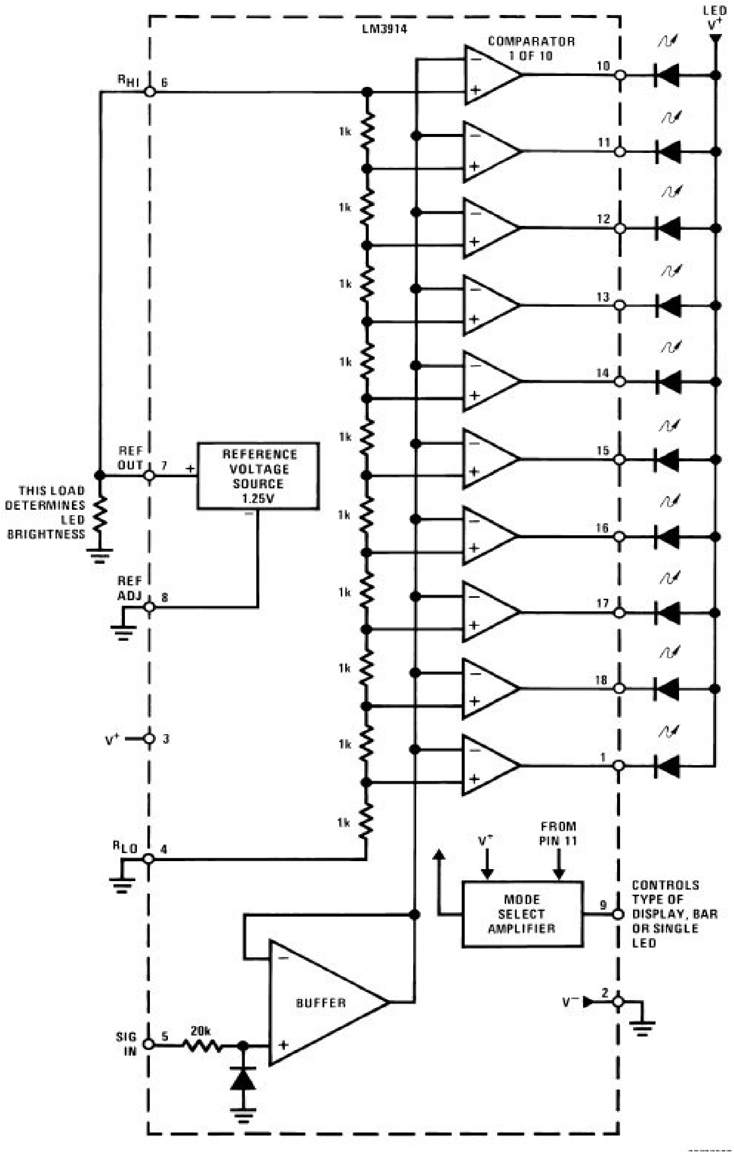
I stumbled over this circuit when I was surfing the web for VSWR protection. It is a rather clever idea to use this chip for an SWR protection. The LM3914 is a digital voltmeter with some “specials” build in. The original version uses diodes for detection but as these have no “absolute” power readout I used my favourite AD8313 again.

Now suppose we want our alarm to set off at a SWR level of 1 : 2 or worse. Our forward detector, in combination with the directional coupler, “sees” a forward power of -10 dBm. This would represent a voltage of roughly 2V. The reflected detector would see 1.6V because a SWR of 1 : 2 means that the reflected power is 10 dB less than the forward power and the AD8313 is set in such way that it produces 40mV/dB. So 10dB less means 400mV less thus 1.6V.

If the SWR gets worse the difference would be smaller as more power gets reflected. By feeding both levels, forward and reflected, to the LM3914 the op amp will subtract them. The block diagram is taken from the data sheet.

The voltage reference source on pin 7 is not needed, that is why it is grounded via a 1K resistor. The data sheet block diagram shows a number of operational amplifiers in a row. The voltage on the input is divided over a network of 1K resistors in series. The bottom one is grounded via pin 4 in the block diagram. By applying a voltage on pin 4 one can set the voltage which is across each 1K resistor. In this way we can set the sensitivity. By adjusting the voltage on pin 4 we can set the sensitivity when the leds will light. Now we know that 1 dB produces a difference of 40mV thus 2 dB will produce 80mV. By building a simple voltage divider which will produce the forward voltage and 2 reflected voltages one can adjust this circuit without endangering precious solid state amplifiers. The circuit here produces a forward voltage of 2.227V, a reflected voltage (no alarm) of 1.822 and the alarm voltage of 1,8848.

The leds on the output are not necessary as one could measure the respective pins going low on the LM3914 but it makes it a bit easier and it produces a nice light show.



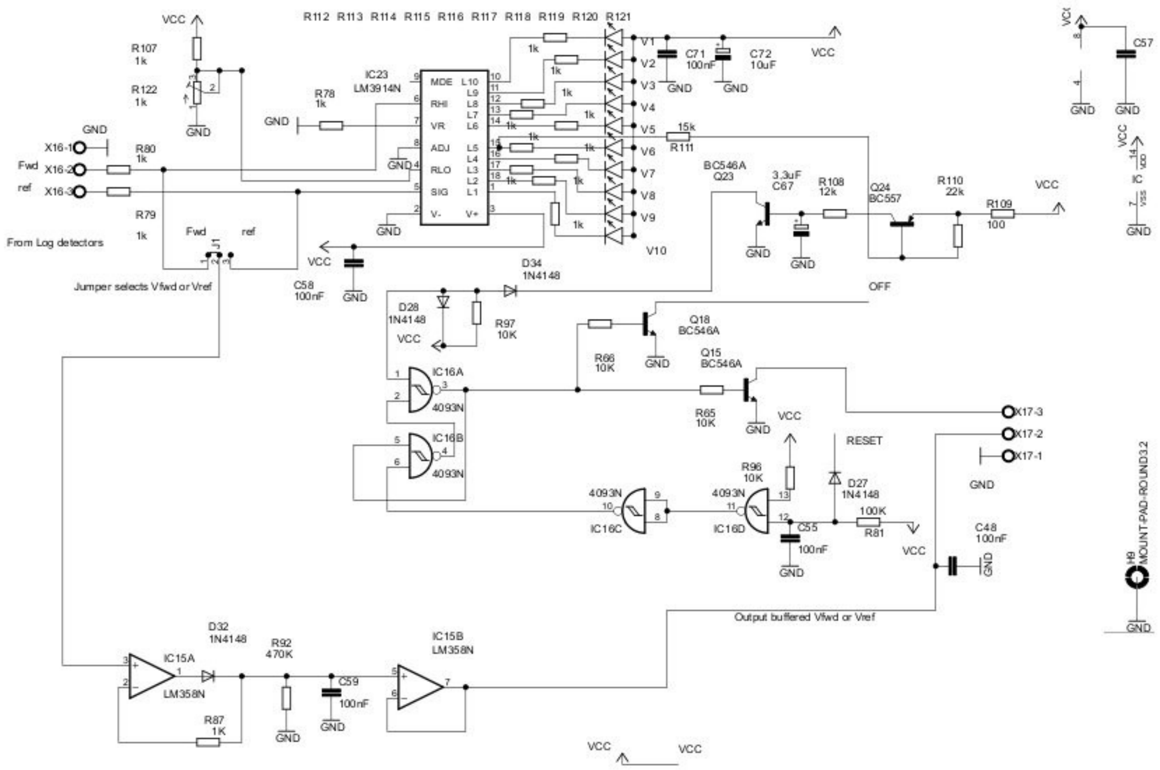
9: Internals of the LM3914

There is another interesting pin available on the chip. Pin 9, if left open it will light a single led. If connected to VCC it will make the LM3914 use bar mode. It might be safer to operate in “bar” mode but so far this not like this on the PCB board. One could easily do so by connecting a small wire between pin 3 and 9.

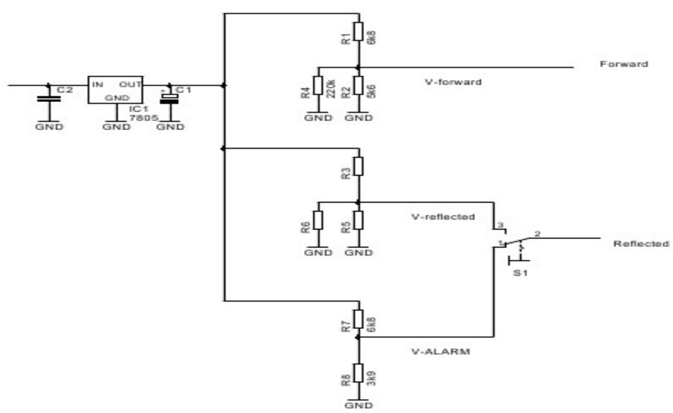
Q23 and Q24 form a high impedance switch for the LM3914. The chips outputs didn't like to be loaded so we had to go this way. Grounding the base of Q24 will make Q24 conduct and the collector of Q23 go low, thus triggering the flip-flop.

The rest of the circuit is again the same as in the current protection.

10: VSWR protection circuit



11: Test circuit for the VSWR protection



9. The voltage protection

The voltage protection is a set of operational amplifiers detecting the voltage. The amplifiers voltage might be too high for the op amp circuit. That is why there is an 1 : 10 voltage divider on the input. That should bring most off the supply voltages of the amplifier in range.

IC24A checks if the input voltage is not too high. If so, led 3 will light. IC24B will check if the input voltage is too low. If so, led 1 will light. If none of them lights the voltage is OK and led 2 will light. Again the rest of the circuit is taken from the current protection.

Setup

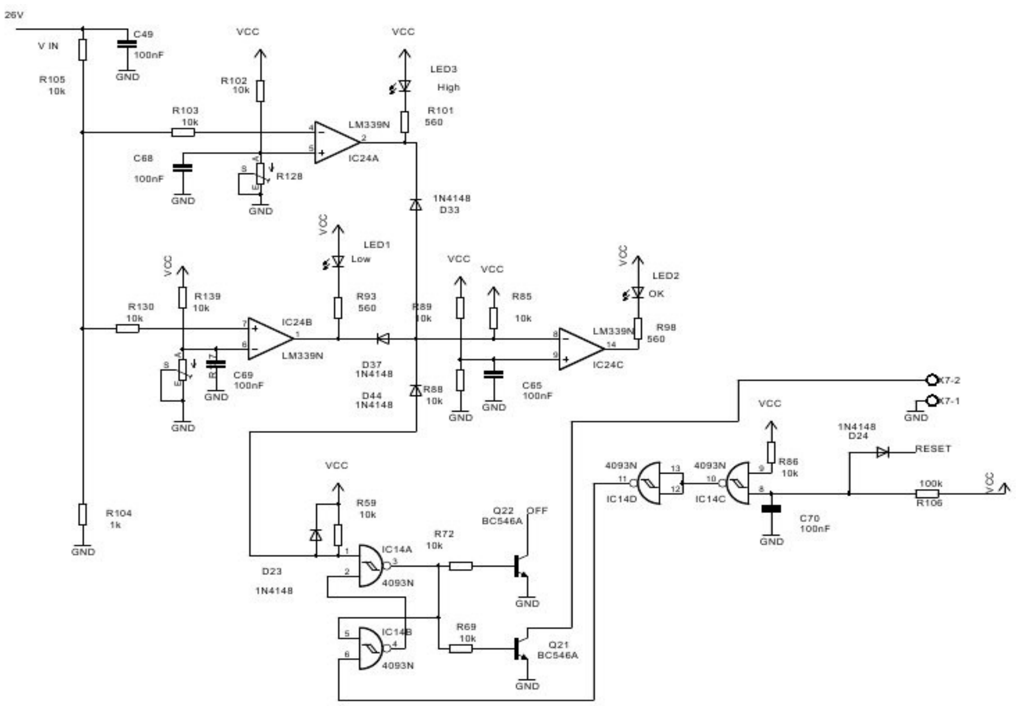
Set up is fairly easy. It is best done with a regulated power supply and an accurate digital voltmeter.

Set a slightly to high voltage and adjust R128 so that led 3 just lights.

Set a slightly too low voltage and adjust R139 so that led 1 just lights.

Apply the correct voltage and led 2 should light.

This should complete the set up of the voltage protection.



12: Voltage protection

10. The temperature protection

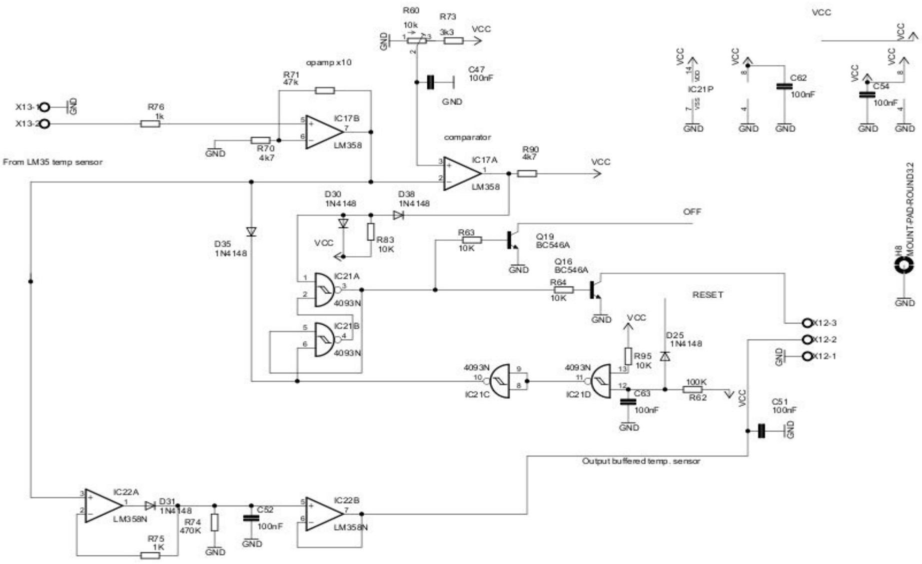
As a temperature sensor, the LM35 is chosen because its output of 10mV per degree C. In case of 25 degrees C the sensor will output 250mV. This absolute readout enables us to set the temperature without heating the amplifier.

On the LM35 chip, a 2k resistor has to be soldered in series with the output. This is described in the data sheet to compensate for wire capacitance. Note this resistor is NOT in the schematic and NOT on the board. It has to be mounted at the LM35!

On the board the voltage from the LM35 is amplified 10 times by IC17B so that more acceptable values are obtained. 250MV for 25 degrees Celsius is now 2.5V The output of IC17B is compared on IC17A. In case that the output voltage from IC17B on pin 2 is higher than the pre-set voltage on pin 3, pin 1 of the op amp will go low and trigger the flip-flop.

The rest of the circuit is the same as in the current protection circuit.

13: Temperature protection



As an input the LM35 as used in the Ericsson 13cms amplifiers works also, just add a small voltage divider.11. Remote controlling the amplifier

One of the things I made together with Graham F5VHX was a Gray to serial converter. This was for my home-brew Gray codes. I did not want to run a wire for each bit from the tower to the shack. Graham came up with a circuit and programmed the software for the transmitter and the receiver. The receiver and transmitter don't differ very much, only for the software in the pic is different. These pic processors had also 2 AD converters inside. These were not implemented in the original software but Graham “added some lines of code” and we had 2 AD converters available. In fact there are 12 high /low inputs and these can be used to show which alarm stage has been “set off” For each alarm stage we use one of the open collectors to transmit this information to the shack. The input of transmitter will produce the same output on the receiver. The output of the pic is transferred to the RS485 protocol, so that the data can be transferred easily to the shack. Goal was to use a RJ45 cable, these are available for the amateur at low prices. If you mix up wires from the RS485 it does NOT work. So be careful.

There isn't really much to tell about the circuit. It is all in the software.

The jumpers

JP1 Switches between binary or Gray (should be grounded in this application.)

JP2 Switches between serial or parallel (should be grounded in this application.)

JP3 Switches between positive or negative (should be grounded in this application.)

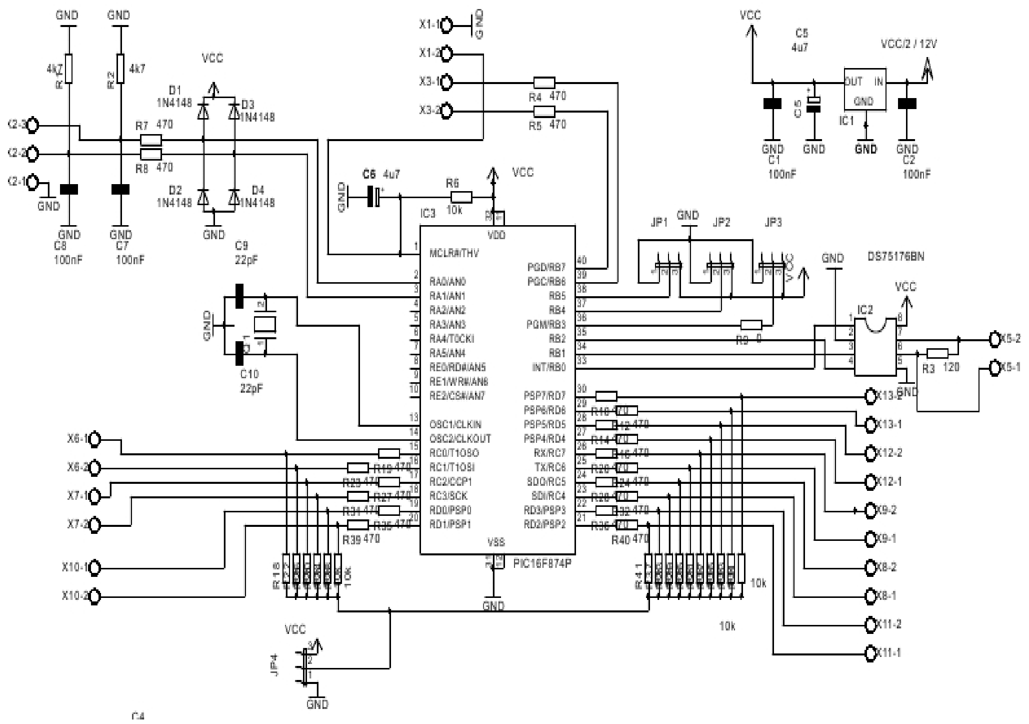
JP4 Switches the level of input / output to go high or low. Normally this should go low in this application.

JP1-3 are normally not needed. Pins might be grounded directly!

TX connections, naming conventions	**RX connections, naming conventions**
x9-3 a/d in channel 1 x9-2 a/d in channel 2 x1-1 logic alarm-1 in x1-2 not used x2-1 not used x2-2 logic alarm-2 in x3-1 logic alarm-3 in x3-2 logic alarm-4 in x4-1 bit-0 in x4-2 bit-1 in x5-1 bit-2 in x5-2 bit-3 in x6-1 bit-4 in x6-2 bit-5 in x7-1 bit-6 in x7-2 bit-7 in x8-1 bit-8 in x8-2 bit-9 in	x1-1 logic alarm-1 out x1-2 pwm out channel 1 x2-1 pwm out channel 2 x2-2 logic alarm-2 out x3-1 logic alarm-3 out x3-2 logic alarm-4 out x4-1 bit-0 out x4-2 bit-1 out x5-1 bit-2 out x5-2 bit-3 out x6-1 bit-4 out x6-2 bit-5 out x7-1 bit-6 out x7-2 bit-7 out x8-1 bit-8 out x8-2 bit-9 out

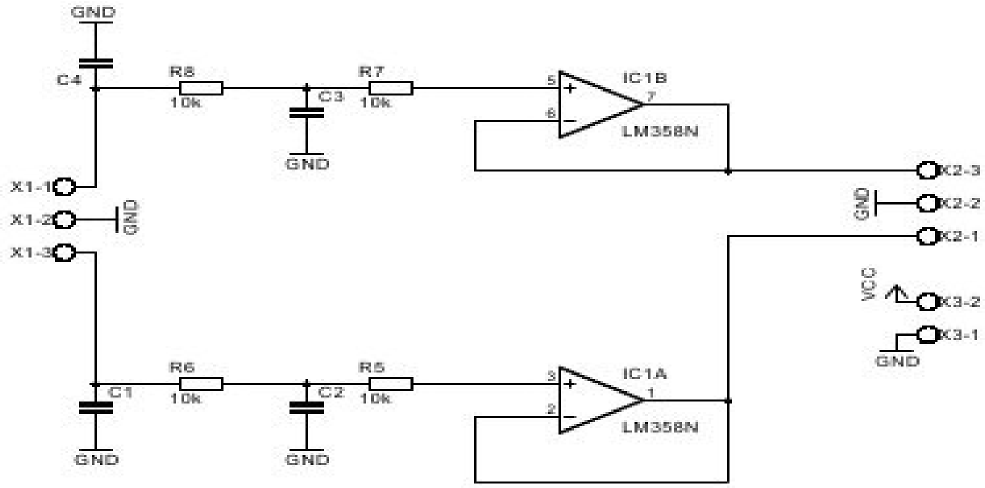
Table 2: Connections on the remote TX and RX

Do not exceed 5v input (D1-D4 are dump diodes to vcc for primitive protection, but this will stress the 7805 regulator if high positive voltage is applied to the a/d input).



14: Remote control RX-TX

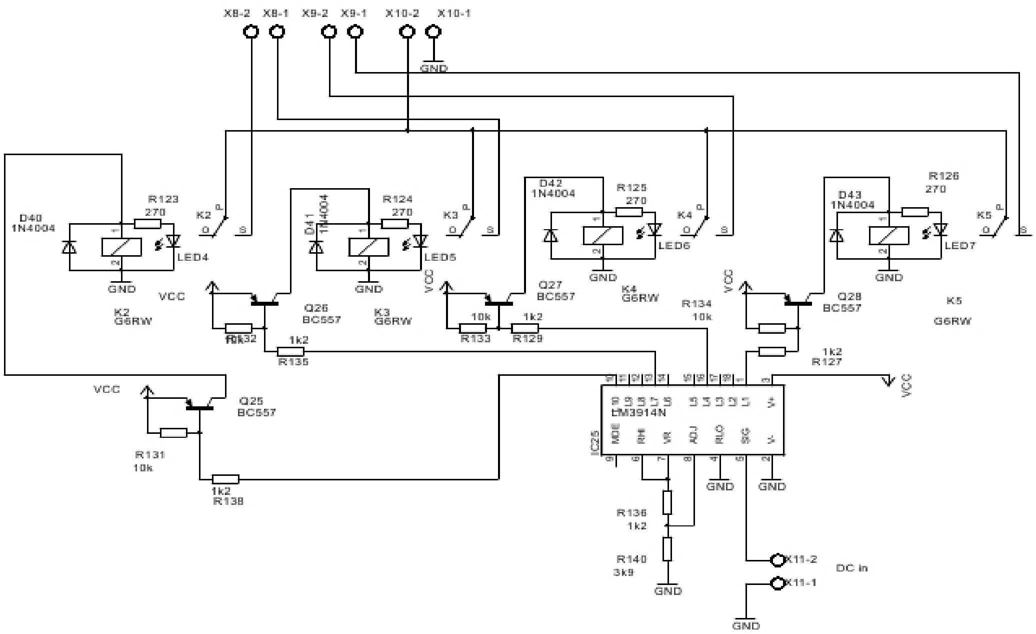
The output of the RX is PWM modulated output. The duty cycle varies depending on the input voltage of the TX. The output needs to be smoothed and buffered by an opamp. Below is a simple schematic. There is no PCB for this but it could be made on a simple experimental board. The capacitors are not critical 33nF will do.



15: PWM to DC converter

12. Voltage dependant switch

Because there are only 2 AD converters available in the pic processor and I wanted to be able to monitor each of the 4 stages on my 1296 amplifier. I decided that I needed a switch for that. Again the LM3914 proved to be a very nice component. A switch in the shack is used to select different voltages for the input of the LM3914. It's voltmeter is used to attract relays which switch the outputs of the 4 current protection circuits. A led is fitted on the coil of each relay to show which relay is attracted. The input of the LM3914 is limited to 9V. In the shack there is a simple voltage regulator and a 4 position rotary switch which selects the voltage from 4 pieces 10k multi turn potentiometers.

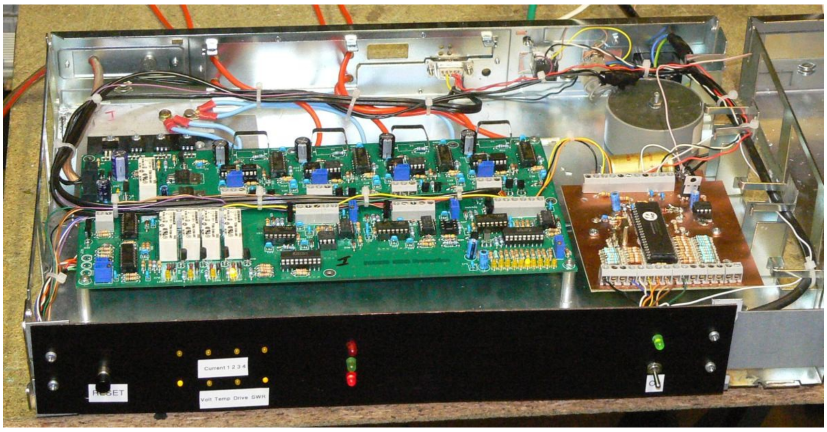


With this circuit, I can monitor each of the 4 currents in my amplifier using one AD converter. The other AD converter is used to monitor power output.

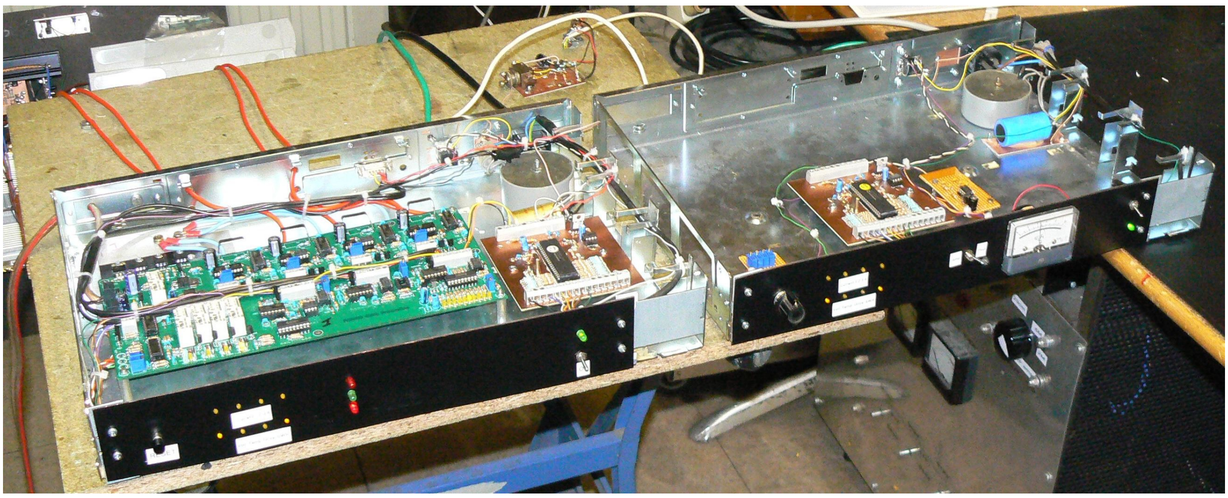
The RJ45 connector could look as follows:

1. GND
2. 12V from the shack to switch the solid state relays to switch on the high current PSU at the base of the tower.
3. RS485
4. RS485
5. Switching voltage for the remote switch
6. Not in use
7. Not in use
8. Not in use

The numbers not in use could be use to transfer any other voltage from the bottom of the tower to the shack. Maybe temperature or reflected power is important for you.



16: A photo of the complete unit



17: The indoor and remote unit side by side

18: Hey it even has cover on it!

12. References

“With a little help from my friends”:

Jack Smeets, PE1KXH: Ideas, support, discussion and fun

Graham Daubney, F5VHX: Ideas, discussion, fun, support and pic progtramming

The PA3CSG website will provide a download for the schematics on a larger scale. Unfortunately these are a bit hard to read. http://pa3csg.hoeplakee.nl/joomla/index.php?option=com_content&view=category&id=44&Itemid=64

Data sheet from Maxim available at: http://datasheets.maxim-ic.com/en/ds/MAX4080-MAX4081.pdf

Data sheet from National Semiconductors available at: http://www.national.com/ds/LM/LM35.pdf

Load for batteries and power supplies: http://www.w1ghz.org/small_proj/small_proj.htm

The VSWR protection circuit : http://www.geocities.com/Area51/Nebula/3736/swr_prot.gif

Data sheet from National Semiconductors available at:http://www.national.com/ds/LM/LM3914.pdf

Application note from Microchip: http://ww1.microchip.com/downloads/en/AppNotes/00538c.pdf

AATiS Log detector: http://www.aatis.de/content/bausatz/AS633_Logarithmischer-VHF/UHF-Detektor

Description of the logaritmic detector with the AD8713 Weinheim papers 2002.

Addendum June 2010

After 3 complete units build the following changes were added:

1. Led 7 of the voltage dependant switch, connected to pin 1 of IC25 keeps burning for a small amount. You can see the led light a little, it never goes out completely. This does not affect the functioning of the circuit.
2. Graham F5VHX promised to design a nice indoor control unit with LCD displays and power reading etc. The design of this unit has been finished, at this time the first units will be build and tested.

Addendum August 2010

The prototype of Graham indoor unit is available and really good functioning.

For those interested in building these unit a few professional made double sided, through plated boards are still available for € 36 (+ shipping). Contact PA3CSG (pa3csg@gmail.com).