

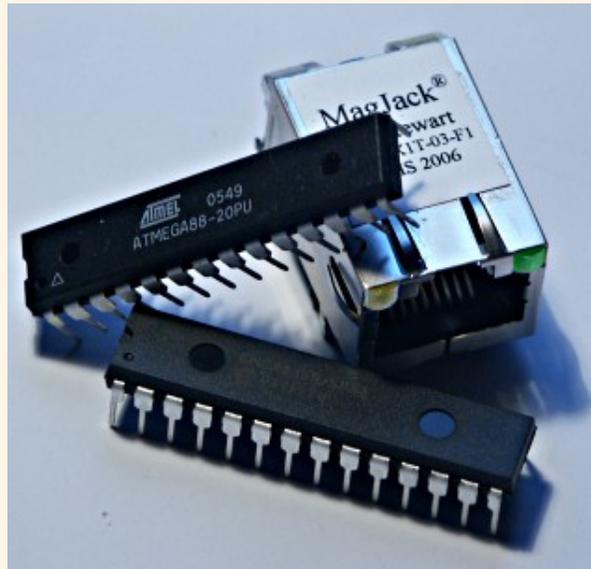


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An AVR microcontroller based Ethernet device



Abstract:

Ethernet has traditionally been a quite complex interface. All Ethernet chips until today had 100 pins or more, where difficult to find in small quantities and difficult to use from a small microcontroller with little memory. Microchip has changed the world with their new ENC28J60 Ethernet chip!

The ENC28J60 is a small chip with 28 pins only and has a SPI interface which is easy to use from any microcontroller.

This opens a whole world of completely new applications. You can easily build small devices which can be spread all over the house and simply connected to ethernet.

You don't need anymore a separate serial connection or other bus. Everything can be easily connected via Ethernet. Distance is no longer a limiting factor.

Even WIFI connectivity is possible because you can connect the devices to a wireless bridge.

All hardware components are available from shop.tuxgraphics.org. The software and circuit diagrams are available for free (GPL V2 license).

Introduction to the ENC28J60 Ethernet controller

The ENC28J60 from Microchip is a fantastic chip. It has Tx/Rx, MAC and PHY in one small chip. There are very few external parts. Basically just a crystal and an Ethernet transformer, aka magnetics. All this comes in an convenient 28-pin DIP package. Easy to solder and perfect for hobby applications.

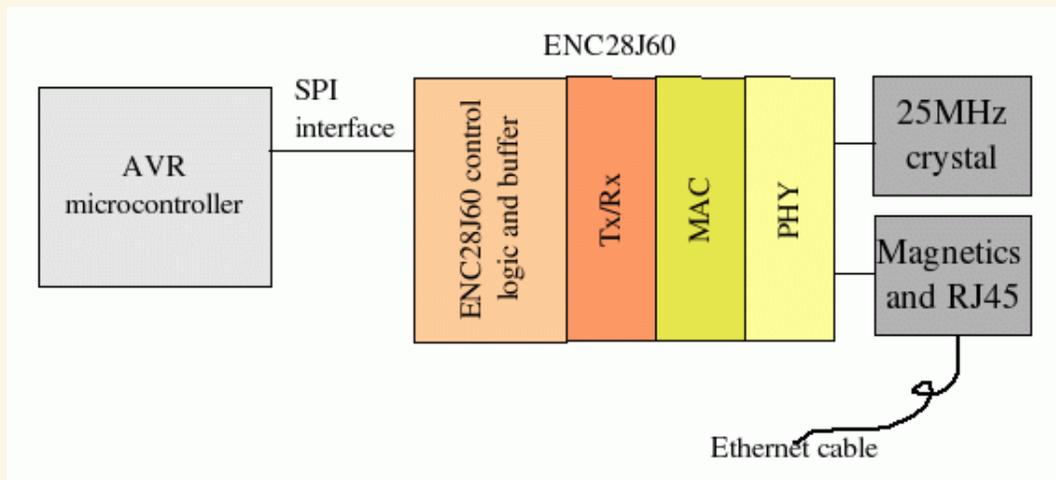


Figure 1: Schematic block diagram.

The microcontroller can then control any hardware you like: You can attach some sensor (light, temperature), you can switch on an off something you can attach a LCD display, etc...

The Plan

In this first article we will build a generic hardware with lots of IO interfaces and analog to digital converter inputs. We will however only control a small relay to switch on or off something. In later articles we can then use the same hardware and do more complicated things.

The main purpose is to show here the circuit diagram and explain the software. We use a UDP application to send commands to the microcontroller. Those commands will then cause the microcontroller to switch on or off the relay.

It think it will be possible to even implement TCP. The current UDP software is less than 3k bytes and that is not even half of the memory on an Atmega88. TCP would then allow us to control the device via a web browser. I have however not tried it yet.

The circuit diagram

Here is the circuit diagram. Most of it is very straight forward and standard for the ENC28J60. The polarity of LED-B is important as it determines the duplex operation of the chip. Standard Half-duplex is what makes most sense for a device which will send and receive only rather little traffic.

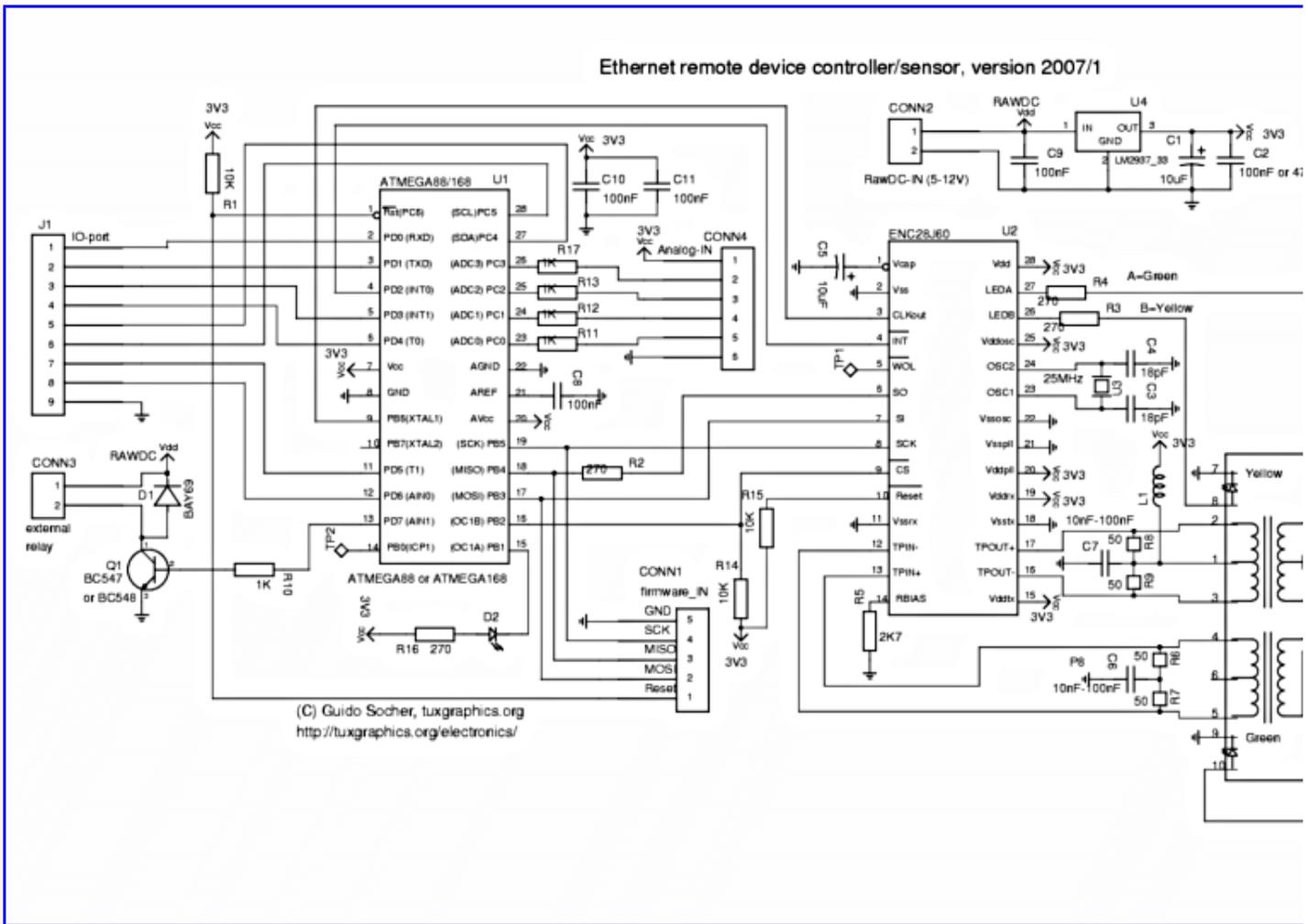


Figure 2: Circuit diagram (click on the drawing to get a printable pdf version). The circuit diagram of the previous hardware version can be found [in the download section](#)

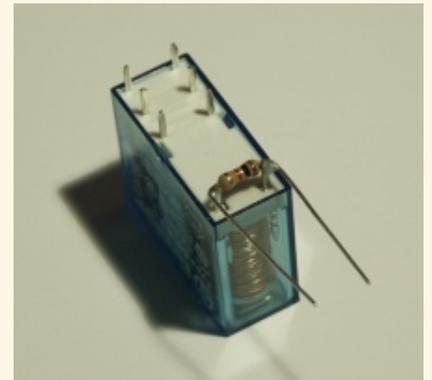
A relay can be connected to connector CONN3. Note the diode D1. It is not useless and it is not the wrong way round in the circuit diagram even though it looks like that. It is there for those who plan to connect a small 6V relay on that output. It protects the whole circuit against the possibly very high voltages which can be induced by the coil of a relay.

If you use a relay with a large coil then you should also add a resistor in parallel to the relay (e.g 1K or 2.2K). The diodes have a finite response time and such a resistor will prevent the voltages to raise too fast before the diode cuts them.

If you plan use 9V raw-DC (or maybe more) in combination with a 6V relay on CONN3 then you can add a small resistor (e.g 33 Ohm, you have to experiment) in series to the relay to compensate for the higher voltages.

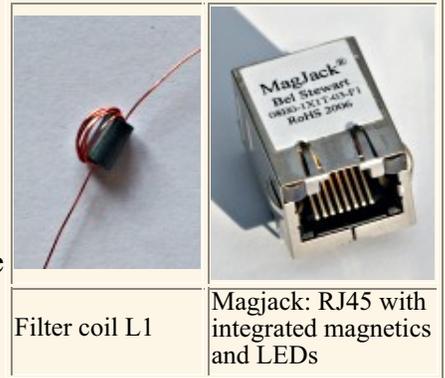
The connectors named "IO-ports" and "Analog-IN" are not used for now. They are meant for future functionality which will be described in later articles. We will only use CONN3 in this project.

Ethernet requires quite high currents because it can be used with rather long cables. The above circuit consumes about 200mA at 3.3V. The LM2937-33 needs therefore cooling if the supply voltage is more than 5V (on Raw-DC-In). A small piece of aluminium is normally enough.



Ethernet Magnetics and Filters

The ENC28J60 requires a transformer with a turn ratio of 1:1 certified for 10base-T. There are some very nice RJ45 connectors called "Magjack" which have already integrated magnetics and optionally integrated LEDs. In addition you need a small filter coil (L1 in the schematic). A 5mm ferrite bead with 5-7 turns of thin wire seems to work well.



Hardware updates 2007

As of quarter one 2007 I have updated the hardware with regards to the following points:

1. The diode D1 was incorrectly connected against GND instead of Vdd. Interestingly nobody noticed that fault. The wrongly connected diode was protecting the transistor against negative voltages but not against voltage peaks induced by a relay coil. If you did however follow my recommendation and use an additional resistor in parallel to the coil then this one will keep already the current flowing through the coil after power disconnection and it seems to be enough to protect the circuit.
2. The ENC28J60 has a clock output. I wanted to use it right from the start but there was a problem with interrupted clock signals at reset which caused sometimes the AVR to malfunction. I contacted microchip support about it but they did not seem to understand the problem. Maybe microchip PIC controllers are less sensitive to non continuous clock signals. I finally figured out that it works if I do not use both software and hardware reset during initialization of the chip. Now I use just reset via software and that works well. The ENC28J60 can supply a 12.5MHz clock signal. This gives a small speed increase over the 8MHz from the atmega88 internal clock. Atmel specifies that the atmega88 can handle 0-20MHz @ 4.5-5.5V and 0-10MHz @ 2.7-5.5V. This suggests that we should use max 10MHz but it can't be a binary behavior starting suddenly at 2.7V. We can assume that it should be something between 10MHz and 20MHz. My tests show that 12.5MHz works stable and reliable at 3.3V.

If you did already build the previous circuit then don't worry. I will keep any new software backward compatible with the old hardware. That is: the new hardware will not run with the old software but the old hardware will run with the new software. There is also no real need to modify or update your existing hardware. Never change a running system! For those who would like to look at the old circuit diagram from 2006 can find it [in the download section](#).

Step by step: Assembly and testing

A problem of all microcontroller based electronics is that it is difficult to develop for the first time. Usually nothing works for some reason and then the big question is where are the errors. Errors are usually made in both software and hardware. You have the advantage that you have already a reliable base. You know at least that the software works and that the circuit diagram is correct because you can base on my work. Still it makes sense to build the hardware step by step and test after each step. This way you can narrow down the area of a possible fault.

Step one:

Solder the LM2937-33 voltage regulator and the needed capacitors onto the board. Connect Raw-DC-In to a 5V lab power supply and use a voltage meter to check that the output is 3.3V. Now take a small 3.5V torch bulb or a 6V bicycle bulb and connect it also to the output. Check that you have still 3.3V with a little bit of load.

Step two:

Solder the ENC28J60, the magjack and all other parts around the ENC28J60 on the board, but **not** the Atmega88 microcontroller. Connect the circuit again to 5V power on Raw-DC-IN (limit the current to about

300mA, check that you get again 3.3V). Now connect an Ethernet cable from your Hub or Switch to the circuit. The green LED on the Magjack should go on and stay on. The link LED on your Hub/Switch should also go on.

Ethernet has a pulse based link negotiation protocol (FPL, Fast Link Pulse). The green LED indicates that this link negotiation works and was successful.

Step three:

Solder the Atmega88 onto the board. Power the circuit up again. Unpack the `eth_rem_dev-1.X` software (download at the end of the article) and run the command `"make test0.hex"` from a shell. This will compile the `test0.hex` file. Load this file into the microcontroller (e.g. with `"avrdude -p m88 -c avrusb500 -e -U flash:w:text0.hex"` or use the make target `"make load_test0"`). If you have one of the tuxgraphics programmers then you can just type `"make load_test1"` under Linux. Note that Atmega88 needs at least `avr-glibc-1.4.X`.

This will cause the red LED (D2) to blink with 1Hz.

Now we have checked all major components of the circuit and there is a good chance that it will work with the final software. I have used during my development also some more test programs which are included as well in the `eth_rem_dev-1.X` package.

- `test1`: Allows you to ping the circuit
- `test2`: Sends a string back

All of them are described a bit more in the README file of the `eth_rem_dev-1.X` package. You can use them also as example programs for your own development.

The last step:

Edit the file `main.c` and change the 2 lines:

```
static uint8_t mymac[6] = {0x54,0x55,0x58,0x10,0x00,0x24};
static uint8_t myip[4] = {10,0,0,24};
```

For the first device you build you will not need to change the `mymac` line. But you will probably need to change the IP address (`myip`). It must be a free address from the address range in your network.

There is a range of private addresses (not routed on the public Internet) which you can use:

| Netmask | Network Addresses |
|---------------|-------------------------------|
| 255.0.0.0 | 10.0.0.0 - 10.255.255.255 |
| 255.255.0.0 | 172.16.0.0 - 172.31.255.255 |
| 255.255.255.0 | 192.168.0.0 - 192.168.255.255 |

Example: your WIFI router might have 192.168.1.1, your PC might have 192.168.1.2. This means you could e.g. use 192.168.1.10 and leave some room for more PCs. If you use DHCP then make sure that the address is not double allocated (exclude it from the DHCP range).

Now compile the software with the command `"make"`. Load the `eth_rem_dev.hex` file into the microcontroller and send your first ping from a shell.

```
ping Ip.Addr.you.assigned
```

You should get a reply with 0% packet loss (stop the command with `ctrl-c`).

Using `eth_rem_dev` to switch on or off something

The only supported useful function in the microcontroller code in this first release is to switch on or off the transistor connected to PD7 (connector CONN3). More functionality will come later.

I have written a small program called `udpcom` which will send out a string over UDP and wait for an answer string. `udpcom` is also included in the `eth_rem_dev-1.X` package. The program is very small and should be portable to many operating systems with minor modifications. If you have ported the code to some not yet supported OS then send me the code and I will include it in the next release.

To compile the `udpcom` command go to the directory `eth_rem_dev-1.X/udpcom` and compile the right version of `udpcom` in one of the subdirectories with the command `"make"`.

```
The command to switch on is: t=1
The command to switch off is: t=0
Query the status: t=?
```

The syntax is: `udpcom password,X=Y IP-addr`

The default password of the `eth_rem_dev-1.X` is "secret". You can change it in the same `main.c` file where you changed the IP address.

Here is an example:

```
./udpcom/unix/udpcom secret,t=1 10.0.0.24
II: data: secret,t=1, ip: 10.0.0.24 port: 1200
OK: 10.0.0.24: t=1
```

Now the transistor connected to PD7 should be on and if you have a relay connected to that transistor the relay should be on too.

```
./udpcom/unix/udpcom secret,t=? 10.0.0.24
II: data: secret,t=?, ip: 10.0.0.24 port: 1200
OK: 10.0.0.24: t=1
```

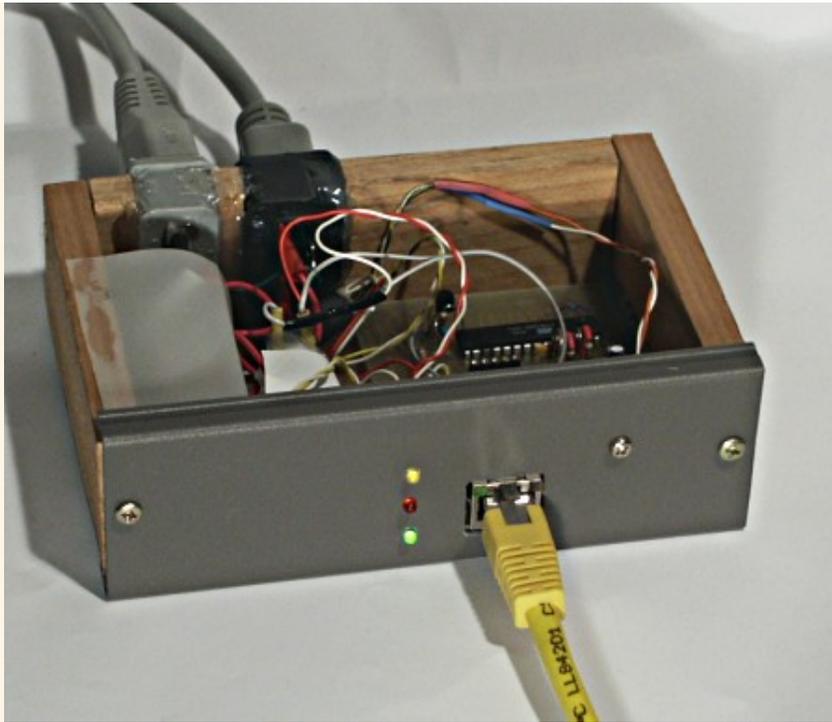
Here we query the status and the answer `"OK: 10.0.0.24: t=1"` indicates that the transistor is "on".

```
./udpcom/unix/udpcom secret,t=0 10.0.0.24
II: data: secret,t=0, ip: 10.0.0.24 port: 1200
OK: 10.0.0.24: t=0
```

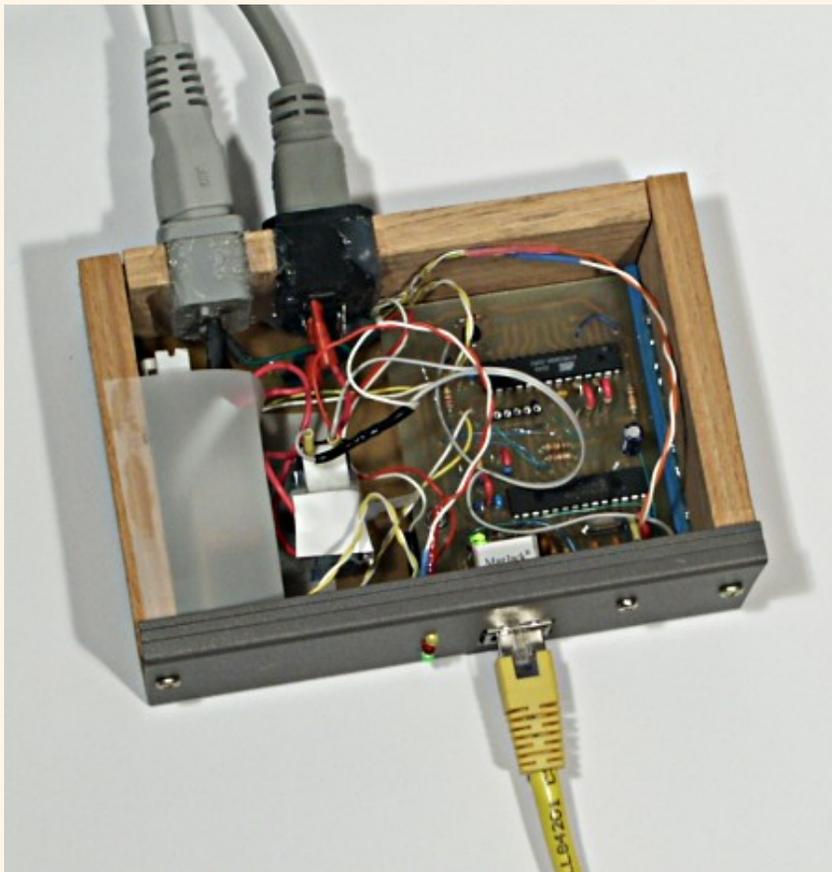
Now the transistor connected to PD7 should be off again.

The ready build Ethernet remote switch device

Here two photos from the device which I have built.



Front view with box open: You can see the two LEDs above the Magjack and 3 additional ones. Green is for power on, red changes when a UDP packet is processed, yellow indicates the current state of the relay (on or off). The connectors on the back are power and relay out. Under the white plastic cover on the left is a small 9V switched power supply circuit.



Top view with box open: You see the little Ethernet board on the right with the microcontroller. Left are (insulated and not really visible): relay and power supply. The LM2937 is mounted with a single screw on the grey aluminum front. The sides are wood and top/bottom of the box are plastic.

Software structure

Before we look at the software on the microcontroller we should study how network socket programming works under Linux. On the microcontroller side we can (and have to) build every bit of the Ethernet frame. Under Linux (or any good OS) we are in a much more civilized environment and can't just do what we want.

A host has one Ethernet address (MAC address) per interface and one or more IP addresses per interface. Those MAC addresses are world wide unique but this is just to make the hardware distribution easier. They just have to be unique in your local environment. That is: Your PCs, your (WIFI) router and the router of your internet provider have to have distinct MAC addresses.

The network applications on the host are then distinguished by port numbers. Only one port number can be active at a time. That is: you can not have two web servers running on port 80 on the same host. When you send a message then a local (random) port number is allocated and the request is sent to the remote IP and well know port number (e.g 80=web).

If you have an application process listening on port X locally for connections (server) then you can not start a second application sending on the same port. However the same program can send and receive on the same port.

The port numbers below 1024 are reserved numbers. We just pick a port number: 1200

```
PC network interface          AVR Ethernet device
MAC1,IP1 src.port=34256 --> MAC2, IP2 dest.port=1200
```

Answer:

```
MAC1,IP1 dest.port=34256 <-- MAC2, IP2 src.port=something(e.g 1200)
```

UDP is unreliable?? That is not really true. On a local LAN there is almost no packet loss unless you have problems with the hardware duplex configuration but that is a different problem and should be fixed asap. The packet loss ratio on a local non congested LAN is better than $10E-9$ or one in 100000000. With normal home traffic volumes on a 24/7 Linux network that is far less than one packet per month.

UDP is on a local network very reliable and all that it means is that we must be able to resend the data without causing harm. We must not implement a "toggle" switch but one command to switch on and one to switch off. If we re-send the on command (because it was lost) the result will still be "on". That's all.

I will list now the names of the AVR microcontroller source code files that way you can easier change and modify things:

```
main.c -- all execution starts here. It starts all initialization and has
         also the main loop.
```

```
enc28j60.c, enc28j60.h -- enc28j60 hardware dependent things
```

```
net.h -- networking constants, byte positions, headers
```

```
ip_arp_udp.c, ip_arp_udp.h -- IP, ARP, ICMP and UDP stack functions
```

```
traffic.txt -- Full decoded messages of the communication, taken with a
              network analyser. This makes it easier to understand what
              is going on in the code.
```

Filters

As you can imagine there is the problem that Ethernet can supply much more data than that little microcontroller can process over the serial SPI interface even if that interface runs with several MHz speed. There is a buffer in the Ethernet controller but it could fill up easily with garbage on a noisy Windows network. The ENC28J60 has therefore filters.

The traffic we want is: UDP traffic with the destination of our MAC address. On top of that we have to process ping (IP/ICMP packets for our MAC address) and ARP packets to our MAC or to broadcast. No IP networking is possible without ARP. All other packets, especially broadcast IP packets can be ignored. The ENC28J60 has a number of simple filters which we will use for this.

There is an uni-cast filter (only packets with our MAC as destination). The only other packets we want are broadcast ARP. There is packet match filter and we program it to destination MAC=FF:FF:FF:FF:FF:FF (broadcast) and only Ethernet content-type=ARP. This is done during the initialization in the file enc28j60.c.

Conclusion

This small Ethernet remote device opens a completely new world of fantastic applications. It's small, it's easy to build and there are endless possibilities to use it.

The communication is fast! There is no delay between the sending of the command and the answer. That is very different from RS232 at standard 9600 baud as used for most microcontroller communication.

I found it really exciting to build this hardware and make it work. It is a simple switch on/off application for now but the circuit has all the IO-ports already prepared to do more.

A note on security

If you plan to switch main-power (230V or 120V) with the relay then get good heat shrink tube and insulate things such that you can't touch any mains carrying parts even if the box is open. It's safer for you and all the equipment on your network.

Download and links

- **Download** page for this article: [the eth rem dev software, diagrams, software updates](#)
- The Linuxfocus "Home Networking, glossary and overview" is 6 years old but most is still valid. It is a basic introduction to networking: linuxfocus.org/English/January2000/article134.shtml
- Here is a tip that I received from a customer: There is a drop-in replacement for the LM2937-33. It allows you to use up-to 30V supply voltages with no special need for cooling: <http://www.dimensionengineering.com/DE-SW0XX.htm> (DE-SW033, switching voltage regulator)
- The tuxgraphics shop: shop.tuxgraphics.org
Here you can get all the parts mentioned in this article.

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