Use a CC1101 Radio module with a Raspberry Pi

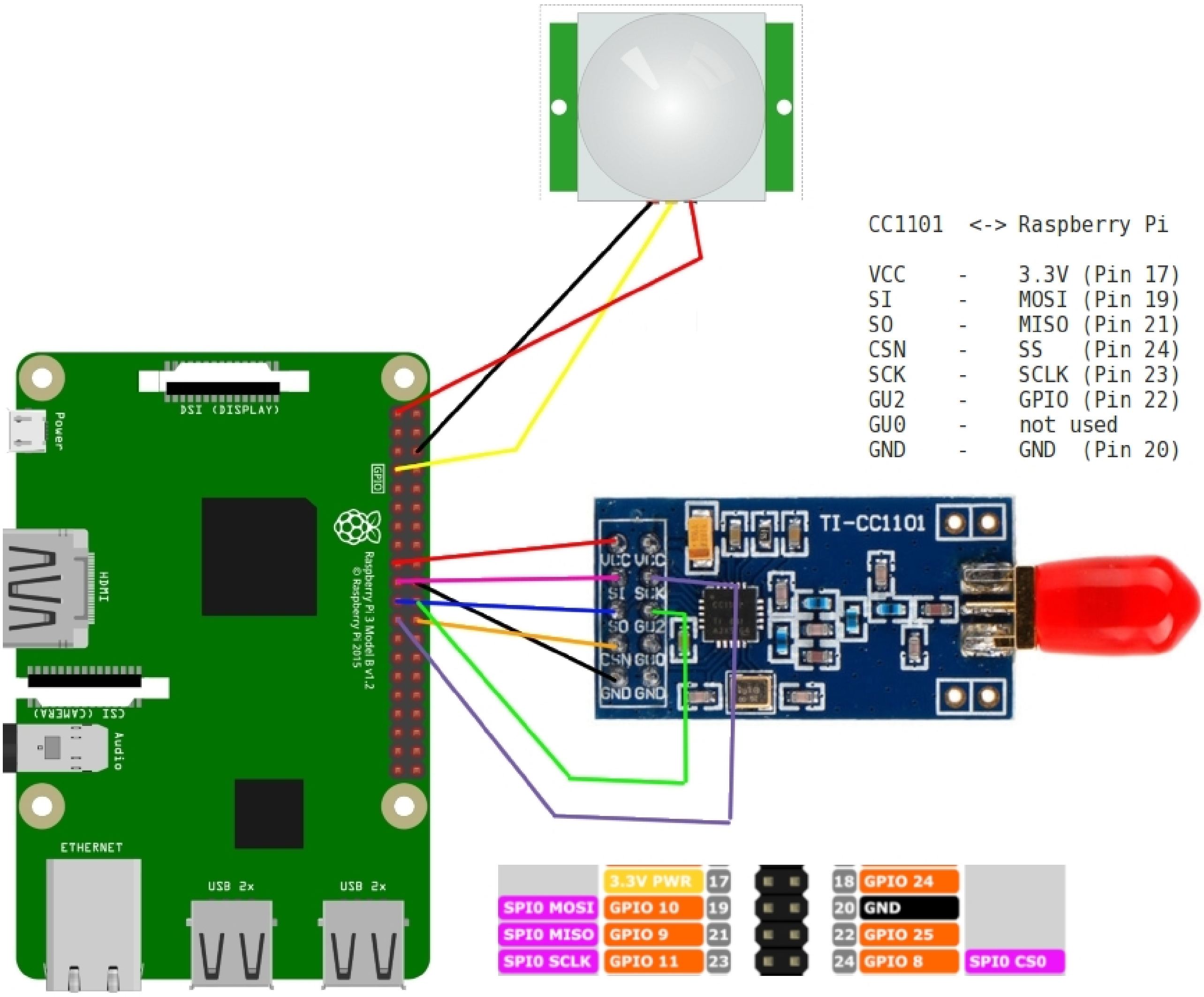
Our previous PDF for Raspberry Pi showed you how to reverse engineer wireless gadgets that use the 433.92MHz AM frequency with OOK signalling, so you can learn codes sent by inexpensive wireless remote contols, and then use those codes to have your Raspberry Pi turn mains sockets on and off using a timer Python script on the Pi. If that sounds like what you want to do, you can read that PDF at http://www.securipi.co.uk/remote-433-receivers.pdf

The CC1101 radio modules have several advantages over the fixed 433.92MHz OOK receivers:

1. Send and receive on 315MHz, 433MHz, 868MHz and 915MHz ISM frequencies.
2. Support for 2-FSK, GFSK, ASK/OOK, 4-FSK & MSK modulation schemes.
3. External RP-SMA antenna socket. So it’s simple to add Yagi antennas for long distance comms.
4. Much of the signal processing is done on the radio boards for us, so less processor intensive.

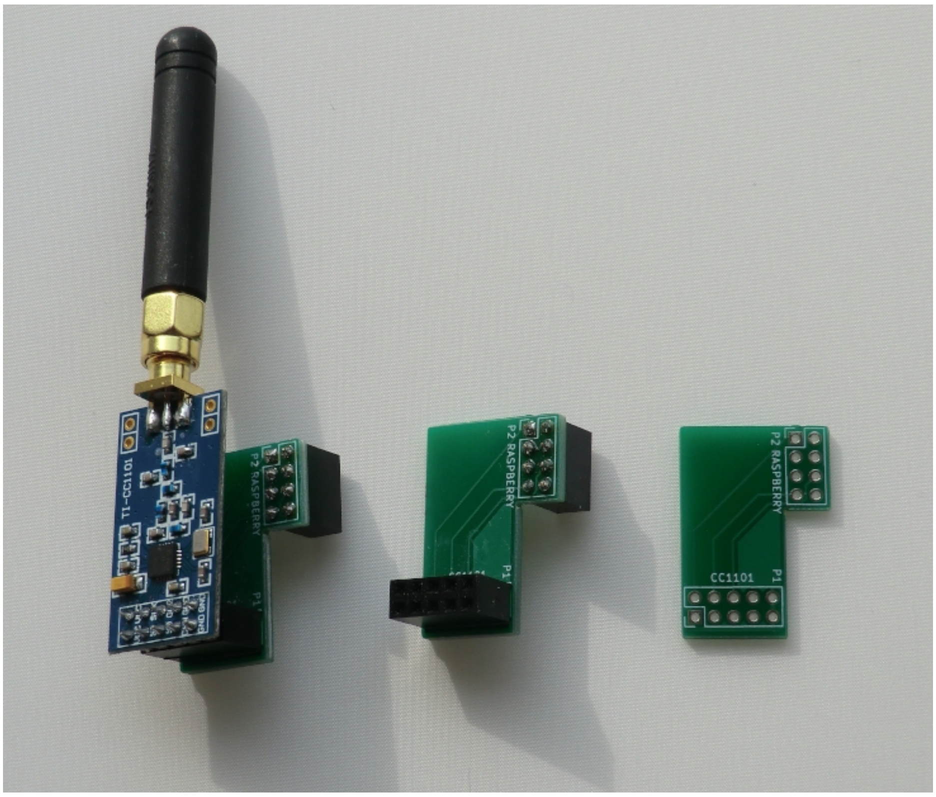
The CC1101 boards we used are available for as little as £3.50 each on eBay UK. You’ll need a pair of CC1101 boards and two Raspberry Pi’s to follow this guide.

The boards attach to the SPI pins on the Pi:



We bought our CC1101 boards from eBay for £3.22/$5 each including the SMA antennas:
https://www.ebay.co.uk/itm/252616019027

You can attach the CC1101 board to the Pi using regular female to female breadboard cables, or you can use a PCB adapter, like this:

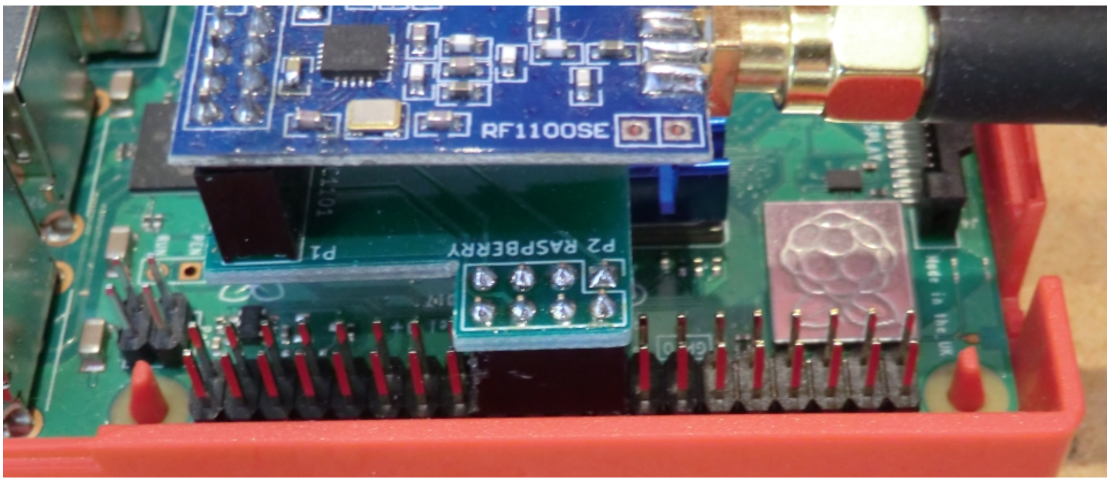


You can get the Gerber files to order your own PCBs from:
https://github.com/salmg/CC1101/tree/master/schematic

Make a zip file from them and upload it to https://www.seeedstudio.io/fusion_pcb.html
and you can get 10 PCBs for $4.90 + $10 P&P, delivered in around 14 days.

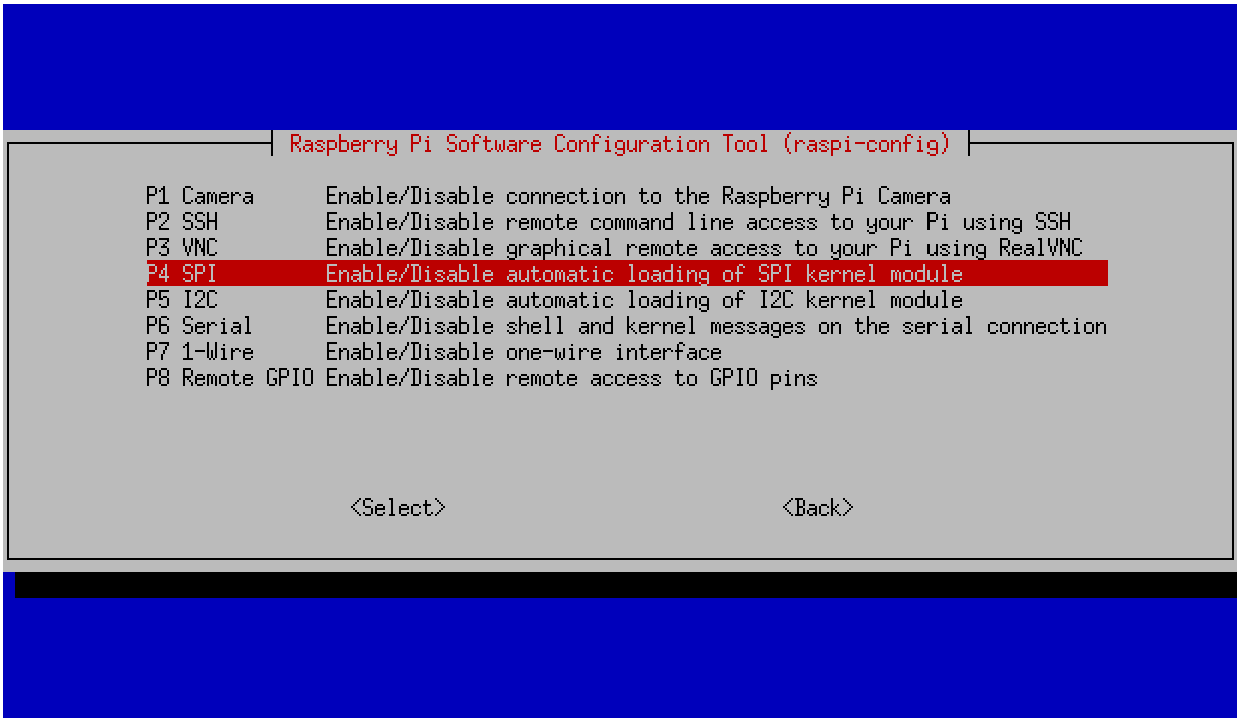
You can get the 5x2 and 4x2 headers from eBay: https://www.ebay.co.uk/itm/382095134487

When the adapter is attached to the Pi you should be able to see 8 free pins either side of it.



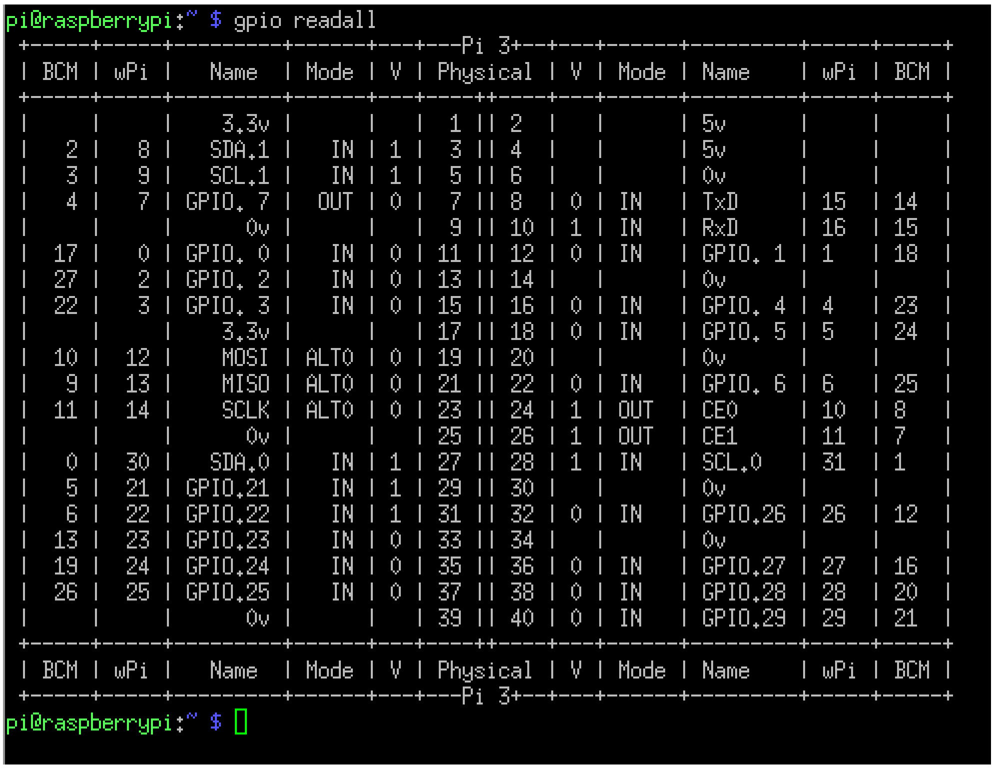
As the adapter communicates over SPI, we need to enable SPI mode on the Raspberry Pi:

```
sudo raspi-config
```



We also need the WiringPi library installed. You can check if it's already installed with:

```
gpio readall
```



```
pi@raspberrypi:~ $ gpio readall
 +-----+-----+---------+------+---+---Pi 3+--+---+------+---------+-----+-----+
 | BCM | wPi |   Name  | Mode | V | Physical | V | Mode | Name    | wPi | BCM |
 +-----+-----+---------+------+---+----++----+---+------+---------+-----+-----+
 |     |     |    3.3v |      |   |  1 || 2  |   |      | 5v      |     |     |
 |   2 |   8 |   SDA.1 |   IN | 1 |  3 || 4  |   |      | 5v      |     |     |
 |   3 |   9 |   SCL.1 |   IN | 1 |  5 || 6  |   |      | 0v      |     |     |
 |   4 |   7 | GPIO. 7 |  OUT | 0 |  7 || 8  | 0 | IN   | TxD     | 15  | 14  |
 |     |     |      0v |      |   |  9 || 10 | 1 | IN   | RxD     | 16  | 15  |
 |  17 |   0 | GPIO. 0 |   IN | 0 | 11 || 12 | 0 | IN   | GPIO. 1 | 1   | 18  |
 |  27 |   2 | GPIO. 2 |   IN | 0 | 13 || 14 |   |      | 0v      |     |     |
 |  22 |   3 | GPIO. 3 |   IN | 0 | 15 || 16 | 0 | IN   | GPIO. 4 | 4   | 23  |
 |     |     |    3.3v |      |   | 17 || 18 | 0 | IN   | GPIO. 5 | 5   | 24  |
 |  10 |  12 |    MOSI | ALT0 | 0 | 19 || 20 |   |      | 0v      |     |     |
 |   9 |  13 |    MISO | ALT0 | 0 | 21 || 22 | 0 | IN   | GPIO. 6 | 6   | 25  |
 |  11 |  14 |    SCLK | ALT0 | 0 | 23 || 24 | 1 | OUT  | CE0     | 10  | 8   |
 |     |     |      0v |      |   | 25 || 26 | 1 | OUT  | CE1     | 11  | 7   |
 |   0 |  30 |   SDA.0 |   IN | 1 | 27 || 28 | 1 | IN   | SCL.0   | 31  | 1   |
 |   5 |  21 | GPIO.21 |   IN | 1 | 29 || 30 |   |      | 0v      |     |     |
 |   6 |  22 | GPIO.22 |   IN | 1 | 31 || 32 | 0 | IN   | GPIO.26 | 26  | 12  |
 |  13 |  23 | GPIO.23 |   IN | 0 | 33 || 34 |   |      | 0v      |     |     |
 |  19 |  24 | GPIO.24 |   IN | 0 | 35 || 36 | 0 | IN   | GPIO.27 | 27  | 16  |
 |  26 |  25 | GPIO.25 |   IN | 0 | 37 || 38 | 0 | IN   | GPIO.28 | 28  | 20  |
 |     |     |      0v |      |   | 39 || 40 | 0 | IN   | GPIO.29 | 29  | 21  |
 +-----+-----+---------+------+---+----++----+---+------+---------+-----+-----+
 | BCM | wPi |   Name  | Mode | V | Physical | V | Mode | Name    | wPi | BCM |
 +-----+-----+---------+------+---+---Pi 3+--+---+------+---------+-----+-----+
pi@raspberrypi:~ $
```

If you don't have WiringPi installed, see: http://wiringpi.com/download-and-install/

Now we have SPI mode enabled and have WiringPi installed, we still need some software to drive the CC1101 boards.

The best software to use can be found at this Github page: https://github.com/SpaceTeddy/CC1101

The readme file at the Github page covers basic installation and testing of the RX_Demo (receiver) and TX_Demo (transmitter) scripts. This is exactly how we installed and configured it on both machines:

```
sudo apt-get install git-core
git clone https://github.com/SpaceTeddy/CC1101
cd CC1101
cp ~/CC1101/examples/raspi/*.cpp ~/CC1101
```

Then on the machine that's going to be the transmitter:

```
sudo g++ -lwiringPi TX_Demo.cpp cc1100_raspi.cpp -o TX_Demo
sudo chmod 755 TX_Demo
```

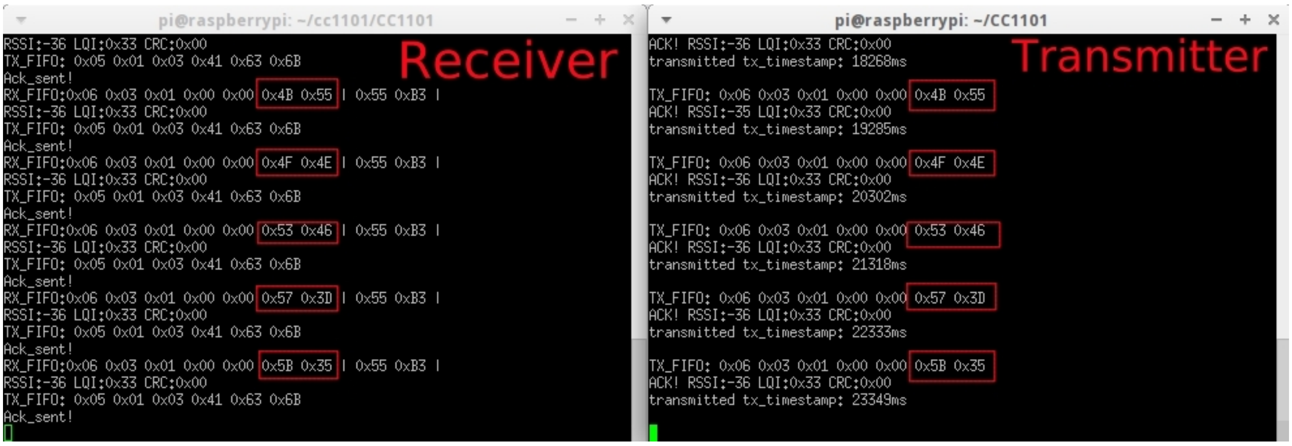
```
sudo ./TX_Demo -v -a1 -r3 -i1000 -t5 -c1 -f434 -m100
```

On the machine that will act as the receiver:

```
sudo g++ -lwiringPi RX_Demo.cpp cc1100_raspi.cpp -o RX_Demo
sudo chmod 755 RX_Demo
```

```
sudo ./RX_Demo -v -a3 -c1 -f434 -m100
```

If that worked you should now see packets going over-the-air between the two Pi's, like this:



Because the boards can work with a wide range of different frequencies, modulation schemes and data rates, they are configured by sending a matching configuration block to each radio over SPI. Once each radio is setup in the same configuration, it's just a case of transmitting a data packet burst on one radio and reading the receive buffer on the other radio.

The RX and TX demo files are great, but they don't do anything really useful for us. In the next examples I'll show you how to attach a PIR to the transmitter Pi, and store times and dates the PIR is triggered in a logfile on the receiver Pi.

You can download our own demos to both your Pi's with:

```
wget securipi.co.uk/cc1101.zip
unzip cc1101.zip
ls
```

Here's the list of files downloaded & what they do:

TX_DemoPir.cpp	Transmits a PIR2 message whenever the PIR detects movement
RX_DemoPir.cpp	Receives a signal and prints "PIR2 Triggered" to console.
RX_DemoPir2.cpp	as above, with time and date logging to file test.txt
RX_DemoPir4.cpp	as above, but also flashes an LED connected to GPIO4 when PIR triggered

Each of the cpp files are source code which needs to be compiled in the same way as the other demos. So for example, to use TX_DemoPir.cpp

```
sudo g++ -lwiringPi TX_DemoPir.cpp cc1100_raspi.cpp -o TX_DemoPir
sudo chmod 755 TX_DemoPir
```

```
sudo ./TX_DemoPir -v -a1 -r3 -i1000 -t5 -c1 -f434 -m100
```

In the silent folder there's another version of the receiver demo code, with all the printf statements commented out and an exit(0) command immediately after it receives a valid code. We've done that so you can call the receiver code from a shell script, and when a valid message is received by the shell script you could send an email to your phone, or turn on an LED, or switch a relay controlling a water pump, or open a door lock.

```
cd silent
ls
```

RX_DemoPir.cpp	receiver with no message to screen, prints PIR2 and exits
receive.sh	shell script, prints "PIR 2 triggered" to console. Loops
receive2.sh	shell script, as above but doesn't loop
receive3.sh	as above, and turns on LED connected to GPIO4 for 3 seconds.

To use the silent versions of the receiver

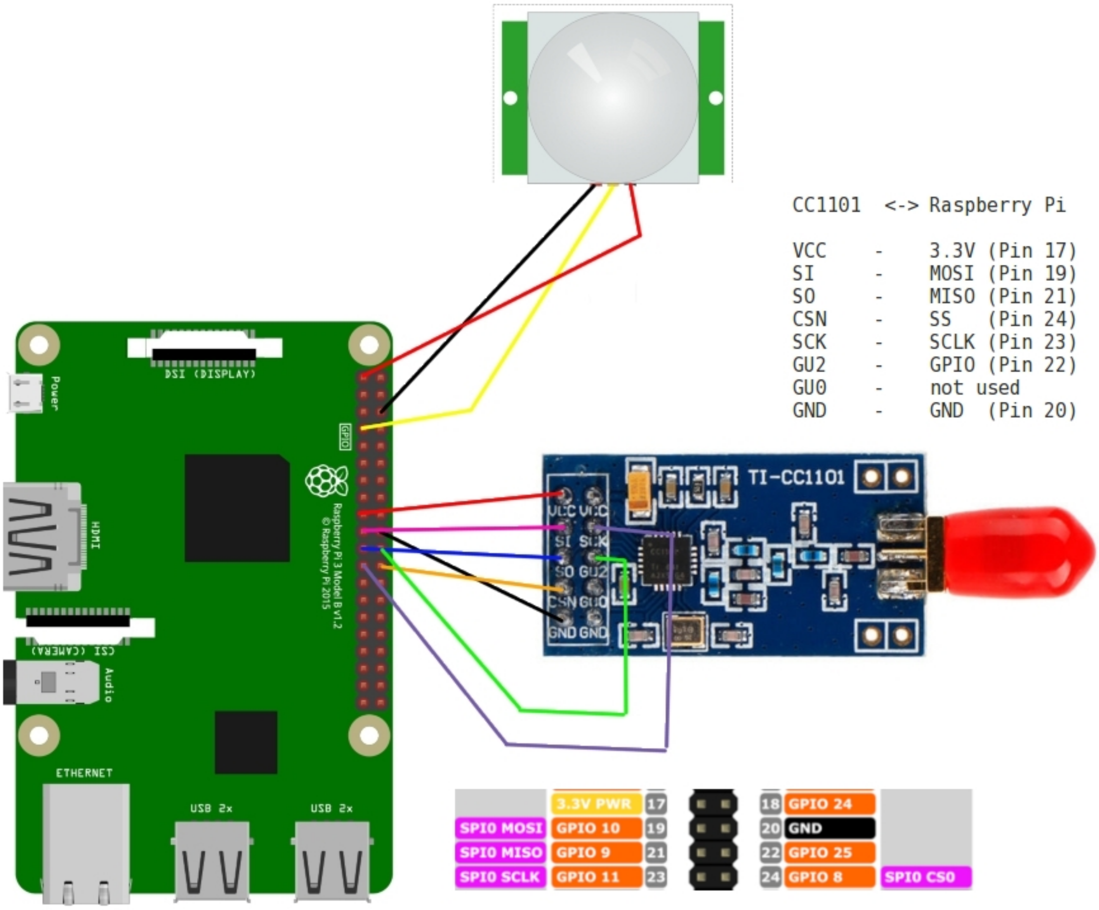
```
sudo g++ -lwiringPi RX_Demo.cpp cc1100_raspi.cpp -o RX_Demo
sudo chmod 755 RX_Demo
```

```
chmod a+x receive3.sh
sudo ./receive3.sh
```

You can inspect & modify the contents of the source .cpp files and .sh files with nano. Example:

```
nano receive3.sh
```

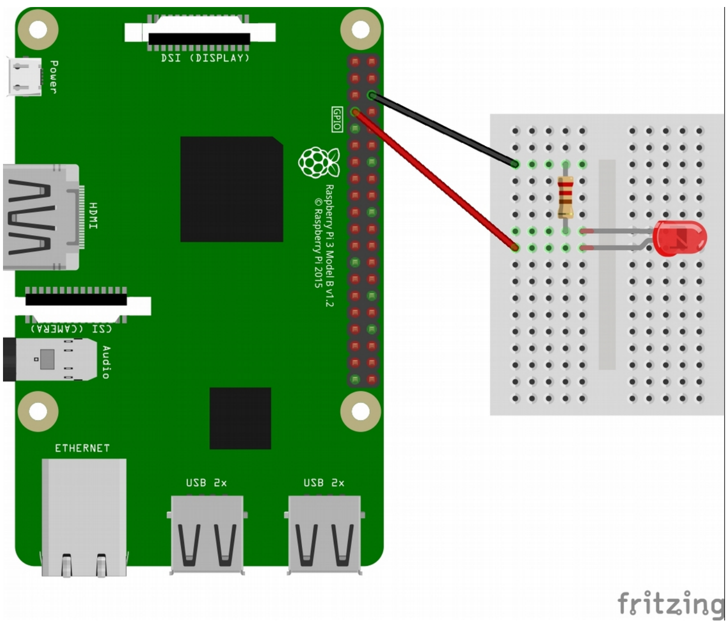
You could use the TX_DemoPir program on several different Raspberry Pi's, all with PIR modules attached and just modify the message sent to PIR1, PIR2, or PIR3 on each different Pi. Then on the receiver code, change this line, which currently looks for the number 2 → if(Rx_fifo[6] == 0x32) to look for PIR1 with 0x31 or look for PIR3 with 0x33.



Attach a PIR sensor to the transmitter Pi. If you pull the white dome off the Pir sensor you'll usually see the pin designations screen-printed on the PCB.

Pir sensor	**Raspberry Pi**
VCC	5 Volts
GND	GND
OUT	GPIO 4 (pin 7 in WiringPi speak)

If you're attaching an LED to the receiver, attach a 220 ohm resistor in series, like this:



In the previous pages we mentioned how the CC1101 radio gets configured - to work on a certain frequency, modulation scheme and gain level - by a configuration block sent over the SPI interface. When you run the standard TX_Demo and RX_Demo examples the current configuration settings for Config Register and PaTable get printed to the terminal, like this:

```
pi@raspberrypi:~/cc1101/CC1101 $ sudo ./RX_Demo -v -a3 -c1 -f434 -m100
CC1100 SW: Verbose option is set `'
Raspberry CC1101 SPI Library test
Init CC1100...
Partnumber: 0x00
Version   : 0x14
...done!
Mode: 3
Frequency: 2
Channel: 1
My_Addr: 3
Config Register:
0x07 0x2E 0x80 0x07 0x57 0x43 0x3E 0x0E 0x45 0x03
0x01 0x08 0x00 0x10 0xB0 0x71 0x5B 0xF8 0x13 0xA0
0xF8 0x47 0x07 0x0C 0x18 0x1D 0x1C 0xC7 0x00 0xB2
0x02 0x26 0x09 0xB6 0x04 0xED 0x2B 0x16 0x11 0x4A
0x40 0x59 0x7F 0x3C 0x81 0x3F 0x0B
PaTable:
0x6C 0x1C 0x06 0x3A 0x51 0x85 0xC8 0xC0
```

If you edit the file cc1100_raspi.cpp you’ll see the config block for the -m100 modulation speed option. The defaults are 868MHZ, and we’ve used 434MHz in the example above, so it got changed around a bit:

```
static uint8_t cc1100_GFSK_100_kb[CFG_REGISTER] = {
                    0x07,  // IOCFG2        GDO2 Output Pin Configuration
                    0x2E,  // IOCFG1        GDO1 Output Pin Configuration
                    0x80,  // IOCFG0        GDO0 Output Pin Configuration
                    0x07,  // FIFOTHR       RX FIFO and TX FIFO Thresholds
                    0x57,  // SYNC1         Sync Word, High Byte
                    0x43,  // SYNC0         Sync Word, Low Byte
                    0x3E,  // PKTLEN        Packet Length
                    0x0E,  // PKTCTRL1      Packet Automation Control
                    0x45,  // PKTCTRL0      Packet Automation Control
                    0xFF,  // ADDR          Device Address
                    0x00,  // CHANNR        Channel Number
                    0x08,  // FSCTRL1       Frequency Synthesizer Control
                    0x00,  // FSCTRL0       Frequency Synthesizer Control
                    0x21,  // FREQ2         Frequency Control Word, High Byte
                    0x65,  // FREQ1         Frequency Control Word, Middle Byte
                    0x6A,  // FREQ0         Frequency Control Word, Low Byte
                    0x5B,  // MDMCFG4       Modem Configuration
                    0xF8,  // MDMCFG3       Modem Configuration
                    0x13,  // MDMCFG2       Modem Configuration
                    0xA0,  // MDMCFG1       Modem Configuration
                    0xF8,  // MDMCFG0       Modem Configuration
                    0x47,  // DEVIATN       Modem Deviation Setting
                    0x07,  // MCSM2         Main Radio Control State Machine Configuration
                    0x0C,  // MCSM1         Main Radio Control State Machine Configuration
                    0x18,  // MCSM0         Main Radio Control State Machine Configuration
                    0x1D,  // FOCCFG        Frequency Offset Compensation Configuration
                    0x1C,  // BSCFG         Bit Synchronization Configuration
                    0xC7,  // AGCCTRL2      AGC Control
                    0x00,  // AGCCTRL1      AGC Control
                    0xB2,  // AGCCTRL0      AGC Control
                    0x02,  // WOREVT1       High Byte Event0 Timeout
                    0x26,  // WOREVT0       Low Byte Event0 Timeout
                    0x09,  // WORCTRL       Wake On Radio Control
                    0xB6,  // FREND1        Front End RX Configuration
                    0x17,  // FREND0        Front End TX Configuration
                    0xEA,  // FSCAL3        Frequency Synthesizer Calibration
                    0x0A,  // FSCAL2        Frequency Synthesizer Calibration
                    0x00,  // FSCAL1        Frequency Synthesizer Calibration
                    0x11,  // FSCAL0        Frequency Synthesizer Calibration
                    0x41,  // RCCTRL1       RC Oscillator Configuration
                    0x00,  // RCCTRL0       RC Oscillator Configuration
                    0x59,  // FSTEST        Frequency Synthesizer Calibration Control,
                    0x7F,  // PTEST         Production Test
                    0x3F,  // AGCTEST       AGC Test
                    0x81,  // TEST2         Various Test Settings
                    0x3F,  // TEST1         Various Test Settings
                    0x0B   // TEST0         Various Test Settings
               };
```

Here's the example of the PaTable settings (power output of the radio for each frequency)

```
                  //Patable index: -30  -20- -15  -10   0    5    7    10 dBm
static uint8_t patable_power_315[8] = {0x17,0x1D,0x26,0x69,0x51,0x86,0xCC,0xC3};
static uint8_t patable_power_433[8] = {0x6C,0x1C,0x06,0x3A,0x51,0x85,0xC8,0xC0};
static uint8_t patable_power_868[8] = {0x03,0x17,0x1D,0x26,0x50,0x86,0xCD,0xC0};
static uint8_t patable_power_915[8] = {0x0B,0x1B,0x6D,0x67,0x50,0x85,0xC9,0xC1};
```

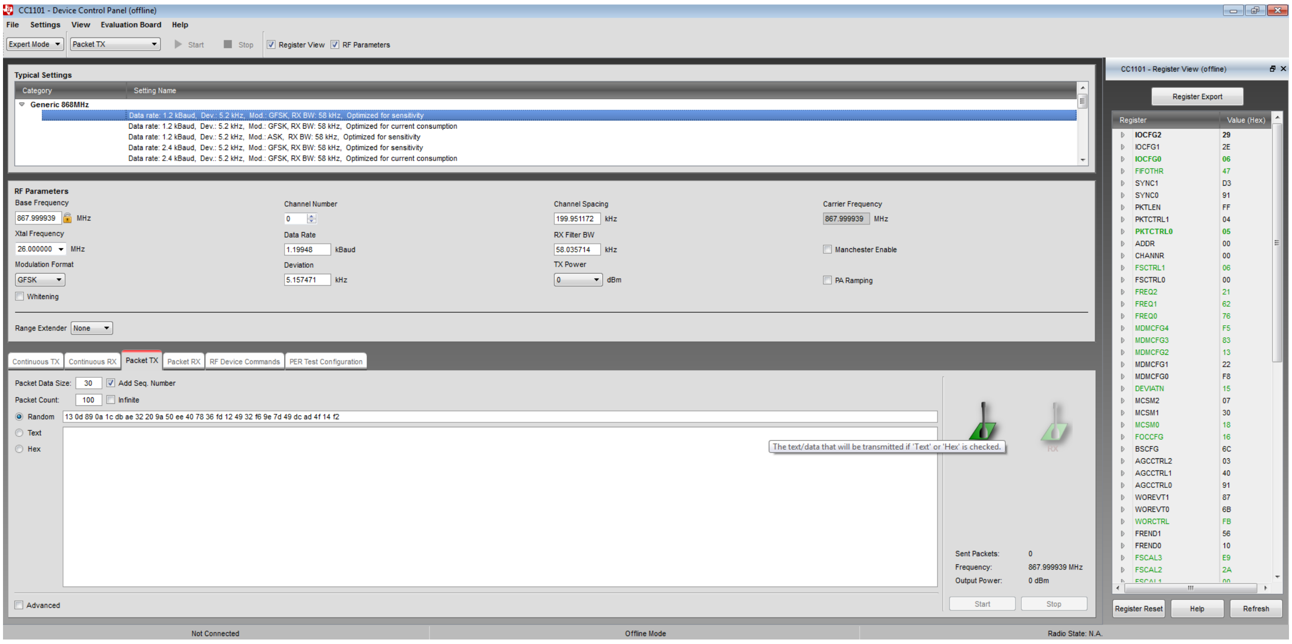
You can see our PaTable setting matches the 433/434MHz setting from the command line RX_Demo options.

Say you want to reverse engineer a wireless gadget of your own, and you've already descovered the frequency, modulation scheme and data rate, how do you then find out the correct config values for the radio? You need a free Windows application from Texas Instruments called Smart RF Studio 7.

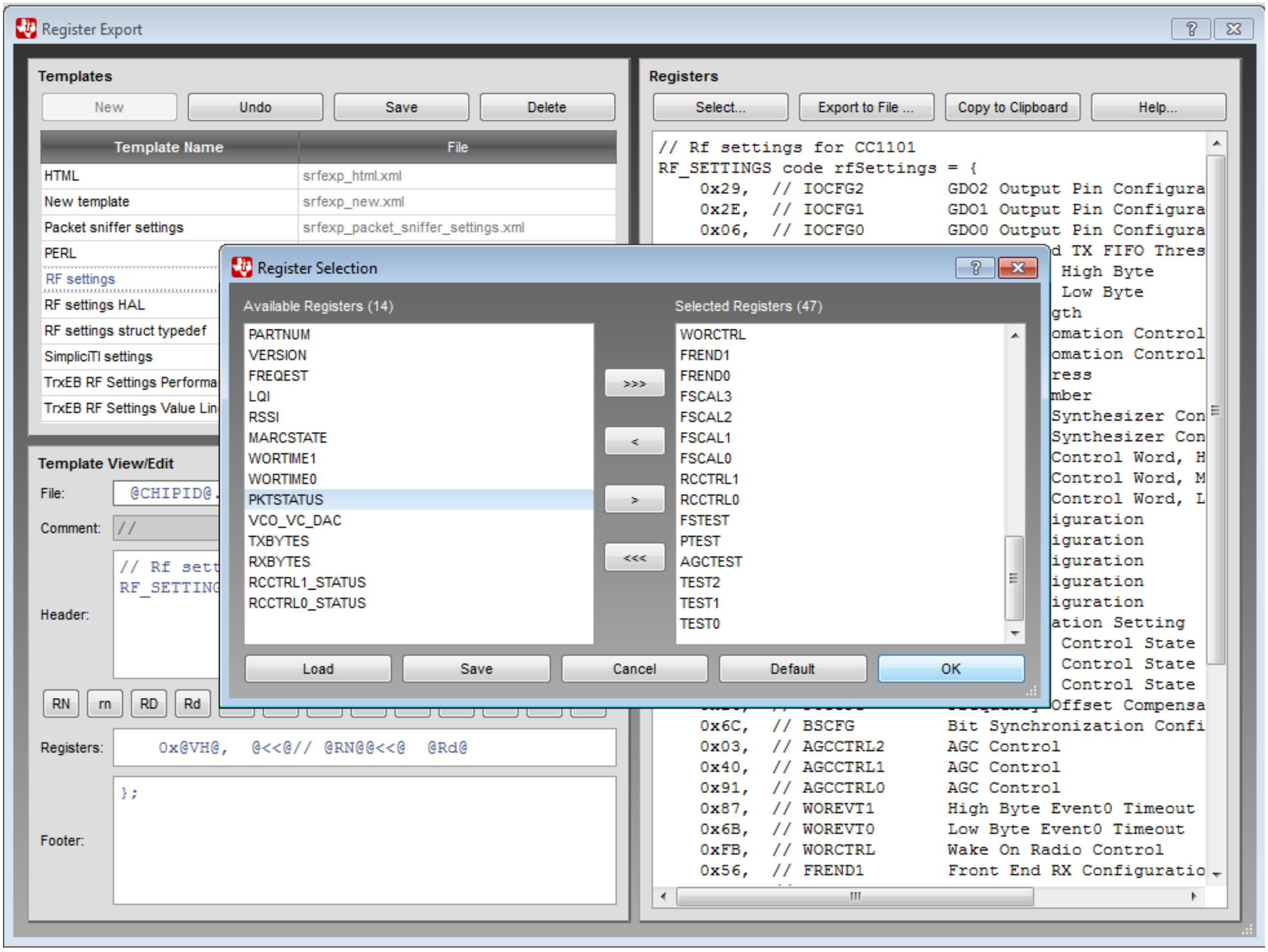
You can download it from http://www.ti.com/tool/download/SMARTRFTM-STUDIO/

Then click the CC1101 button's red circle and choose Open RF Device in Offline Mode.

The main screen for Smart RF Studio 7 looks like this:



In the center panel you can choose RF Parameters: Base Frequency, Modulation Format, Data Rate and TX Power. When you change these values, the hex values on the right of the screen change too. When all the options are set you can export the Hex values needed to configure the radio by clicking the Register Export button on the top right of the window.

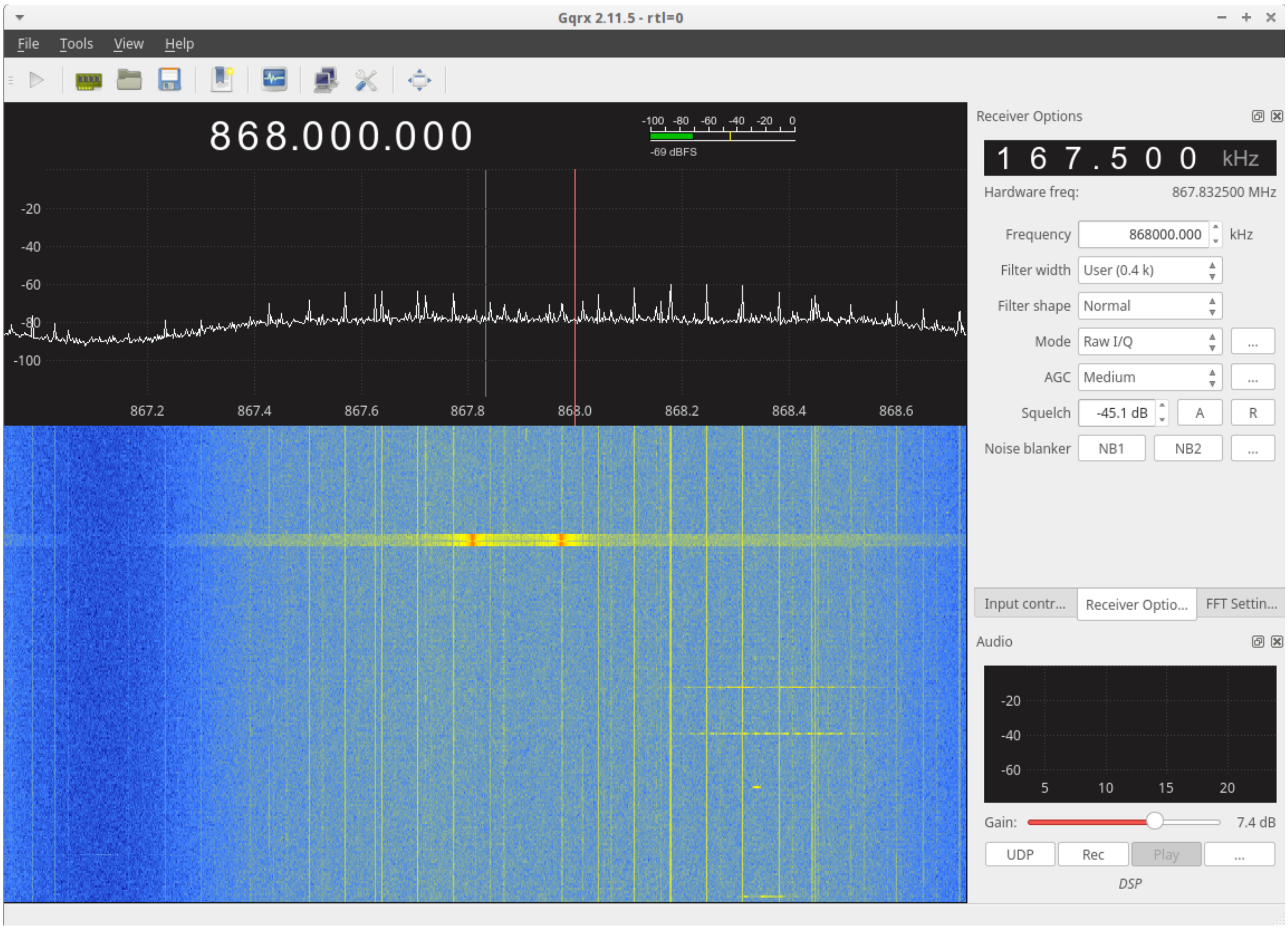


I've chosen template RF settings, then clicked on Select in the Registers tab, moved all 61 values to the right hand pane, and then scrolled down to TEST0, selected everything below that starting with PARTNUM, and moved them back to the left pane. I'm then left with a block of 47 values that can be cut and pasted back into SpaceTeddy's cc1100_raspi.cpp file, as replacements.

That only leaves us with the question of how do you discover that frequency, modulation scheme and data rate of your current RF devices, that you might want to make the CC1101 module receive from, or replicate the transmission signal of another device.

Say I have a wireless alarm system in my home that I know operates around the 868MHz band. I'd first get a USB RTL-SDR/TV dongle for around £10-£20 from eBay (search on eBay for RTL-SDR) and then install GQRX on my Ubuntu Linux PC following this short guide: http://gqrx.dk/download/install-ubuntu You also need to blacklist the kernel driver otherwise it assumes you want to use it as a TV stick – see http://oh2bsc.com/2015/02/17/getting-started-with-sdr-radio-using-dvb-t-usb-dongle-and-gqrx/

GQRX is then installed to the Internet folder on my list of Programs.



In the picture above I've set the frequency to 868 MHz and clicked the play button in the top left. A waterfall display then scrolls down the screen and when any RF gadget transmits it appears in the waterfall. I pressed the keyfob for my car, and two red & yellow bursts appeared. Often 868MHz gadgets operate on FSK, and because two bursts appear at the same time, I'm assuming the modulation scheme is 2-FSK (supported by CC1101). We could export this sample to Audacity or InSpectrum to work out the data rate or we could use Universal Radio Hacker.

Universal Radio Hacker is a set of tools for capturing and analysing RF signals from an RTL-SDR USB dongle. Assuming you’ve tried GQRX, URH will run fine too.

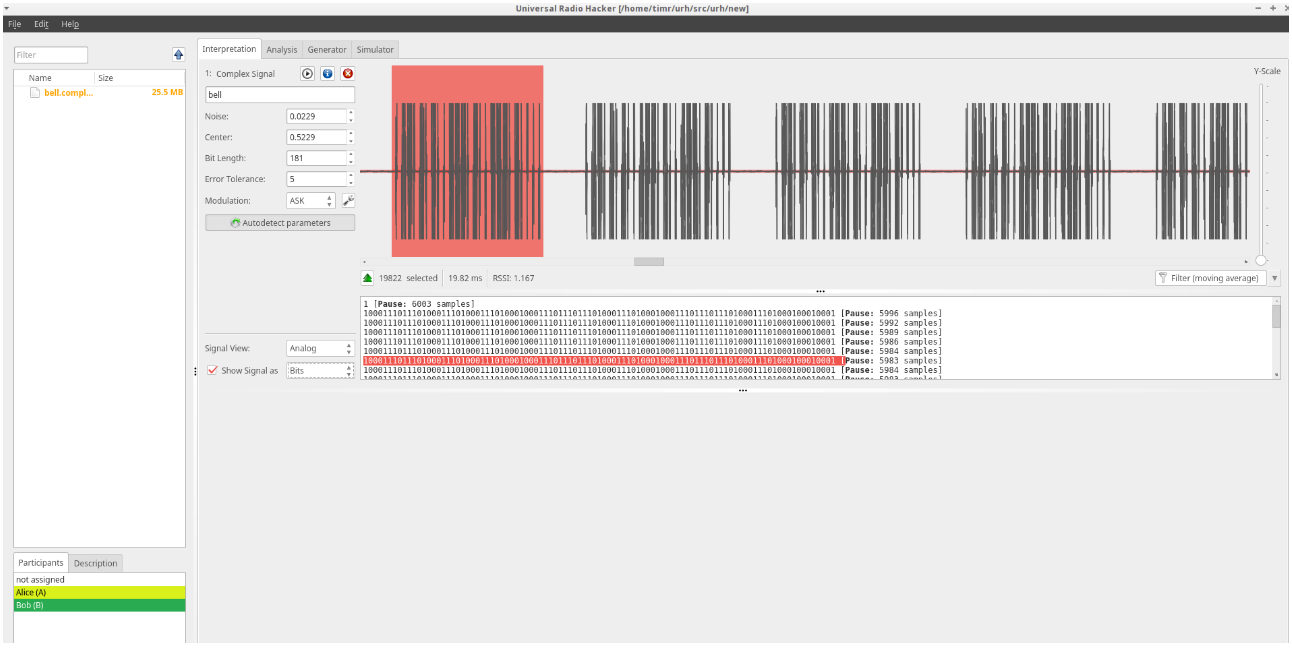
https://github.com/jopohl/urh

The manual is here: https://github.com/jopohl/urh/raw/master/data/userguide.pdf

And the excellent YouTube tutorial videos start here: https://www.youtube.com/watch?v=kuubkTDAxwA

I chose to run without installation, like this:

```
git clone https://github.com/jopohl/urh/
cd urh/src/urh
./main.py
```



If you want to do long range communications of say 1KM using two CC1101 modules, then you’ll need a pair of decent Yagi antennas and free space between the two sites. The antennas are £30 each from Farnell : http://uk.farnell.com/lprs/yagi-434a/antenna-yagi-7-element-434mhz/dp/2096215 or http://uk.farnell.com/lprs/yagi-869a/antenna-yagi-9-element-869-915mhz/dp/2096216

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We sell lots of electronic parts and kits for Raspberry Pi and Arduino in our eBay shop: http://stores.ebay.co.uk/ConvertStuffUK

and also here:

https://tri.co.uk/

If you spot any typos please email tim@trcomputers.co.uk