Department of Applied Electronics and Intelligent Systems

Embedded Architectures & Operating Systems

7. Laboratory

Interfacing to the Raspberry Pi Input/Outputs

7.1. Introduction

In this laboratory, you will see practical examples that explain how to use general-purpose input/outputs (**GPIOs**) to interface to different types of electronic circuits. The **GPIO** interfacing is performed first using **sysfs**, in order to remember the skills presented in a previous laboratory. Next, memory-mapped approaches are investigated that have impressive performance but are largely specific to the **RPi** platform. Finally, the **wiringPi** library of C functions is discussed in detail.

7.2. Equipment Required

To be able to achieve all the laboratory's goals, it is required to have the following hardware/software components:

- A **Raspberry Pi** development board with a Raspbian OS;
- Some components: 1 LED, 2 resistors (4K7 & 150 Ω) and a transistor (BC171);
- One push button;
- A breadboard and several hook-up wires.

7.3. General-Purpose Input/Outputs

You can interface to the RPi's GPIO header pins in the following ways:

1. **Digital output:** How you can use a GPIO to turn an electrical circuit on or off. The examples in this laboratory use an LED, but the principles hold for any circuit type; for example, you

could even use a relay to turn on/off high powered devices. But, driver circuits are required to ensure that you do not draw too much current from a GPIO.

2. **Digital input:** ensure you can read in a digital output from an electrical circuit into a software application running under Linux.
3. **Analog output:** you can use PWM to output a proportional signal that can be used as an analog voltage level or as a control signal for certain types of devices, such as servo motors.

Although there are 54 GPIO lines in the Raspberry Pi's processor, only 26 are brought out to the P1 connector on the board (less on the non-plus models); the other pins are used for actually making the processor act like a computer (things like the SD card, USB connector, and LEDs).

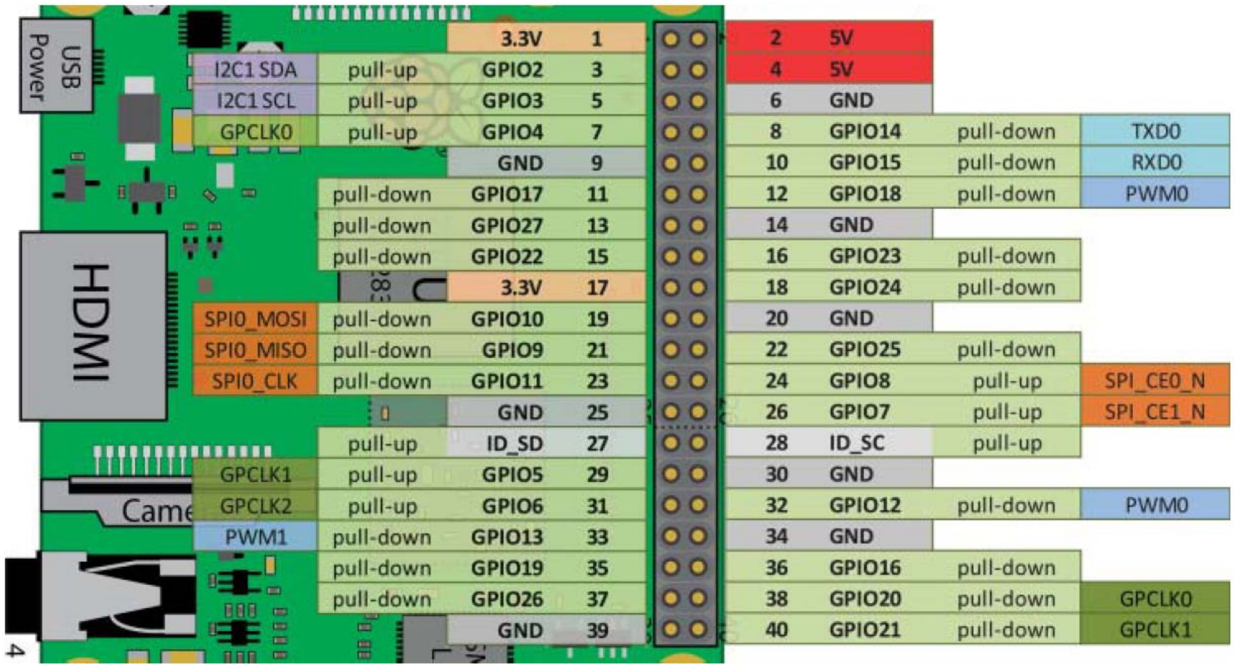


Figure 7.1. 40 pins **RPi** header

Figure 7.1 provides you with a first view of the functionality of the inputs and outputs on the GPIO header. Many of these pins are multiplexed, meaning they have more functions (or ALT modes) than what is displayed in the figure. This figure illustrates the most commonly used functionality.

The 26 GPIO pins can be individually configured as inputs or outputs, and use 3.3V logic levels where a HIGH logic level is represented as nominally 3.3 volts and a LOW by zero volts. **They cannot tolerate higher voltages (like 5 volts) without being damaged.**

7.4. Internal Pull-Up and Pull-Down Resistors

Each pin of the **RPi** has pull-up and pull-down resistors. These pull-up and pull-down resistors can be external or internal. Such external resistors are typically “strong” pull-up/down resistors in that they “strongly” tie the input to a high/low value using relatively small resistance values (e.g., 5 kΩ–10 kΩ or maybe less). The **RPi** has “weak” internal pull-up and internal pull-down resistors that can be configured using memory-based GPIO control techniques, see **Figure 7.2**. You need to factor these resistor values into the behavior of your input/output circuits, and you need to be able to alter the internal resistor configuration in certain circumstances. For example, you may even want to turn them off for a particular circuit.

Practical exercise: Interestingly, if you connect nothing to GPIO4, which is Pin 7 when you read it, a value of 1 will be returned. That is because this input is connected via an internal pull-up resistor to the 3.3V line. Whereas GPIO27 is low when it is interrogated with nothing connected to it. Please check all of these.

```
pi@raspberrypi: /sys/class/gpio $ echo 4 > export
pi@raspberrypi: /sys/class/gpio $ cd gpio4
pi@raspberrypi: /sys/class/gpio/gpio4 $ cat direction
out
pi@raspberrypi: /sys/class/gpio/gpio4 $ echo in > direction
pi@raspberrypi: /sys/class/gpio/gpio4 $ cat value
1
```

It should be clear at this stage that you need to understand the GPIO configuration, including these internal resistors, to use the GPIO pins properly. ***In the default configuration, e.g. after a reset, pull-up and pull-down resistors are connected accordingly with*** **Figure 7.1**.

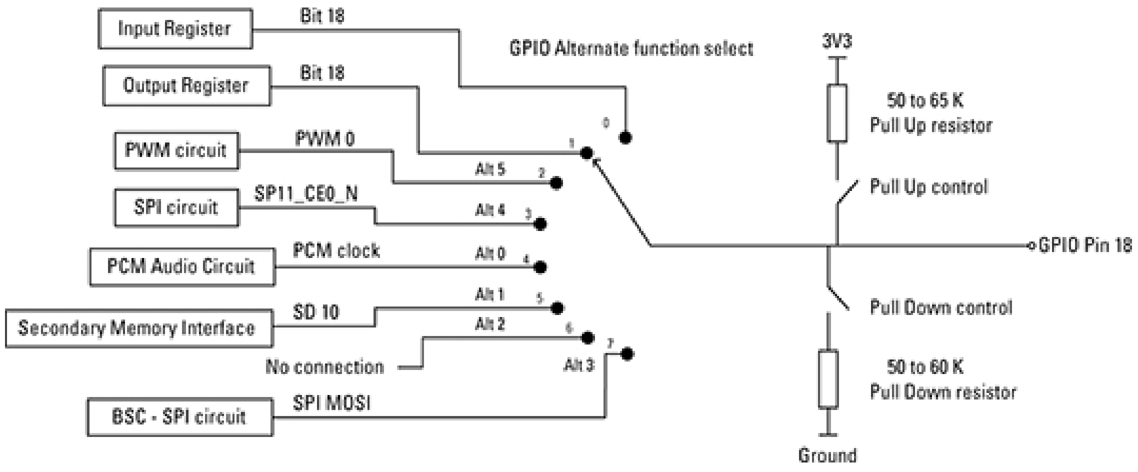


Figure 7.2. GPIO18 alternate functions

Also, note that Pin 3 (GPIO2 - SDA) and Pin 5 (GPIO3 - SCL) have two permanent onboard 1.8 kΩ "strong" pull-up resistors attached to the PCB.

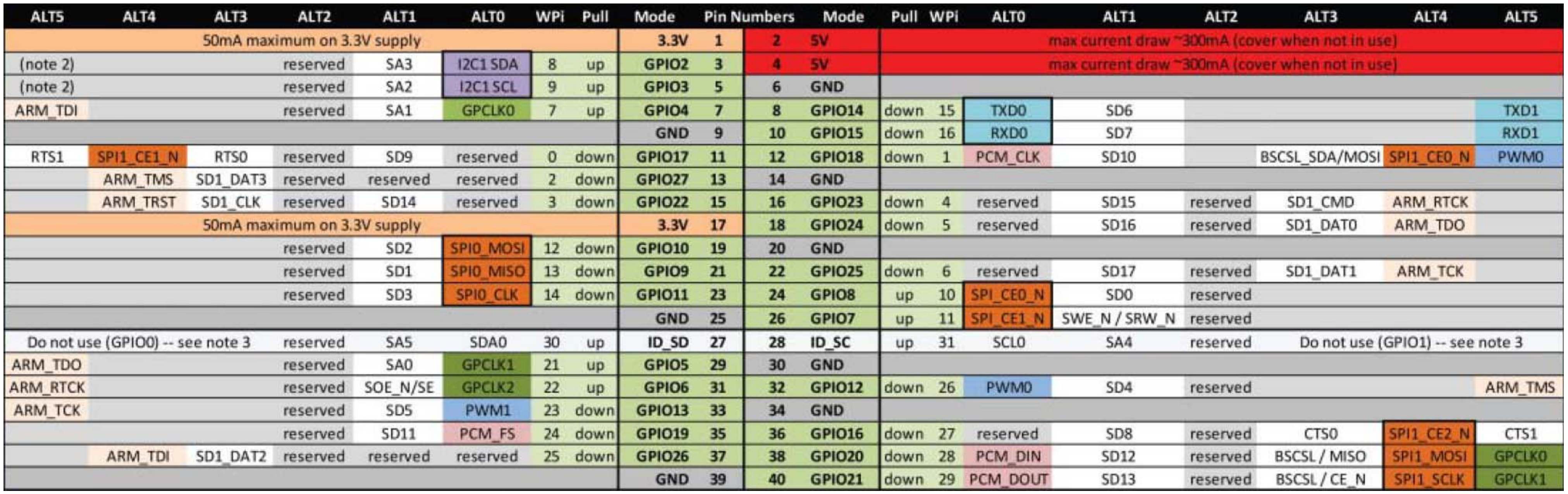
As well as configuring pins to have either a pull-up or a pull-down resistor configuration, there are also different modes for each pin. This is called the ALT mode for the pin. **Figure 7.3** provides a full list of alternative ways for each of the GPIO header pins.

You can see the basic arrangement for one pin, GPIO 18 in **Figure 7.2**. The general-purpose input/output (GPIO) pins can be switched between input or output and have a pull-up, or pull-down resistor enabled, but there are a host of other peripherals in the Raspberry Pi chip that can be switched to these pins. So, all the other pins have a similar arrangement but with different blocks to select from. The numbers on the switch are the three-bit register value that has to be set in the collection of alternate function select registers.

The first thing to spot in **Figure 7.3** is that there are two types of "nothing here": **(a)** one is blank and **(b)** the other is labeled as "reserved". It's likely that these reserved functions are used for factory testing of the chip or for purposes not disclosed in the datasheet. The blank ones are simply not implemented.

For the full story, the BCM2835 ARM Peripherals document (http://www.raspberrypi.org/wp-content/uploads/2012/02/BCM2835-ARM-Peripherals.pdf) is where you want to look, but here's a quick look at some of the functions:

1. **ALT 0:** Where most of the interesting and useful alternate functions are as far as the **Raspberry Pi** is concerned. The **SDA** and **SCL** 0 and 1 are the two I^{2}C buses, and the **TXD0** and **RXD0** are the serial connections. The **GPCLK** lines are a general-purpose clock output that can be set to run at a fixed frequency independent of any software. The **PWM** (pulse-width modulation is supported in hardware on pins GPIO12, GPIO13) pins provide the two pulse-width modulated outputs; the **SPI** 0 is the serial peripheral interface bus lines. Finally, the **PCM** pins provide pulse code modulated audio outputs.
2. **ALT 1:** The pins are used as a secondary memory bus. Due to the design of the Raspberry Pi, this is of no use at all.
3. **ALT 2:** The only ALT 2 pins brought out to the GPIO pin header are reserved.
4. **ALT 3:** The most useful pins here are the **CTS0** and **RTS0** lines; these are handshaking lines for the serial module if you need them. The **BSC** lines are for the Broadcom Serial Controller, which is a fast mode I^{2}C-compliant bus supporting 7-bit and 10-bit addressing and having the timing controlled by internal registers. The SD1 lines are probably for the control of an SD card.
5. **ALT 4:** The **SPI 1** lines are a second **SPI** bus. And the **ARM** pins are for a **JTAG** interface. **JTAG** is a way of talking to the chip without any software on it. It's very much used for the initial tests on a system during development, although it can be used for hardware debugging as well.



ALT5	ALT4	ALT3	ALT2	ALT1	ALT0	WPi	Pull	Mode	Pin Numbers		Mode	Pull	WPi	ALT0	ALT1	ALT2	ALT3	ALT4	ALT5
50mA maximum on 3.3V supply								3.3V	1	2	5V	max current draw ~300mA (cover when not in use)							
(note 2)			reserved	SA3	I2C1 SDA	8	up	GPIO2	3	4	5V	max current draw ~300mA (cover when not in use)							
(note 2)			reserved	SA2	I2C1 SCL	9	up	GPIO3	5	6	GND								
ARM_TDI			reserved	SA1	GPCLK0	7	up	GPIO4	7	8	GPIO14	down	15	TXD0	SD6				TXD1
								GND	9	10	GPIO15	down	16	RXD0	SD7				RXD1
RTS1	SPI1_CE1_N	RTS0	reserved	SD9	reserved	0	down	GPIO17	11	12	GPIO18	down	1	PCM_CLK	SD10		BSCSL_SDA/MOSI	SPI1_CE0_N	PWM0
	ARM_TMS	SD1_DAT3	reserved	reserved	reserved	2	down	GPIO27	13	14	GND								
	ARM_TRST	SD1_CLK	reserved	SD14	reserved	3	down	GPIO22	15	16	GPIO23	down	4	reserved	SD15	reserved	SD1_CMD	ARM_RTCK	
50mA maximum on 3.3V supply								3.3V	17	18	GPIO24	down	5	reserved	SD16	reserved	SD1_DAT0	ARM_TDO	
			reserved	SD2	SPI0_MOSI	12	down	GPIO10	19	20	GND								
			reserved	SD1	SPI0_MISO	13	down	GPIO9	21	22	GPIO25	down	6	reserved	SD17	reserved	SD1_DAT1	ARM_TCK	
			reserved	SD3	SPI0_CLK	14	down	GPIO11	23	24	GPIO8	up	10	SPI_CE0_N	SD0	reserved			
								GND	25	26	GPIO7	up	11	SPI_CE1_N	SWE_N / SRW_N	reserved			
Do not use (GPIO0) -- see note 3			reserved	SA5	SDA0	30	up	ID_SD	27	28	ID_SC	up	31	SCL0	SA4	reserved	Do not use (GPIO1) -- see note 3		
ARM_TDO			reserved	SA0	GPCLK1	21	up	GPIO5	29	30	GND								
ARM_RTCK			reserved	SOE_N/SE	GPCLK2	22	up	GPIO6	31	32	GPIO12	down	26	PWM0	SD4	reserved			ARM_TMS
ARM_TCK			reserved	SD5	PWM1	23	down	GPIO13	33	34	GND								
			reserved	SD11	PCM_FS	24	down	GPIO19	35	36	GPIO16	down	27	reserved	SD8	reserved	CTS0	SPI1_CE2_N	CTS1
	ARM_TDI	SD1_DAT2	reserved	reserved	reserved	25	down	GPIO26	37	38	GPIO20	down	28	PCM_DIN	SD12	reserved	BSCSL / MISO	SPI1_MOSI	GPCLK0
								GND	39	40	GPIO21	down	29	PCM_DOUT	SD13	reserved	BSCSL / CE_N	SPI1_SCLK	GPCLK1

Figure 7.3. The **RPi** alternate functions

6. **ALT 5:** The useful pins here are the secondary serial port data and handshaking lines. The **PWM** lines are precisely the same **PWM** lines that are switched to **GPIO12** and **13** under **ALT** 0. There are also two of the general-purpose clock lines along with another copy of the ARM JTAG signals.

7.5. The hardware part

Figure 7.4 is presented a circuit based on which you can connect to the **RPi** in a safe way to drive an LED, using a BC 171 component – an NPN transistor. This circuit is all you need to test all the code that is presented in this laboratory. In this example the **GPIO** pin (**GPIO4**), which is connected to Pin 7 on the **GPIO** header, see **Figure 7.4**, provides the low current required to switch the transistor on or off, depending on whether the **GPIO** state is high or low.

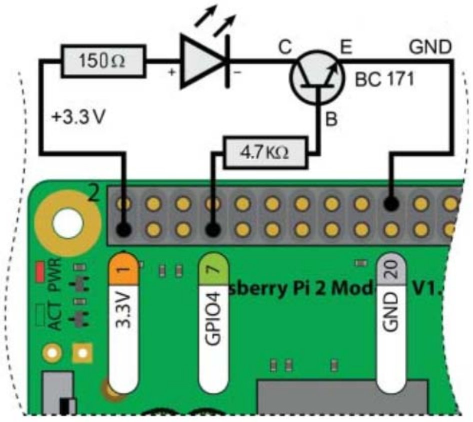


Figure 7.4. Driving a LED by a GPIO pin using an NPN transistor

WARNING: Be very careful when wiring circuits such as those in **Figure 7.4**. Incorrect connections or the use of the wrong header pin can destroy your RPi. **It is mandatory, to wire such circuits with the power to the RPi disconnected**. Only power up the **RPi** once you have carefully checked the circuit configuration.

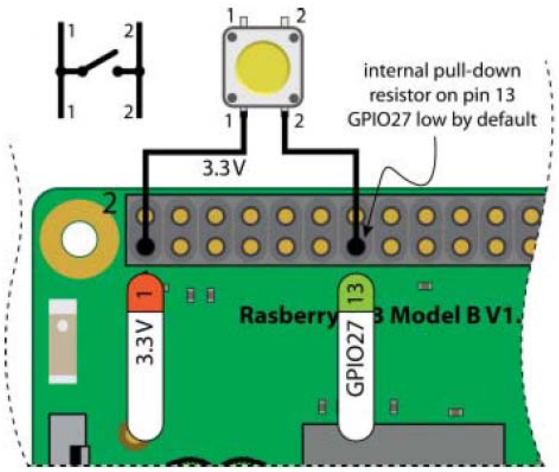


Figure 7.5. Connecting a pushbutton to the **RPi** using the internal pull-down resistor

Please build, also, the circuit presented in **Figure 7.5**. The circuit shown in **Figure 7.5** consists of a normally open push button that is connected to the **RPi Pin 13** (**GPIO27**). You can notice that in a normal situation, a pull-up or pull-down resistors on pushbutton switches are required, but none are present in this circuit. This is not accidental, because **Pin 13** on the **GPIO** header is connected by default to GND using an internal pull-down resistor.

The LED circuit, presented in **Figure 7.4**, should be left connected when building this input circuit (shown in **Figure 7.5**) because both circuits are used throughout this laboratory.

7.6. Memory-Based GPIO Control

Based on the full datasheet for the Broadcom BCM2835 Peripherals is possible to use such low-level I/O detail to bypass the Linux kernel, using direct memory manipulation to take control of the SoC's inputs and outputs. While this approach can achieve much better I/O performance, you should avoid using it if possible, because your programs will not be portable to other embedded Linux platforms. Besides, since the Linux kernel is unaware of such direct memory manipulations, you could potentially generate resource conflicts.

Linux uses a virtual memory system, which means that there is a difference between the physical address used by the hardware and the virtual address that is used to access the device. In 32-bit Linux the virtual memory system utilizes the full 32-bit addressing to allocate a virtual space that is much larger than the available physical memory; 32-bit addressing supports 2^{32} addresses (i.e., 4 GB), whereas there is 1 GB of RAM available on the **RPi 3**. The extended address range allows for memory paging and the mapping of physical devices (e.g., peripherals) into a unified address space.

The GPIO peripheral base address on the RPi 2/3 is 0x3f20 0000.

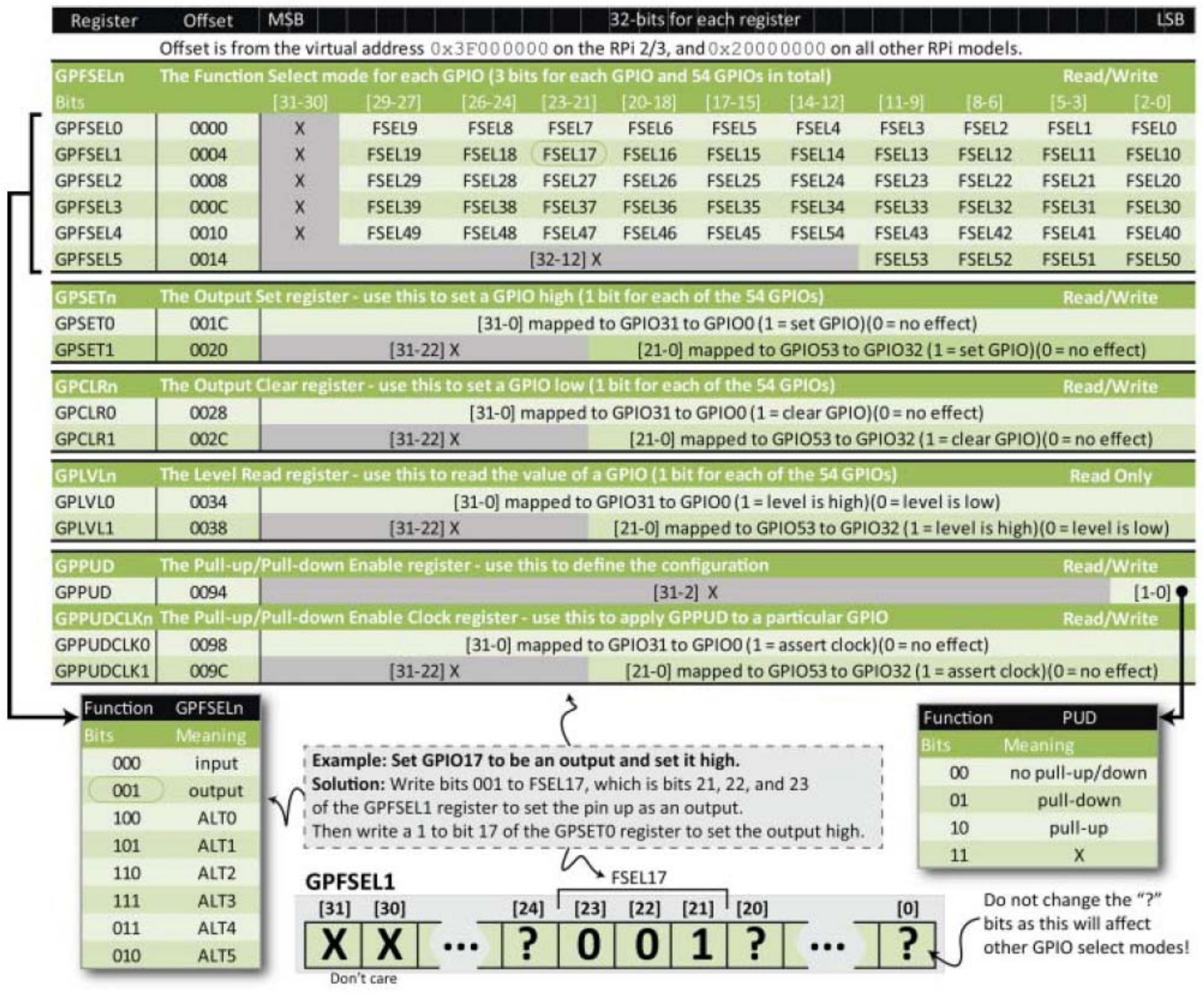
GPIO Control Using devmem2

You can query the value at a memory address using C code that accesses **/dev/mem** directly. However, to become familiar with the steps, it is best that you build and install Jan-Derk Bakker's **devmem2** program, which is a handy command-line tool for reading from and writing to memory locations:

```
pi@raspberrypi:~ $ wget http://www.lartmaker.nl/lartware/port/devmem2.c
pi@raspberrypi:~ $ gcc devmem2.c -o devmem2
pi@raspberrypi:~ $ ./devmem2
pi@raspberrypi:/sys/class/gpio $ ls
Usage: ./devmem2 { address } [ type [ data ] ]
        address  : memory address to act upon
```

type : access operation type: [b]yte, [h]alfword, [w]ord
data : data to be written

The registers that are important for GPIO control are described in **Figure 7.6**.



Register	Offset	MSB				32-bits for each register						LSB
	Offset is from the virtual address 0x3F000000 on the RPi 2/3, and 0x20000000 on all other RPi models.											
GPFSELn	The Function Select mode for each GPIO (3 bits for each GPIO and 54 GPIOs in total)											Read/Write
Bits		[31-30]	[29-27]	[26-24]	[23-21]	[20-18]	[17-15]	[14-12]	[11-9]	[8-6]	[5-3]	[2-0]
GPFSEL0	0000	X	FSEL9	FSEL8	FSEL7	FSEL6	FSEL5	FSEL4	FSEL3	FSEL2	FSEL1	FSEL0
GPFSEL1	0004	X	FSEL19	FSEL18	FSEL17	FSEL16	FSEL15	FSEL14	FSEL13	FSEL12	FSEL11	FSEL10
GPFSEL2	0008	X	FSEL29	FSEL28	FSEL27	FSEL26	FSEL25	FSEL24	FSEL23	FSEL22	FSEL21	FSEL20
GPFSEL3	000C	X	FSEL39	FSEL38	FSEL37	FSEL36	FSEL35	FSEL34	FSEL33	FSEL32	FSEL31	FSEL30
GPFSEL4	0010	X	FSEL49	FSEL48	FSEL47	FSEL46	FSEL45	FSEL54	FSEL43	FSEL42	FSEL41	FSEL40
GPFSEL5	0014	[32-12] X							FSEL53	FSEL52	FSEL51	FSEL50
GPSETn	The Output Set register - use this to set a GPIO high (1 bit for each of the 54 GPIOs)											Read/Write
GPSET0	001C	[31-0] mapped to GPIO31 to GPIO0 (1 = set GPIO)(0 = no effect)										
GPSET1	0020	[31-22] X				[21-0] mapped to GPIO53 to GPIO32 (1 = set GPIO)(0 = no effect)						
GPCLRn	The Output Clear register - use this to set a GPIO low (1 bit for each of the 54 GPIOs)											Read/Write
GPCLR0	0028	[31-0] mapped to GPIO31 to GPIO0 (1 = clear GPIO)(0 = no effect)										
GPCLR1	002C	[31-22] X				[21-0] mapped to GPIO53 to GPIO32 (1 = clear GPIO)(0 = no effect)						
GPLVLn	The Level Read register - use this to read the value of a GPIO (1 bit for each of the 54 GPIOs)											Read Only
GPLVL0	0034	[31-0] mapped to GPIO31 to GPIO0 (1 = level is high)(0 = level is low)										
GPLVL1	0038	[31-22] X				[21-0] mapped to GPIO53 to GPIO32 (1 = level is high)(0 = level is low)						
GPPUD	The Pull-up/Pull-down Enable register - use this to define the configuration											Read/Write
GPPUD	0094	[31-2] X										[1-0]
GPPUDCLKn	The Pull-up/Pull-down Enable Clock register - use this to apply GPPUD to a particular GPIO											Read/Write
GPPUDCLK0	0098	[31-0] mapped to GPIO31 to GPIO0 (1 = assert clock)(0 = no effect)										
GPPUDCLK1	009C	[31-22] X				[21-0] mapped to GPIO53 to GPIO32 (1 = assert clock)(0 = no effect)						

Function	GPFSELn
Bits	Meaning
000	input
001	output
100	ALT0
101	ALT1
110	ALT2
111	ALT3
011	ALT4
010	ALT5

Function	PUD
Bits	Meaning
00	no pull-up/down
01	pull-down
10	pull-up
11	X

Example: Set GPIO17 to be an output and set it high.
Solution: Write bits 001 to FSEL17, which is bits 21, 22, and 23 of the GPFSEL1 register to set the pin up as an output.
Then write a 1 to bit 17 of the GPSET0 register to set the output high.

Figure 7.6. Examples of the registers available for memory-mapped GPIO manipulation

If the circuit is connected as in **Figure 7.4**, it is possible to use the devmem2 program to control the **LED** circuit. Assuming that the **devmem2** program is currently present in the pi user home directory, you can use it to read the value of the **GPLVL0** register on the **RPi**:

```
pi@raspberrypi: /sys/class/gpio $ echo 4 > export
pi@raspberrypi: /sys/class/gpio $ cd gpio4
pi@raspberrypi: /sys/class/gpio/gpio4 $ echo out > direction
pi@raspberrypi: /sys/class/gpio/gpio4 $ cat value
0
pi@raspberrypi: /sys/class/gpio/gpio4 $ sudo ~/devmem2 0x3F200034
```

]

```
/dev/mem opened.
Memory mapped at address 0x76f0e000.
Value at address 0x3F200034 (0x76f0e034): 0xC1EF
pi@raspberrypi: /sys/class/gpio/gpio4 $ echo 1 > value
pi@raspberrypi: /sys/class/gpio/gpio4 $ sudo ~/devmem2 0x3F200034
/dev/mem opened.
Memory mapped at address 0x76f0e000.
Value at address 0x3F200034 (0x76f0e034): 0xC1FF
```

Notice that the difference is 0x10, which is 10000 in binary (i.e., 1 followed by 4 zeros, or 1<<4). **GPIO4** is in the first bank of addresses. For **GPIO32** to **GPIO53**, you have to read the **GPLVL1** register. The output above indicates that the output is low the first time that the **GPLVL0** register is displayed, and high the second time.

You can use the same **devmem2** program to set the LED to be off by setting bit 4 on the **GPCLR0** (0028) register, and the **LED** to be on by setting bit 4 on the **GPSET0** (001C) register:

```
pi@raspberrypi: /sys/class/gpio/gpio4 $ cat value
1
pi@raspberrypi: /sys/class/gpio/gpio4 $ sudo ~/devmem2 0x3F200028 w 0x10
/dev/mem opened.
Memory mapped at address 0x76fd6000.
Value at address 0x3F200028 (0x76fd6028): 0x6770696F
Written 0x10; readback 0x6770696F
pi@raspberrypi: /sys/class/gpio/gpio4 $ cat value
0
pi@raspberrypi: /sys/class/gpio/gpio4 $ sudo ~/devmem2 0x3F20001C w 0x10
/dev/mem opened.
Memory mapped at address 0x76f10000.
Value at address 0x3F20001C (0x76f1001c): 0x0x6770696F
Written 0x10; readback 0x6770696F
pi@raspberrypi: /sys/class/gpio/gpio4 $ cat value
1
```

Here you can see that setting these bits has a direct impact on the **sysfs** value entry for the GPIO4 entry.

Homework: Move the B (base) connection of the BC171 transistor through 4.7K resistor at the **GPIO10** - pin 19 of the **RPi** header, see **Figure 7.1**. Now turn on and off the LED.

GPIO Control Using C and /dev/mem

Figure 7.6 also provides details and an example of how to configure the mode of a pin. All of the GPIOs can be set to read or write mode, or they can be set to an ALT mode, which is listed in **Figure 7.3**. The mode is set using a 3-bit value as listed in the table on the bottom left of **Figure 7.6**. For example, by setting the 3-bit value to be 000 then the pin will act as an input.

The location to which you should write the 3-bit mode is described in **Figure 7.6**. For example, to set **GPIO17** to be an output, you can write 001 to the FSEL17 value, which is bits 21, 22, and 23 in the **GPFSEL1** register. Importantly, you need to ensure that you only manipulate those specific 3 bits when you change **FSEL17**, because to change any other bits will impact on **GPIO10–GPIO19**, likely changing their pin modes. Below is a listing that provides a C code example that sets up GPIO4 as output and flashes an LED. It also sets up GPIO27 as an input, so that the LED will continue to flash until a pushbutton is pressed. The comments in the code listing describe the bit manipulations that are used.

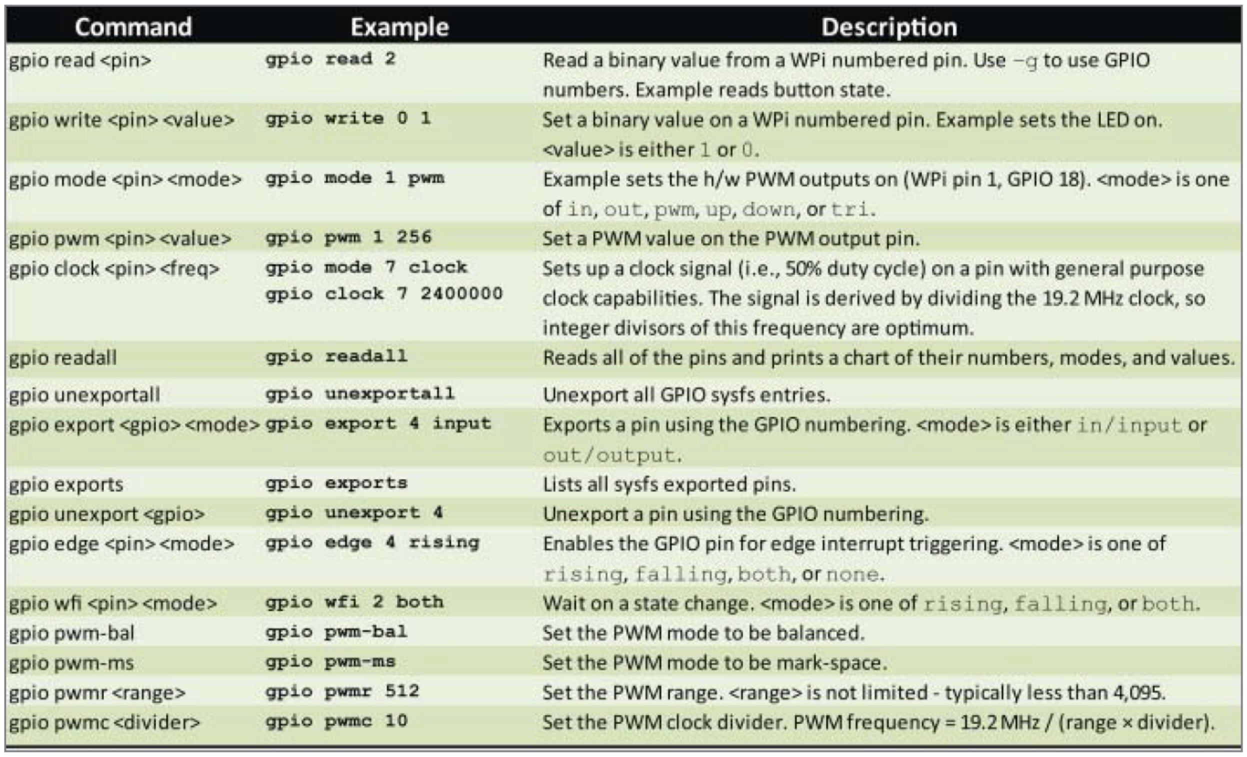
In a previous laboratory I told you that the **NetBeans IDE** will be the default development tools for this discipline. But, the following program requires to be run as a root in order to work properly – this is a little bit difficult from **NetBeans IDE**. So, as result please develop the program directly on the **Rasberry Pi** platform. After the built of the program, executed it using the **sudo** tool.

```
#include <stdio.h>
#include <stdlib.h>
#include <fcntl.h>
#include <errno.h>
#include <sys/mman.h>
#include <stdint.h>                 // for uint32_t - 32-bit unsigned integer

// GPIO_BASE is 0x20000000 on RPi models other than the RPi 2/3
#define GPIO_BASE 0x3F200000        // on the RPi 2/3
#define GPSET0 0x1c                 // output set register ----------- from Figure 7.6
#define GPCLR0 0x28                 // output clear register
#define GPLVL0 0x34                 // read register
static volatile uint32_t *gpio;     // pointer to the gpio (*int)

int main ( int argc, char** argv )
{
   int fd, x;
   printf ("Start of GPIO memory-manipulation test program.\n");
   if ( getuid() != 0 )
      {
```

```
   printf("You must run this program as root. Exiting.\n");
   return -1;
   }

if ( (fd = open("/dev/mem", O_RDWR | O_SYNC)) < 0 )
   {
   printf("Unable to open /dev/mem: %s\n", strerror(errno));
   return -2;          //busy
   }

// get a pointer that points to the peripheral base for the GPIOs
gpio = (uint32_t *) mmap (0, getpagesize(), PROT_READ|PROT_WRITE,
                                        MAP_SHARED, fd, GPIO_BASE);
if ( (int32_t) gpio < 0 )
   {
   Printf ("Memory mapping failed: %s\n", strerror(errno));
   return -2;          //busy
   }

// Here the gpio pointer points to the GPIO peripheral base address.
// Set up the LED GPIO FSEL4 mode = 001 at addr GPFSEL0 (0000).
// Writing NOT 7 (i.e., ~111) clears bits 12, 13 and 14.
*gpio = (*gpio & ~(7 << 12) | (1 << 12));
// Set up the button GPIO FSEL27 mode = 000 at addr GPFSEL2 (0008).
// Remember that adding two 32-bit value moves the addr by 8 bytes.
*(gpio + 2) = (*(gpio + 2) & ~(7 << 21));
// Writing the 000 is not necessary but is there for clarity.

do {
   // Turn the LED on using bit 4 on the GPSET0 register
   *(gpio + (GPSET0/4)) = 1 << 4;
   usleep(50000);
   *(gpio + (GPCLR0/4)) = 1 << 4; // turn the LED off
   usleep(50000);
} while((*(gpio+(GPLVL0/4))&(1<<27))==0); // only true if bit 27 high

printf("Button was pressed - end of example program.\n");
close(fd);

return (EXIT_SUCCESS);
```

```
}
```

Homework: Re-design the program, previously presented, so that the blinking of the LED will start after the button is pressed.



Command	Example	Description
gpio read <pin>	`gpio read 2`	Read a binary value from a WPi numbered pin. Use `-g` to use GPIO numbers. Example reads button state.
gpio write <pin> <value>	`gpio write 0 1`	Set a binary value on a WPi numbered pin. Example sets the LED on. <value> is either `1` or `0`.
gpio mode <pin> <mode>	`gpio mode 1 pwm`	Example sets the h/w PWM outputs on (WPi pin 1, GPIO 18). <mode> is one of `in`, `out`, `pwm`, `up`, `down`, or `tri`.
gpio pwm <pin> <value>	`gpio pwm 1 256`	Set a PWM value on the PWM output pin.
gpio clock <pin> <freq>	`gpio mode 7 clock` `gpio clock 7 2400000`	Sets up a clock signal (i.e., 50% duty cycle) on a pin with general purpose clock capabilities. The signal is derived by dividing the 19.2 MHz clock, so integer divisors of this frequency are optimum.
gpio readall	`gpio readall`	Reads all of the pins and prints a chart of their numbers, modes, and values.
gpio unexportall	`gpio unexportall`	Unexport all GPIO sysfs entries.
gpio export <gpio> <mode>	`gpio export 4 input`	Exports a pin using the GPIO numbering. <mode> is either `in/input` or `out/output`.
gpio exports	`gpio exports`	Lists all sysfs exported pins.
gpio unexport <gpio>	`gpio unexport 4`	Unexport a pin using the GPIO numbering.
gpio edge <pin> <mode>	`gpio edge 4 rising`	Enables the GPIO pin for edge interrupt triggering. <mode> is one of `rising`, `falling`, `both`, or `none`.
gpio wfi <pin> <mode>	`gpio wfi 2 both`	Wait on a state change. <mode> is one of `rising`, `falling`, or `both`.
gpio pwm-bal	`gpio pwm-bal`	Set the PWM mode to be balanced.
gpio pwm-ms	`gpio pwm-ms`	Set the PWM mode to be mark-space.
gpio pwmr <range>	`gpio pwmr 512`	Set the PWM range. <range> is not limited - typically less than 4,095.
gpio pwmc <divider>	`gpio pwmc 10`	Set the PWM clock divider. PWM frequency = 19.2 MHz / (range × divider).

Figure 7.7. Some of the **gpio** command options

7.7. WiringPi

The **WiringPi** is a pin-based **GPIO** access library written in C for the BCM2835, BCM2836 and BCM2837 SoC devices used in all **Raspberry Pi** versions. So, **WiringPi** (www.wiringpi.com) is an extensive **GPIO** control library for the **RPi** platform. The library function syntax is similar to that in the Arduino Wiring library, and it is a popular choice among **RPi** users. The **wiringPi** library also has third-party bindings for **Python**, **Ruby**, and **Perl**.

WiringPi utilizes the **sysfs** and memory-mapped techniques described in this laboratory and in a previous one, to create a highly efficient library and command set that has been custom developed for the **RPi** platform. It is recommended that you use this library for controlling the **GPIOs** on the **RPi** when fast **GPIO** switching is required; however, be aware that this approach is mostly specific to the **RPi** platform and not to embedded Linux devices in general.

Installing wiringPi

To install the **wiringPi** do as follows:

```
pi@raspberrypi:~ $ sudo apt-get install wiringpi
```

In most cases, the **wiringPi is** pre-installed with standard **Raspbian** systems, so it is not required to install once again.

The gpio Command

Installed as part of the **wiringPi** build, the **gpio** program is a handy command-line tool for accessing and controlling the GPIOs on the **RPi**. **Figure 7.7** provides a summary of some of the available commands, along with some example usage.

For historical reasons, **wiringPi** tends use a different numbering scheme than the physical pin number or **GPIO** number. These numbers are displayed in the **WPi** column in **Figure 7.3**. However, many **gpio** commands can also accept regular **GPIO** numbering by using a **-g** option. So, you can use the **gpio** command to write Linux scripts to control the GPIOs.

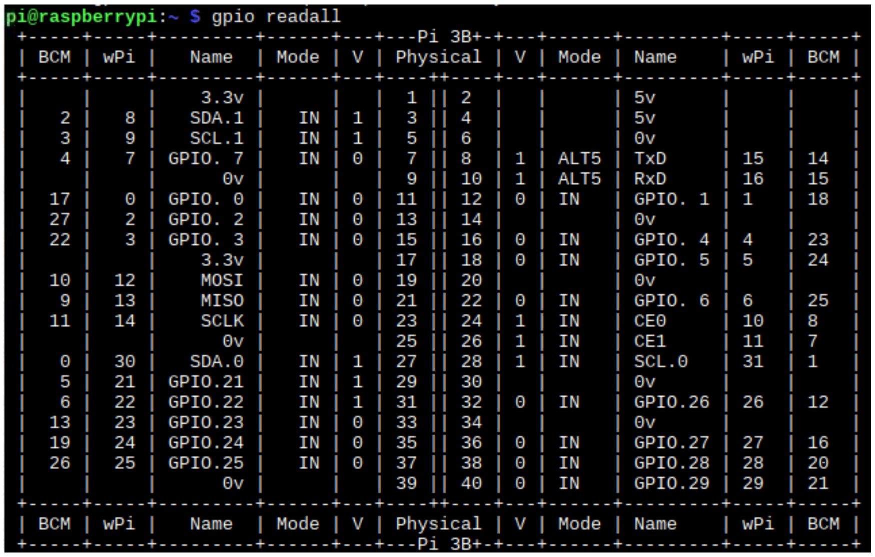
To check the version of the **wiringPi** use:

```
pi@raspberrypi:~ $ gpio -v
```

To reads all the normally accessible pins, prints a table of their numbers along with their modes and current values you can use:

```
pi@raspberrypi:~ $ gpio readall
```

This command will detect the version/model of your **RPi** and printout the pin diagram appropriate to your Pi, as it is presented in **Figure 7.8**.



```
pi@raspberrypi:~ $ gpio readall
 +-----+-----+---------+------+---+---Pi 3B+-+---+------+---------+-----+-----+
 | 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 |   IN | 0 |  7 || 8  | 1 | ALT5 | TxD     | 15  | 14  |
 |     |     |      0v |      |   |  9 || 10 | 1 | ALT5 | 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 |   IN | 0 | 19 || 20 |   |      | 0v      |     |     |
 |   9 |  13 |    MISO |   IN | 0 | 21 || 22 | 0 | IN   | GPIO. 6 | 6   | 25  |
 |  11 |  14 |    SCLK |   IN | 0 | 23 || 24 | 1 | IN   | CE0     | 10  | 8   |
 |     |     |      0v |      |   | 25 || 26 | 1 | IN   | 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 3B+-+---+------+---------+-----+-----+
```

Figure 7.8. The results of the **gpio readall**

This command will detect the version/model of your **RPi** and will printout the pin diagram appropriate to your **RPi** system.

In **Figure 7.8**, the **BCM** is the pin number when using GPIO (aka BCM) numbering scheme, and **wPi** is the pin number when using the **wiringPi**'s own pin numbering scheme. So when using **wiringPi**, if you choose **wiringPiSetup()**, it will default to using the **wPi** pin numbers, and **wiringPiSetupGpio()** will result in using the **GPIO/BCM** numbers. In the "Physical" column are the pin numbers on the connector. The "V" column indicates the voltage level of the pins. As you may notice, the "0/1" value is applicable for GPIO pins only, and leave blank for the rest. V = 0 indicates the voltage level on the pin is LOW; the exact voltage value is 0V. In contrast, V = 1 indicates the voltage level on the pin is HIGH, the voltage value is around 3.3V.

The "Mode" shows how the pin is being used. Here is the list of valid modes able to set for **GPIO**: in/out/pwm/clock/up/down/tri. However, you also see the "ALT[#]" listed in the Mode column. This ALT[#] indicates the GPIO pin is being used as alternative function – a specific function, not as general purpose function.

- **in**: the GPIO pin is used as input without software-register-pull-up or software-register-pull-down. In this mode, if the pin is not connected to any reference point, the input state will be unknown (it is floated).
- **out**: the GPIO pin is used as an output, and without software-register-pull-up or software-register-pull-down. In this mode, if the pin is not connected to any reference point, the input state will be unknown (it is floated).
- **pwm**: the GPIO pin is used as hardware Pulse-Width-Modulation mode which is square waveform generation. This mode is usually used to control DC motor speed or LED dimming. Keep in mind that only BCM 18 (or GPIO.1) supports PWM output mode.
- **clock**: the GPIO pin is used as a clock generator. The frequency of clock is driven from main crystal frequency of Raspberry Pi. Note that only BCM 4 (or GPIO.7) supports CLOCK output mode.
- **up**: The GPIO pin is used as an input with software-register-pull-up. In this mode, if the pin is not connected to any reference point, the input state will be HIGH (or 1).
- **down**: The GPIO pin is used as an input with software-register-pull-down. In this mode, if the pin is not connected to any reference point, the input state will be LOW (or 0).
- **tri**: The GPIO pin is used as input without software-register-pull-down or up. In this mode, if the pin is not connected to any reference point, the input state will be LOW or HIGH.
- **ALT[#]**: The GPIO pin is used as a special function. You can check the list of those special functions at this link.

Programming with wiringPi

WiringPi contains a comprehensive library of C functions for controlling **RPi** GPIOs, regardless of the board model. The following listing provides a first **wiringPi** program that displays information about the board that you are using. Again, it is assumed for these examples that the board is connected to the LED and Button circuits, as illustrated in **Figure 7.4** and **Figure 7.5**. Mainly because the **wiringPi** library is used, the linker requires **–lwiringPi** option.

Use NetBeans to implement and run the following program:

```
#include <stdio.h>
#include <stdlib.h>
#include <wiringPi.h>

#define LED_GPIO 4      // this is GPIO4,  Pin 7
#define BUTTON_GPIO 27  // this is GPIO27, Pin 13

int main(int argc, char** argv)
{
   wiringPiSetupGpio();          // use the GPIO numbering form
   pinMode(LED_GPIO, OUTPUT);     // the LED set up as an output
   pinMode(BUTTON_GPIO, INPUT);   // the Button set up as an input

   int model, rev, mem, maker, overVolted;
   piBoardId(&model, &rev, &mem, &maker, &overVolted);

   printf ("\n This is an RPi: %s", piModelNames[model]);
   printf ("\n   with revision number: %s", piRevisionNames[rev]);
   printf ("\n   manufactured by: %s", piMakerNames[maker]);
   printf ("\n   it has: %d RAM and o/v: %d", mem, overVolted);

   printf ("\n\n Button GPIO has ALT mode: %d", getAlt(BUTTON_GPIO));
   printf ("\n   and value: %d", digitalRead(BUTTON_GPIO));

   printf ("\n\n LED GPIO has ALT mode: %d", getAlt(LED_GPIO));
   printf ("\n   and value: %d", digitalRead(LED_GPIO));

   return (EXIT_SUCCESS);
}
```

This code can be built using **gcc** by linking to the **wiringPi** library, based on **-lwiringPi** that explicitly links to **libwiringPi.so**.

Toggling an LED Using wiringPi

The following listing provides a code example for toggling a GPIO.

```
#include <stdio.h>
#include <stdlib.h>
#include <wiringPi.h>

#define LED_GPIO 4                        // this is GPIO4, Pin 7

int main(int argc, char** argv)
{
   wiringPiSetupGpio();                   // use GPIO, not WPi, labels
   printf ( "Starting fast GPIO toggle on GPIO%d", LED_GPIO );
   printf ( "Press CTRL+C to quit..." );
   pinMode(LED_GPIO, OUTPUT);             // GPIO4 is an output pin

   while(1)
      {                                   // loop forever - await ^C press
      digitalWrite(LED_GPIO, HIGH);       // LED on
      usleep(500000);
      digitalWrite(LED_GPIO, LOW);        // LED off
      usleep(500000);
      }                                   // the duty cycle somewhat
return 0;                                 // program will never reach here!
}
```

Develop a new program so that the LED goes on and on only when the user presses the button.

Homework: Develop a new program so that the LED will be on all the time and will go off only when the user presses the button. Use for this **digitalRead(**BUTTON_GPIO) function.