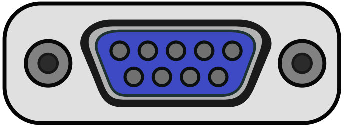
Linux serial drivers

This file is an old chapter of Free Electrons' embedded Linux kernel and driver development training materials (http://free-electrons.com/training/kernel/), which has been removed and is no longer maintained.

PDF version and sources are available on http://free-electrons.com/doc/legacy/serial-drivers/



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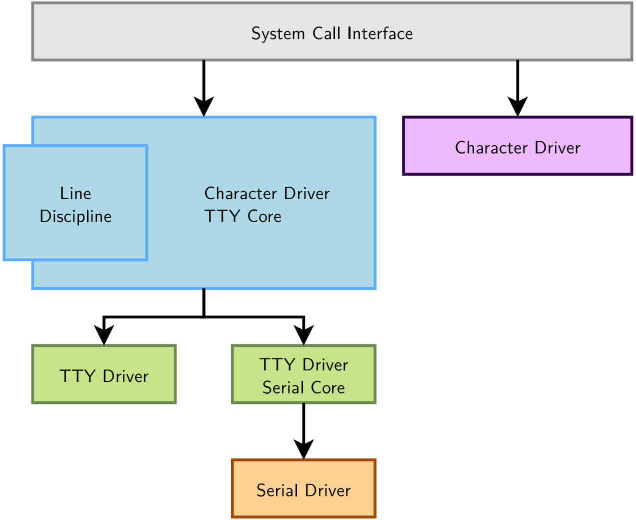
Architecture (1)



Architecture (2)

- To be properly integrated in a Linux system, serial ports must be visible as TTY devices from user space applications
- Therefore, the serial driver must be part of the kernel TTY subsystem
- Until 2.6, serial drivers were implemented directly behind the TTY core
  - A lot of complexity was involved
- Since 2.6, a specialized TTY driver, `serial_core`, eases the development of serial drivers
  - See `include/linux/serial_core.h` for the main definitions of the `serial_core` infrastructure
- The line discipline that cooks the data exchanged with the `tty` driver. For normal serial ports, `N_TTY` is used.

Data Structures

- A data structure representing a driver: `uart_driver`
  - Single instance for each driver
  - `uart_register_driver()` and `uart_unregister_driver()`
- A data structure representing a port: `uart_port`
  - One instance for each port (several per driver are possible)
  - `uart_add_one_port()` and `uart_remove_one_port()`
- A data structure containing the pointers to the operations: `uart_ops`
  - Linked from `uart_port` through the `ops` field

uart_driver

- Usually
  - Defined statically in the driver
  - Registered in `module_init()`
  - Unregistered in `module_cleanup()`
- Contains
  - `owner`, usually set to `THIS_MODULE`
  - `driver_name`
  - `dev_name`, the device name prefix, usually `ttyS`
  - `major` and `minor`
    - Use `TTY_MAJOR` and `64` to get the normal numbers. But they might conflict with the 8250-reserved numbers
  - `nr`, the maximum number of ports
  - `cons`, pointer to the console device (covered later)

uart_driver Code Example (1)

```c
static struct uart_driver atmel_uart = {
    .owner = THIS_MODULE,
    .driver_name = "atmel_serial",
    .dev_name = ATMEL_DEVICENAME,
    .major = SERIAL_ATMEL_MAJOR,
    .minor = MINOR_START,
    .nr = ATMEL_MAX_UART,
    .cons = ATMEL_CONSOLE_DEVICE,
};

static struct platform_driver atmel_serial_driver = {
    .probe = atmel_serial_probe,
    .remove = atmel_serial_remove,
    .suspend = atmel_serial_suspend,
    .resume = atmel_serial_resume,
    .driver = {
        .name = "atmel_usart",
        .owner = THIS_MODULE,
    },
};
```

Example code from `drivers/serial/atmel_serial.c`

uart_driver Code Example (2)

```
static int __init atmel_serial_init(void)
{
    /* Warning: Error management removed */
    uart_register_driver(&atmel_uart);
    platform_driver_register(&atmel_serial_driver);
    return 0;
}

static void __exit atmel_serial_exit(void)
{
    platform_driver_unregister(&atmel_serial_driver);
    uart_unregister_driver(&atmel_uart);
}

module_init(atmel_serial_init);
module_exit(atmel_serial_exit);
```

uart_port

- Can be allocated statically or dynamically
- Usually registered at `probe()` time and unregistered at `remove()` time
- Most important fields
  - `iotype`, type of I/O access, usually `UPIO_MEM` for memory-mapped devices
  - `mapbase`, physical address of the registers
  - `irq`, the IRQ channel number
  - `membase`, the virtual address of the registers
  - `uartclk`, the clock rate
  - `ops`, pointer to the operations
  - `dev`, pointer to the device (`platform_device` or other)

uart_port Code Example (1)

```
static int atmel_serial_probe(struct platform_device *pdev)
{
    struct atmel_uart_port *port;

    port = &atmel_ports[pdev->id];
    port->backup_imr = 0;

    atmel_init_port(port, pdev);

    uart_add_one_port(&atmel_uart, &port->uart);

    platform_set_drvdata(pdev, port);

    return 0;
}

static int atmel_serial_remove(struct platform_device *pdev)
{
    struct uart_port *port = platform_get_drvdata(pdev);

    platform_set_drvdata(pdev, NULL);
    uart_remove_one_port(&atmel_uart, port);

    return 0;
}
```

uart_port Code Example (2)

```
static void atmel_init_port(
    struct atmel_uart_port *atmel_port,
    struct platform_device *pdev)
{
    struct uart_port *port = &atmelt_port->uart;
    struct atmel_uart_data *data = pdev->dev.platform_data;

    port->iotype = UPIO_MEM;
    port->flags = UPF_BOOT_AUTOCONF;
    port->ops = &atmel_pops;
    port->fifosize = 1;
    port->line = pdev->id;
    port->dev = &pdev->dev;

    port->mapbase = pdev->resource[0].start;
    port->irq = pdev->resource[1].start;

    tasklet_init(&atmel_port->tasklet, atmel_tasklet_func,
        (unsigned long)port);
```

uart_port Code Example (3)

```
    if (data->regs)
        /* Already mapped by setup code */
        port->membase = data->regs;
    else {
        port->flags |= UPF_IOREMAP;
        port->membase = NULL;
    }

    /* for console, the clock could already be configured */
    if (!atmel_port->clk) {
        atmel_port->clk = clk_get(&pdev->dev, "usart");
        clk_enable(atmel_port->clk);
        port->uartclk = clk_get_rate(atmel_port->clk);
        clk_disable(atmel_port->clk);
        /* only enable clock when USART is in use */
    }
}
```

uart_ops

- Important operations
  - tx_empty(), tells whether the transmission FIFO is empty or not
  - set_mctrl() and get_mctrl(), allow to set and get the modem control parameters (RTS, DTR, LOOP, etc.)
  - start_tx() and stop_tx(), to start and stop the transmission
  - stop_rx(), to stop the reception
  - startup() and shutdown(), called when the port is opened/closed
  - request_port() and release_port(), request/release I/O or memory regions
  - set_termios(), change port parameters
- See the detailed description in Documentation/serial/driver

Implementing Transmission

- The `start_tx()` method should start transmitting characters over the serial port
- The characters to transmit are stored in a circular buffer, implemented by a `struct uart_circ` structure. It contains
  - `buf[]`, the buffer of characters
  - `tail`, the index of the next character to transmit. After transmit, tail must be updated using

    ```
    tail = tail &(UART_XMIT_SIZE - 1)
    ```
- Utility functions on `uart_circ`
  - `uart_circ_empty()`, tells whether the circular buffer is empty
  - `uart_circ_chars_pending()`, returns the number of characters left to transmit
- From an `uart_port` pointer, this structure can be reached using `port->state->xmit`

Polled-Mode Transmission

```
foo_uart_putc(struct uart_port *port, unsigned char c) {
    while(__raw_readl(port->membase + UART_REG1) & UART_TX_FULL)
        cpu_relax();
    __raw_writel(c, port->membase + UART_REG2);
}

foo_uart_start_tx(struct uart_port *port) {
    struct circ_buf *xmit = &port->state->xmit;

    while (!uart_circ_empty(xmit)) {
        foo_uart_putc(port, xmit->buf[xmit->tail]);
        xmit->tail = (xmit->tail + 1) & (UART_XMIT_SIZE - 1);
        port->icount.tx++;
    }
}
```

Transmission with Interrupts (1)

```
foo_uart_interrupt(int irq, void *dev_id) {
    [...]
    if (interrupt_cause & END_OF_TRANSMISSION)
        foo_uart_handle_transmit(port);
    [...]
}

foo_uart_start_tx(struct uart_port *port) {
    enable_interrupt_on_txrdy();
}
```

Transmission with Interrupts (2)

```
foo_uart_handle_transmit(port) {
    struct circ_buf *xmit = &port->state->xmit;
    if (uart_circ_empty(xmit) || uart_tx_stopped(port)) {
        disable_interrupt_on_txrdy();
        return;
    }

    while (!uart_circ_empty(xmit)) {
        if (!(__raw_readl(port->membase + UART_REG1) &
            UART_TX_FULL))
            break;
        __raw_writel(xmit->buf[xmit->tail],
            port->membase + UART_REG2);
        xmit->tail = (xmit->tail + 1) & (UART_XMIT_SIZE - 1);
        port->icount.tx++;
    }

    if (uart_circ_chars_pending(xmit) < WAKEUP_CHARS)
        uart_write_wakeup(port);
}
```

Reception

- On reception, usually in an interrupt handler, the driver must
  - Increment `port->icount.rx`
  - Call `uart_handle_break()` if a BRK has been received, and if it returns TRUE, skip to the next character
  - If an error occurred, increment `port->icount.parity`, `port->icount.frame`, `port->icount.overrun` depending on the error type
  - Call `uart_handle_sysrq_char()` with the received character, and if it returns TRUE, skip to the next character
  - Call `uart_insert_char()` with the received character and a status
    - Status is TTY_NORMAL is everything is OK, or TTY_BREAK, TTY_PARITY, TTY_FRAME in case of error
  - Call `tty_flip_buffer_push()` to push data to the TTY layer

Understanding Sysrq

- Part of the reception work is dedicated to handling `Sysrq`
  - Sysrq are special commands that can be sent to the kernel to make it reboot, unmount filesystems, dump the task state, nice real-time tasks, etc.
  - These commands are implemented at the lowest possible level so that even if the system is locked, you can recover it.
  - Through serial port: send a `BRK` character, send the character of the `Sysrq` command
  - See `Documentation/sysrq.txt`
- In the driver
  - `uart_handle_break()` saves the current time + 5 seconds in a variable
  - `uart_handle_sysrq_char()` will test if the current time is below the saved time, and if so, will trigger the execution of the Sysrq command

Reception Code Sample (1)

```
foo_receive_chars(struct uart_port *port) {
    int limit = 256;

    while (limit-- > 0) {
        status = __raw_readl(port->membase + REG_STATUS);
        ch = __raw_readl(port->membase + REG_DATA);
        flag = TTY_NORMAL;

        if (status & BREAK) {
            port->icount.break++;
            if (uart_handle_break(port))
                continue;
        }
        else if (status & PARITY)
            port->icount.parity++;
        else if (status & FRAME)
            port->icount.frame++;
        else if (status & OVERRUN)
            port->icount.overrun++;

        [...]
```

Reception Code Sample (2)

```
            [...]
            status &= port->read_status_mask;

            if (status & BREAK)
                flag = TTY_BREAK;
            else if (status & PARITY)
                flag = TTY_PARITY;
            else if (status & FRAME)
                flag = TTY_FRAME;

            if (uart_handle_sysrq_char(port, ch))
                continue;

            uart_insert_char(port, status, OVERRUN, ch, flag);
        }

        spin_unlock(& port->lock);
        tty_flip_buffer_push(port->state->port.tty);
        spin_lock(& port->lock);
    }
```

Modem Control Lines

- Set using the `set_mctrl()` operation
  - The `mctrl` argument can be a mask of `TIOCM_RTS` (request to send), `TIOCM_DTR` (Data Terminal Ready), `TIOCM_OUT1`, `TIOCM_OUT2`, `TIOCM_LOOP` (enable loop mode)
  - If a bit is set in `mctrl`, the signal must be driven active, if the bit is cleared, the signal must be driven inactive
- Status using the `get_mctrl()` operation
  - Must return read hardware status and return a combination of `TIOCM_CD` (Carrier Detect), `TIOCM_CTS` (Clear to Send), `TIOCM_DSR` (Data Set Ready) and `TIOCM_RI` (Ring Indicator)

set_mctrl() Example

```
foo_set_mctrl(struct uart_port *uart, u_int mctrl) {
    unsigned int control = 0, mode = 0;

    if (mctrl & TIOCM_RTS)
        control |= ATMEL_US_RTSEN;
    else
        control |= ATMEL_US_RTSDIS;

    if (mctrl & TIOCM_DTS)
        control |= ATMEL_US_DTREN;
    else
        control |= ATMEL_US_DTRDIS;

    __raw_writel(port->membase + REG_CTRL, control);

    if (mctrl & TIOCM_LOOP)
        mode |= ATMEL_US_CHMODE_LOC_LOOP;
    else
        mode |= ATMEL_US_CHMODE_NORMAL;

    __raw_writel(port->membase + REG_MODE, mode);
}
```

get_mctrl() example

```
foo_get_mctrl(struct uart_port *uart, u_int mctrl) {
    unsigned int status, ret = 0;

    status = __raw_readl(port->membase + REG_STATUS);

    /*
     * The control signals are active low.
     */
     if (!(status & ATMEL_US_DCD))
         ret |= TIOCM_CD;
     if (!(status & ATMEL_US_CTS))
         ret |= TIOCM_CTS;
     if (!(status & ATMEL_US_DSR))
         ret |= TIOCM_DSR;
     if (!(status & ATMEL_US_RI))
         ret |= TIOCM_RI;

     return ret;
}
```

termios

- *The termios functions describe a general terminal interface that is provided to control asynchronous communication ports*
- A mechanism to control from user space serial port parameters such as
  - Speed
  - Parity
  - Byte size
  - Stop bit
  - Hardware handshake
  - Etc.
- See `termios(3)` for details

set_termios()

- The `set_termios()` operation must
  - apply configuration changes according to the arguments
  - update `port->read_config_mask` and `port->ignore_config_mask` to indicate the events we are interested in receiving
- ```
  static void set_termios(struct uart_port *port,
  struct ktermios *termios, struct ktermios *old)
  ```
  - `port`, the port, `termios`, the new values and `old`, the old values
- Relevant `ktermios` structure fields are
  - `c_cflag` with word size, stop bits, parity, reception enable, CTS status change reporting, enable modem status change reporting
  - `c_iflag` with frame and parity errors reporting, break event reporting
  ```

set_termios() example (1)

```
static void atmel_set_termios(struct uart_port *port,
    struct ktermios *termios, struct ktermios *old)
{
    unsigned long flags;
    unsigned int mode, imr, quot, baud;

    mode = __raw_readl(port->membase + REG_MODE);
    baud = uart_get_baud_rate(port, termios, old, 0, port->uartclk / 16);
    /* Read current configuration */
    quot = uart_get_divisor(port, baud);

    /* Compute the mode modification for the byte size parameter */
    switch (termios->c_cflag & CSIZE) {
    case CS5:
        mode |= ATMEL_US_CHRL_5;
        break;
    case CS6:
        mode |= ATMEL_US_CHRL_6;
        break;
    [...]
    default:
        mode |= ATMEL_US_CHRL_8;
        break
```

set_termios() example (2)

```
/* Compute the mode modification for the stop bit */
if (termios->c_cflag & CSTOPB)
    mode |= ATMEL_US_NBSTOP_2;

/* Compute the mode modification for parity */
if (termios->c_cflag & PARENB) {
    /* Mark or Space parity */
    if (termios->c_cflag & CMSPAR) {
        if (termios->c_cflag & PARODD)
            mode |= ATMEL_US_PAR_MARK;
        else
            mode |= ATMEL_US_PAR_SPACE;
    } else if (termios->c_cflag & PARODD)
        mode |= ATMEL_US_PAR_ODD;
    else
        mode |= ATMEL_US_PAR_EVEN;
} else
    mode |= ATMEL_US_PAR_NONE;

/* Compute the mode modification for CTS reporting */
if (termios->c_cflag & CRTSCTS)
    mode |= ATMEL_US_USMODE_HWHS;
else
```

set_termios() Example (3)

```
/* Compute the read_status_mask and ignore_status_mask
 * according to the events we're interested in. These
 * values are used in the interrupt handler. */
port->read_status_mask = ATMEL_US_OVRE;
if (termios->c_iflag & INPCK)
    port->read_status_mask |= (ATMEL_US_FRAME | ATMEL_US_PARE);
if (termios->c_iflag & (BRKINT | PARMRK))
    port->read_status_mask |= ATMEL_US_RXBRK;

port->ignore_status_mask = 0;
if (termios->c_iflag & IGNPAR)
    port->ignore_status_mask |= (ATMEL_US_FRAME | ATMEL_US_PARE);
if (termios->c_iflag & IGNBRK) {
    port->ignore_status_mask |= ATMEL_US_RXBRK;
    if (termios->c_iflag & IGNPAR)
        port->ignore_status_mask |= ATMEL_US_OVRE;
}
/* The serial_core maintains a timeout that corresponds to the
 * duration it takes to send the full transmit FIFO. This timeout has
 * to be updated. */
uart_update_timeout(port, termios->c_cflag, baud);
```

set_termios() Example (4)

```
    /* Finally, apply the mode and baud rate modifications. Interrupts,
     * transmission and reception are disabled when the modifications
     * are made. */

    /* Save and disable interrupts */
    imr = UART_GET_IMR(port);
    UART_PUT_IDR(port, -1);
    /* disable receiver and transmitter */
    UART_PUT_CR(port, ATMEL_US_TXDIS | ATMEL_US_RXDIS);
    /* set the parity, stop bits and data size */
    UART_PUT_MR(port, mode);
    /* set the baud rate */
    UART_PUT_BRGR(port, quot);
    UART_PUT_CR(port, ATMEL_US_RSTSTA | ATMEL_US_RSTRX);
    UART_PUT_CR(port, ATMEL_US_TXEN | ATMEL_US_RXEN);
    /* restore interrupts */
    UART_PUT_IER(port, imr);
    /* CTS flow-control and modem-status interrupts */
    if (UART_ENABLE_MS(port, termios->c_cflag))
        port->ops->enable_ms(port);
}
```

Console

- To allows early boot messages to be printed, the kernel provides a separate but related facility: `console`
  - This console can be enabled using the `console=` kernel argument
- The driver developer must
  - Implement a `console_write()` operation, called to print characters on the console
  - Implement a `console_setup()` operation, called to parse the `console=` argument
  - Declare a `struct console` structure
  - Register the console using a `console_initcall()` function

Console: Registration

```
static struct console serial_txx9_console = {
    .name = TXX9_TTY_NAME,
    .write = serial_txx9_console_write,
    /* Helper function from the serial_core layer */
    .device = uart_console_device,
    .setup = serial_txx9_console_setup,
    /* Ask for the kernel messages buffered during
     * boot to be printed to the console when activated */
    .flags = CON_PRINTBUFFER,
    .index = -1,
    .data = &serial_txx9_reg,
};

static int __init serial_txx9_console_init(void)
{
    register_console(&serial_txx9_console);
    return 0;
}

/* This will make sure the function is called early during the boot process.
 * start_kernel() calls console_init() that calls our function */
console_initcall(serial_txx9_console_init);
```

Console: Setup

```
static int __init serial_txx9_console_setup(struct console *co,
    char *options)
{
    struct uart_port *port;
    struct uart_txx9_port *up;
    int baud = 9600;
    int bits = 8;
    int parity = 'n';
    int flow = 'n';

    if (co->index >= UART_NR)
        co->index = 0;
    up = &serial_txx9_ports[co->index];
    port = &up->port;
    if (!port->ops)
        return -ENODEV;

    /* Function shared with the normal serial driver */
    serial_txx9_initialize(&up->port);

    if (options)
        /* Helper function from serial_core that parses the console= string */
        uart_parse_options(options, &baud, &parity, &bits, &flow);

    /* Helper function from serial_core that calls the ->set_termios() */
    /* operation with the proper arguments to configure the port */
    return uart_set_options(port, co, baud, parity, bits, flow);
}
```

Console: Write

```
static void serial_txx9_console_putchar(struct uart_port *port, int ch)
{
^^Istruct uart_txx9_port *up = (struct uart_txx9_port *)port;
^^I/* Busy-wait for transmitter ready and output a single character. */
^^Iwait_for_xmitr(up);
^^Isio_out(up, TXX9_SITFIFO, ch);
}

static void serial_txx9_console_write(struct console *co,
    const char *s, unsigned int count)
{
    struct uart_txx9_port *up = &serial_txx9_ports[co->index];
    unsigned int ier, flcr;

    /* Disable interrupts */
    ier = sio_in(up, TXX9_SIDICR);
    sio_out(up, TXX9_SIDICR, 0);

    /* Disable flow control */
    flcr = sio_in(up, TXX9_SIFLCR);
    if (!(up->port.flags & UPF_CONS_FLOW) && (flcr & TXX9_SIFLCR_TES))
        sio_out(up, TXX9_SIFLCR, flcr & ~TXX9_SIFLCR_TES);

    /* Helper function from serial_core that repeatedly calls the given putchar() */
    /* callback */
    uart_console_write(&up->port, s, count, serial_txx9_console_putchar);

    /* Re-enable interrupts */
    wait_for_xmitr(up);
    sio_out(up, TXX9_SIFLCR, flcr);
    sio_out(up, TXX9_SIDICR, ier);
```