CAMERA DRIVER DEVELOPMENT

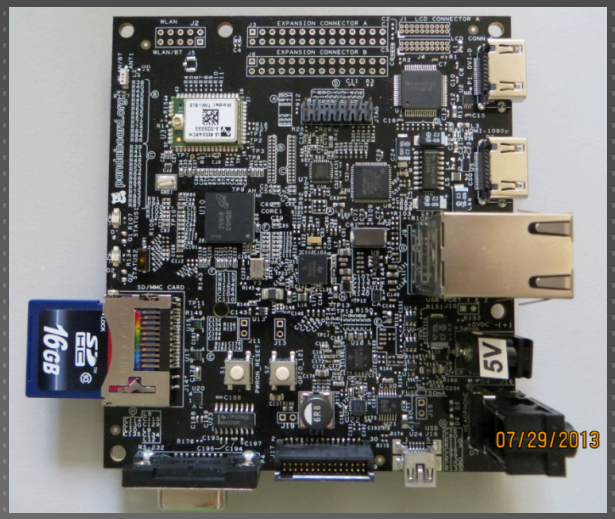
Kyle Xu

OUTLINE

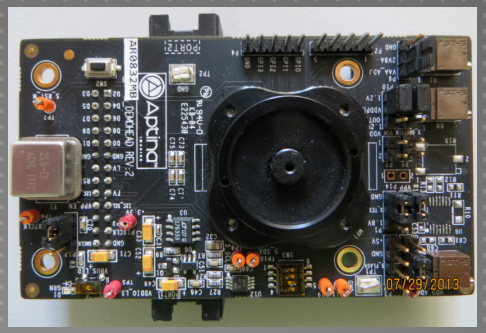
- Prepare the Hardware
- Set up Environment
- Write a Camera Driver
- Solve Remaining Problems

PREPARE THE HARDWARE

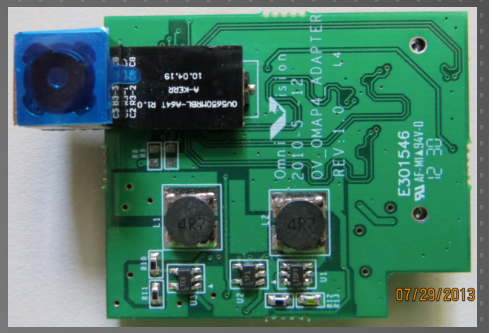
- TI OMAP4 Pandaboard
- Aptina AR0832 Image Sensor
- Ominivision OV5650 Image Sensor
- Adapters and Connectors
- Datasheets



Pandaboard

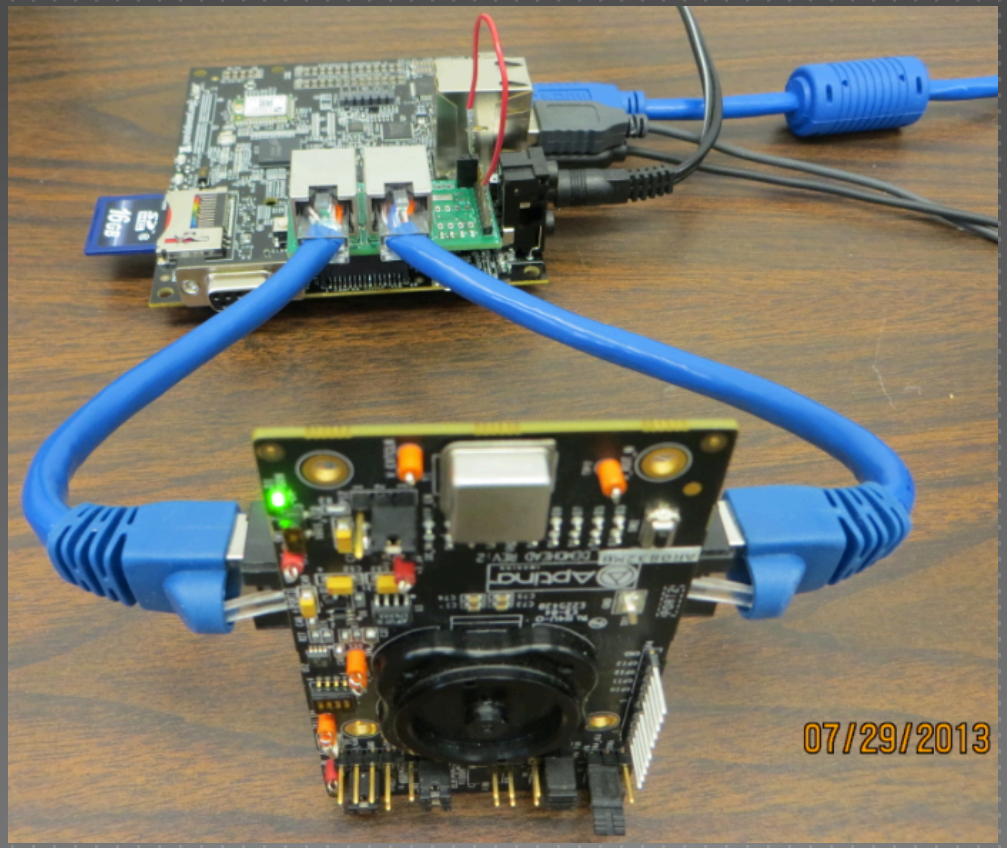


AR0832



OV5650

PREPARE THE HARDWARE



System Setup

OUTLINE

- Prepare the Hardware
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SET UP ENVIRONMENT

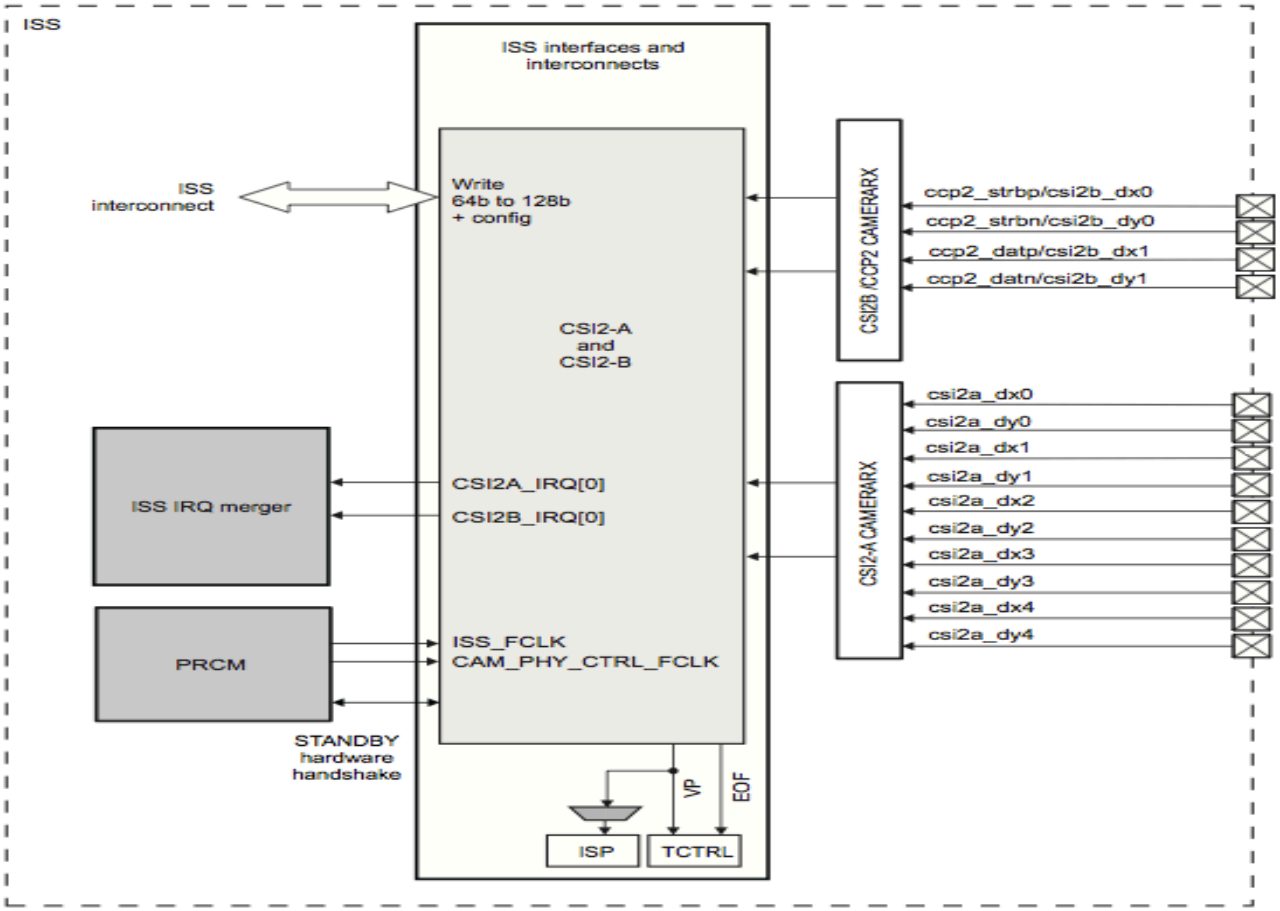
- Install Ubuntu 12.04 on Pandaboard
- Powerful and fast server for cross compilation
  - 32-core
  - 5 min on server vs. 5 hours on Pandaboard
- Understand Data Path and Interfaces

DATA PATH

Camera Serial Interface (CSI-2)

Image Sub-System (ISS) ← Image Sensor

Figure 8-64. ISS CSI2-A/CSI2-B Integration



INTERFACE: CSI-2

- N data lanes and one data clock lane
  - Each lane is a pair of +/- lines.
- I2C standard control interface (CCI)
  - SCL
  - SDA

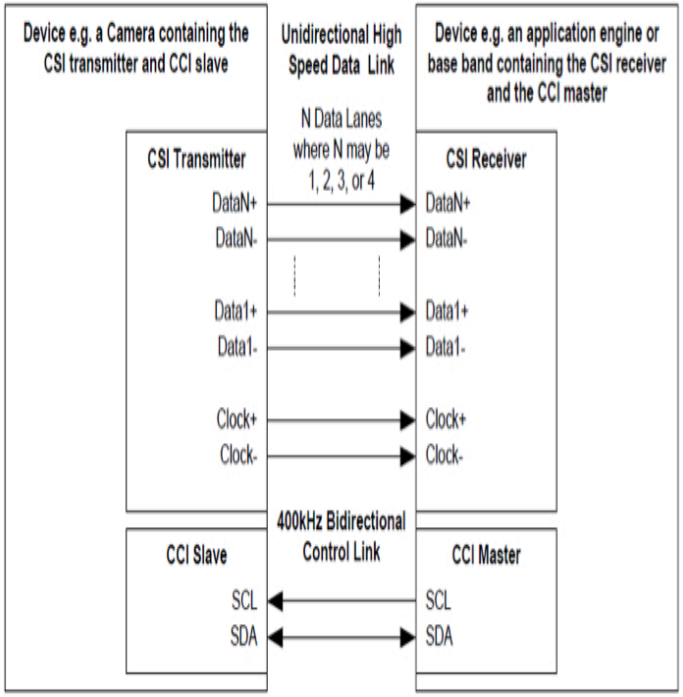


Figure 1 CSI-2 and CCI Transmitter and Receiver Interface

INTERFACE: Hardware Level

- Pandaboard Camera Expansion Connector (J-17)
  - 5 CSI-2 lanes (including one CLK lane)
  - I2C control lines (SCL, SDA)
  - Other lines for battery power, camera clock, GPIO…
- Image Sensor
  - 2 CSI-2 data lanes + 1 CSI-2 clock lane
  - I2C control lines (as slave)
  - Powered from on board battery

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WRITE A CAMERA DRIVER

- Describe the camera to the board
- Write the driver file
  - a. Voltage Regulator and Clock
  - b. I2C Bus
  - c. V4L2
  - d. Driver Framework
  - e. Complete Template
- Implement the driver to Linux Kernel

DESCRIBE THE CAMERA TO THE BOARD

- Create ar0832.h to describe camera's platform information
  - struct ar0832_platform_data containing fields about voltage regulator, clock, power on/off methods
- Edit board-omap4panda-camer.c
  - Assign values or functions to ar0832_platform_data's fields.
  - Tells the board about camera's name, slave address and assign one I2C bus to it.
  - Describe CSI-2 interface connection.

DESCRIBE THE CAMERA TO THE BARD

- Sample Code I:

```
static struct ar0832_platform_data ar0832_platform_data = {

        .reg_vaa = NULL,
        .reg_vdd = NULL,

        .clk_xvclk = "auxclk1_ck",

        .pre_poweron = NULL,
        .post_poweroff = NULL,
};
```

Assign Value for Platform Data

DESCRIBE THE CAMERA TO THE BARD

- Sample Code II:

```
// Add for AR0832 Image Sensor

#define AR0832_I2C_ADDRESS   (0x54)

static struct i2c_board_info ar0832_camera_i2c_device = {
        I2C_BOARD_INFO("ar0832", AR0832_I2C_ADDRESS),
        .platform_data = &ar0832_platform_data,
};


static struct iss_subdev_i2c_board_info ar0832_camera_subdevs[] = {
        {
                .board_info = &ar0832_camera_i2c_device,
                .i2c_adapter_id = 3,
        },
        { NULL, 0, },
};
```

DESCRIBE THE CAMERA TO THE BARD

- Sample Code III:

```
// Add for AR0832 Image Sensor
        {
                .subdevs = ar0832_camera_subdevs,
                .interface = ISS_INTERFACE_CSI2A_PHY1,
                .bus = { .csi2 = {
                        .lanecfg        = {
                                .clk = {
                                        .pol = 0,
                                        .pos = 1,
                                },
                                .data[0] = {
                                        .pol = 0,
                                        .pos = 2,
                                },
                                .data[1] = {
                                        .pol = 0,
                                        .pos = 3,
                                },
                        },
                } },
        },
```

CSI-2 Interface

WRITE A CAMERA DRIVER

- Describe the camera to the bard
- Write the driver file
  - a. Voltage Regulator and Clock
  - b. I2C Bus
  - c. V4L2
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A. VOLTAGE REGULATOR AND CLOCK

- Use pre-defined regulator and clock symbols from the board.
- Regulator: regulator_get, regulator_put
  regulator_enable, regulator_disable
- Clock: clk_get, clk_put
  clk_enable, clk_disable
- Both regulator and clock are hardwired in our case.

B. I2C BUS

- I2C is used to read/write values from/to camera's registers to achieve various controls.
- Use kernel API i2c_transfer for communication.
- Based on datasheet to determine the bit sequence to be send.

B. I2C BUS

```c
static int ar0832_reg_read_16(struct i2c_client *client, u16 reg, u16 *val)
{
        int ret;
        u8 data[4] = {0};
        struct i2c_msg msg = {
                .addr   = client->addr,
                .flags  = 0,
                .len    = 2,
                .buf    = data,
        };

        data[0] = (u8)(reg >> 8);
        data[1] = (u8)(reg & 0xff);

        ret = i2c_transfer(client->adapter, &msg, 1);
        if (ret < 0)
                goto err;

        msg.flags = I2C_M_RD;
        msg.buf = data + 2;
        ret = i2c_transfer(client->adapter, &msg, 1);
        if (ret < 0)
                goto err;

        *val = ((data[2] << 8) | data[3]);
        printk("%s(0x%04x) = 0x%04x\n", __FUNCTION__, reg, *val);
        return 0;

err:
        dev_err(&client->dev, "Failed reading register 0x%02x!\n", reg);
        return ret;
}
```

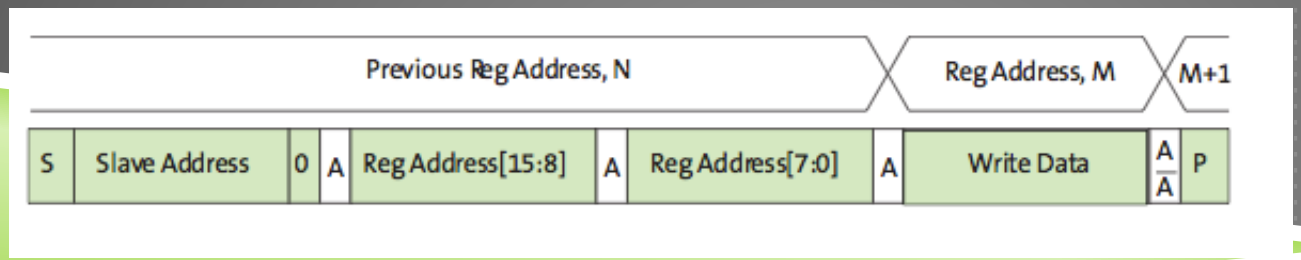
I2C Read

B. I2C BUS

```c
static int ar0832_reg_write_16(struct i2c_client *client, u16 reg, u16 val)
{
        int ret;
        unsigned char data[4] = { (u8)(reg >> 8), (u8)(reg & 0xff), (u8)(val >> 8), (u8)(val & 0xff) };
        struct i2c_msg msg = {
                .addr   = client->addr,
                .flags  = 0,
                .len    = 4,
                .buf    = data,
        };

        ret = i2c_transfer(client->adapter, &msg, 1);
        if (ret < 0) {
                dev_err(&client->dev, "Failed writing register 0x%02x!\n", reg);
                return ret;
        }

        printk("%s(0x%04x) = 0x%04x\n", __FUNCTION__, reg, val);
        usleep_range(5000, 7500);
        return 0;
}
```



I2C Write

C. V4L2

- V4L2, the second version of Video for Linux, is a video capture application programming interface for Linux.
- Closely integrated with the Linux kernel; a bridge between kernel space and user space. It takes care of device register and file handle in the kernel space.
- Regard ISS as v4l2 device and image sensor as a v4l2 sub-device.

C.V4L2

- 1.V4l2 Sub-device Internal Operations
  - .registered: Called when camera is registered.

    Read some registers' values to check connection.

  - .open: Called when the camera node is opened by an application.

    Initialize the format information (frame size, code…)

  - .closed: Called when the camera node is closed.

C.V4L2

```
static int ar0832_open(struct v4l2_subdev *subdev, struct v4l2_subdev_fh *fh)
{
        struct v4l2_mbus_framefmt *format;

        format = v4l2_subdev_get_try_format(fh, 0);
        format.code = V4L2_MBUS_FMT_SGRBG10_1X10;
        format.width = ar0832_frame_sizes[MODE_3264X2448].width;
        format.height = ar0832_frame_sizes[MODE_3264X2448].height;
        format.field = V4L2_FIELD_NONE;
        format.colorspace = V4L2_COLORSPACE_SRGB;

        return 0;
}
```

Open Function

C.V4L2

2. V4L2 Sub-device Operations

- v4l2_subdev_ops
  - v4l2_subdev_pad_ops
    - .enum_mbus_code
    - .enum_frames_code
    - .get_fmt
    - .set_fmt
  - v4l2_subdev_vedio_ops
    - .s_stream
  - v4l2_subdev_core_ops
    - .s_power

C. V4L2

- v4l2_subdev_pad_ops
  - For cameras that support multiple frame size and image sample format, these operation allow users to choose from the options.
- v4l2_subdev_vedio_ops
  - .s_stream is called when streaming starts. It writes different configuration values to camera's registers based on the chosen frame size and format.
- v4l2_subdev_core_ops
  - .s_power puts camera in power saving mode (on==0) or normal operation mode (on==1).

C. V4L2

- 3. V4L2 Control

  Implementing the controls that are compatible with the image sensor and exporting those control symbols to user space applications.

  Consists of two main objects:

  - v4l2_ctrl: Describes the control properties and keeps track of the control's value.
  - v4l2_ctrl_handler: Keeps track on controls.

C. V4L2

- 3.1: Initializing v4l2 controls:

```
v4l2_ctrl_handler_init(&foo->ctrl_handler, nr_of_controls);
v4l2_ctrl_new_std(&foo->ctrl_handler, &foo_ctrl_ops,
                V4L2_CID_BRIGHTNESS, 0, 255, 1, 128);
v4l2_ctrl_new_std(&foo->ctrl_handler, &foo_ctrl_ops,
                V4L2_CID_CONTRAST, 0, 255, 1, 128);
v4l2_ctrl_new_std_menu(&foo->ctrl_handler, &foo_ctrl_ops,
                V4L2_CID_POWER_LINE_FREQUENCY,
                V4L2_CID_POWER_LINE_FREQUENCY_60HZ, 0,
                V4L2_CID_POWER_LINE_FREQUENCY_DISABLED);
```

C. V4L2

- 3.2: Hook v4l2 controls to the driver

```
struct foo_dev {
        ...
        struct v4l2_subdev sd;
        ...
        struct v4l2_ctrl_handler ctrl_handler;
        ...
};

foo->sd.ctrl_handler = &foo->ctrl_handler;
```

C.V4L2

- 3.3: Implementing v4l2 controls:

```
 static const struct v4l2_ctrl_ops foo_ctrl_ops = {
         .s_ctrl = foo_s_ctrl,
 };

static int foo_s_ctrl(struct v4l2_ctrl *ctrl)
{
        struct foo *state = container_of(ctrl->handler, struct foo, ctrl_handler);

        switch (ctrl->id) {
        case V4L2_CID_BRIGHTNESS:
                write_reg(0x123, ctrl->val);
                break;
        case V4L2_CID_CONTRAST:
                write_reg(0x456, ctrl->val);
                break;
        }
        return 0;
}
```

D. DRIVER FRAMEWORK

- Standard I2C Device Driver Code
  - loadable module: module_init/module_exit
  - I2C Device: i2c_add_driver/i2c_del_driver
  - struct i2c_driver
    - .id_table: Used to identify the supported chip based on name and I2C slave address; Must be same as described in board-omap4panda-camera.c file.
    - .probe: Function called when supported chip is found and the driver is added.
    - .remove: Function called before driver is deleted.

D. DRIVER FRAMEWORK

```
static const struct i2c_device_id ar0832_id[] = {
        { "ar0832", 0 },
        { }
};
MODULE_DEVICE_TABLE(i2c, ar0832_id);

static struct i2c_driver ar0832_i2c_driver = {
        .driver = {
                .name = "ar0832",
        },
        .probe          = ar0832_probe,
        .remove         = ar0832_remove,
        .id_table       = ar0832_id,
};

static int __init ar0832_mod_init(void)
{
        return i2c_add_driver(&ar0832_i2c_driver);
}

static void __exit ar0832_mod_exit(void)
{
        i2c_del_driver(&ar0832_i2c_driver);
}

module_init(ar0832_mod_init);
module_exit(ar0832_mod_exit);

MODULE_DESCRIPTION("Aptina AR0832 Camera driver");
MODULE_AUTHOR("Kyle Xu <sx3@rice.edu>");
MODULE_LICENSE("GPL");
```

Standard I2C Device Driver Code

D. DRIVER FRAMEWORK

- Probe and Remove Methods
  - Probe: Initialize format image information that contained as fields in device specific structure.
    Enable v4l2 interface: v4l2_i2c_subdev_init and sets v4l2 internal operations.
  - Remove: Disable v4l2 interface:
    v4l2_device_unregister_subdev
    v4l2_ctrl_handler_free

D. DRIVER FRAMEWORK

```
ar0832->format.code = V4L2_MBUS_FMT_SGRBG10_1X10;
ar0832->format.width = ar0832_frame_sizes[MODE_3264X2448].width;
ar0832->format.height = ar0832_frame_sizes[MODE_3264X2448].height;
ar0832->format.field = V4L2_FIELD_NONE;
ar0832->format.colorspace = V4L2_COLORSPACE_SRGB;
// More initialization here

v4l2_i2c_subdev_init(&ar0832->subdev, client, &ar0832_subdev_ops);
ar0832->subdev.internal_ops = &ar0832_subdev_internal_ops;
ar0832->subdev.flags |= V4L2_SUBDEV_FL_HAS_DEVNODE;
// ar0832->subdev.entity.type = MEDIA_ENT_T_V4L2_SUBDEV_SENSOR;
```

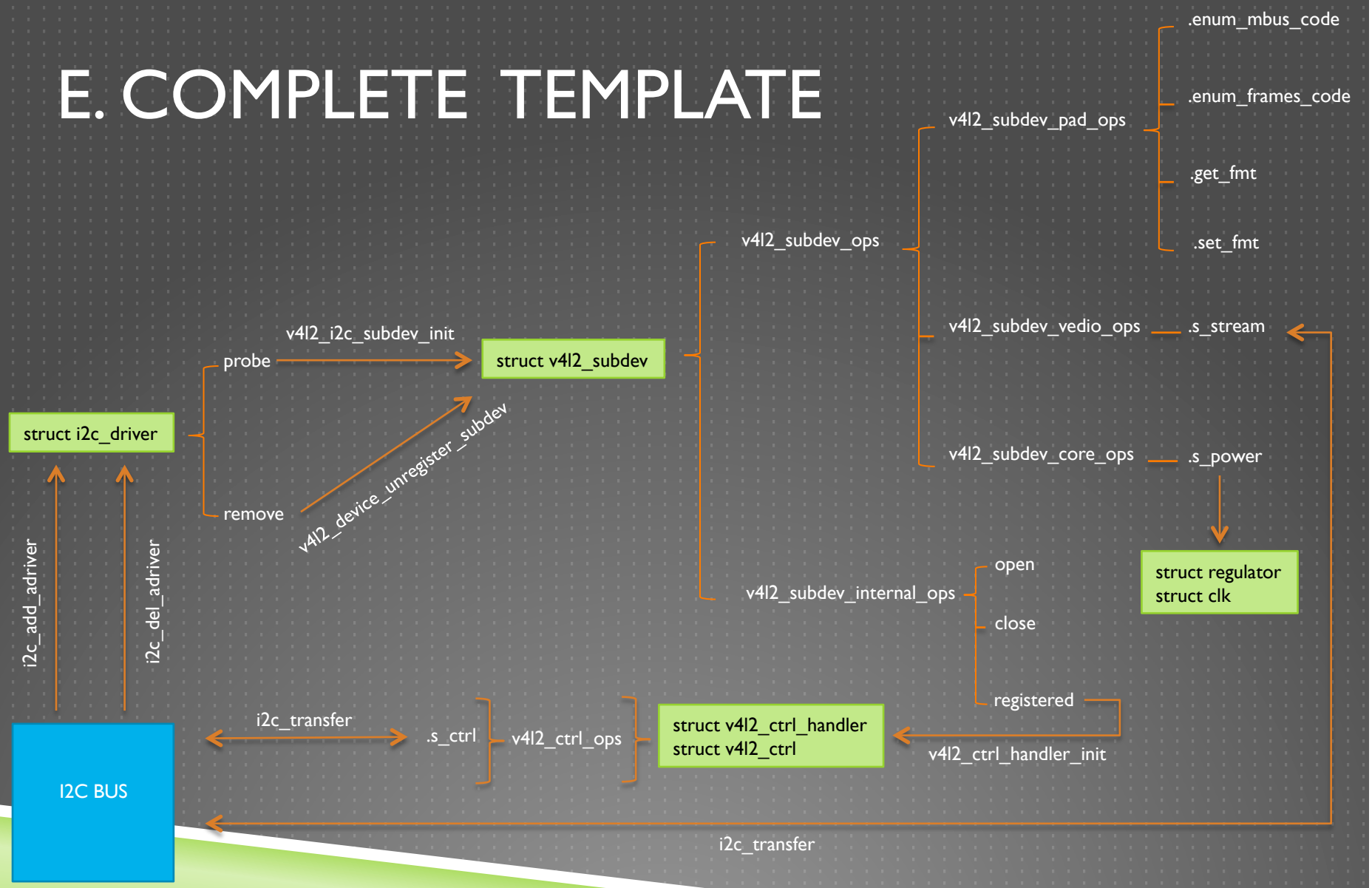
Extract from Probe Function

```
static int ar0832_remove(struct i2c_client *client)
{
        struct v4l2_subdev *subdev = i2c_get_clientdata(client);
        struct ar0832 *ar0832 = to_ar0832(subdev);

        v4l2_ctrl_handler_free(&ar0832->ctrl_handler);
        ar0832_put_resources(ar0832);
        media_entity_cleanup(&subdev->entity);
        v4l2_device_unregister_subdev(subdev);
        kfree(ar0832);
        return 0;
}
```

Remove Function

E. COMPLETE TEMPLATE



WRITE A CAMERA DRIVER

- Describe the camera to the bard
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IMPLEMENT THE DRIVER TO LINUX KERNEL

- Edit Kconfig files:
  - kernel_source/drivers/media/Kconfig
  - kernel_source/arch/arm/mach-omap2/Kconfig

```
config VIDEO_OV5640
        tristate "OmniVision OV5640 sensor support"
        depends on I2C && VIDEO_V4L2
        help
          This is a ov5640 camera driver

config VIDEO_OV5650
        tristate "OmniVision OV5650 sensor support"
        depends on I2C && VIDEO_V4L2
        help
          This is a ov5650 camera driver

config VIDEO_AR0832
        tristate "Aptina AR0832 sensor support"
        depends on I2C && VIDEO_V4L2
        help
          This is a ar0832 camera driver
```

Kconfig Driver

```
config MACH_OMAP4_PANDA_CAMERA_SUPPORT
        bool "OMAP4 Panda Board Camera support"
        depends on MACH_OMAP4_PANDA
        select MEDIA_SUPPORT
        select MEDIA_CONTROLLER
        select VIDEO_DEV
        select VIDEO_V4L2_SUBDEV_API
        select V4L_PLATFORM_DRIVERS
        select VIDEO_OMAP4
        select VIDEO_OV5640
        select VIDEO_OV5650
        select VIDEO_AR0832
        help
          Enable Camera HW support for PandaBoard.
          This is for using the OMAP4 ISS CSI2A Camera sensor
          interface.
```

Kconfig Board

IMPLEMENT THE DRIVER TO LINUX KERNEL

- Edit Makefile.
  - kernel_source/drivers/media/Makefile

```
obj-$(CONFIG_VIDEO_OV5640)      += ov5640.o
obj-$(CONFIG_VIDEO_OV5650)      += ov5650.o
obj-$(CONFIG_VIDEO_AR0832)      += ar0832.o
```

Driver Makefile

- Cross-compile on server.
- Install and swap to the new kernel!

OUTLINE

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SOLVE REMAINING PROBLEMS

- Compile and install the driver only without re-compile the entire kernel.
- Weird i2c slave address
- AR0832's full register table

REFERENCES

- http://www.ti.com/lit/ug/swpu231an/swpu231an.pdf
- http://www.mipi.org/specifications/camera-interface#CSI2
- http://lxr.free-electrons.com/source/include/media/v4l2-subdev.h?v=3.4;a=arm
- https://en.wikipedia.org/wiki/Video4Linux
- https://www.kernel.org/doc/Documentation/video4linux/v4l2-framework.txt
- https://www.kernel.org/doc/Documentation/video4linux/v4l2-controls.txt
- Aptina AR0832 Data Sheet