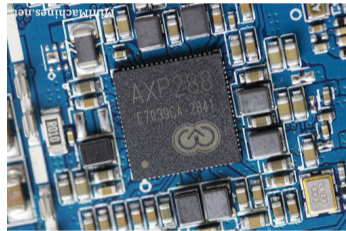




Power Management Integrated Circuits: Keep the power in your hands

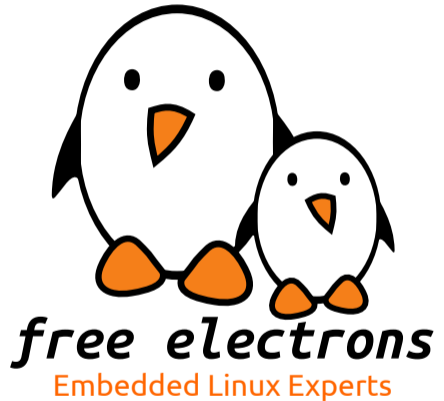
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- ▶ Quentin Schulz
- ▶ Embedded Linux and kernel engineer at **free electrons**
 - ▶ Embedded Linux **expertise**
 - ▶ **Development**, consulting and training
 - ▶ Strong open-source focus
 - ▶ Linux kernel contributors, ARM SoC support, kernel maintainers
 - ▶ Worked on drivers for AXP20X/AXP22X PMICs,





What's a PMIC?

Commonly integrated features

- Regulators

- Power supplies

Miscellaneous - PMIC-specific parts

- ADC for current values

- MFD



What's a PMIC?

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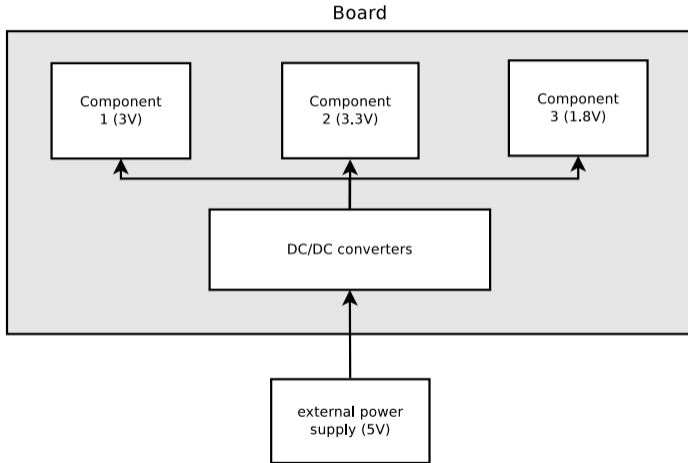


What's a PMIC?

- ▶ PMIC = Power Management Integrated Circuit,
- ▶ handles the power sequence of the board,
- ▶ supplies power to the different components inside the board,
- ▶ protects the board from unsupported overvoltage and undervoltage,
- ▶ might handle different external power supplies,
- ▶ can provide other misc features (GPIO, ADC, ...),
- ▶ is usually software-controllable (often as an i^2c device),
- ▶ is not mandatory (e.g. Raspberry Pi and Orange Pi),

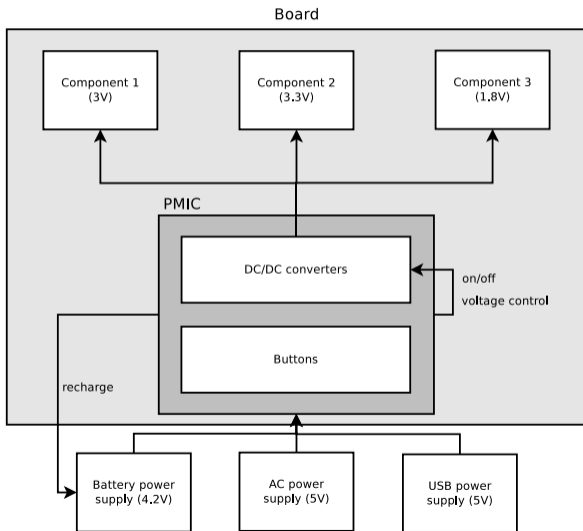


Boards without a PMIC



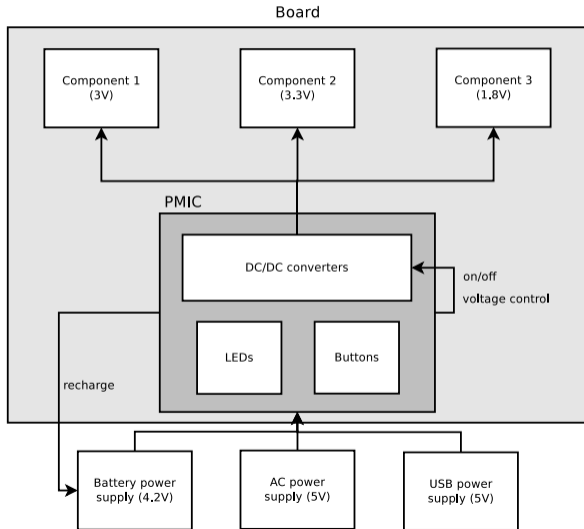


Active Semi ACT8865 (Atmel Sama5d3 Xplained)



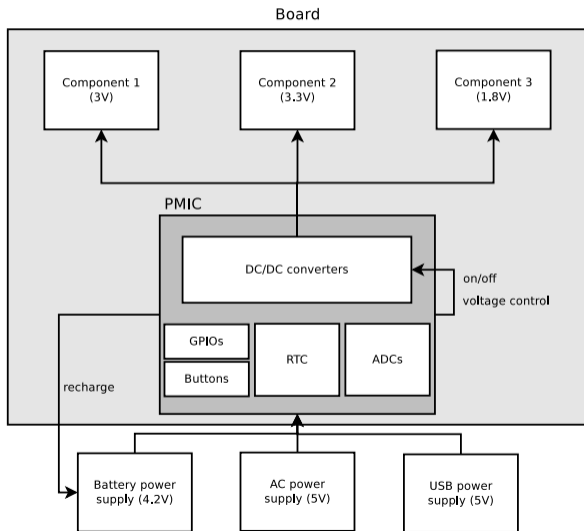


TI TPS65217x (BeagleBone Black)





Boards with an X-Powers AXP20X PMIC





Commonly integrated features

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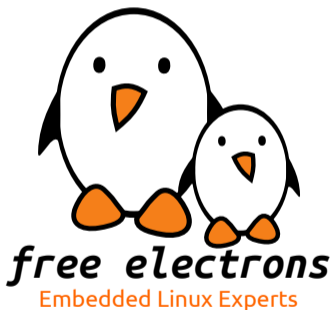
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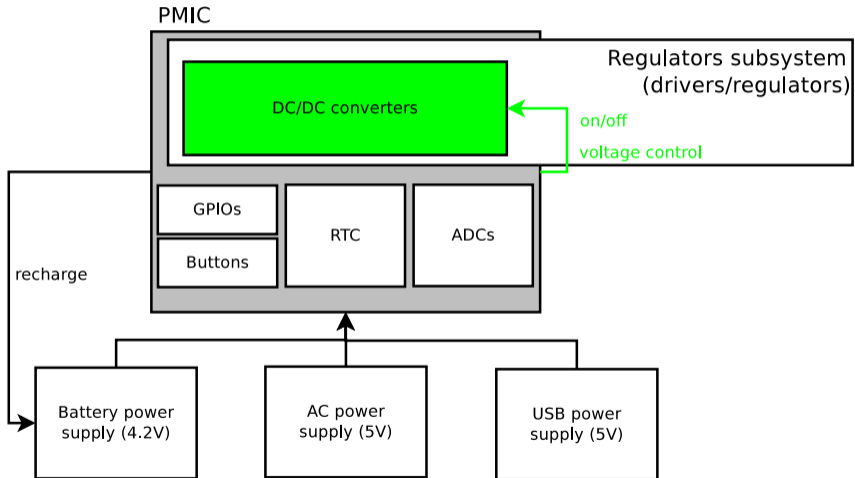
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Regulators





Regulators

- ▶ PMIC supplies power to components requiring different input voltages (5V, 3V3, 1V8, ...),
- ▶ DC-DC converters and LDO regulators handle the different voltages,
- ▶ to save power, regulators can stop supplying power to their unused components,
- ▶ some components support a range of input voltages,
- ▶ PMIC handles all that,
- ▶ their regulator adapts its voltage depending on some parameters (e.g. load, thermal throttling),
- ▶ variable regulators allow to reduce power consumption (undervolting) and increase power (overvolting),
 - ▶ allows CPU/GPU DVFS (Dynamic Voltage and Frequency Scaling),
 - ▶ is the core of battery life and power consumption,
- ▶ regulators are part of the regulator framework (`drivers/regulators/`),



Regulator driver example: AXP20X regulators driver

drivers/regulators/axp20x-regulator.c

```
static struct regulator_ops axp20x_ops = {  
    .set_voltage_sel      = regulator_set_voltage_sel_regmap,  
    .get_voltage_sel      = regulator_get_voltage_sel_regmap,  
    .list_voltage         = regulator_list_voltage_linear,  
    .enable               = regulator_enable_regmap,  
    .disable               = regulator_disable_regmap,  
    .is_enabled           = regulator_is_enabled_regmap,  
};
```



Regulator driver example: AXP20X regulators driver

drivers/regulators/axp20x-regulator.c

```
static const struct regulator_desc axp20x_regulators[] = {
    [AXP20X_DCDC2] = {
        .name           = "dcdc2",
        .supply_name    = "vin2",
        .of_match       = of_match_ptr("dcdc2"),
        .regulators_node = of_match_ptr("regulators"),
        .type           = REGULATOR_VOLTAGE,
        .id             = AXP20X_DCDC2,
        .n_voltages     = (2275 - 700) / (25 + 1),
        .owner          = THIS_MODULE,
        .min_uV         = 700 * 1000,
        .uV_step        = 25 * 1000,
        .vsel_reg       = AXP20X_DCDC2_V_OUT,
        .vsel_mask      = 0x3f,
        .enable_reg     = AXP20X_PWR_OUT_CTRL,
        .enable_mask    = 0x10,
        .ops            = &axp20x_ops,
    },
};
```



Regulator driver example: AXP20X regulators driver

drivers/regulators/axp20x-regulator.c

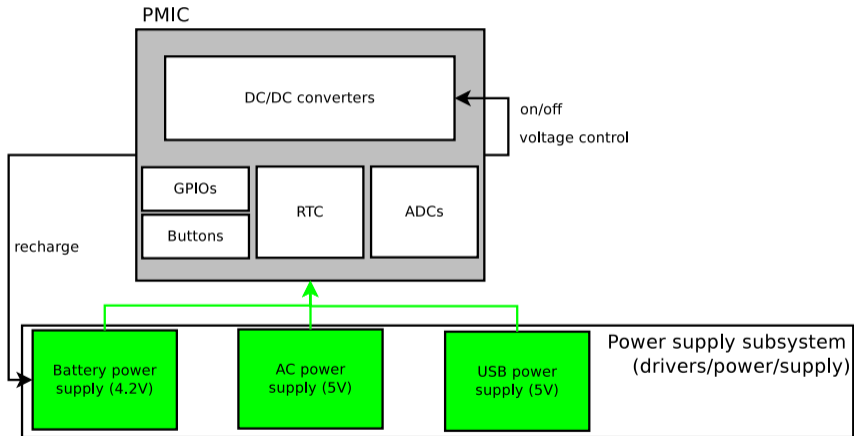
```
static int axp20x_regulator_probe(struct platform_device *pdev)
{
    struct regulator_dev *rdev;
    struct axp20x_dev *axp20x = dev_get_drvdata(pdev->dev.parent);
    const struct regulator_desc *regulators;
    struct regulator_config config = {
        .dev = pdev->dev.parent,
        .regmap = axp20x->regmap,
        .driver_data = axp20x,
    };

    [...]
    for (i = 0; i < ARRAY_SIZE(axp20x_regulators); i++) {
        rdev = devm_regulator_register(&pdev->dev, axp20x_regulators[i], &config);
        if (IS_ERR(rdev)) {
            dev_err(&pdev->dev, "Failed to register %s\n",
                    regulators[i].name);

            return PTR_ERR(rdev);
        }
    }
    return 0;
}
```



Power supplies





The PMIC

- ▶ takes care of all possible supported external supplies:
 - ▶ AC (socket), USB, battery, ...
- ▶ defines the power sequence for the board,
- ▶ protects from overvoltage/undervoltage (e.g. X-Powers AXP's are designed for 5V boards but handles 0.3-11V)
- ▶ chooses the most suitable one depending on the status of each (low battery, not enough current supplied by a power supply, ...)
- ▶ may handle the battery (recharging, handling recharge cycles),



Power Supply subsystem

- ▶ is located in `drivers/power/supply`,
- ▶ has typically one driver per physical input power supply,
- ▶ can expose different data^[1], such as current voltage and current, battery capacity, battery type, temperature, ...
- ▶ can set as many data, such as minimum and maximum allowed voltage or current, battery voltage when full,
- ▶ exposed information is specific to a PMIC (e.g. AXP20X can read current voltage and current values of the AC and USB power supplies unlike AXP22X),

[1]http://lxr.free-electrons.com/source/include/linux/power_supply.h



Power Supply driver example: AXP20X USB driver

drivers/power/supply/axp20x_usb_power.c

```
static enum power_supply_property axp20x_usb_power_properties[] = {
    POWER_SUPPLY_PROP_PRESENT,
    POWER_SUPPLY_PROP_VOLTAGE_MIN,
    POWER_SUPPLY_PROP_VOLTAGE_NOW,
};

static int axp20x_usb_power_prop_writeable(struct power_supply *psy,
                                           enum power_supply_property psp)
{
    return psp == POWER_SUPPLY_PROP_VOLTAGE_MIN;
}

static const struct power_supply_desc axp20x_usb_power_desc = {
    .name = "axp20x-usb",
    .type = POWER_SUPPLY_TYPE_USB,
    .properties = axp20x_usb_power_properties,
    .num_properties = ARRAY_SIZE(axp20x_usb_power_properties),
    .property_is_writeable = axp20x_usb_power_prop_writeable,
    .get_property = axp20x_usb_power_get_property,
    .set_property = axp20x_usb_power_set_property,
};
```



Power Supply driver example: AXP20X USB driver

`include/linux/power_supply.h`

```
union power_supply_propval {  
    int intval;  
    const char *strval;  
};
```



Power Supply driver example: AXP20X USB driver

drivers/power/supply/axp20x_usb_power.c

```
static int axp20x_usb_power_get_property(struct power_supply *psy, enum power_supply_property psp,
                                         union power_supply_propval *val)
{
    struct axp20x_usb_power *power = power_supply_get_drvdata(psy);
    switch (psp) {
        case POWER_SUPPLY_PROP_PRESENT:
            return axp20x_usb_power_is_present(power, &val->intval);
        [...]
    }
    return -EINVAL;
}

static int axp20x_usb_power_set_property(struct power_supply *psy, enum power_supply_property psp,
                                         const union power_supply_propval *val)
{
    struct axp20x_usb_power *power = power_supply_get_drvdata(psy);

    switch (psp) {
        case POWER_SUPPLY_PROP_VOLTAGE_MIN:
            return axp20x_usb_power_set_voltage_min(power, val->intval);
        [...]
    }
    return -EINVAL;
}
```



Power Supply driver example: AXP20X USB driver

drivers/power/supply/axp20x_usb_power.c

```
static int axp20x_usb_power_probe(struct platform_device *pdev)
{
    /* Custom structure */
    struct axp20x_usb_power *power;
    struct power_supply_config psy_cfg = {};

    power = devm_kzalloc(&pdev->dev, sizeof(*power), GFP_KERNEL);
    if (!power)
        return -ENOMEM;

    /* For use in other functions which call power_supply_get_drvdata */
    psy_cfg.drv_data = power;
    [...]
    power->supply = devm_power_supply_register(&pdev->dev, axp20x_usb_power_desc, &psy_cfg);
    if (IS_ERR(power->supply))
        return PTR_ERR(power->supply);
    [...]
    return 0;
}
```



Miscellaneous - PMIC-specific parts

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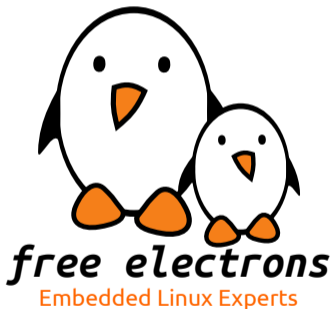
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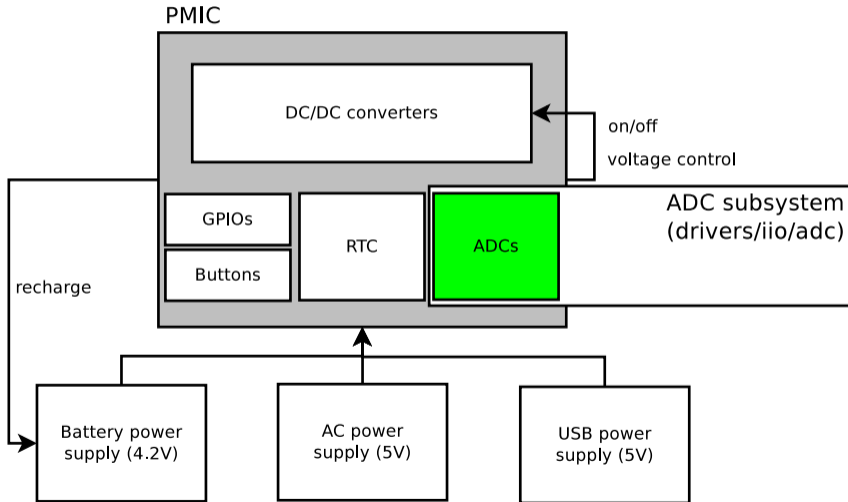


Parts specific to some PMICs

- ▶ Buttons: detect when the power reset button is pushed to shutdown the system (`drivers/power/reset`),
- ▶ GPIO: e.g. the AXP PMICs have several pins you can use either as GPIO or ADC,
- ▶ RTC with backup battery to keep time between reboots,
- ▶ Fuel gauge (if logically separated from the battery driver),
- ▶ ADC: e.g. AXP PMICs can expose what is the current voltage/current of a power supply,



ADC driver





- ▶ some PMICs can give some data in real time,
 - ▶ internal temperature, supplied voltage, consumed current, (dis)charging current, battery percentage, ...
- ▶ often stored in registers of an embedded Analog to Digital Converter (ADC),
- ▶ proper way: have a driver for this ADC feeding data to the power supply drivers,
 - ▶ the subsystem for ADC drivers is Industrial I/O (`drivers/iio/adc`)



IIO driver example: AXP20X ADC driver

drivers/iio/adc/axp20x_adc.c

```
#define AXP20X_ADC_CHANNEL(_channel, _name, _type, _reg)      \
{                                                            \
    .type = _type,                                          \
    .indexed = 1,                                          \
    .channel = _channel,                                    \
    .address = _reg,                                       \
    .info_mask_separate = BIT(IIO_CHAN_INFO_RAW) |        \
                          BIT(IIO_CHAN_INFO_SCALE),      \
    .datasheet_name = _name,                               \
}

enum axp20x_adc_channel_v {
    AXP20X_ACIN_V = 0,
    AXP20X_VBUS_V,
    [...]
};

enum axp20x_adc_channel_i {
    AXP20X_ACIN_I = 0,
    AXP20X_VBUS_I,
    [...]
};
```



IIO driver example: AXP20X ADC driver

drivers/iio/adc/axp20x_adc.c

```
/* Describe your IIO channels */
static const struct iio_chan_spec axp20x_adc_channels[] = {
    AXP20X_ADC_CHANNEL(AXP20X_VBUS_V, "vbus_v", IIO_VOLTAGE,
                       AXP20X_VBUS_V_ADC_H),
    AXP20X_ADC_CHANNEL(AXP20X_VBUS_I, "vbus_i", IIO_CURRENT,
                       AXP20X_VBUS_I_ADC_H),
    [...]
};

static int axp20x_adc_scale(struct iio_chan_spec const *chan, int *val, int *val2)
{
    switch (chan->type) {
    case IIO_VOLTAGE:
        if (chan->channel == AXP20X_VBUS_I) {
            *val = 0;
            *val2 = 375000;
            return IIO_VAL_INT_PLUS_MICRO;
        }
        return -EINVAL;
    [...]
    }
}
```



IIO driver example: AXP20X ADC driver

drivers/iio/adc/axp20x_adc.c

```
static int axp20x_read_raw(struct iio_dev *indio_dev, struct iio_chan_spec const *chan, int *val,
                          int *val2, long mask)
{
    struct axp20x_adc_iio *info = iio_priv(indio_dev);
    switch (mask) {
    case IIO_CHAN_INFO_RAW:
        *val = axp20x_read_variable_width(info->regmap, chan->address, 12);
        if (*val < 0)
            return *val;
        return IIO_VAL_INT;
    case IIO_CHAN_INFO_SCALE:
        return axp20x_adc_scale(indio_dev, chan, val);
    default:
        return -EINVAL;
    }
}

/* Specify the functions used when reading or writing to a sysfs entry */
static const struct iio_info axp20x_adc_iio_info = {
    .read_raw = axp20x_read_raw,
    .write_raw = axp20x_write_raw,
    .driver_module = THIS_MODULE,
};
```



IIO driver example: AXP20X ADC driver

drivers/iio/adc/axp20x_adc.c

```
/* Feed a consumer driver via an IIO channel */
static struct iio_map axp20x_maps[] = {
    {
        /* Name of the driver */
        .consumer_dev_name = "axp20x-usb-power-supply",
        /* The name under which the IIO channel will be gotten from the consumer driver */
        .consumer_channel = "vbus_v",
        /* The datasheet_name of the IIO channel to feed */
        .adc_channel_label = "vbus_v",
    }, {
        .consumer_dev_name = "axp20x-usb-power-supply",
        .consumer_channel = "vbus_i",
        .adc_channel_label = "vbus_i",
    }, { /* sentinel */ },
};
```



IIO driver example: AXP20X ADC driver

drivers/iio/adc/axp20x_adc.c

```
static int axp20x_probe(struct platform_device *pdev)
{
    struct axp20x_adc_iio *info;
    struct iio_dev *indio_dev;
    int ret;

    indio_dev = devm_iio_device_alloc(&pdev->dev,
                                     sizeof(*info));

    if (!indio_dev)
        return -ENOMEM;

    /* For use in other functions which call
     * iio_priv */
    info = iio_priv(indio_dev);

    indio_dev->name = "axp20x_ac";
    [...]

    indio_dev->dev.parent = &pdev->dev;
    indio_dev->dev.of_node = pdev->dev.of_node;
    indio_dev->modes = INDIO_DIRECT_MODE;
    indio_dev->info = axp20x_adc_iio_info;
    indio_dev->num_channels =
        ARRAY_SIZE(axp20x_adc_channels);
    indio_dev->channels = axp20x_adc_channels;
    ret = iio_map_array_register(indio_dev,
                                axp20x_maps);

    if (ret < 0)
        return ret;

    ret = iio_device_register(indio_dev);
    if (ret < 0)
        return ret;
    return 0;
}
```



IIO driver example: AXP20X ADC driver

drivers/power/supply/axp20x_usb_power.c

```
static int axp20x_usb_power_get_property(struct power_supply *psy,
                                         enum power_supply_property psp,
                                         union power_supply_propval *val)
{
    struct axp20x_usb_power *power = power_supply_get_drvdata(psy);

    switch (psp) {
    [...]
    case POWER_SUPPLY_PROP_VOLTAGE_NOW:
        ret = iio_read_channel_processed(power->vbus_v, &val->intval);
        val->intval *= 1000;
        return 0;
    }
    return -EINVAL;
}
```




IIO driver example: AXP20X ADC driver

drivers/power/supply/axp20x_usb_power.c

```
static int axp20x_usb_power_probe(struct platform_device *pdev)
{
    struct axp20x_usb_power *power;
    [...]
    power->vbus_v = devm_iio_channel_get(&pdev->dev, "vbus_v");
    if (IS_ERR(power->vbus_v)) {
        if (PTR_ERR(power->vbus_v) == -ENODEV)
            return -EPROBE_DEFER;
        return PTR_ERR(power->vbus_v);
    }
    [...]
    power->supply = devm_power_supply_register(&pdev->dev, usb_power_desc, &psy_cfg);
    if (IS_ERR(power->supply))
        return PTR_ERR(power->supply);
    return 0;
}
```



Parts specific to boards - Fuel gauge

- ▶ battery percentage is approximated from its voltage,
- ▶ battery voltage does not linearly decrease in time or load,
- ▶ rather follows a curve, called the Open Circuit Voltage (OCV) curve,
- ▶ the curve is battery-specific (might be given by the battery vendor),
- ▶ the curve depends on several factors (environment, number of charges, age of battery, usage, ...),
- ▶ the battery percentage approximation by software must be done in userspace,
- ▶ use of `POWER_SUPPLY_PROP_VOLTAGE_OCV` property:
 - ▶ if software approximated, to give points on the OCV curve,
 - ▶ if hardware approximated, to get/set the points defining OCV curve used in the PMIC,

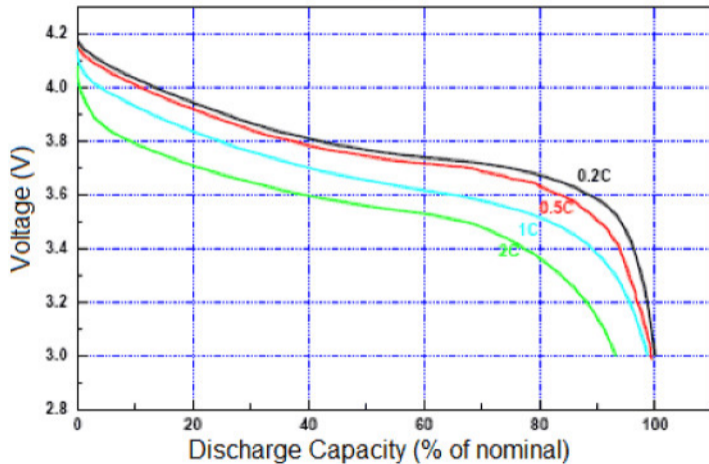
Worth reading:

<https://training.ti.com/sites/default/files/BatteryMonitoringBasics.ppt>



Parts specific to boards - Fuel gauge

Discharge Profile

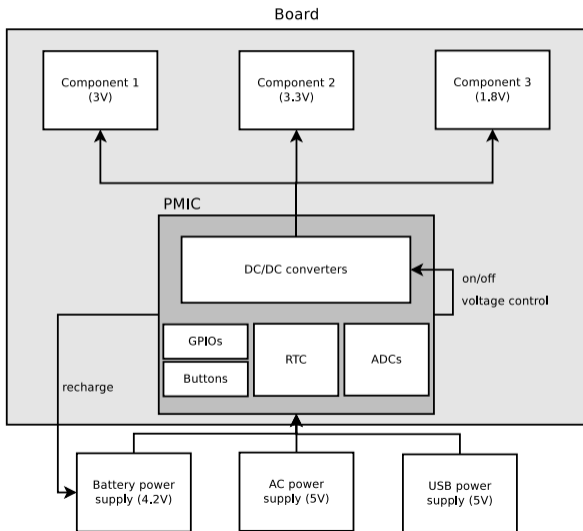


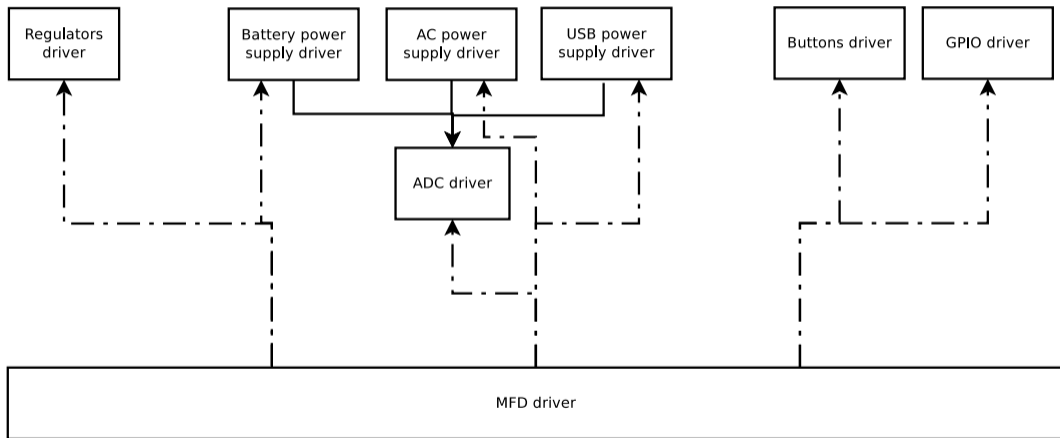
Discharge: 3.0V cutoff at room temperature.



MFD - The glue between all this

- ▶ probes the different drivers of the PMIC (called MFD cells),
- ▶ maps the interrupts to the drivers which need them,
- ▶ usually passes a regmap to the MFD cells so it makes sure the drivers do not write to and access the same registers at the same time,







MFD driver example: AXP20X MFD driver

drivers/mfd/axp20x.c

```
static struct resource axp20x_usb_power_supply_resources[] = {
    DEFINE_RES_IRQ_NAMED(AXP20X_IRQ_VBUS_PLUGIN, "VBUS_PLUGIN"),
};

static struct mfd_cell axp20x_cells[] = {
    {
        .name           = "axp20x-usb-power-supply",
        .of_compatible = "x-powers,axp202-usb-power-supply",
        .num_resources  = ARRAY_SIZE(axp20x_usb_power_supply_resources),
        .resources      = axp20x_usb_power_supply_resources,
    }, [...]
};

int axp20x_device_probe(struct i2c_client *i2c, const struct i2c_device_id *id)
{
    /* Do all the regmap configuration, regmap_irqs included */
    ret = mfd_add_devices(&i2c->dev, -1, axp20x_cells,
        ARRAY_SIZE(axp20x_cells), NULL, irq_base, NULL);

    if (ret)
        return ret;
    return 0;
}
```

Questions?

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<http://free-electrons.com/pub/conferences/2017/elc/schulz-pmics-keep-power-in-your-hands.pdf>