

Linux Power!

(From the perspective of a PMIC vendor)

Matti Vaittinen

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ROHM Semiconductor

Goal

What is PMIC

Regulator errors and notifications

Functional-safety helpers in regulator subsystem

What and Why is a PMIC?

PMIC drivers

- MFD and sub-devices

- Regulators

Monitoring for abnormal conditions

- Severity levels and limit values

- Regulator errors and notifications

- Helpers and examples

Wrap it up

About Me

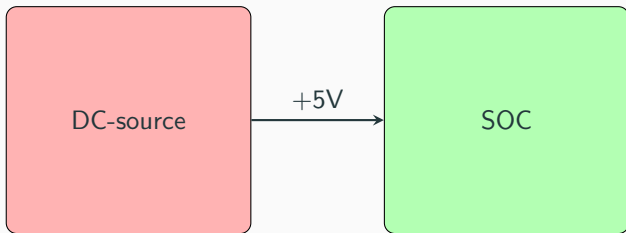
- Matti Vaittinen
- Kernel/Driver developer at ROHM Semiconductor
- Worked at Nokia BTS projects (networking, clock & sync) 2006 – 2018
- Currently mainly developing/maintaining upstream Linux device drivers for ROHM ICs



What and Why is a PMIC?

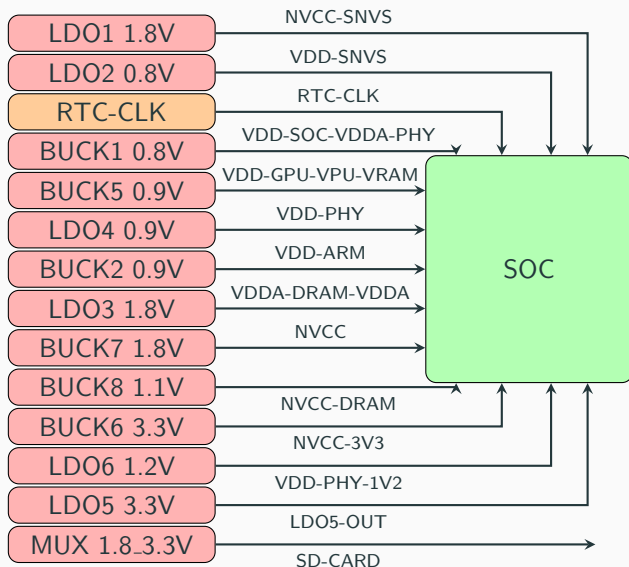
Powering a processor

- Processor and peripherals need power
- Can be as simple as a dummy DC power source with correct voltage



Powering a modern SOC 1/2

Modern SOC
can require
multiple specific
voltages



Powering a modern SOC 2/2

And specific timings...

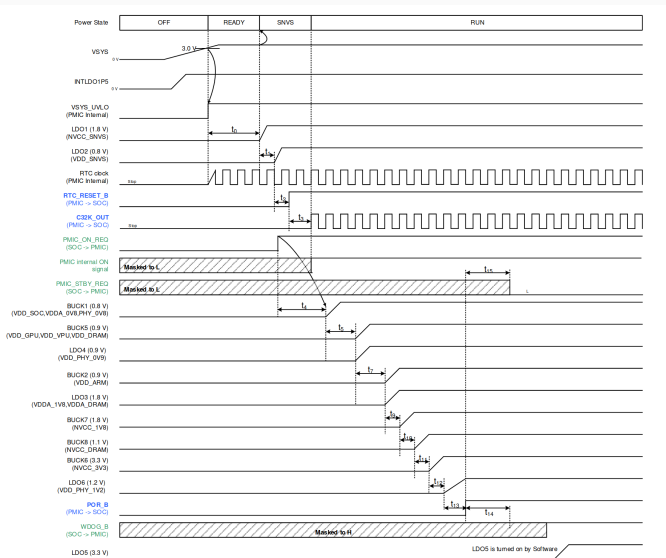


Figure 3-21. Power ON Sequence

More control...

Power savings by:

- Shutting down not needed devices
- Stand-by state(s)
- DVS (Dynamic Voltage Scaling)

Powering-on a system at given time / by an event.

- RTC
- HALL sensor, ...

More functionality

- Battery / charger
- Watchdog
- Functional-safety
 - Voltage monitoring
 - Current monitoring
 - Temperature monitoring

More control...

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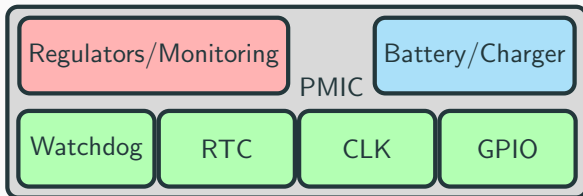
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PMIC - Power Management Integrated Circuit

- Multiple DC sources with specific start-up / shut-down sequence
- Voltage control
- Functional-safety
- Auxiliary blocks to support various needs



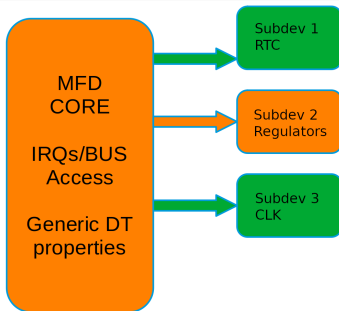
PMIC drivers

Multi Function Devices

Often MFD drivers

- **Regulator**
- RTC
- Power supply
- Watchdog
- GPIO
- CLK ...

Why? (I have 1 reason on mind, may be more)

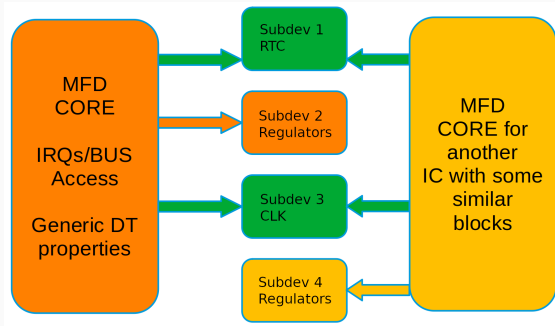


Multi Function Devices

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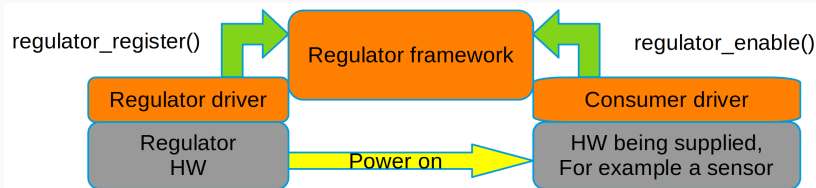
- **Regulator**
- RTC
- Power supply
- Watchdog
- GPIO
- CLK ...

Allows re-use



Regulator (provider) and consumer

- Provider is driver interfacing the hardware. Eg, sits “below” the regulator framework. Between regulator framework and HW
- Consumer is driver who wishes to control the regulator using the regulator framework. Eg, sits “on top of” the regulator framework
- PMIC driver is the provider driver (usually just referred as a regulator driver)



Regulator driver ops

Regulator driver relies on callbacks

Regulator (provider) registers callbacks to regulator framework.
Framework handles regulators using these ops.

```
include/linux/regulator/driver.h
```

```
struct regulator_ops {  
    // snip  
    int (*enable) (struct regulator_dev *);  
    int (*disable) (struct regulator_dev *);  
    int (*is_enabled) (struct regulator_dev *);  
    int (*set_voltage_sel) (struct regulator_dev *, unsigned selector);  
    int (*get_voltage_sel) (struct regulator_dev *);  
    // snip  
};  
  
struct regulator_desc {  
    /* Plenty of regulator properties */  
    /* Also information for the helpers */  
    /* Finally the ops */  
    const struct regulator_ops *ops;  
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```

Regulator constraints

Regulators can have constraints.

Not to be mixed with limits discussed during the rest of the presentation.

- struct `regulation_constraints`
include/linux/regulator/machine.h
- hard limits forced by the regulator framework.
- can be given by driver in dynamic init data
- can be given via device-tree
- voltage / current range, prevent disabling, step size ...



Credit: Peggy und Marco
Lachmann-Anke, Pixabay

Monitoring for abnormal conditions



Credit: Gerhard, Pixabay

Detecting unexpected

Linux has 3 severity categories

The categories - PROTECTION, ERROR, WARNING - inform the hardware state.

PROTECTION

- Unconditional shutdown by HW

ERROR

- Irrecoverable error, system not expected to be usable. Error handling by software.

WARNING - NEW(ish)

- Something is off-limit, system still usable but a recovery action should be taken to prevent escalation to errors

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Safety limits, device-tree

Property format:

- `regulator-<event >-<severity >-<unit >= value`

Over current:

- `regulator-oc-protection-microamp`
- `regulator-oc-error-microamp`
- `regulator-oc-warn-microamp`

Similar for over voltage (ov), under voltage (uv) and temperature (temp)

Values:

- `0 =>disable`
- `1 =>enable`
- `other =>new limit`

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Values:

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What if hardware does not support given limit?

Callbacks for configuring the limits

```
include/linux/regulator/driver.h
```

```
struct regulator_ops {  
    // snip  
    int (*set_over_current_protection)(struct regulator_dev *,  
        int lim_uA, int severity, bool enable);  
    int (*set_over_voltage_protection)(struct regulator_dev *,  
        int lim_uV, int severity, bool enable);  
    int (*set_under_voltage_protection)(struct regulator_dev *,  
        int lim_uV, int severity, bool enable);  
    int (*set_thermal_protection)(struct regulator_dev *,  
        int lim, int severity, bool enable);  
};
```

```
struct regulator_desc {  
    // snip  
    const struct regulator_ops *ops;  
};
```

```
struct regulator_dev *devm_regulator_register(struct device *dev,  
    const struct regulator_desc *regulator_desc,  
    const struct regulator_config *config);
```

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Simplified example

drivers/regulator/bd9576-regulator.c

```
static int bd9576_set_ocp(struct regulator_dev *rdev, int lim_uA,
                          int severity, bool enable)
{
    ...

    /* Return -EINVAL for unsupported configurations */
    if ((lim_uA && !enable) || (!lim_uA && enable))
        return -EINVAL;

    /*
     * Select the correct register and appropriate register-value
     * conversion for given severity and limit..
     */
    if (severity == REGULATOR_SEVERITY_PROT) {
        ...
    } else {
        ...
    }

    /* Write configuration to registers */
    return bd9576_set_limit(range, num_ranges, d->regmap,
                            reg, mask, Vfet);
}
```

Two types of information

- ERRORs
- NOTIFICATIONs

• ERROR

- set by provider
- queried (polled) by consumer
- `regulator_get_error_flags()`

• NOTIFICATION

- sent by provider (usually) from interrupt
- invoke consumer callback (blocking notifier call-chain)
- In some (many) cases IRQ is held active for whole duration of error
- no polling needed
- `regulator_register_notifier()`
- can send also other events

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Regulator error flags

```
include/linux/regulator/consumer.h
```

```
#define REGULATOR_ERROR_UNDER_VOLTAGE  
#define REGULATOR_ERROR_OVER_CURRENT  
#define REGULATOR_ERROR_REGULATION_OUT  
#define REGULATOR_ERROR_FAIL  
#define REGULATOR_ERROR_OVER_TEMP  
#define REGULATOR_ERROR_UNDER_VOLTAGE_WARN  
#define REGULATOR_ERROR_OVER_CURRENT_WARN  
#define REGULATOR_ERROR_OVER_VOLTAGE_WARN  
#define REGULATOR_ERROR_OVER_TEMP_WARN
```

Regulator notifications

```
include/linux/regulator/consumer.h
```

```
#define REGULATOR_EVENT_UNDER_VOLTAGE  
#define REGULATOR_EVENT_OVER_CURRENT  
#define REGULATOR_EVENT_REGULATION_OUT  
#define REGULATOR_EVENT_FAIL  
#define REGULATOR_EVENT_OVER_TEMP  
...  
#define REGULATOR_EVENT_UNDER_VOLTAGE_WARN  
#define REGULATOR_EVENT_OVER_CURRENT_WARN  
#define REGULATOR_EVENT_OVER_VOLTAGE_WARN  
#define REGULATOR_EVENT_OVER_TEMP_WARN  
#define REGULATOR_EVENT_WARN_MASK
```

Event IRQ helper

A helper provided for IRQ handling and sending the notification

- Supports keeping IRQ disabled for a period of time
- Supports forcibly shutting down the system if accessing the PMIC fails

```
void *regulator_irq_helper(struct device *dev,  
                           const struct regulator_irq_desc *d, int irq,  
                           int irq_flags, int common_errs,  
                           int *per_rdev_errs, struct regulator_dev **rdev,  
                           int rdev_amount);
```

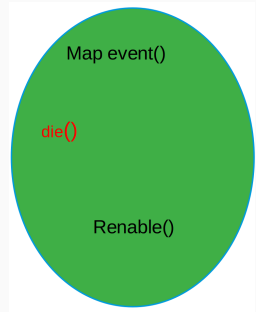
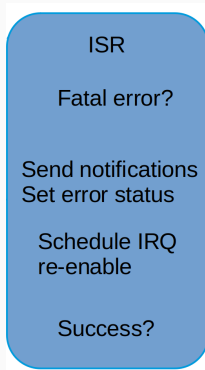
Helper break-out

events

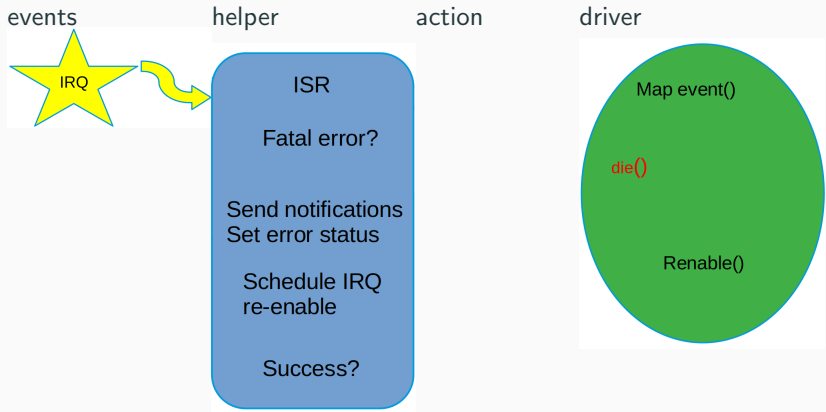
helper

action

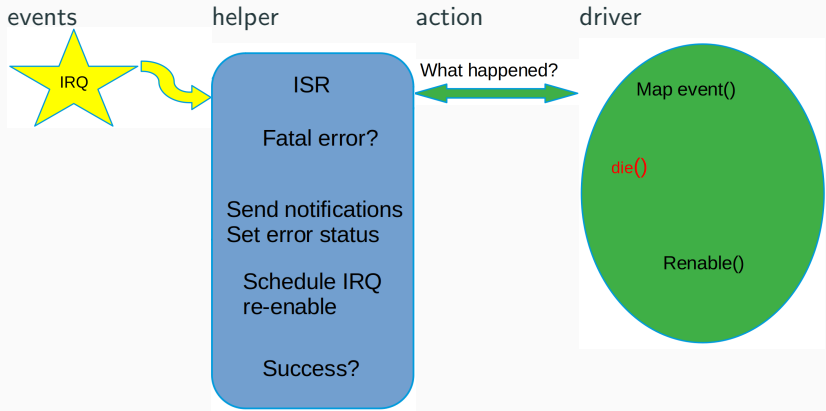
driver



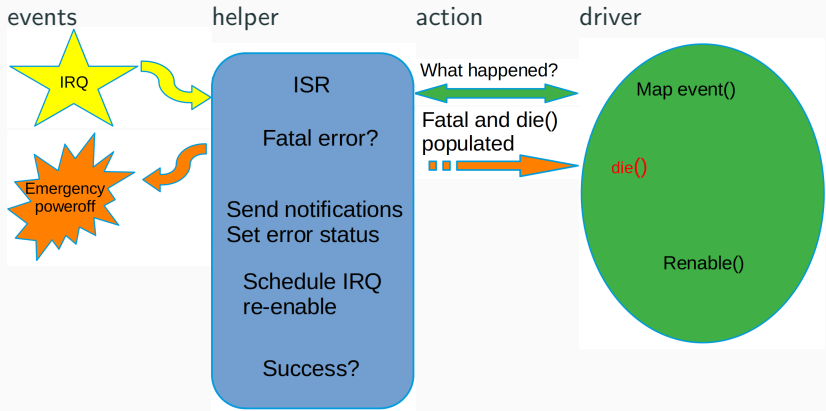
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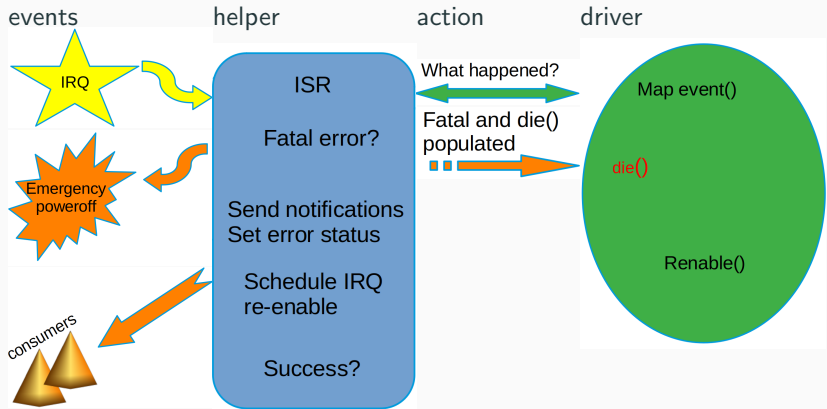
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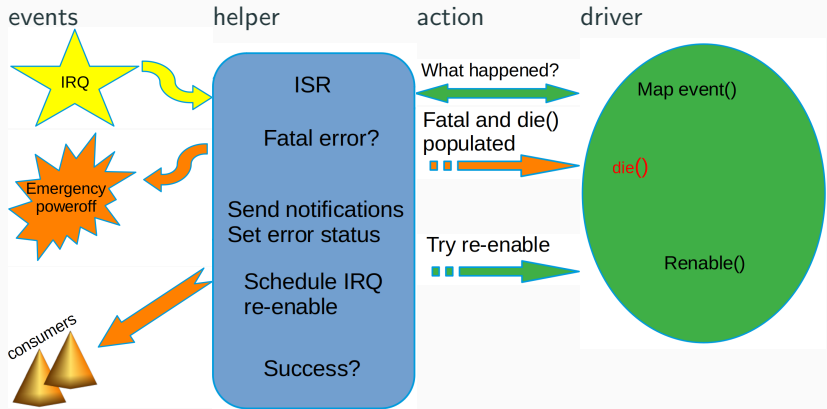
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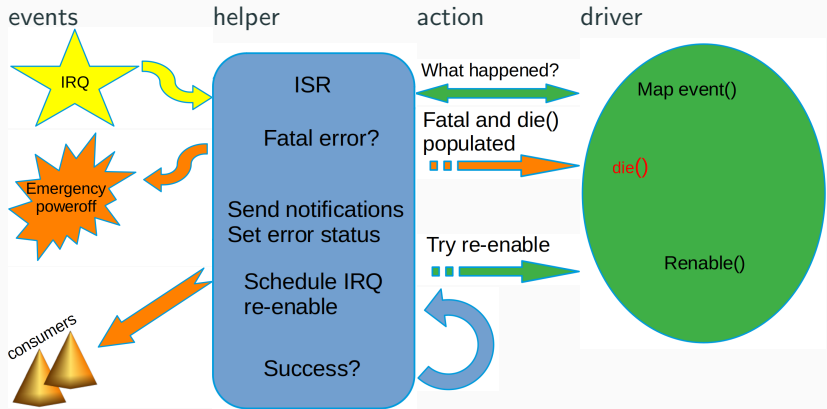
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Helper break-out



Helper break-out



Helper configuration

```
include/linux/regulator/driver.h
```

```
struct regulator_irq_desc {  
    const char *name;  
    int fatal_cnt;  
  
    int reread_ms;  
    int irq_off_ms;  
  
    bool skip_off;  
    bool high_prio;  
  
    void *data;  
    int (*die)(struct regulator_irq_data *rid);  
    int (*map_event)(int irq, struct regulator_irq_data *rid,  
        unsigned long *dev_mask);  
    int (*renable)(struct regulator_irq_data *rid);  
};  
  
void *regulator_irq_helper(struct device *dev,  
    const struct regulator_irq_desc *d, int irq,  
    int irq_flags, int common_errs,  
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(or a devm-variant)

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Event mapping

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int (*map_event)(int irq, struct regulator_irq_data *rid,  
                unsigned long *dev_mask);
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```
struct regulator_irq_data {  
    struct regulator_err_state *states;  
    int num_states;  
    void *data;  
    long opaque;  
};
```

```
struct regulator_err_state {  
    struct regulator_dev *rdev;  
    unsigned long notifs;  
    unsigned long errors;  
    int possible_errs;  
};
```

```
int (*reable)(struct regulator_irq_data *rid);
```

```
int regulator_irq_map_event_simple(int irq,  
                                   struct regulator_irq_data *rid,  
                                   unsigned long *dev_mask)
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Event mapping example

drivers/regulator/bd9576-regulator.c

```
static int bd9576_ovd_handler(int irq, struct regulator_irq_data *rid,
                               unsigned long *dev_mask)
{
    ret = regmap_read(d->regmap, BD957X_REG_INT_OVD_STAT, &val);
    if (ret)
        return REGULATOR_FAILED_RETRY;

    rid->opaque = val & OVD_IRQ_VALID_MASK;
    *dev_mask = 0;

    if (!(val & OVD_IRQ_VALID_MASK))
        return 0;

    *dev_mask = val & BD9576_xVD_IRQ_MASK_VOUT1TO4;

    for_each_set_bit(i, dev_mask, 4) {
        stat = &rid->states[i];

        stat->notifs = rdata->ovd_notif;
        stat->errors = rdata->ovd_err;
    }

    return 0;
}
```

Event mapping example

drivers/regulator/bd9576-regulator.c

```
static int bd9576_ovd_handler(int irq, struct regulator_irq_data *rid,
                               unsigned long *dev_mask)
{
    ret = regmap_read(d->regmap, BD957X_REG_INT_OVD_STAT, &val);
    if (ret)
        return REGULATOR_FAILED_RETRY;

    rid->opaque = val & OVD_IRQ_VALID_MASK;
    *dev_mask = 0;

    if (!(val & OVD_IRQ_VALID_MASK))
        return 0;

    *dev_mask = val & BD9576_xVD_IRQ_MASK_VOUT1TO4;

    for_each_set_bit(i, dev_mask, 4) {
        stat = &rid->states[i];

        stat->notifs = rdata->ovd_notif;
        stat->errors = rdata->ovd_err;
    }

    return 0;
}
```

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    for_each_set_bit(i, dev_mask, 4) {
        stat = &rid->states[i];

        stat->notifs    = rdata->ovd_notif;
        stat->errors    = rdata->ovd_err;
    }

    return 0;
}
```


Helper registration 1/3

Fill the helper configuration

drivers/regulator/bd9576-regulator.c

```
static const struct regulator_irq_desc bd9576_notif_ovd = {  
    .name = "bd9576-ovd",  
    .irq_off_ms = 1000,  
    .map_event = bd9576_ovd_handler,  
    .renable = bd9576_ovd_renable,  
    .data = &bd957x_regulators,  
};
```

Helper registration 2/3

Create an array of regulators this IRQ may concern

drivers/regulator/bd9576-regulator.c

```
struct regulator_dev *ovd_devs[BD9576_NUM_OVD_REGULATORS];

for (i = 0; i < num_rdev; i++) {
    struct bd957x_regulator_data *r = &ic_data->regulator_data[i];
    const struct regulator_desc *desc = &r->desc;

    r->rdev = devm_regulator_register(&pdev->dev, desc, &config);

    rdevs[i] = r->rdev;
    if (i < BD957X_VOUTS1)
        ovd_devs[i] = r->rdev;
}
```

Helper registration 3/3

Fill possible errors this IRQ may indicate and register the helper

drivers/regulator/bd9576-regulator.c

```
int ovd_errs = REGULATOR_ERROR_OVER_VOLTAGE_WARN |  
               REGULATOR_ERROR_REGULATION_OUT;  
  
ret = devm_regulator_irq_helper(&pdev->dev, &bd9576_notif_ovd,  
                                irq, 0, ovd_errs, NULL,  
                                &ovd_devs[0],  
                                BD9576_NUM_OVD_REGULATORS);
```

Wrap it up

- Powering up a modern SOC is not simple
- PMIC is an IC trying to integrate powering related features into single chip
- Many PMICs include functional-safety features
- There is some existing support for indicating abnormal events

Questions?

Thank You for listening!
(or time to wake up) :)

