Linux Power!
(From the perspective of a PMIC vendor)
Matti Vaittinen
Jan 10 2023
ROHM Semiconductors

1. Breath, smile, look at them
2. Eyecontact. They are your friends. On your side
3. Breath
4. Welcome. I am not excited to be here. I am terrified
5. I am afraid of social situations and don't like making myself known
6. So, of course I am climbing up on the stage to give a talk, right? ... How stupid one can be?
7. Well, as I am here, I will talk a little bit about powring a SoC on a Linux based system

Linux Power!

(From the perspective of a PMIC vendor)

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Topics
Goal
What is PMIC
Regulator errors and notifications
Functional-safety helpers in regulator subsystem

1. Shallow overview on what is PMIC and why it is needed
2. Linux oriented Short glance of drivers can be needed for a PMIC
3. functional safety and reporting hw issues

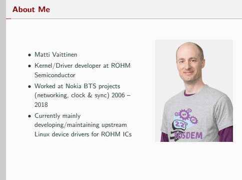
Topics

Goal

What is PMIC

Regulator errors and notifications

Functional-safety helpers in regulator subsystem



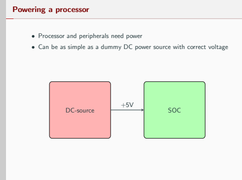
1. This is the formal me
2. Linux developer who started working with Linux at 2005
3. Today I work at ROHM Semiconductors
4. HW vendor, no forest from the trees.
5. Anyone with insight on how notifiers are or could be used - please explain!

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

Following section aims to give an idea about What a PMIC is and Why PMICs are needed?

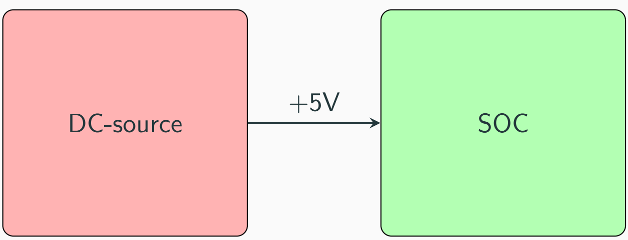
What and Why is a PMIC?

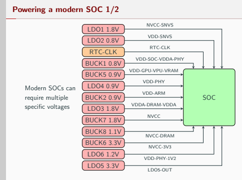


could be this simple. Just passive source

Powering a processor

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

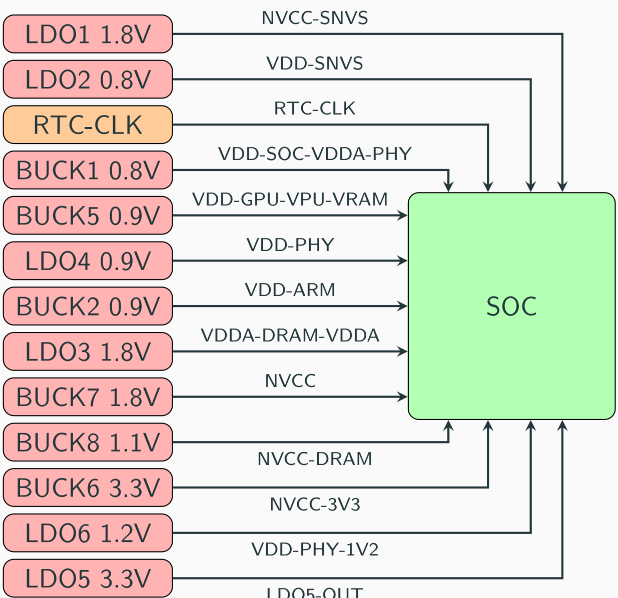


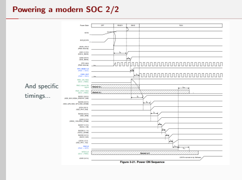


1. almost a real SOC.
2. pic omits state GPIOs

Powering a modern SOC 1/2

Modern SOCs can require multiple specific voltages





1. TIMINGs - explain state transitions
2. from PMIC spec
3. shows also internal changes

Powering a modern SOC 2/2

And specific timings...

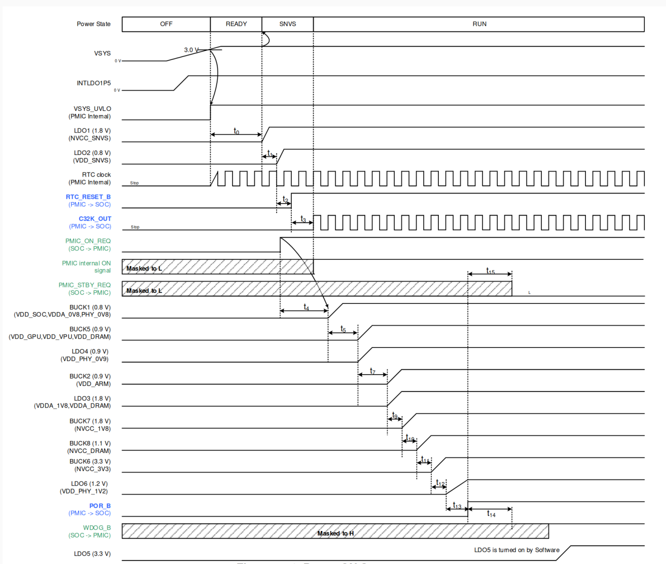


Figure 3-21. Power ON Sequence

More control...

Power savings by:

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

1. Importance of power saving increases
2. Toggling outputs on/off
3. Changing voltages
4. Predefined states changed by GPIO (avoid I2C shut-down races I2C depends on some other block - other can't be shut down?)

More control...

Power savings by:

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

Automated power on
Powering-on a system at given time...
- RTC
...Or by an event
- HALL sensor, ...

1. Monitor turn-on input when SOC is shut down
2. For example RTC / HALL sensor (lid)

Automated power on

Powering-on a system at given time...

- RTC

...Or by an event

- HALL sensor, ...

More requirements...

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

More needs

1. battery powered devices everywhere =¿ charging logic
2. Watchdog cut power - can be external or in power-supply
3. montor abnormal events (temp, over voltage, ocp)

More requirements...

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

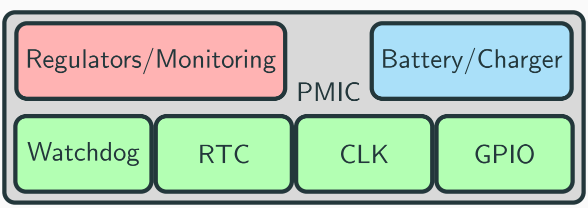
PMICs
PMIC - Power Management Integrated Circuit
• Multiple DC sources with specific start-up / shut-down sequence
• Voltage control
• Functional-safety
• Auxiliary blocks to support various needs
Regulators/Monitoring PMIC Battery/Charger
Watchdog RTC CLK GPIO

1. PMICs created to support previous use-cases
2. Often very SOC specific
3. Still also generic ones done - very customizable (amount of outputs, voltages, sequences)

PMICs

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



1. What some typical PMIC drivers look like
2. MFD
3. Regulators

PMIC drivers

Multi Function Devices
Why? (I have 1 reason on mind, may be more)
Often MFD drivers
- Regulator
- RTC
- Power supply
- Watchdog
- GPIO
- CLK ...

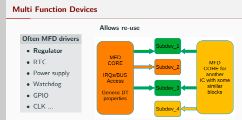
1. MFD "core" driver (Lee says there is no such "thing" as MFD)
2. core driver often provides bus access and IRQ controller code
3. core driver is created as any "standard driver" on that bus
4. Sub devices are (seemingly independent) platform devices
5. mfd-cell array describes subdevices (drivers)
6. mfd registration instantiates subdevices and runs driver probes
7. MODALIAS for module loading
8. Ask why MFD? (spoiler, re-use)

Multi Function Devices

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

Often MFD drivers

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



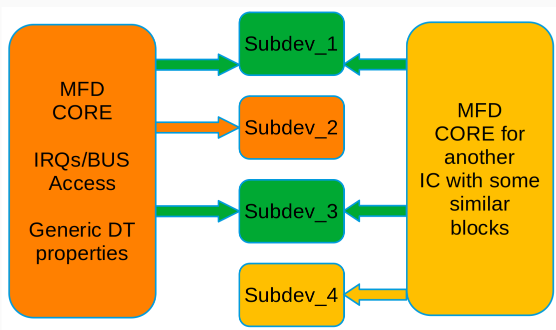
1. Many devices re-use digital blocks from previous generations while adding something new
2. MFD sub-devices can be re-used and new drivers written only for new blocks (ideally)

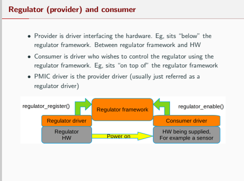
Multi Function Devices

Allows re-use

Often MFD drivers

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

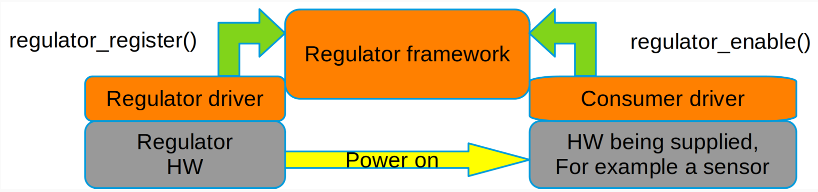




1. regulator framework sits between hardware driver and regulator user
2. provides control/information interface to consumer drivers - regulator API
3. hardware driver interfaces PMIC and translates regulator framework requests to register reads/writes
4. example, regulator consumer can be sensor driver, enabling sensor power when sensor is needed
5. sensor requests and enables the regulator via regulator API
6. regulator framework calls correct callbacks from regulator driver

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)



Monitoring for abnormal conditions

1. rest of the show explains how regulator framework can be used to deliver errors. From PMIC vendor perspective - sorry

Monitoring for abnormal conditions

Detecting undexpected
Linux has 3 severity categories
- 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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1. PROTECTION example, severe overvoltage - PMIC shuts down all or offending outputs
2. Could be also temperature-error or over-current

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1. Some PMICs may not automatically shut down outputs - SW should do it
2. ERROR still indicate fatal issues - HW not working

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1. WARNING included in kernel 5.14
2. Intended to be used for invoking corrective action(s)
3. Has been requested from us - there probably are use-cases
4. I have no insight as to what they could be - very interested in learning any concrete examples - ask from audience

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Safety limits, devicetree
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 (oc), under voltage (uv) and temperature (temp)
Values:
- 0 =>disable
- 1 =>enable
- other =>new limit

1. Often board specific - Can be provided via device-tree
2. property format from box
3. pause

Safety limits, devicetree

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1. value sets new limit
2. 1 / 0 special values - they are used to indicate enable / disable
3. pause

Safety limits, devicetree

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What if hardware does not support given limit?

1. I have no good answer.
2. What happens if silently ignored?
3. What happens if regulator registration fails?
4. If limit is silently ignored - problems for example when changing a component and new driver does not support limits
5. If registration fails, system may not boot, boot without display etc.
6. Currently just log a warning
7. In general, is there a way to mark NOT supported properties to binding docs? Would it help? Including ALL regulator bindings does hide this at avalidation
8. pause
9. I know you are eager to see the code :) So, let's look at some

Safety limits, devicetree

Property format:

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What if hardware does not support given limit?

1. Callbacks for over-current, over- and under-voltage, over temperature
2. Arguments include the limit, severity (PROT, ERR, WARN) and enable/disable

Callbacks for configuring the limits

```
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);
```

1. Callbacks are amongst the other regulator ops which is pointed from the regulator description

Callbacks for configuring the limits

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1. The description with ops is passed to regulator registration

Callbacks for configuring the limits

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```

1. Example of over-current protection example using pieces of ROHM BD9576 driver as example
2. Regulator framework parses dt properties and invokes callback with values found from DT
3. Driver typically checks for parameter sanity/support
4. Driver decides the register and values to write based on severity and limit
5. for example BD9576 has different register and limit ranges for warning and protection
6. From the PMIC operation POV there is no difference between ERROR and WARNING
7. Finally if limits were sane, the driver updates new limits to registers and returns Ok

Simplified example

```
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);
}
```

Informing the unexpected
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
• no polling needed
• regulator_register_notifier()
• can send also other events

1. So, when an abnormal event is detected by HW (something exeeds the limit) we need to inform consumers
2. The regulator framework can use ERRORs or NOTIFICATIONs
3. Errors visible via sysfs

Informing the unexpected

Two types of information

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1. Errors are simple status which is stored in framework
2. Errors need to be polled by consumers
3. Polling is not always preferred

Informing the unexpected

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1. Notifications are sent by HW when problem occurs
2. No polling needed - except to know when condition is back to normal
3. Not all notifications are errors...

Informing the unexpected

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Regulator error flags
#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
include/linux/regulator/consumer.h

1. The available ERROR definitions
2. I've used REGULATION-OUT for over-voltage
3. Not sure where REGULATOR-ERROR-FAIL is used

Regulator error flags

```
#define REGULATOR_ERROR_UNDER_VOLTAGE
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```

include/linux/regulator/consumer.h

Regulator notifications

#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

include/linux/regulator/consumer.h

Regulator notifications

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include/linux/regulator/consumer.h

Notifications
Usually IRQ backed
1. PMIC detects error and generates IRQ
2. IRQ handler sends notification
3. Regulator consumer action is executed
In some (many) cases IRQ is held active for whole duration of error
- Maybe because these IRQs are considered as a last thing?
- Maybe because there is need to ensure IRQ is not missed?
- Does not play well with all systems

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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 accesing 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);

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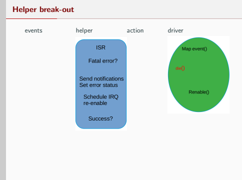
A helper provided for IRQ handling and sending the notification

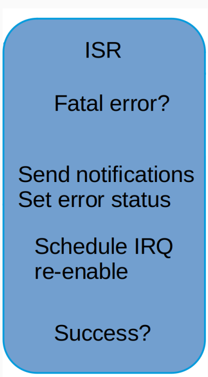
- Supports keeping IRQ disabled for a period of time
- Supports forcibly shutting down the system if accesing the PMIC fails

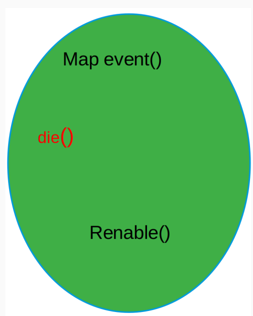
```
void *regulator_irq_helper(struct device *dev,
                    const struct regulator_irq_desc *d, int irq,
                    int irq_flags, int common_errs,
                    int *per_rdev_errs, struct regulator_dev **rdev,
                    int rdev_amount);
```

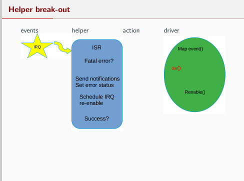


Helper break-out

events | helper | action | driver

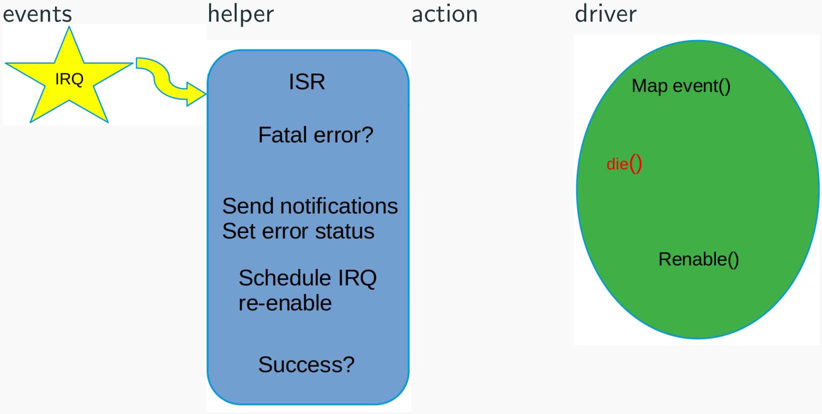


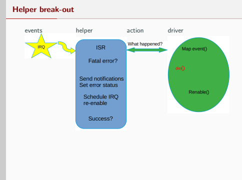




Helper break-out

events helper action driver





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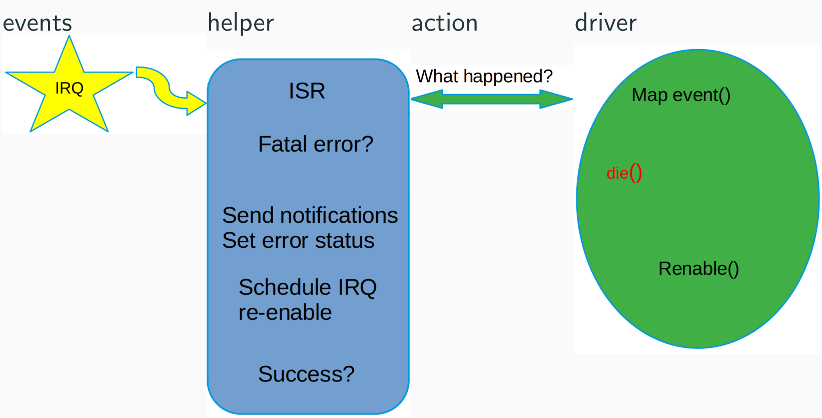

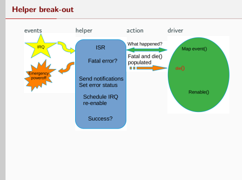

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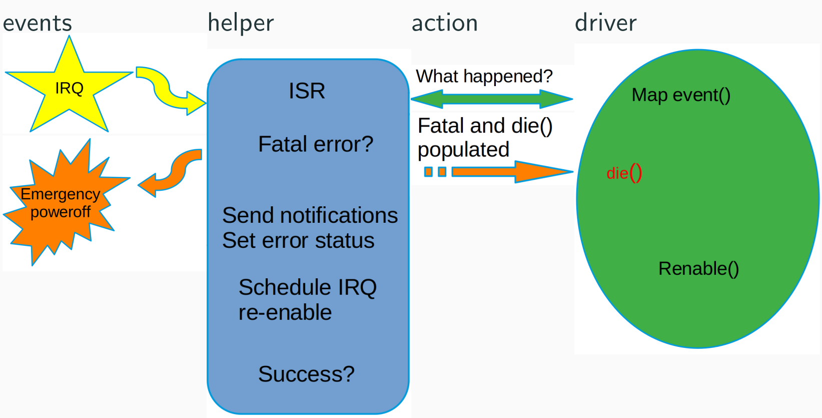
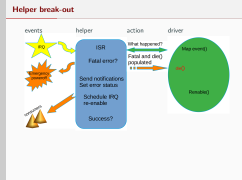


Linux Power!

2023-01-17

└─Helper break-out



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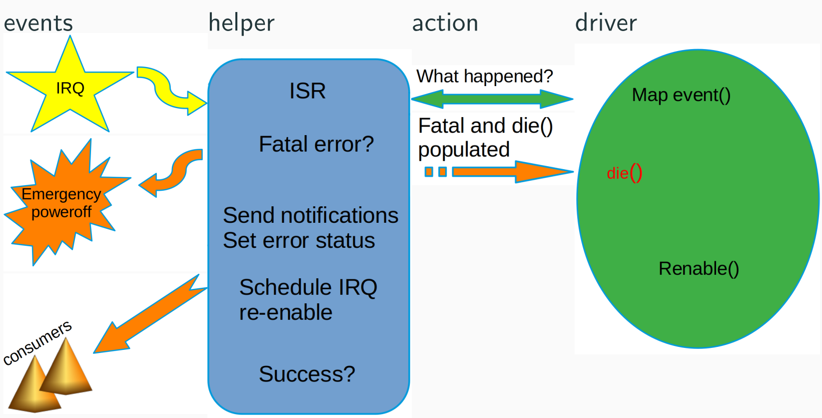

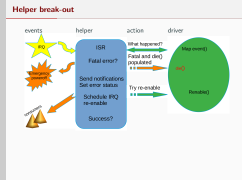

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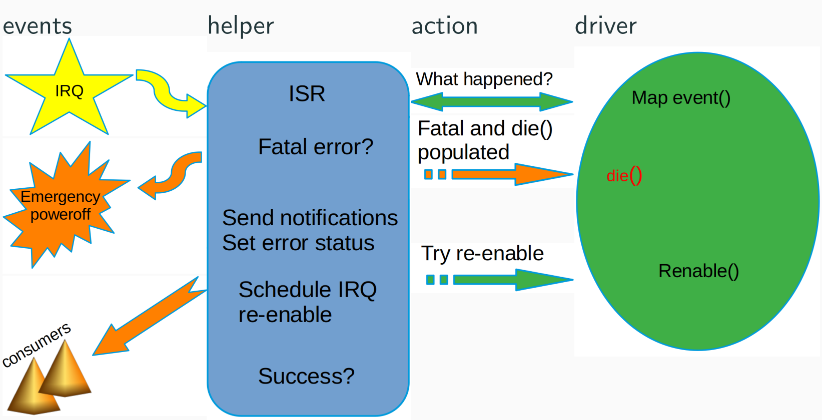

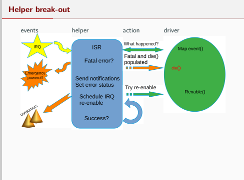

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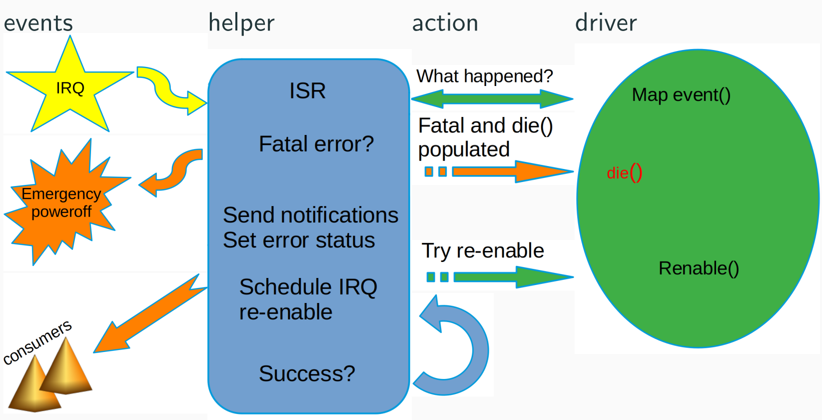

Helper configuration

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        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);
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void *regulator_irq_helper(struct device *dev,
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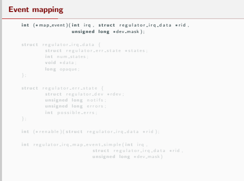

Event mapping

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int (*map_event)(int irq, struct regulator_irq_data *rid,
                 unsigned long *dev_mask);

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 (*renable)(struct regulator_irq_data *rid);

int regulator_irq_map_event_simple(int irq,
                        struct regulator_irq_data *rid,
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```

Event mapping example

```
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;
        }

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        }

        return 0;
}
```

Helper registration 1/2
Fill the helper configuration
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,
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Helper registration 2/2

Create an array of regulators this IRQ may concern

```
struct regulator_dev *rdevs[BD9576_NUM_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;
}
```

Fill possible errors this IRQ may indicate and register the helper

```
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],
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Wrap it up

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- 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

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No answers guaranteed
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Thank You for listening!
(or time to wake up) :)

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