Designing a Multi-PMIC Linux Driver: *Key Decisions for Mainline Submission*

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Speaker Introduction

Shree Ramamoorthy

Software Engineer, Texas Instruments

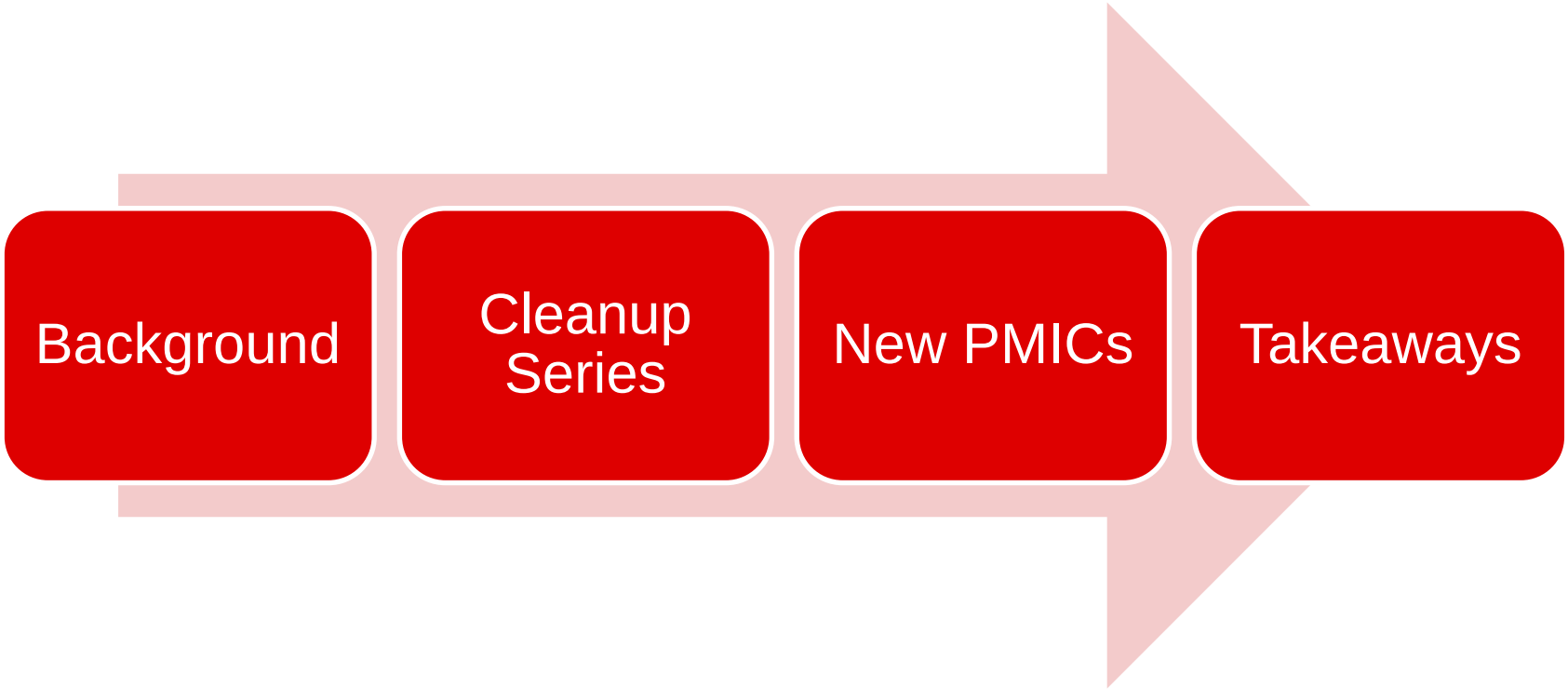
- Dallas, Texas
- Power Management Integrated Circuit Team
- Linux device driver development
- Customer GUIs

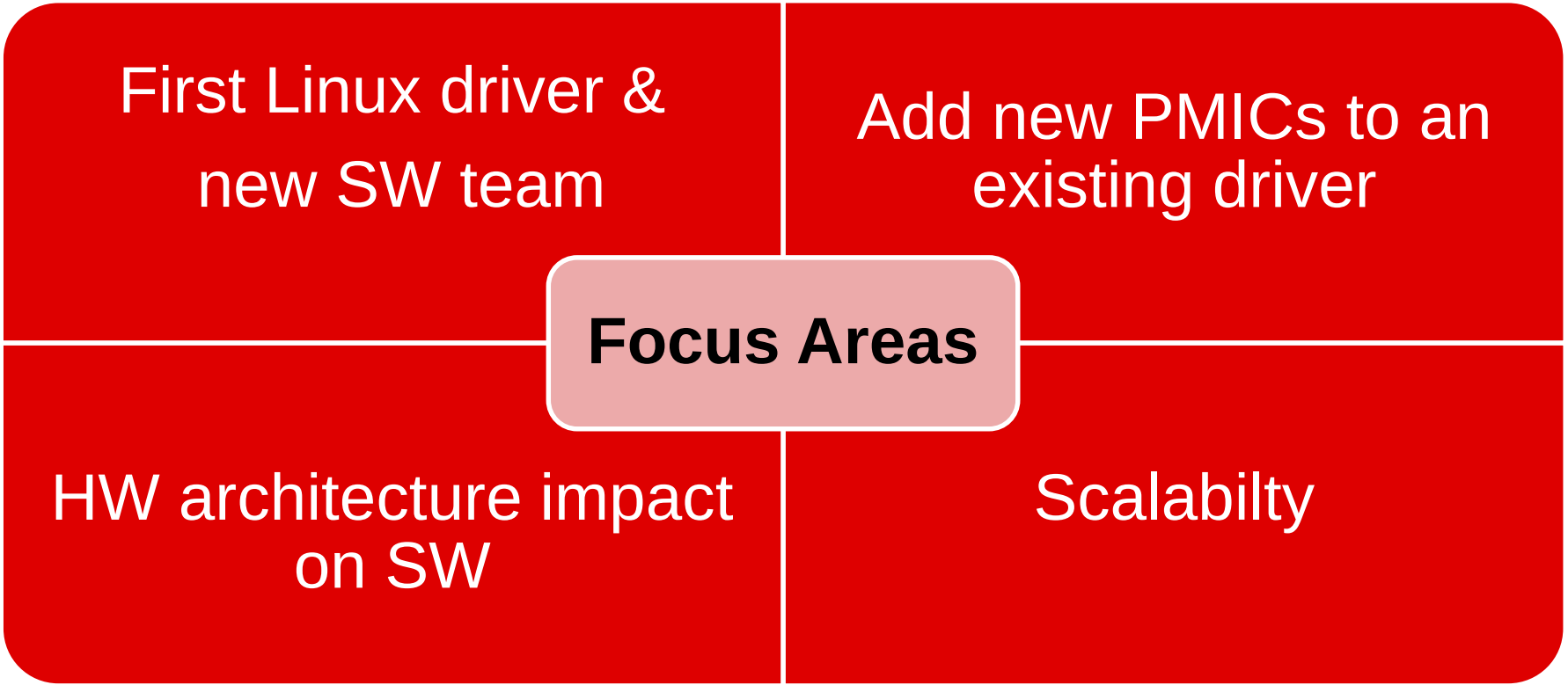
About us: TI and Open Source

Upstream FIRST!

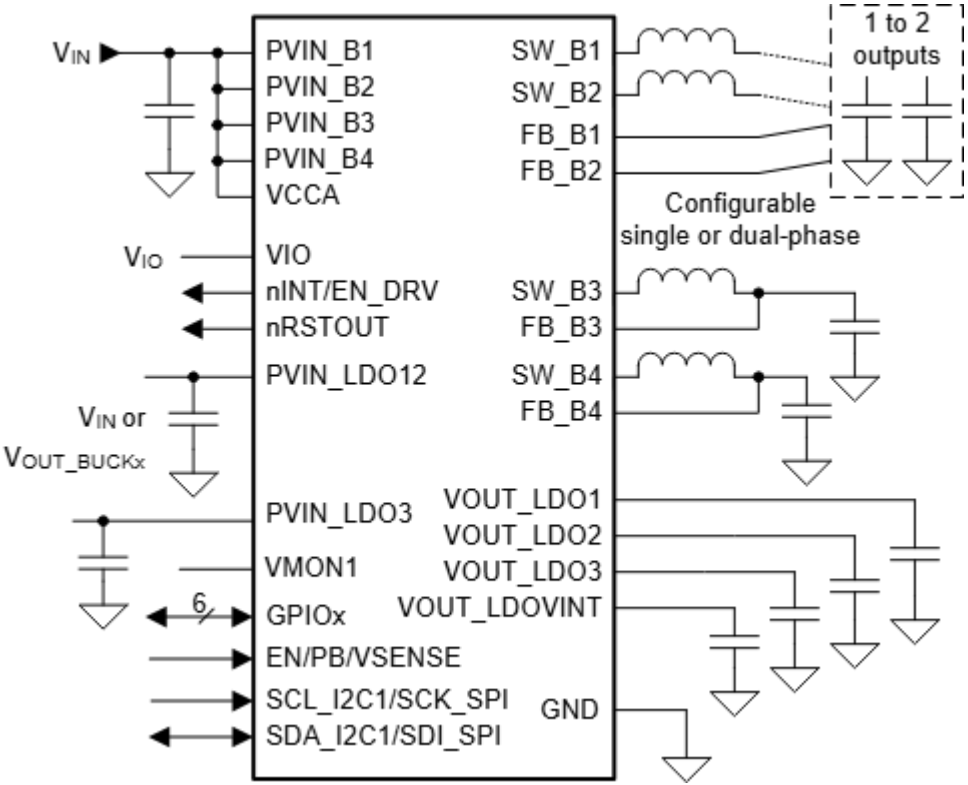
- ✔ Upstream FIRST mentality!
- ✔ Decades of contribution and collaboration
- ✔ Focus on long term, sustainable and quality products
- ✔ Upstream & opensource ecosystem in device architecture
- ✔ Ingrained culture to give back to the community

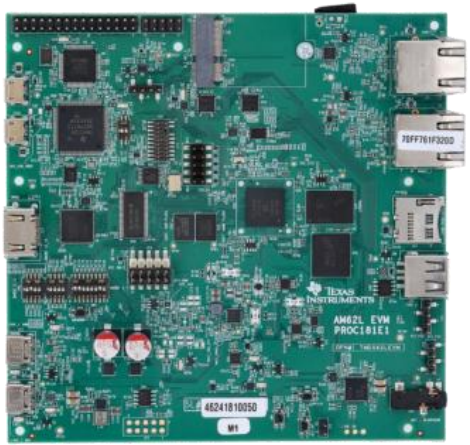
Overview

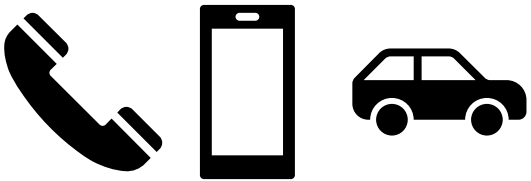



First Linux driver &
new SW team
Add new PMICs to an
existing driver
Focus Areas
HW architecture impact
on SW
Scalabilty

What is a PMIC?







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Why do PMICs need a Linux Driver?

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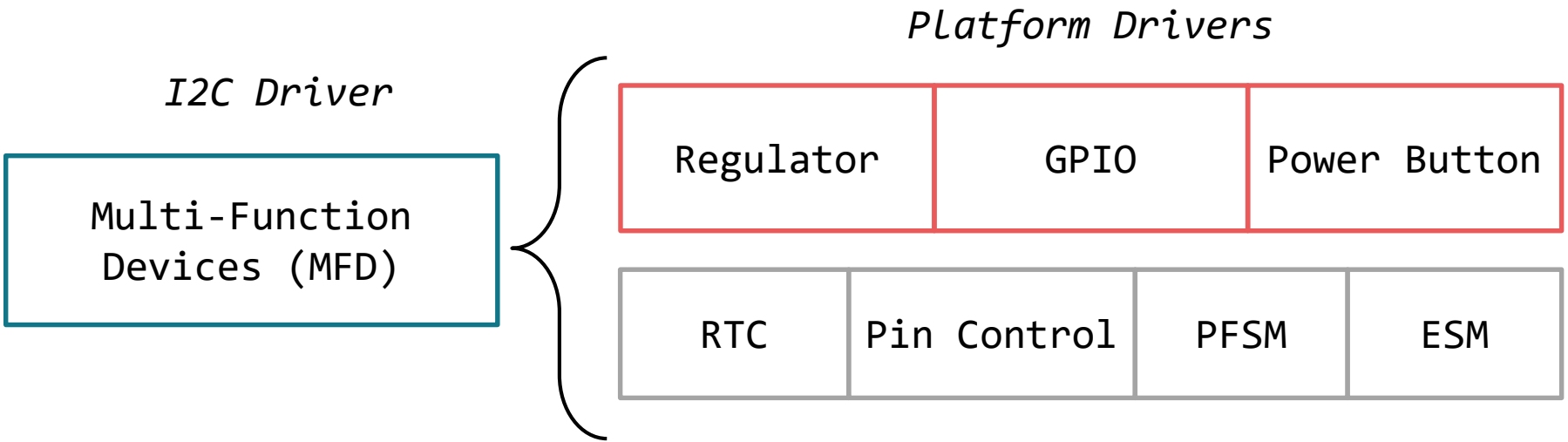
PMIC Linux Driver Structure

Legend
MFD Driver: always included
Subsystems typically included
PMIC feature-specific



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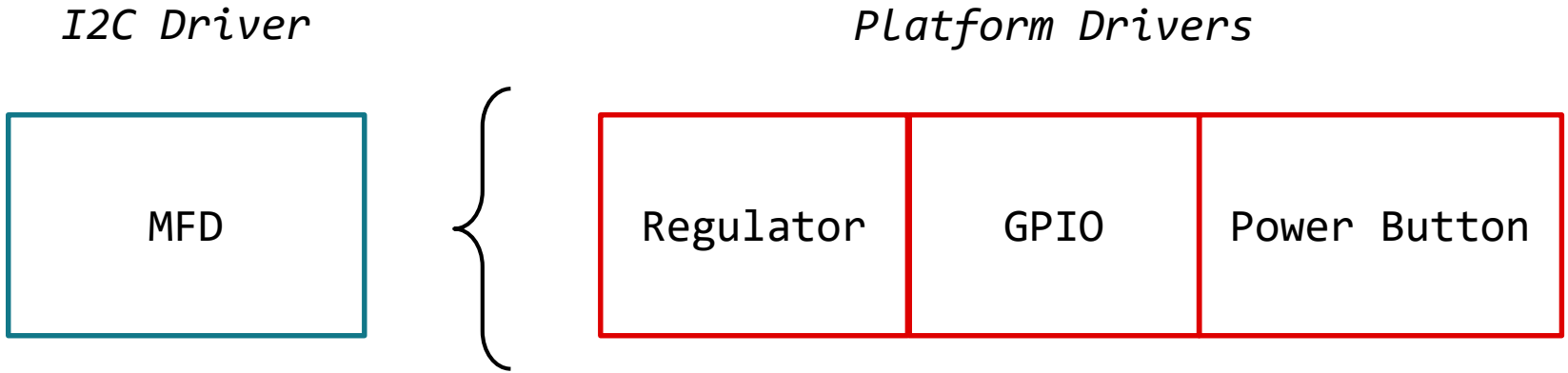
Existing TPS65219 Driver Structure



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PMIC Feature Comparison

TPS65214	TPS65215	TPS65219
3 Buck Regulators		
2 LDOs		4 LDOs
1 GPO		2 GPOs
1 GPIO with configurable output during device operation	Same GPIO features	

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Goal

- Prioritize code re-use *without* sacrificing readability.
- Simplify the integration of additional PMICs.
- Reduce future development effort.

Applied to Kernel Version #	Patch Series
6.14	Cleanup: MFD
	Cleanup: Regulator
	Cleanup: GPIO
6.15	MFD
6.16	Regulator
6.17	GPIO

Cleanup Series

MFD, Regulator, and GPIO

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MFD

- Migrated to `MFD_CELL` macros

```
static const struct mfd_cell tps65219_cells[] = {
-       {
-               .name = "tps65219-regulator",
-               .resources = tps65219_regulator_resources,
-               .num_resources = ARRAY_SIZE(tps65219_regulator_resources),
-       },
-       { .name = "tps65219-gpio", },
+       MFD_CELL_RES("tps65219-regulator", tps65219_regulator_resources),
+       MFD_CELL_NAME("tps65219-gpio"),
 };
```


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MFD

- Removed unused, custom-defined macros
- Replaced direct struct definitions with header file include

```
+#include <linux/regmap.h>
 #include <linux/regulator/driver.h>

-struct regmap;
-struct regmap_irq_chip_data;
-
-#define TPS65219_1V35                                   1350000
-#define TPS65219_1V8                                    1800000
```


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Regulator

- Updated error handling to `dev_err_probe()` instead `dev_err()`

```
-   if (IS_ERR(rdev)) {
-         dev_err(tps->dev, "failed to register %s regulator\n", regulators[i].name);
-         return PTR_ERR(rdev);
-   }
+   if (IS_ERR(rdev))
+         return dev_err_probe(tps->dev, PTR_ERR(rdev),
+                              "Failed to register %s regulator\n",
+                              regulators[i].name);
```


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GPIO

- Replaced custom GPIO direction macros with existing kernel-defined macros

```
-#define TPS65219_GPIO_DIR_IN                    1
-#define TPS65219_GPIO_DIR_OUT                   0

-       if (tps65219_gpio_get_direction(gc, offset) == TPS65219_GPIO_DIR_OUT)
+       if (tps65219_gpio_get_direction(gc, offset) == GPIO_LINE_DIRECTION_OUT)

-       return tps65219_gpio_change_direction(gc, offset, TPS65219_GPIO_DIR_IN);
+       return tps65219_gpio_change_direction(gc, offset, GPIO_LINE_DIRECTION_IN);
```


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Add new PMICs' Linux driver support

TPS65214 and TPS65215

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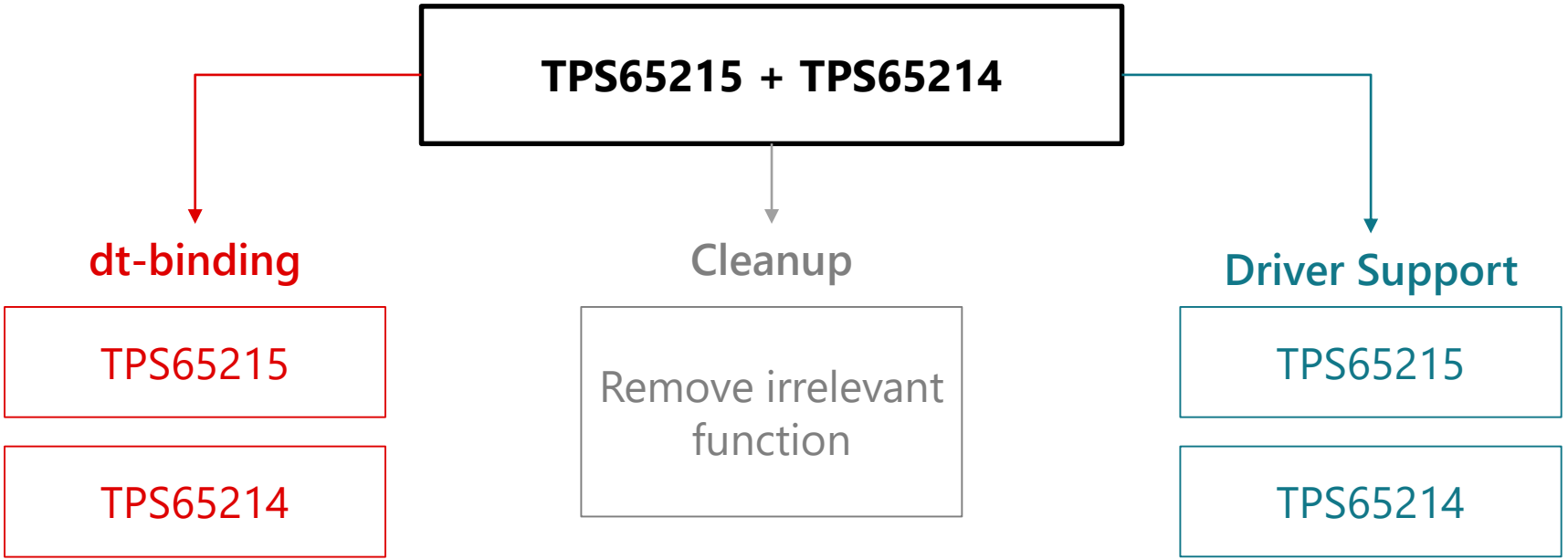
MFD Series



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HW Architecture Impact #1

- TPS65215 and TPS65219: different `status_base` and `ack_base` registers.
- Importance of cross-functional collaboration.

```
+static const struct regmap_irq_chip tps65215_irq_chip = {
+         .name = "tps65215_irq",
+         .main_status = TPS65219_REG_INT_SOURCE,
+         .num_main_regs = 1,
+         .num_main_status_bits = 8,
+         .irqs = tps65215_irqs,
+         .num_irqs = ARRAY_SIZE(tps65215_irqs),
+         .status_base = TPS65215_REG_INT_LDO_2,
+         .ack_base = TPS65215_REG_INT_LDO_2,
+         .clear_ack = 1,
+         .num_regs = 8,
+         .sub_reg_offsets = tps65215_sub_irq_offsets,
+};
```

HW Architecture Impact #2

- TPS65215 and TPS65219: different bits for `regmap_irq_sub_irq_map` (bits 5 & 6).

```
 static unsigned int bit5_offsets[] = {TPS65219_REG_INT_LDO_1_2_POS};
 static unsigned int bit6_offsets[] = {TPS65219_REG_INT_LDO_3_4_POS};
+static unsigned int tps65215_bit5_offsets[] = {TPS65215_REG_INT_LDO_1_POS};
+static unsigned int tps65215_bit6_offsets[] = {TPS65215_REG_INT_LDO_2_POS};

+static struct regmap_irq_sub_irq_map tps65215_sub_irq_offsets[] = {
+         REGMAP_IRQ_MAIN_REG_OFFSET(bit0_offsets),
+         REGMAP_IRQ_MAIN_REG_OFFSET(bit1_offsets),
+         REGMAP_IRQ_MAIN_REG_OFFSET(bit2_offsets),
+         REGMAP_IRQ_MAIN_REG_OFFSET(bit3_offsets),
+         REGMAP_IRQ_MAIN_REG_OFFSET(bit4_offsets),
+         REGMAP_IRQ_MAIN_REG_OFFSET(tps65215_bit5_offsets),
+         REGMAP_IRQ_MAIN_REG_OFFSET(tps65215_bit6_offsets),
+         REGMAP_IRQ_MAIN_REG_OFFSET(bit7_offsets),
+};
```

HW Architecture Impact #3

- TPS65219's LDO3 mapped to TPS65215's LDO2.
- Result: multiple PMIC-specific structs added to MFD driver.

```
+static const struct regmap_irq tps65215_irqs[] = {
+        TPS65219_REGMAP_IRQ_REG(TPS65215_INT_LDO1_SCG, TPS65215_REG_INT_LDO_1_POS),
+        TPS65219_REGMAP_IRQ_REG(TPS65215_INT_LDO1_OC, TPS65215_REG_INT_LDO_1_POS),
+        TPS65219_REGMAP_IRQ_REG(TPS65215_INT_LDO1_UV, TPS65215_REG_INT_LDO_1_POS),
+        TPS65219_REGMAP_IRQ_REG(TPS65215_INT_LDO2_SCG, TPS65215_REG_INT_LDO_2_POS),
+        TPS65219_REGMAP_IRQ_REG(TPS65215_INT_LDO2_OC, TPS65215_REG_INT_LDO_2_POS),
+        TPS65219_REGMAP_IRQ_REG(TPS65215_INT_LDO2_UV, TPS65215_REG_INT_LDO_2_POS),
         // 27 lines removed for clarity
+        TPS65219_REGMAP_IRQ_REG(TPS65219_INT_LDO1_RV_SD, TPS65219_REG_INT_TO_RV_POS),
+        TPS65219_REGMAP_IRQ_REG(TPS65215_INT_LDO2_RV_SD, TPS65219_REG_INT_TO_RV_POS),
+};
```

Why did each PMIC add similar code churn?

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Patch Diff Analysis

TPS65215	TPS65214
2 files changed	2 files changed
209 insertions(+)	184 insertions(+)
12 deletions(-)	7 deletions(-)

Driving forces behind code churn

1. PMIC-specific structs added to promote readability
2. Introduced new `tps65219_chip_data` struct

```
struct tps65219_chip_data {
    const struct regmap_irq_chip *irq_chip;
    const struct mfd_cell *cells;
    int n_cells;
};
static const struct tps65219_chip_data chip_info_table[] = {
    [TPS65219] = {
          .irq_chip = &tps65219_irq_chip,
          .cells = tps65219_cells,
          .n_cells = ARRAY_SIZE(tps65219_cells),
         },
};
```

Driving forces behind code churn

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```
struct tps65219_chip_data {
    const struct regmap_irq_chip *irq_chip;
    const struct mfd_cell *cells;
    int n_cells;
};
static const struct tps65219_chip_data chip_info_table[] = {
    [TPS65219] = {
          .irq_chip = &tps65219_irq_chip,
          .cells = tps65219_cells,
          .n_cells = ARRAY_SIZE(tps65219_cells),
         },
};
```


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struct tps65219_chip_data {
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    const struct mfd_cell *cells;
    int n_cells;
};
static const struct tps65219_chip_data chip_info_table[] = {
    [TPS65219] = {
          .irq_chip = &tps65219_irq_chip,
          .cells = tps65219_cells,
          .n_cells = ARRAY_SIZE(tps65219_cells),
        },
};
```


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struct tps65219_chip_data {
    const struct regmap_irq_chip *irq_chip;
    const struct mfd_cell *cells;
    int n_cells;
};
static const struct tps65219_chip_data chip_info_table[] = {
    [TPS65219] = {
          .irq_chip = &tps65219_irq_chip,
          .cells = tps65219_cells,
          .n_cells = ARRAY_SIZE(tps65219_cells),
        },
};
```


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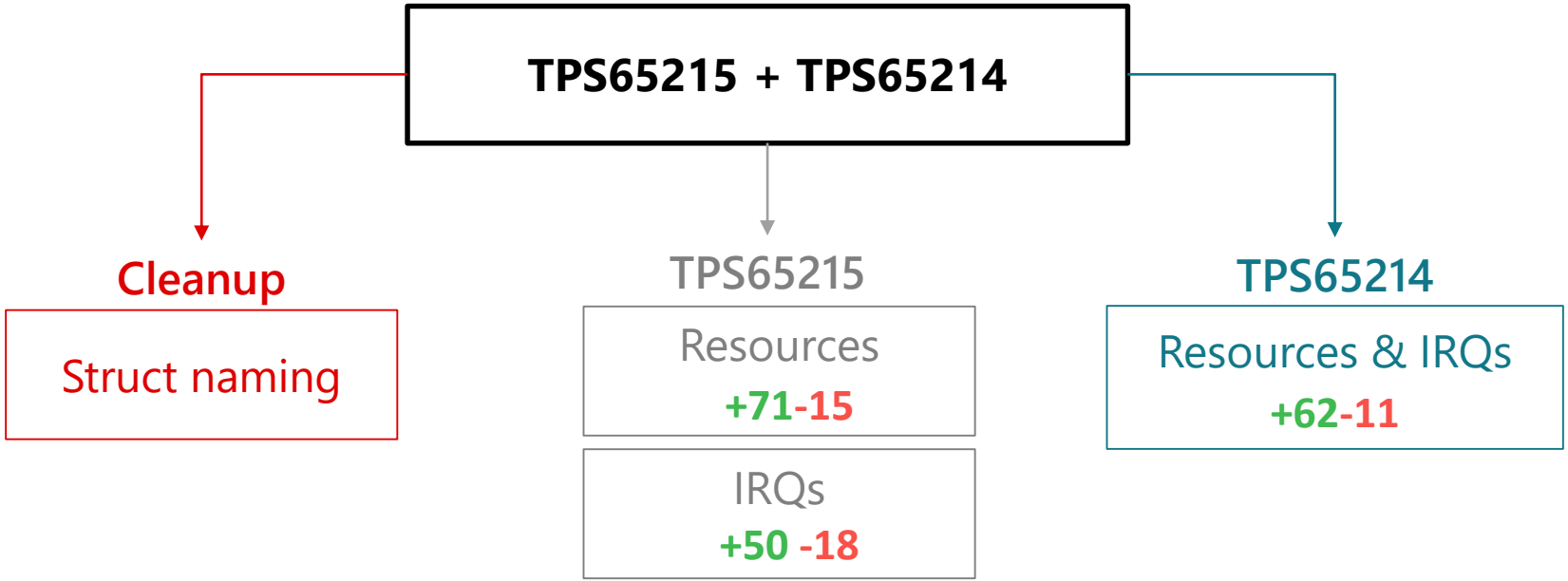
Regulator Series



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Restructure regulator driver

- **Goal**: Little to no changes for the `probe()`.
- **Attempt:** abstract registering regulators & IRQ handling into helper functions.
- **Lesson Learned:** resulting diff was hard to read & did not pass kernel build tests.
- **Implementation**
  - Created common structs for overlapping information.
  - Added device-specific structs.
  - Handle common structs first in `probe()`, then device-specific.
  - Add new PMIC to `chip_data` struct.
- **Result**: Easier for reviewers and patch organization.

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Regulator chip_data struct

```
struct tps65219_chip_data {
    size_t rdesc_size;
    size_t common_rdesc_size;
    size_t dev_irq_size;
    size_t common_irq_size;
    const struct regulator_desc *rdesc;
    const struct regulator_desc *common_rdesc;
    struct tps65219_regulator_irq_type *irq_types;
    struct tps65219_regulator_irq_type *common_irq_types;
};
```


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Register regulators in probe()

```
struct tps65219_chip_data {
    size_t rdesc_size;
    size_t common_rdesc_size;
    size_t dev_irq_size;
    size_t common_irq_size;
    const struct regulator_desc *rdesc;
    const struct regulator_desc *common_rdesc;
    struct tps65219_regulator_irq_type *irq_types;
    struct tps65219_regulator_irq_type *common_irq_types;
};
```

```
for (i = 0; i <  pmic->common_rdesc_size; i++) {
        rdev = devm_regulator_register(&pdev->dev, &pmic->common_rdesc[i], &config);
        if (IS_ERR(rdev))
            return dev_err_probe(tps->dev, PTR_ERR(rdev), "Failed to register %s regulator\n",
                                                          pmic->common_rdesc[i].name);
 }
 // Then, do the same to register PMIC-specific regulators
```


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Register regulators in probe( )

```
struct tps65219_chip_data {
    size_t rdesc_size;
    size_t common_rdesc_size;
    size_t dev_irq_size;
    size_t common_irq_size;
    const struct regulator_desc *rdesc;
    const struct regulator_desc *common_rdesc;
    struct tps65219_regulator_irq_type *irq_types;
    struct tps65219_regulator_irq_type *common_irq_types;
};
```

```
for (i = 0; i <  pmic->common_rdesc_size; i++) {
        rdev = devm_regulator_register(&pdev->dev, &pmic->common_rdesc[i], &config);
        if (IS_ERR(rdev))
            return dev_err_probe(tps->dev, PTR_ERR(rdev), "Failed to register %s regulator\n",
                                                          pmic->common_rdesc[i].name);
 }
 // Repeat the same implementation to register PMIC-specific regulators
```


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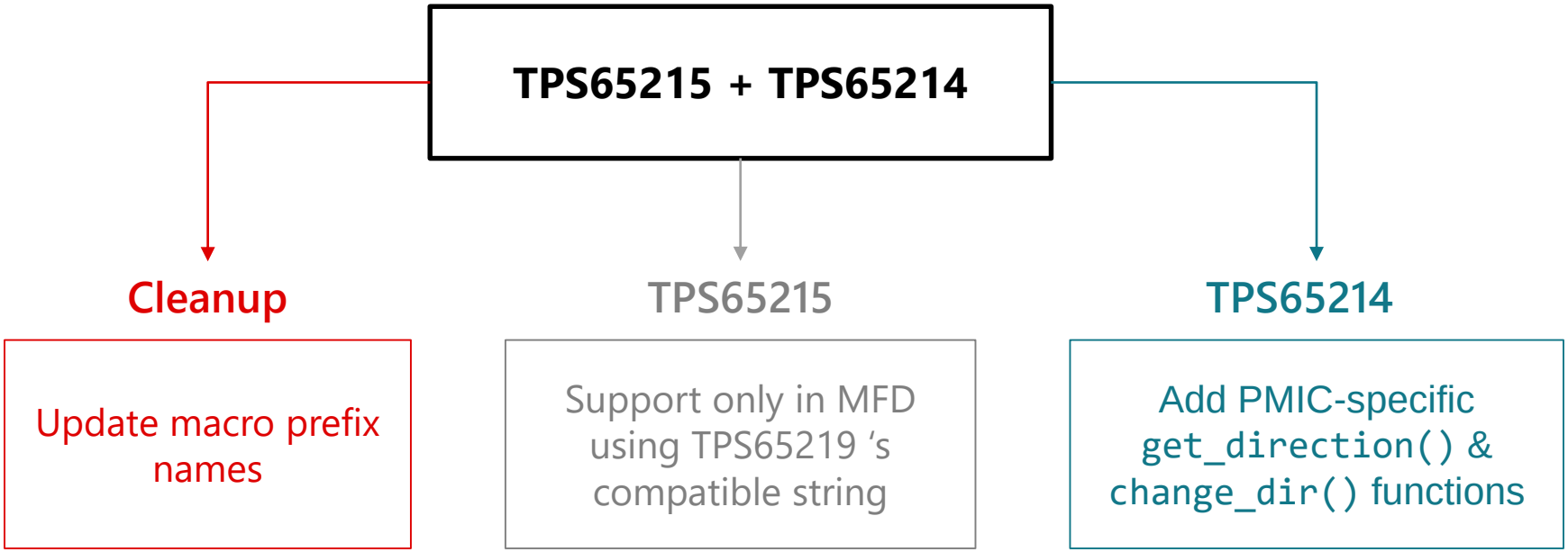
GPIO Series


TPS65215 + TPS65214
Cleanup
Update macro prefix names
TPS65215
Support only in MFD using TPS65219 's compatible string
TPS65214
Add PMIC-specific get_direction() & change_dir() functions

HW Architecture Impact #1

- The different GPIO direction registers and bit assignments for input and output values.
- Input and output were assigned to opposite values for the PMICs.
- Required PMIC-specific `_get_direction()` functions.

Register Address	Bit	TPS65219 Field	TPS65214 Field
0x1E	1	GPO2_EN	GPIO_CONFIG: 0x0 = input 0x1 = output
0x1F	3	MULTI_DEVICE_EN: 0x0 = GPO 0x1 = GPIO	GPIO_VSEL_CONFIG: 0x0 = GPIO

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HW Architecture Impact #2

- TPS65214: `GPIO_CONFIG` can be changed during device operation.
- `GPIO_VSEL_CONFIG` is configured as GPIO.
- Required PMIC-specific `_change_direction()` functions.

Register Address	Bit	TPS65219 Field	TPS65214 Field
0x1E	1	GPO2_EN	GPIO_CONFIG: 0x0 = input 0x1 = output
0x1F	3	MULTI_DEVICE_EN: 0x0 = GPO 0x1 = GPIO	GPIO_VSEL_CONFIG: 0x0 = GPIO

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GPIO Mapping from Linux to PMIC

- TPS65214 has 2 pins vs. TPS65215 & TPS65219 have 3 pins.
- **Consideration**
  - Maintain mapping to support backwards compatibility.
  - Existing driver mapped Linux GPIO offset 0 to the PMIC GPIO pin.
- **Highlight**
  - Reached out to the original author to gain context on mapping.
  - 1:1 patch reviews before submitting the next upstream version
- **Result**
  - Existing code calculation supports all PMICs.
  - Add comments explaining the GPIO mapping for future developers/users.
  - Corrected understanding after gaining context from the original author

Takeaways

- Understand the driver precedent and possible feature history.
- Think about the patch from a reviewer's POV.
- Consider requesting to merge interdependent subsystem patch series.
- MFD Driver Idea: Organize all `regulator_resources` and `regmap_irq` structs into common & device-specific structs.

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Acknowledgments

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- Dhruva Gole
- Bryan Brattlof
- Maintainers!
- + Many more ☺

Q&A

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