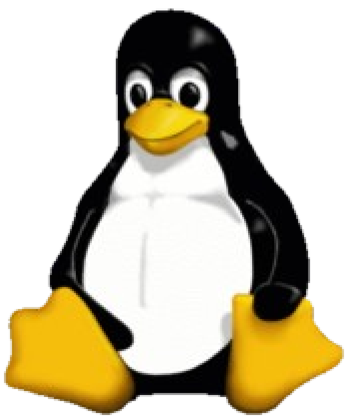
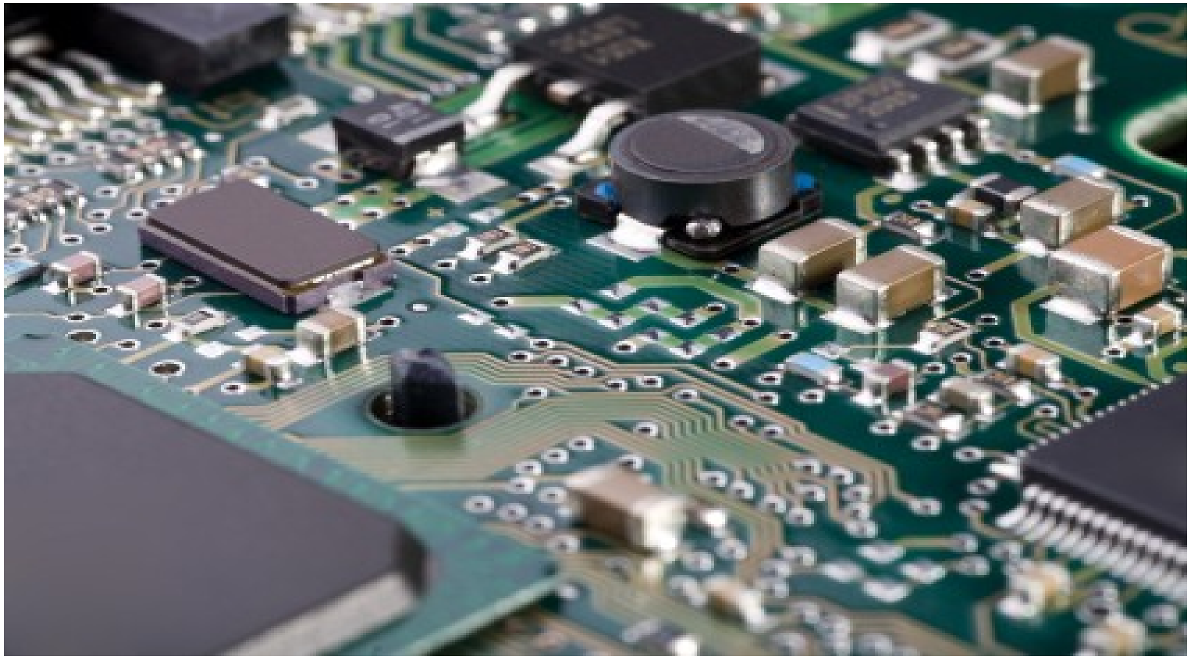


The Linux Kernel Voltage and Current Regulator Subsystem.

- **Introduction to Regulator Based Systems.**
  - Static & Dynamic System Power
  - Regulator Basics & Power Domains
  - PMP / Internet Tablet Example
- **Kernel Regulator Framework**
  - Consumer Interface
  - Regulator Driver Interface
  - Machine Interface
  - sysfs Interface (ABI)
- **Real World Examples**
  - CPUfreq & CPU Idle
  - LCD Backlight
  - Audio
  - NAND/NOR
- **Resources & Status**
- **Thanks**
- **Q & A**

Introduction to Regulator Based Systems



Static & Dynamic System Power

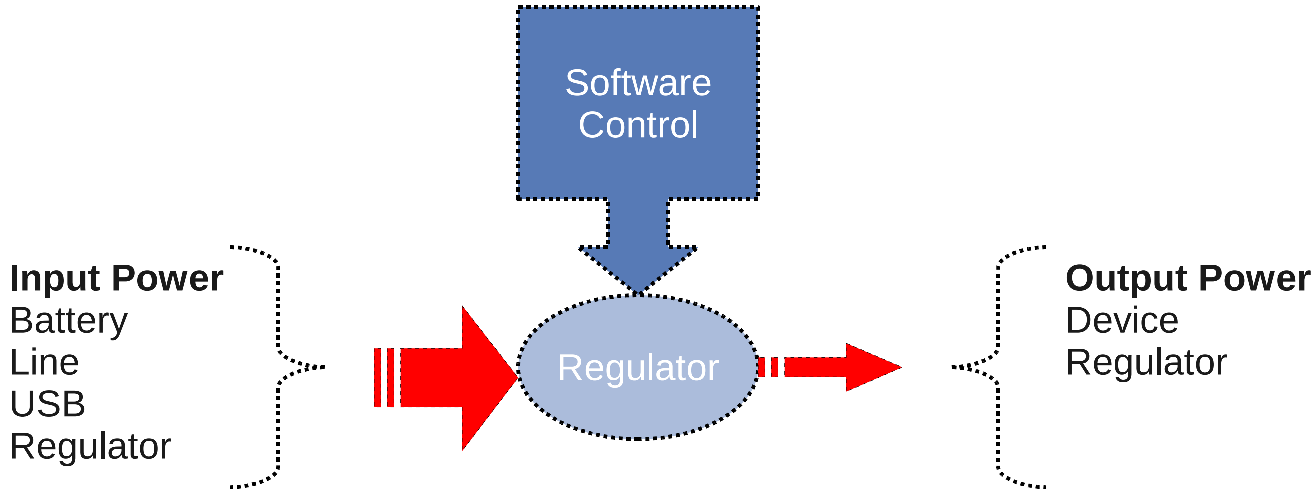
- Semiconductor power consumption has two components – *static* and *dynamic*.

$$\mathbf{Power}_{(Total)} = \mathbf{P}_{(static)} + \mathbf{P}_{(dynamic)}$$

- Static power is leakage current.
  - Smaller than dynamic power when system is active.
  - Main power drain in system standby state.
- Dynamic power is active current.
  - Signals switching. (e.g. clocks)
  - Analog circuits changing state (e.g. audio playback).

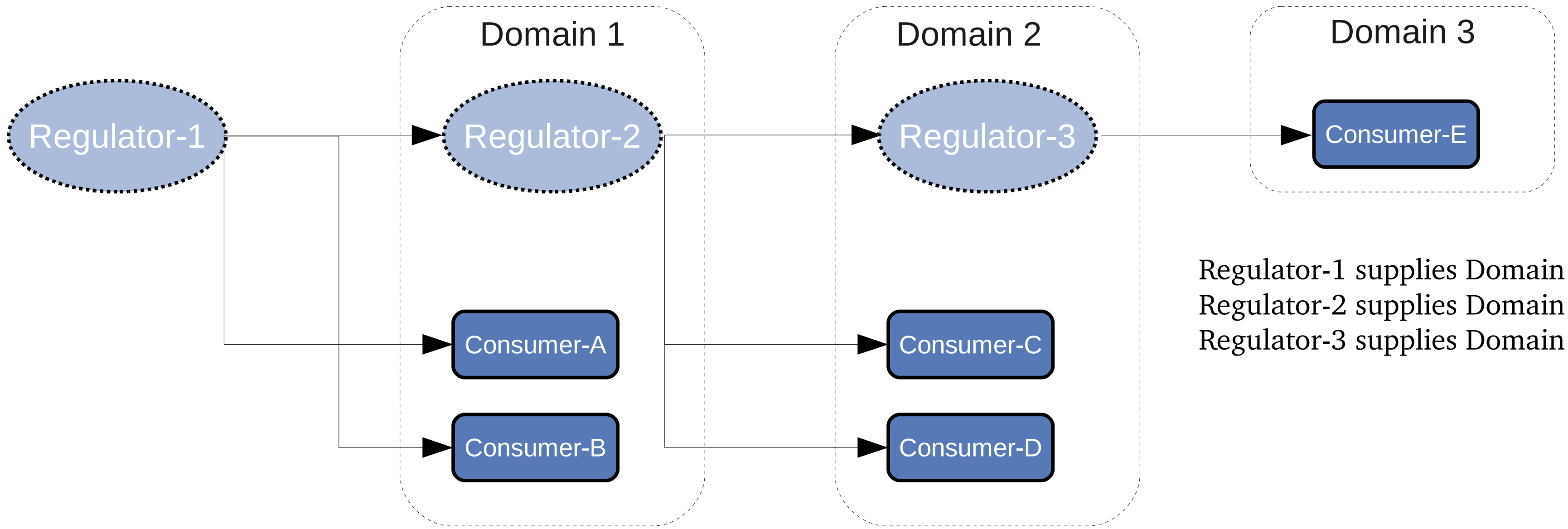
$$\mathbf{Power}_{(dynamic)} = \mathbf{CV^2F}$$

- Regulators can be used to save static and dynamic power



- Regulates the output power from input power.
  - Voltage control – *"input is 5V output is 1.8V"*
  - Current limiting – *"limit output current to 20mA max"*
  - Simple switch – *"switch output power on/off"*

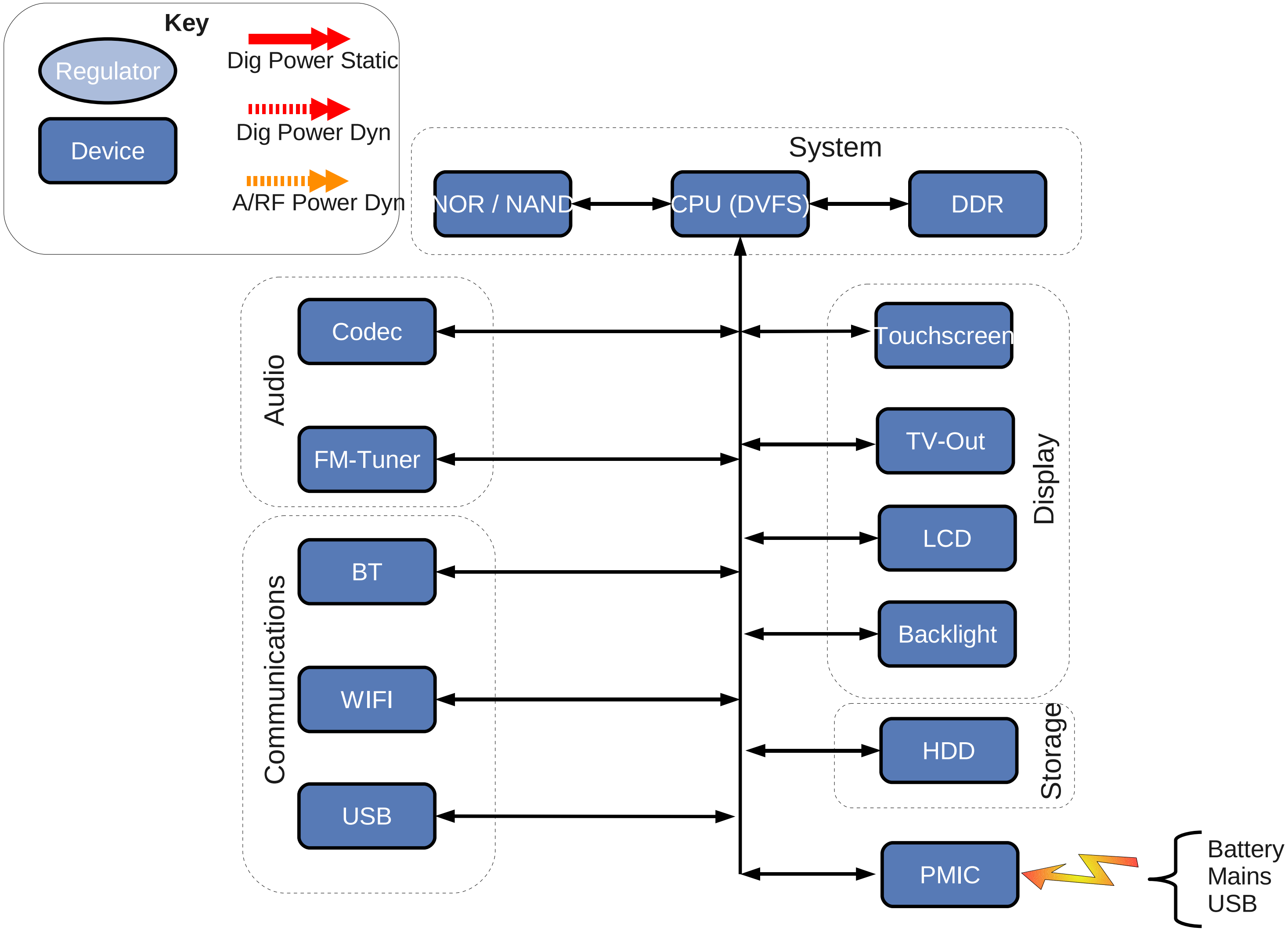
Power Domains



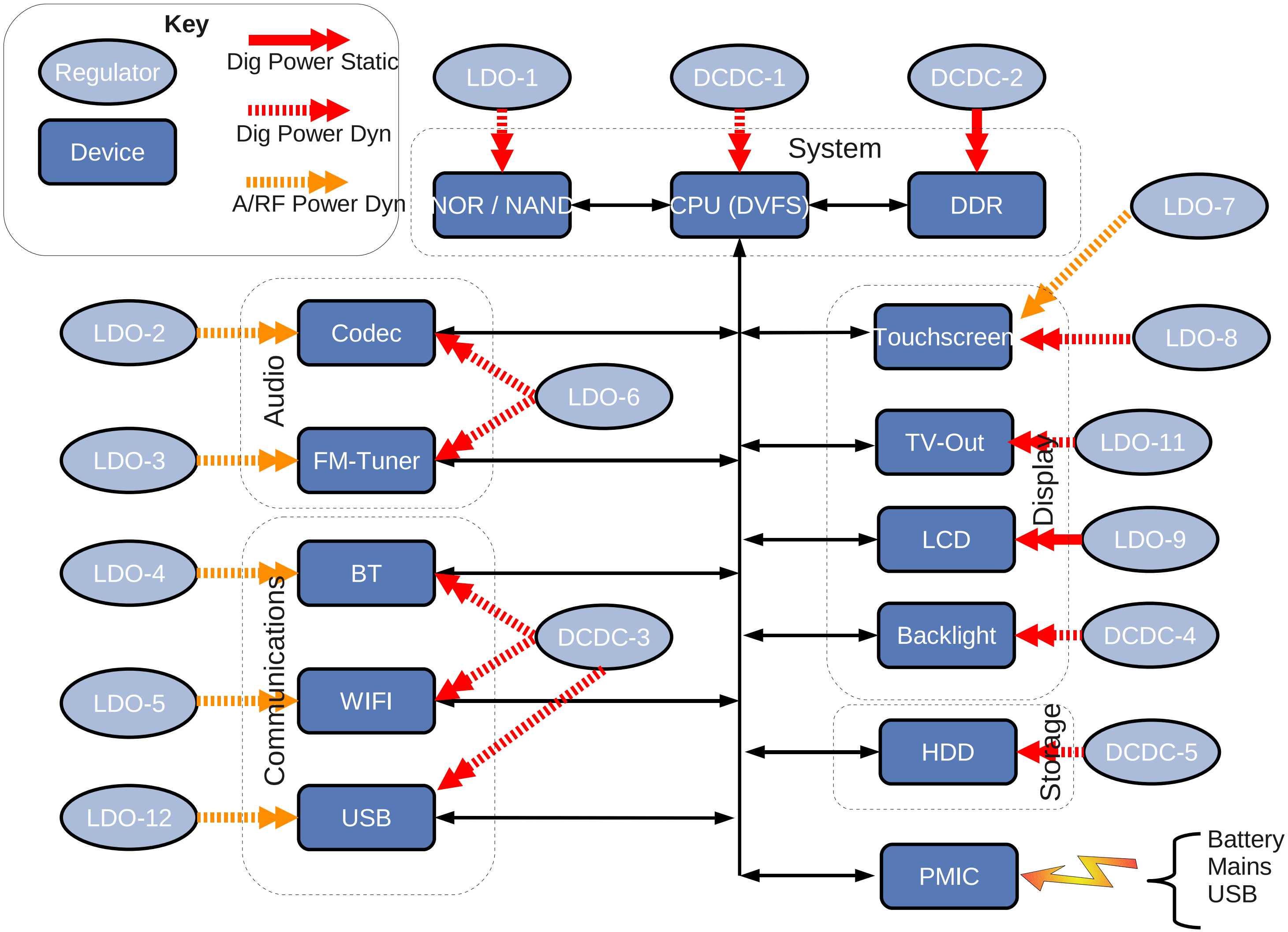
Regulator-1 supplies Domain 1
Regulator-2 supplies Domain 2
Regulator-3 supplies Domain 3

- Power domain supplied power by the **output** of a
  - regulator,
  - switch
  - or by another power domain.
- Has power constraints to protect hardware.

System Architecture (PMP, Internet Tablet)



System Architecture (PMP, Internet Tablet)



Kernel Regulator Framework

- Designed to provide a standard kernel interface to control voltage and current regulators.
- Allow systems to dynamically control regulator power output in order to save power and prolong battery life.
- Applies to both
  - voltage regulators (where voltage output is controllable)
  - current sinks (where current limit is controllable)
- Divided into four separate interfaces.
  - **Consumer** interface for device drivers
  - **Regulator** drivers interface for regulator drivers
  - **Machine** interface for board configuration
  - **sysfs** interface for userspace

Regulator Consumer Interface

- Consumers are client device drivers that use regulator(s) to control their power supply.
- Consumers are constrained by the constraints of the power domain they are on
  - Consumers can't request power settings that may damage themselves, other consumers or the system.
- Classified into two types
  - Static (only need to enable/disable)
  - Dynamic (need to change voltage/ current limit)

Consumer Interface - Basics

- Access to regulator is by

```
regulator = regulator_get(dev, "Vcc");
regulator_put(regulator);
```

- Enable and disable

```
int regulator_enable(regulator);
int regulator_disable(regulator);
int regulator_force_disable(regulator);
```

- Status

```
int regulator_is_enabled(regulator);
```

Consumer Interface - Voltage

- Consumers can request their supply voltage with

```
int regulator_set_voltage(struct regulator *regulator, int min_uV, int
  max_uV);
```

- Constraints are checked before changing voltage.

```
regulator_set_voltage(regulator, 100000, 150000);
```

- Supply voltage can be found with

```
int regulator_get_voltage(struct regulator *regulator);
```

Consumer Interface - Current

- Consumers can request their supply current limit with

```
int regulator_set_current_limit(struct regulator *regulator, int
   min_uA, int max_uA);
```

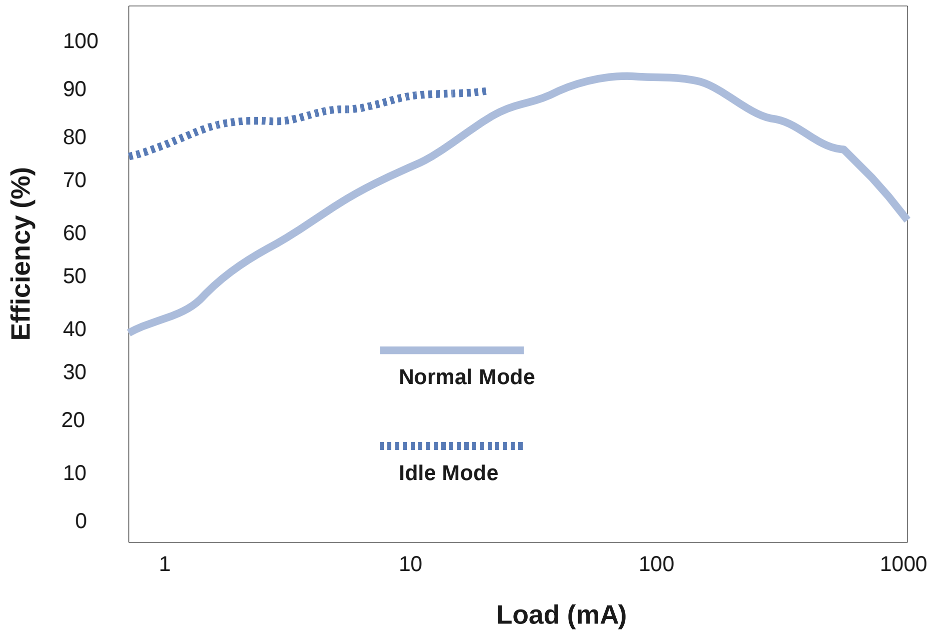
- Constraints are checked before changing current limit.

```
regulator_set_current_limit(regulator, 1000, 2000);
```

- Supply current limit can be found with

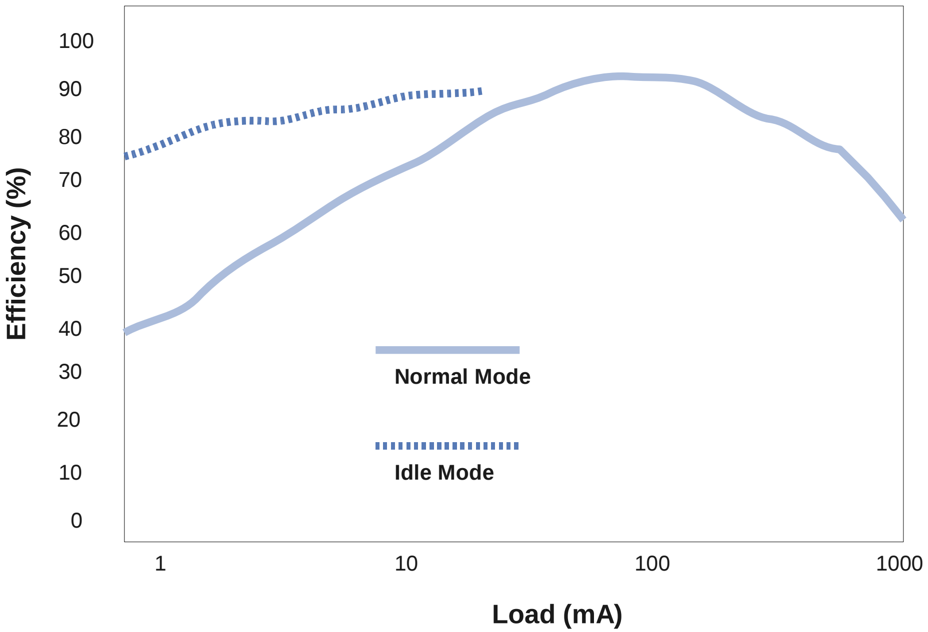
```
int regulator_get_current_limit(struct regulator *regulator);
```

Consumer Interface – Op Modes



- Regulators are not 100% efficient.
- Efficiency can vary depending on load.
- Regulators can change op mode to increase efficiency.

Consumer Interface – Op Modes



Consumer with 10mA load:-

70% @ Normal = ~13mA

90% @ Idle = ~11mA

Saving ~2mA

We sum total load for regulators > 1 consumer before changing mode.

Optimum efficiency can be requested by calling

```
regulator_set_optimum_mode(regulator, 10000); // 10mA
```

Consumer Interface - Events

- Regulator hardware can notify software of certain events.
  - Regulator failures.
  - Over temperature.
- Consumers can then handle as required.
- Failure to handle......

Consumer Interface - Summary

- Consumer registration

  `regulator_get(), regulator_put()`

- Regulator output power control and status.

  `regulator_enable(), regulator_disable(), regulator_force_disable(), regulator_is_enabled()`

- Regulator output voltage control and status

  `regulator_set_voltage(), regulator_get_voltage()`

- Regulator output current limit control and status

  `regulator_set_current_limit(), regulator_get_current_limit()`

- Regulator operating mode control and status

  `regulator_set_mode(), regulator_get_mode(), regulator_set_optimum_mode()`

- Regulator events

  `regulator_register_notifier(), regulator_unregister_notifier()`

- Regulator drivers must be registered with the framework before they can be used by consumers.

```
struct regulator_dev *regulator_register(struct regulator_desc
   *regulator_desc, struct device *dev, struct regulator_init_data
   *init_data, void *driver_data);

void regulator_unregister(struct regulator_dev *rdev);
```

- Events can be propagated to consumers

```
int regulator_notifier_call_chain(struct regulator_dev *rdev, unsigned
   long event, void *data);
```

Driver Interface - Operations

```
struct regulator_ops {

	/* get/set regulator voltage */
	int (*set_voltage) (struct regulator_dev *, int min_uV, int max_uV);
	int (*get_voltage) (struct regulator_dev *);

	/* get/set regulator current  */
	int (*set_current_limit) (struct regulator_dev *, int min_uA, int max_uA);
	int (*get_current_limit) (struct regulator_dev *);

	/* enable/disable regulator */
	int (*enable) (struct regulator_dev *);
	int (*disable) (struct regulator_dev *);
	int (*is_enabled) (struct regulator_dev *);

	/* get/set regulator operating mode (defined in regulator.h) */
	int (*set_mode) (struct regulator_dev *, unsigned int mode);
	unsigned int (*get_mode) (struct regulator_dev *);

	/* report regulator status ... most other accessors report
	 * control inputs, this reports results of combining inputs
	 * from Linux (and other sources) with the actual load.
	 */
	int (*get_status)(struct regulator_dev *);

	/* get most efficient regulator operating mode for load */
	unsigned int (*get_optimum_mode) (struct regulator_dev *, int input_uV, int output_uV, int load_uA);

	/* the operations below are for configuration of regulator state when
	 * its parent PMIC enters a global STANDBY/HIBERNATE state */

	/* set regulator suspend voltage */
	int (*set_suspend_voltage) (struct regulator_dev *, int uV);

	/* enable/disable regulator in suspend state */
	int (*set_suspend_enable) (struct regulator_dev *);
	int (*set_suspend_disable) (struct regulator_dev *);

	/* set regulator suspend operating mode (defined in regulator.h) */
	int (*set_suspend_mode) (struct regulator_dev *, unsigned int mode);
};
```

Driver Interface - Summary

- Regulator drivers can register their services with the core.

  `regulator_register(), regulator_unregister()`

- Regulators can send events to the core and hence to all consumers.

  `regulator_notifier_call_chain()`

- Regulator driver private data.

  `rdev_get_drvdata()`

- Fabric driver that is machine specific and describes
  - Power domains

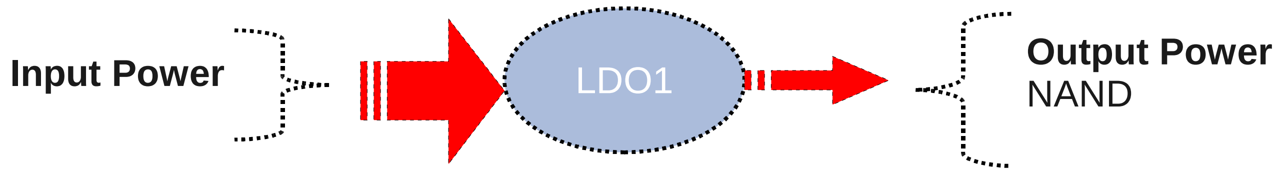
    “Regulator 1 supplies consumers x,y,z.”
  - Power domain suppliers

    “Regulator 1 is supplied by default (Line/Battery/USB).” ***OR***

    “Regulator 1 is supplied by regulator 2.”
  - Power domain constraints

    “Regulator 1 output must be >= 1.6V and <=1.8V”

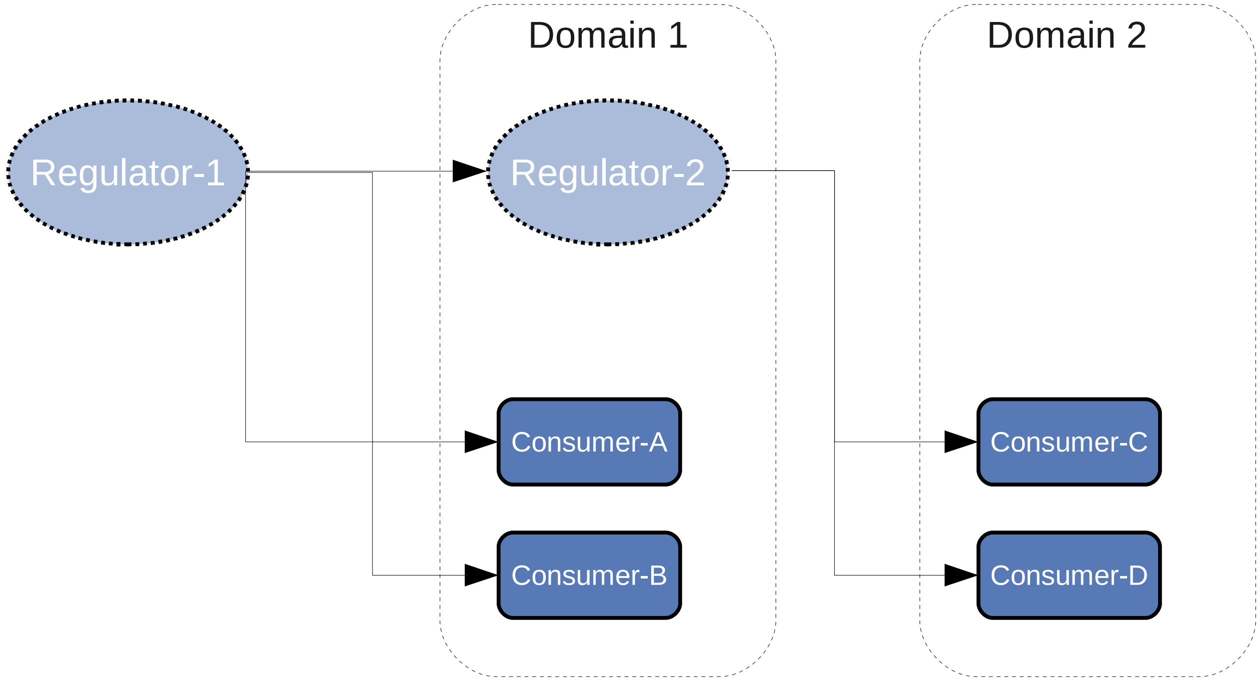
Fabric that glues regulators to consumer devices
e.g. NAND is supplied by LDO1



This attaches LDO1 to supply power to the NAND “Vcc” supply pin(s).

Machine Interface - Constraints

- Defines safe operating limits for power domain.
- Prevents system damage through unsafe consumer requests.
  - Voltage or current over the devices operating range.
  - Voltage or current too low for safe operation.



- Some regulators are supplied power by other regulators.
- Ensure regulator 1 is enabled before trying to enable regulator 2.

CPU supply and regulator initialisation data.

```
/* CPU */
static struct regulator_consumer_supply sw1a_consumers[] = {
        {
                .supply = "cpu_vcc",
        }
};

static struct regulator_init_data sw1a_data = {
        .constraints = {
                .name = "SW1A",
                .min_uV = 1275000,
                .max_uV = 1600000,
                .valid_ops_mask = REGULATOR_CHANGE_VOLTAGE |
                                  REGULATOR_CHANGE_MODE,
                .valid_modes_mask = REGULATOR_MODE_NORMAL |
                                    REGULATOR_MODE_FAST,
                .state_mem = {
                         .uV = 1400000,
                         .mode = REGULATOR_MODE_NORMAL,
                         .enabled = 1,
                 },
                .initial_state = PM_SUSPEND_MEM,
                .always_on = 1,
                .boot_on = 1,
        },
        .num_consumer_supplies = ARRAY_SIZE(sw1a_consumers),
        .consumer_supplies = sw1a_consumers,
};
```

- Exports regulator and consumer information to user space
- Is **read** only
  - Voltage
  - Current limit
  - State
  - Operating Mode
  - Constraints
- Could be used to provide more power usage info to powertop

Real World Examples

- CPUfreq scales CPU frequency to meet processing demands
  - Voltage can also be scaled with frequency.
  - Increased with frequency to increase performance/stability.
  - Decreased with frequency to save power.

```
regulator_set_voltage(regulator, 1600000, 1600000); //1.6V
```

- CPU Idle can place the CPU in numerous low power idle states.
  - Idle states draw less power and may take advantage of regulator efficiency by changing regulator operating mode.

```
regulator_set_optimum_mode(regulator, 10000); // 10mA
```

- LCD back lighting is usually a significant drain of system power.
- Power can be saved by lowering brightness when it's possible to do so.
    - e.g. Some backlights are based on white LED's and can have brightness changed by changing current.

```
regulator_set_current_limit(regulator, 10000, 10000);
```

Audio

- Audio hardware consumes requires analog power when there is no audio playback or capture.
- Power could be saved when idle by turning off analog supplies when not in use.
- Power could additionally be saved by turning off components that are not being used in the current use case
  - FM-Tuner could be disabled when MP3's are played.
  - Speaker Amp can be disabled when Headphones are used.

```
regulator_enable(regulator)
regulator_disable(regulator)
```

- NAND & NOR devices consume more power during IO than idle.
- NAND/NOR consumer driver can change regulator operating mode to gain efficiency savings when idle.

```
regulator_set_optimum_mode(regulator, 1000); // 1mA
```

State	Max Load (mA)
Read/Write	35
Erase	40
Erase + rw	55
Idle	1

NAND / NOR chip max load (from datasheet)

Status

- Subsystem in Mainline kernel since 2.6.27
- Support numerous PMIC devices – list is growing.
- Actively maintained by Liam Girdwood and Mark Brown.
- On the web
  - http://www.slimlogic.co.uk/?p=48
  - http://opensource.wolfsonmicro.com/node/15
- git://git.kernel.org/pub/scm/linux/kernel/git/lrg/voltage-2.6.git

Thanks

Questions ?