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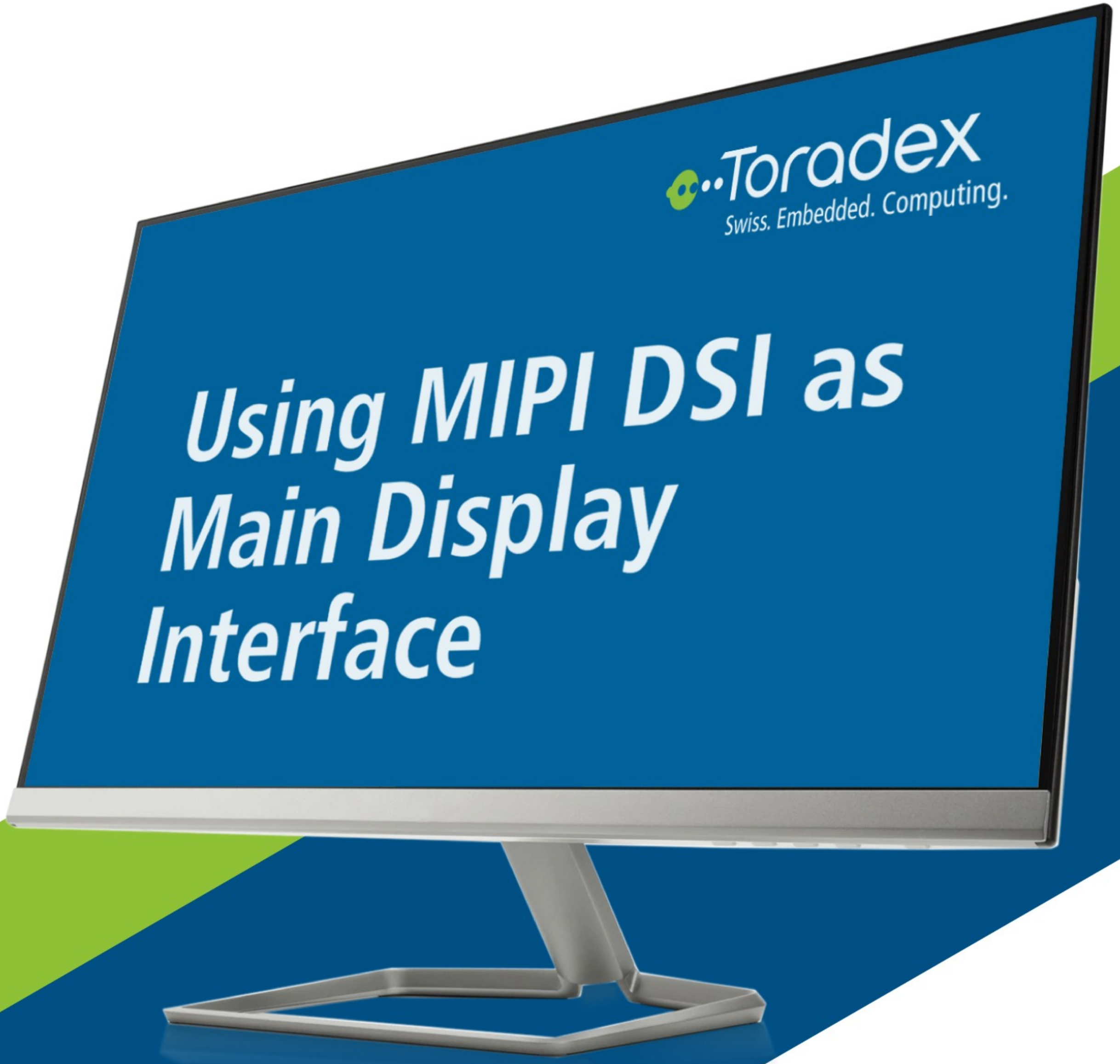

Presented by

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Embedded Linux BSP
Toradex

WITH YOU TODAY…

- Joined Toradex 2011
- Spearheaded Embedded Linux Adoption
- Introduced Upstream First Policy
- Top 10 U-Boot Contributor
- Top 10 Linux Kernel ARM SoC Contributor
- Industrial Embedded Linux Platform Torizon Fully Based on Mainline Technology
  - Mainline U-Boot with Distroboot
  - KMS/DRM Graphics with Etnaviv & Nouveau
  - OTA with OSTree
  - Docker

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WHAT WE'LL COVER TODAY…

- MIPI Display Serial Interface (MIPI DSI)
- Verdin MIPI DSI Display Adapter System Design
- Introduction of the Linux DSI Subsystem
- Linux DRM Stack DSI Bridge Chip Integration
- DSI Bridge Chip Ecosystem
- Bridge Chips Supported in Mainline
- Auto-Detection of DSI Adapters Based on EEPROM Contents
- U-Boot: Reading EEPROM Contents and Selecting Applicable Device Tree Overlay
- U-Boot FIT Image: Board Specific Device Trees and Display Adapter Specific Device Tree Overlays
- Live Demo: DSI Auto-Detection

MIPI Display Serial Interface (MIPI DSI)

- Specification by the Mobile Industry Processor Interface (MIPI) Alliance
- High-speed differential signaling point-to-point serial bus interface between a host processor and a display module
- High performance, low power, low electromagnetic interference (EMI)
- Reduced pin count
- Compatibility across different vendors
- One high speed clock lane and one or more data lanes
- Low power (LP) mode or high speed (HS) mode

MIPI Display Serial Interface (cont.)

- MIPI DSI Specification
  - Initial Version: May 2006
  - Current Version: MIPI DSI v1.3.1 (December 2015)

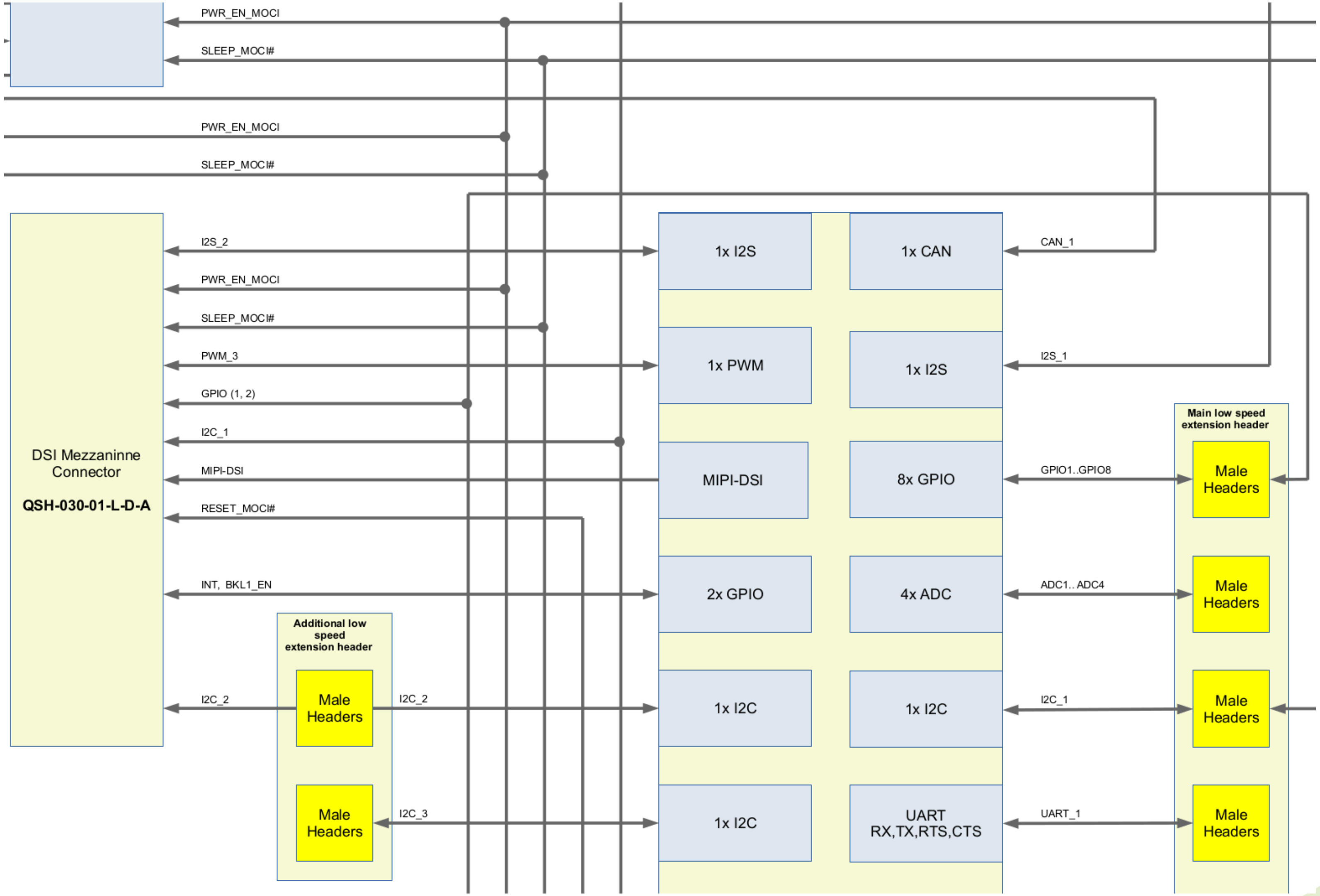
- Successor MIPI DSI-2 Specification
  - Initial Version: January 2016
  - Current Version: v1.1 (May 2018)
  - Support for both D-PHY and C-PHY
  - Supports ultra-high definition (4K and 8k)

MIPI Display Serial Interface (cont.)

- Physical Layer:
  - MIPI D-PHY
    - D-PHY 1.01: 1.0Gbps/lane
    - D-PHY 1.1: 1.5Gbps/lane
    - D-PHY 1.2: 2.5Gbps/lane
    - D-PHY 2.0: 4.5Gbps/lane
- MIPI Display Command Set (MIPI DCS)
- Incorporates Display Stream Compression (DSC)
  - Standard from the Video Electronics Standards Association (VESA)
- De-facto standard display interface featured by modern higher-end SoCs
- No long-term available discrete MIPI DSI display panels
- Bridge chips converting to more common display interfaces like parallel RGB, LVDS, (e)DP or HDMI

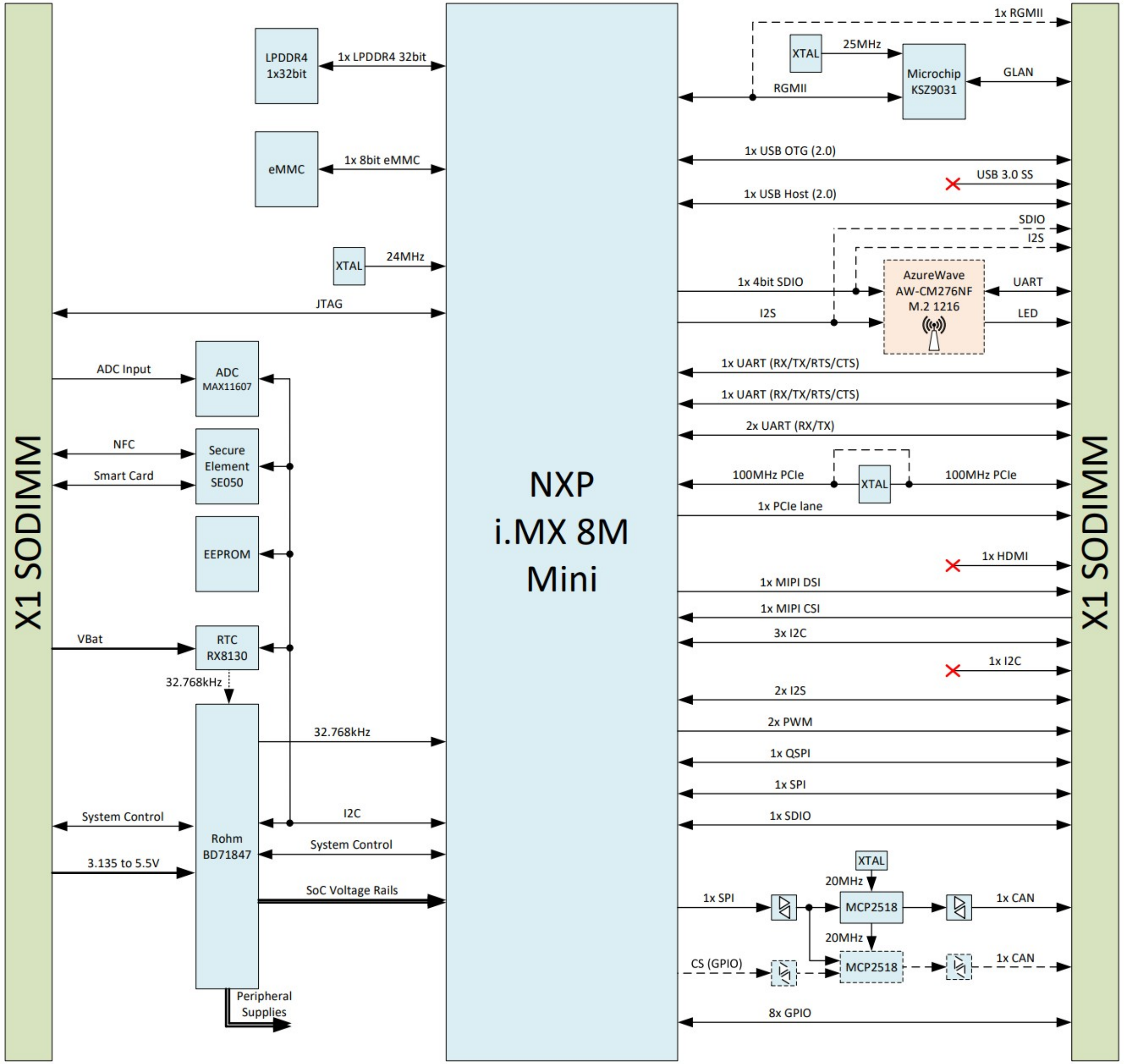
Verdin MIPI DSI Display Adapter System Design

- Generic system concept
- DSI display adapter boards integrating various bridge chips
- ST M24C02 2kb EEPROM to store identification/parametrisation
- DSI Mezzanine Connector
  - MIPI DSI: 1 clk + 4 data lanes
  - GPIOs
    - BKL1_EN
    - Touch interrupt
  - 2 x I2C: bridge chip + DDC/EDID
  - PWM: backlight
  - I2S: optional audio
  - Generic system control signals
    - PWR_EN_MOCI, SLEEP_MOCI#, RESET_MOCI#



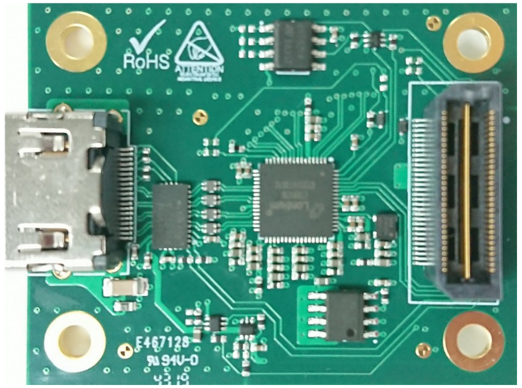
Verdin iMX8M Mini

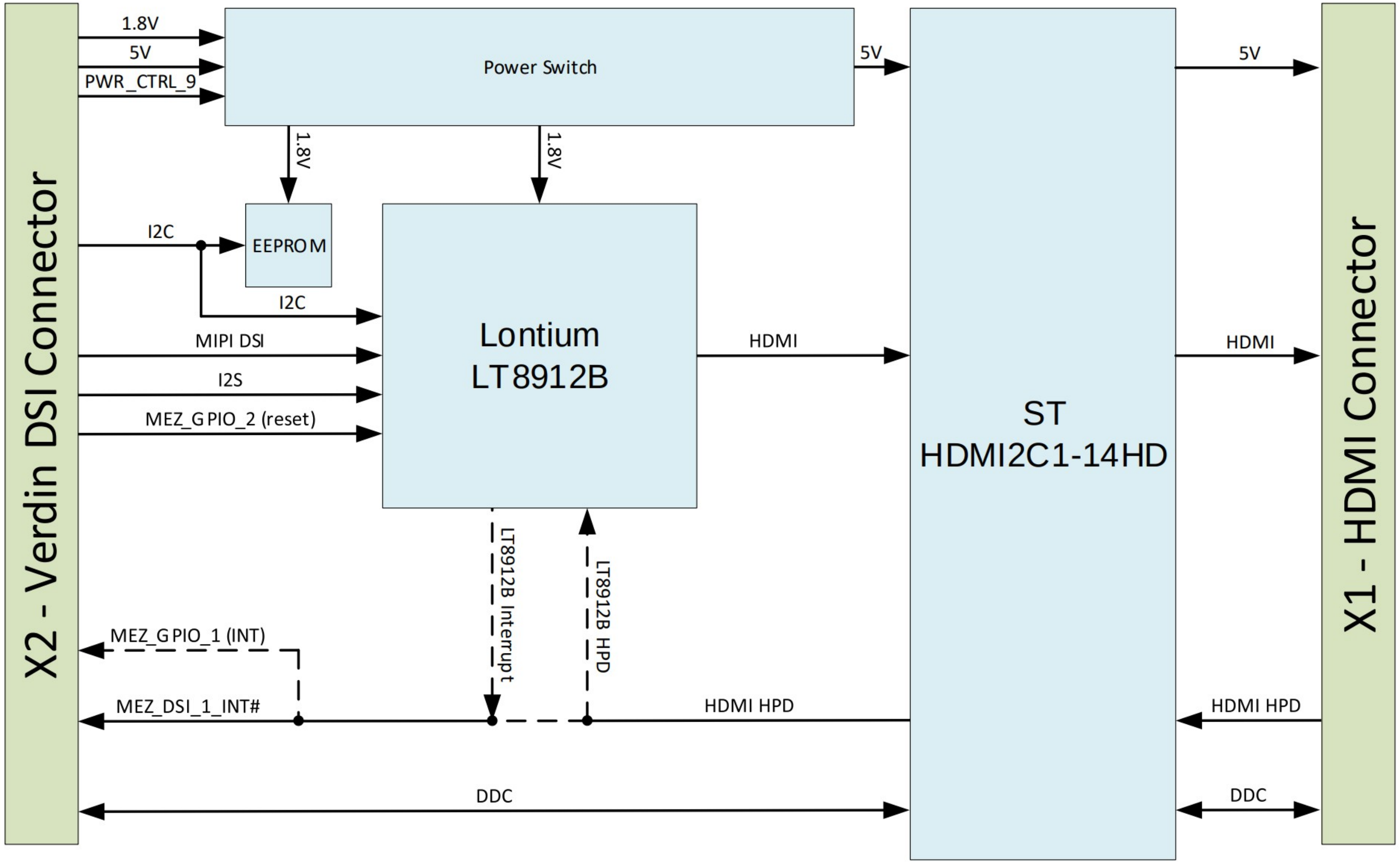
- NXP i.MX 8M Mini SoC
- Single display controller, LCDIF
- MIPI DSI output with up to four data lanes
  Northwest Logic MIPI DSI host controller IP
- MIPI D-PHY 1.2
  maximum data transfer per lane only 1.5Gbps
- Resolutions up 1920x1080p60 and 1800x1200p60



Verdin DSI to HDMI Adapter

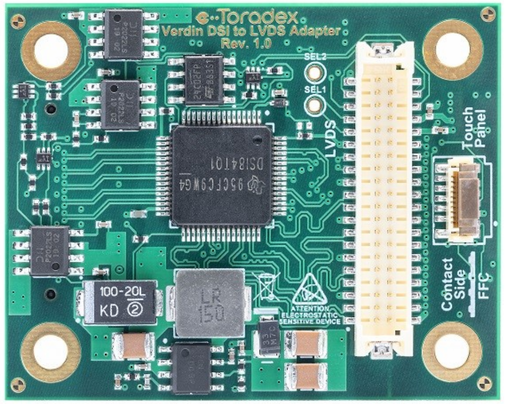
- Lontium Semiconductor LT8912B MIPI DSI to HDMI bridge
- HDMI V1.4 1080p (1920x1080), 8-bit RGB, up to 60Hz
- ST HDMI2C1-14HD ESD protection and signal conditioning
- Type A standard HDMI connector

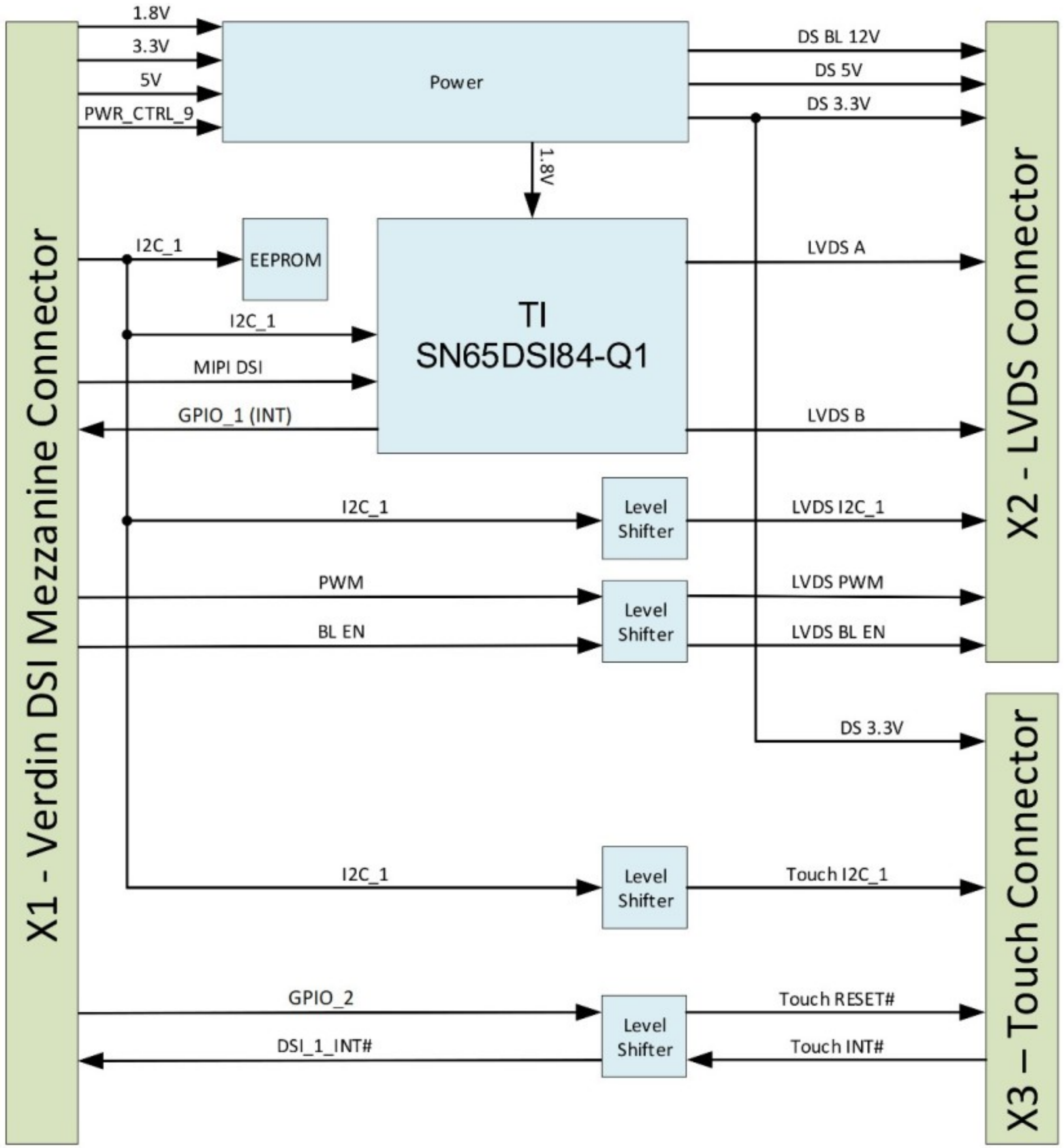




Verdin DSI to LVDS Adapter

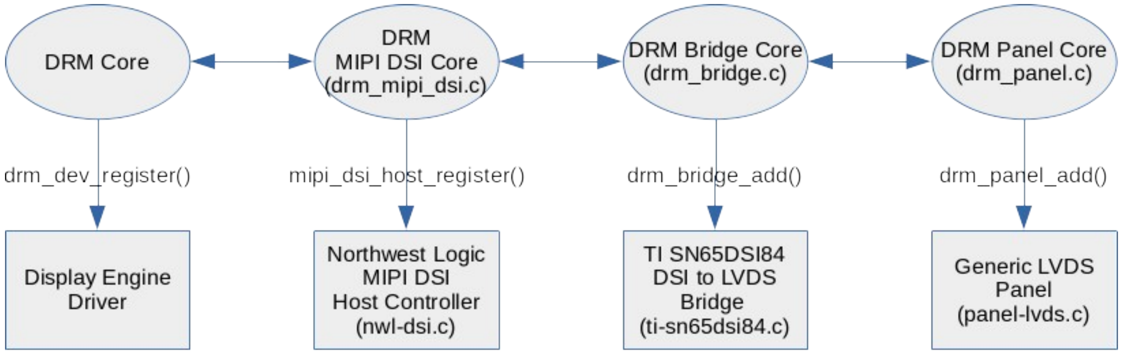
- Texas Instruments SN65DSI84
  MIPI DSI to dual-link LVDS bridge
- single/dual-lane LVDS up-to 1920x1200/1366x768, 60fps, 24bpp
- LVDS and touch connectors compatible with
  Toradex Capacitive Touch Display 10.1" LVDS

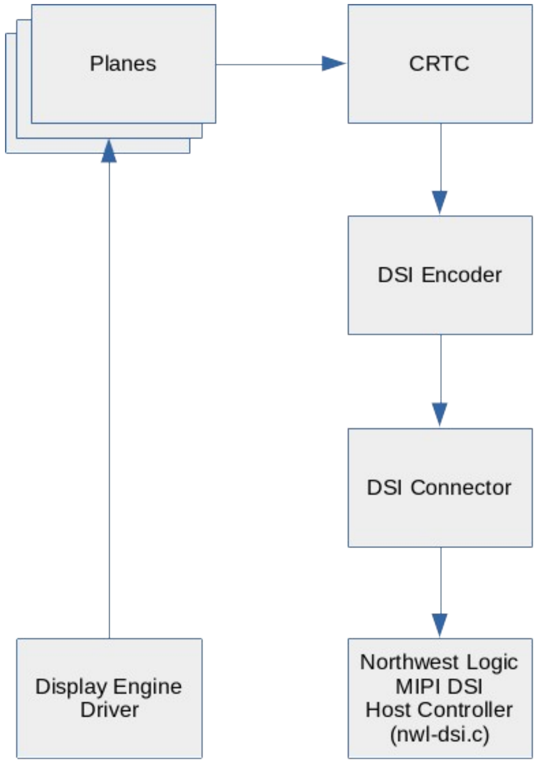




Introduction of the Linux DSI Subsystem

- DRM MIPI DSI Core: Common logic and helpers to deal with MIPI DSI peripherals





Linux DRM Stack
DSI Bridge Chip Integration

- DRM bridge
  - drm_bridge_funcs: attach, enable, disable
  - drm_bridge_add()
- DRM connector
  - drm_connector_funcs: fill_modes, detect, destroy
  - drm_connector_helper_funcs: get_modes, mode_valid
  - drm_connector_init/_helper_add/_attach_encoder(), drm_panel_attach()
- I2C device
  - Detected using regular id_table and of_match_table
  - Regmap: devm_regmap_init_i2c()
  - i2c_set_clientdata()
- MIPI DSI device
  - mipi_dsi_device_register_full()
  - mipi_dsi_attach()

DSI Bridge Chip Integration Pitfalls

- Availability of “super secret” data sheets
- Ancient downstream or bare skeleton drivers only
- Lots of hard-coded parameters
- Link bring-up sequences not well documented
  - May require a lot of trial and error
- Divider/frequency limitations on either controller side, bridge side or both
  - May require running outside of recommended range

How About Bridge Chips Used in our Current Adapters?

- Lontium Semiconductor LT8912B MIPI DSI to HDMI bridge
  - Adopted downstream driver from Rockchip Linux on GitHub
    - Forward ported to later DRM API
    - Fixed confusing use of same name for struct and instance
    - Reworked driver to be a proper I2C device
    - Full register set taken from Lontium pseudo code driver
    - Improved regmap integration
    - Properly reserve i2c sub addresses
    - Added regular I2C based DDC/EDID handling
    - Added GPIO based hot-plug detection
    - Hot-plug detect GPIO handling crashed using GPIO expander (cansleep variant of gpiod_get_value fixed it)
    - Bus_format was not properly set
  - Not pretty but hey it works (;-p)
  - Further clean-up and upstreaming pending

How About Bridge Chips Used in our Current Adapters? (cont.)

- Texas Instruments SN65DSI84 MIPI DSI to dual-link LVDS bridge
  - Downstream driver taken from a patch in CompuLab Yocto Meta Layer on GitHub
    - Luckily already adopted to usage on i.MX 8M Mini
    - Hard-coded for single-channel LVDS use-case
  - Implementing support for dual channel LVDS pending
  - Further clean-up and upstreaming pending

DSI Bridge Chip Ecosystem

- Vendors still reluctant to mainlining drivers
- Few mainline supported bridge chips
- Few examples to copy from

- Procurement of actual silicon may be difficult

- Conformance of MIPI DSI host IP vs. bridge chip silicon

Bridge Chips Supported in Mainline

- drivers/gpu/drm/bridge
- Differentiate between SoC internal IP, discrete external bridge chips and directly connected panels
- Northwest Logic MIPI DSI host controller as found on NXP i.MX 8 series

- Analog Devices ADV7533/35 MIPI/DSI Receiver with HDMI Transmitter
- Parade PS8640 MIPI DSI to eDP Converter
- Texas Instruments SN65DSI86 DSI to eDP bridge
- Toshiba TC358764 DSI/LVDS bridge
- Toshiba TC358768AXBG/TC358778XBG MIPI DSI bridge chips

- Raspberry Pi 7-inch Touch Display
- Toshiba TC358762 DSI to DPI aka parallel RGB bridge

Auto-Detection of DSI Adapters Based on EEPROM Contents

- Straight forward idea 1:
  - Regular device tree: setting bridge status to disabled vs. okay
  - Device graph: Linking endpoint and remote-endpoint nodes?
- Full flexibility requires device tree overlays
- Straight forward idea 2:
  - Just storing device tree overlay in EEPROM
  - While simple DTBOs may be below 1kb more complex ones quickly account for more than 2kb in size!
- Compromise: Just store product number as part of regular Toradex factory configuration block aka ConfigBlock
- Select device tree overlay to be applied based on product number

```
&hdmi_bridge {
        status = "disabled";
};

&lvds_bridge {
        status = "okay";

        port {
                dsi84_in: endpoint {
                        remote-endpoint = <&mipi_dsi_bridge1_out>;
                };
        };
};

&mipi_dsi {
        port@1 {
                reg = <1>;

                mipi_dsi_bridge1_out: endpoint {
                        remote-endpoint = <&dsi84_in>;
                };
        };
};
```

U-Boot: Reading EEPROM Contents and Selecting Applicable Device Tree Overlay

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- Generalised ConfigBlock handling from NAND/eMMC to EEPROMs
- Table with product ID to device tree overlay file name mapping
- Distroboot script to apply device tree overlays based both on auto-detection as well as overlays.txt file

- HDMI may do hot-plug detect
- DDC/EDID vs. custom display-specific parametrisation (cascading device tree overlays)

- LVDS usually requires further parametrisation
  - Single/dual-channel
  - Colour format
  - Panel resolution and timing

Device Tree Overlays

```
// Verdin DSI to HDMI Adapter orderable at Toradex.

...

	fragment@0 {
		target-path = "/i2c@30a30000"; /* Verdin I2C_2_DSI */
		__overlay__ {
			clock-frequency = <10000>;
			pinctrl-names = "default";
			pinctrl-0 = <&pinctrl_i2c2>;
			status = "okay";
		};
	};

	fragment@1 {
		target-path = "/i2c@30a50000"; /* Verdin I2C_1 */
		__overlay__ {
			hdmi@48 {
				compatible = "lontium,lt8912";
				ddc-i2c-bus = <&i2c2>;
				hpd-gpios = <&gpio3 15 GPIO_ACTIVE_HIGH>;
				pinctrl-names = "default";
				pinctrl-0 = <&pinctrl_gpio_hpd>, <&pinctrl_gpio1>,
					    <&pinctrl_gpio2>;
				reg = <0x48>;
				reset-gpios = <&gpio5 5 GPIO_ACTIVE_LOW>;

				port {
					lt8912_1_in: endpoint {
						remote-endpoint = <&mipi_dsi_bridge1_out>;
					};
				};
			};
		};
	};

	fragment@2 {
		target-path = "/mipi_dsi@32e10000";
		__overlay__ {
			port@1 {
				reg = <1>;

				mipi_dsi_bridge1_out: endpoint {
					remote-endpoint = <&lt8912_1_in>;
				};
			};
		};
	};
};
```

```
// Verdin DSI to LVDS Adapter orderable at Toradex.

...

	fragment@0 {
		target-path = "/";
		__overlay__ {
			backlight {
				compatible = "pwm-backlight";
				...
			};
		};
	};

	fragment@1 {
		target-path = "/pwm@30660000"; /* Verdin PWM_3_DSI */
		__overlay__ {
			...
			status = "okay";
		};
	};

	fragment@2 {
		target-path = "/i2c@30a30000"; /* Verdin I2C_2_DSI */
		__overlay__ {
			...
			status = "okay";
		};
	};

	fragment@3 {
		target-path = "/i2c@30a50000"; /* Verdin I2C_1 */
		__overlay__ {
			bridge@2c {
				compatible = "ti,sn65dsi83";
				...

				port {
					dsi85_in: endpoint {
						remote-endpoint = <&mipi_dsi_bridge1_out>;
					};
				};
			};

			touch@4a {
				compatible = "atmel,maxtouch";
				...
			};
		};
	};

	fragment@4 {
		target-path = "/mipi_dsi@32e10000";
		__overlay__ {
			port@1 {
				reg = <1>;

				mipi_dsi_bridge1_out: endpoint {
					remote-endpoint = <&dsi85_in>;
				};
			};
		};
	};
};
```

U-Boot FIT Image: Board Specific Device Trees and Display Adapter Specific Device Tree Overlays

- FIT image allows convenient packing of Linux kernel binary together with various device trees, device tree overlays and/or ramdisks
- May be booted as follows:
  bootm ${loadaddr}#config@${soc}-${fdt_module}-${fdt_board}.dtb#${display_adapter_dtbo}
- In our case fdt_module is deduced from the EEPROM on the module, fdt_board from the one on the carrier board and display_adapter_dtbo from the one on the display adapter

```
$ mkimage -l tezi.itb
FIT description: U-Boot fitImage for Toradex Easy Installer
Created:         Tue Jun  9 01:57:39 2020
 Image 0 (kernel@1)
  Description:  Linux kernel
  ...
 Image 1 (fdt@freescale_fsl-imx8mm-verdin-nonwifi-dev.dtb)
  Description:  Flattened Device Tree blob
  ...
 Image 2 (fdt@freescale_fsl-imx8mm-verdin-wifi-dev.dtb)
  Description:  Flattened Device Tree blob
  ...
 Image 3 (fdt@verdin-imx8mm_lt8912_overlay.dtbo)
  Description:  Flattened Device Tree blob
  ...
 Image 4 (fdt@verdin-imx8mm_sn65dsi84_overlay.dtbo)
  Description:  Flattened Device Tree blob
  ...
 Image 5 (ramdisk@1)
  Description:  tezi-initramfs
  ...
 Default Configuration: 'config@freescale_fsl-imx8mm-verdin-nonwifi-dev.dtb'
 Configuration 0 (config@freescale_fsl-imx8mm-verdin-nonwifi-dev.dtb)
  Description:  1 Linux kernel, FDT blob, ramdisk
  Kernel:       kernel@1
  Init Ramdisk: ramdisk@1
  FDT:          fdt@freescale_fsl-imx8mm-verdin-nonwifi-dev.dtb
  Hash algo:    sha1
  Hash value:   unavailable
 Configuration 1 (config@freescale_fsl-imx8mm-verdin-wifi-dev.dtb)
  Description:  0 Linux kernel, FDT blob, ramdisk
  Kernel:       kernel@1
  Init Ramdisk: ramdisk@1
  FDT:          fdt@freescale_fsl-imx8mm-verdin-wifi-dev.dtb
  Hash algo:    sha1
  Hash value:   unavailable
```

Device Tree Overlay Pitfalls

```
Applying Overlay: devicetree/verdin-imx8mm_sn65dsi84_overlay.dtbo
3743 bytes read in 15 ms (243.2 KiB/s)
failed on fdt_overlay_apply(): FDT_ERR_NOTFOUND
base fdt does did not have a /__symbols__ node
make sure you've compiled with -@
```

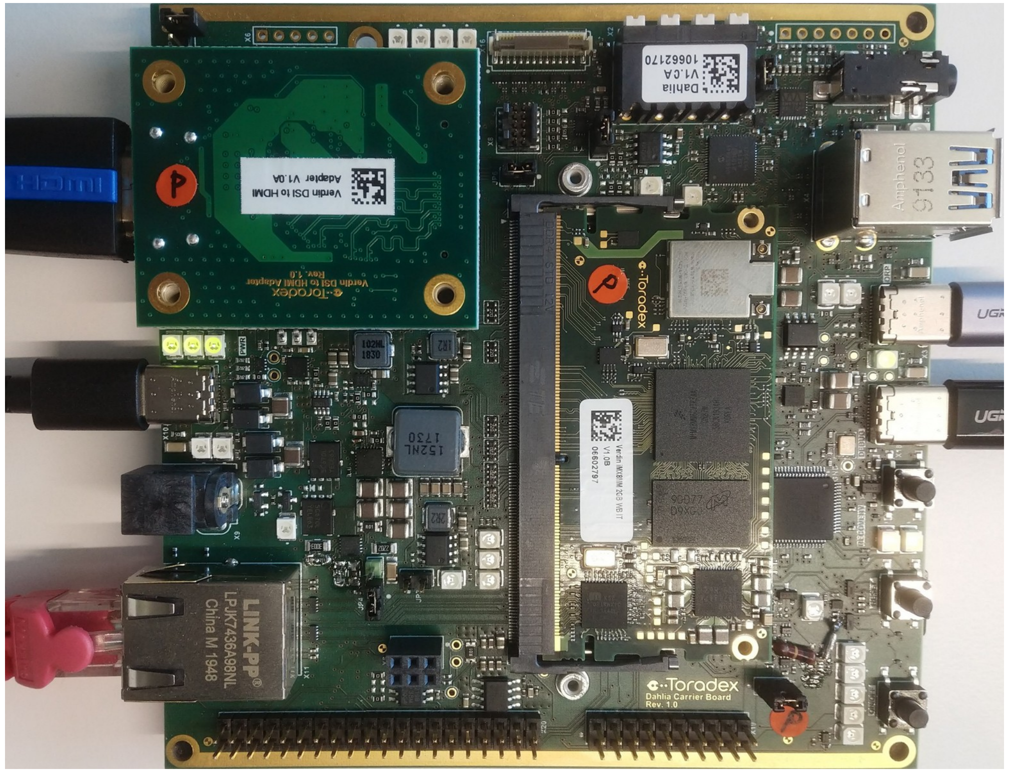
- More complex device tree overlays may require symbols
  - Make sure device trees and overlays are all compiled with DTC_FLAGS='-@'
- Referencing nodes via hex addresses from within device tree overlays proves to be case sensitive!
  - Make sure all adhere to consistent lower-case hex numbering

```
Applying Overlay: devicetree/verdin-imx8mm_sn65dsi84_overlay.dtbo
3743 bytes read in 15 ms (243.2 KiB/s)
failed on fdt_overlay_apply(): FDT_ERR_NOTFOUND
21498368 bytes read in 189 ms (108.5 MiB/s)
ERROR: Did not find a cmdline Flattened Device Tree
Could not find a valid device tree
```

- Troubleshooting what really got applied
  - Use dtc -I fs on target and dump /proc/device-tree

```
root@verdin-imx8mm:~# opkg install dtc_1.5.1-r0_aarch64.ipk
Installing dtc (1.5.1) on root
Configuring dtc.
root@verdin-imx8mm:~# dtc -I fs /proc/device-tree -O dts -o dump.dts
```

Live Demo: DSI Auto-Detection



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- https://developer.toradex.com/software/toradex-easy-installer

Q&A

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