

# S12ZVH: Hardware Design Guidelines

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## 1 Introduction

This application note describes external hardware required by different modules of S12ZVH family of MCUs. The S12ZVH family was designed to be used in basic/low automotive instrumentation clusters that include analog stepper motors, an LCD, and/or CAN communications. This application note will cover details on the following modules and pins: the Voltage Regulator, Reset Circuitry, ADC module, Battery Sensing module, high current pins, interrupt pins, unused pins, and the CANPHY module, including its dedicated voltage regulator. This note also covers general PCB layout recommendations that help reduce electromagnetic emissions and improve electromagnetic immunity.

As the S12ZVH family is aimed at automotive instrumentation clusters, we will analyze the different requirements for this application in terms of external hardware required for its operation, and the advantages this family offers over typical solutions. For more specific information about this family of MCUs and their features, refer to <http://www.freescale.com/S12ZVH>.

Some external hardware like capacitors and resistors are needed to ensure proper operation of the different modules in the MCU. The most common configurations include current limiter circuits, debounce capacitors, pull resistors, filter and bulk capacitors, and inductors, among others. These electronic configurations are needed depending on the application to be

### Contents

1	Introduction.....	1
2	Voltage regulators.....	3
3	Reset circuit.....	6
4	Programming circuit.....	7
5	Clock circuit.....	7
6	Interrupt pins.....	9
7	LCD pins and contrast.....	9
8	Special and unused pins.....	9
9	High-Current pins.....	10
10	Analog pins and battery sensing.....	10
11	CANPHY.....	10
12	Printed circuit board design recommendations.....	11
13	Conclusion.....	12
14	References.....	12

## Introduction

designed, and in this case we consider an automotive instrument cluster. This is a list of the modules that need special attention in hardware terms:

- Voltage regulators (Main regulator and CAN dedicated voltage regulator)
- Reset circuit
- Programming circuit (BDM)
- Clock circuit (Main OSC and 32 kHz)
- Interrupt pins
- LCD pins and contrast
- Special and unused pins
- Analog pins (Analog-To-Digital Converter)
- High-Current pins (Stepper Motor Controller)
- CANPHY pins

Not all modules and pins are available on all the S12ZVH family members. Currently there are two versions on this family, a 144 LQFP package and a 100 LQFP package. This application note will describe the functionality available in the 144 LQFP package because this comes with the most complete module's functionality. The pinout for this version can be found in [Figure 1](#).

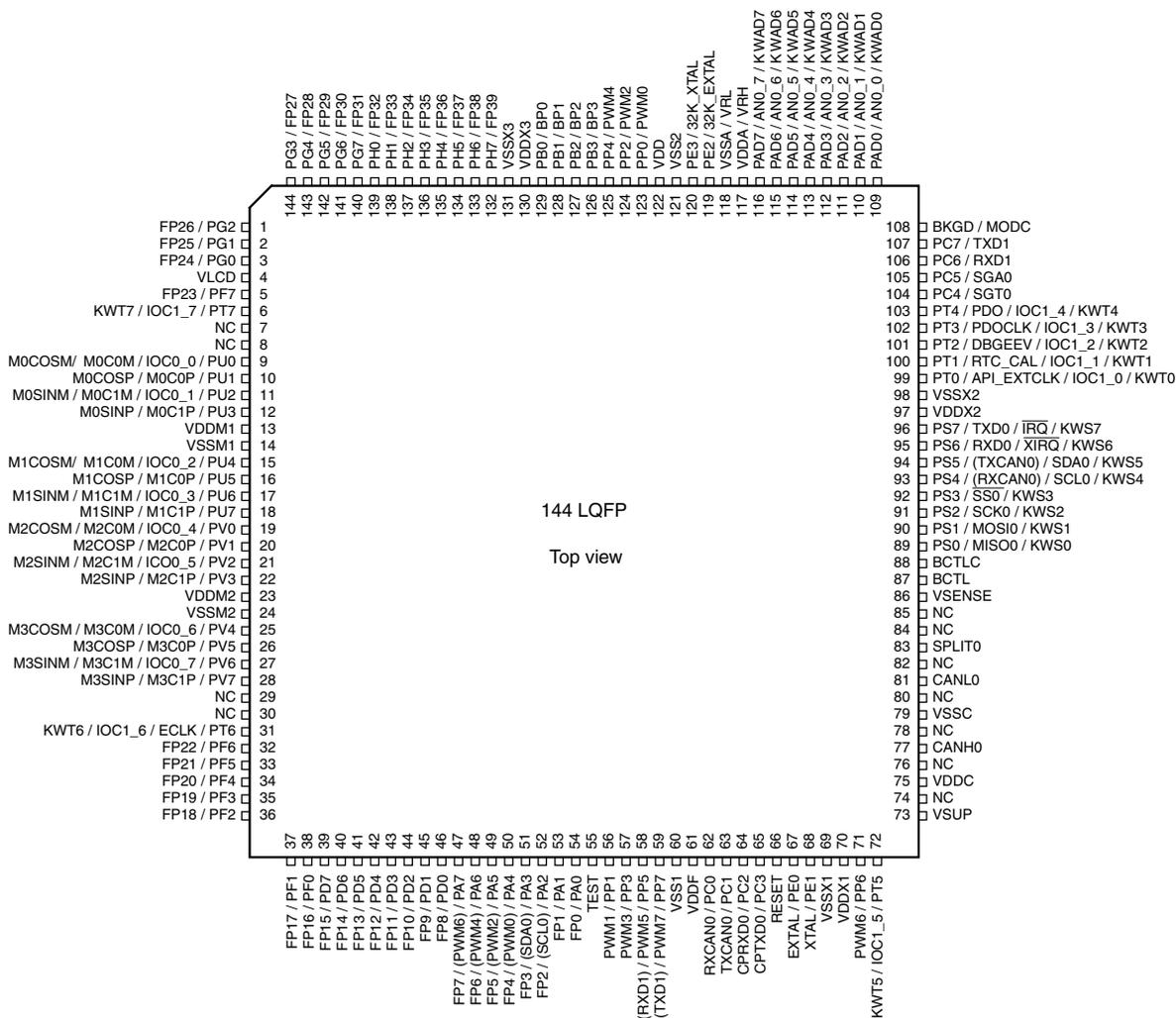


Figure 1. S12ZVH 144-LQFP pinout



## Voltage regulators

to add an external PNP pass transistor. The voltage regulator has a dedicated pin called BCTL that controls the base of the PNP pass transistor as a linear amplifier. For correct behavior of the transistor, it is suggested to add a pull-up resistor on the base (5.6 K). The collector of the pass transistor is connected to the VDDX node, while the emitter is connected to VSUP (refer to [Figure 2](#)). The signal on the BCTL pin is analog. It is recommended that the pass transistor is placed as close as possible to the BCTL pin to avoid noise coupling or signal degradation on the base controller.

The VDDX node requires the following external capacitors:

- For loop stability (critical operation) a 10  $\mu$ F wet chemical on this node is required. The 10  $\mu$ F wet chemical capacitor can be replaced by a ceramic capacitor between 3.3 to 4.7  $\mu$ F X7R.
- 100 nF or larger X7R ceramic or tantalum capacitors help to protect against spikes created by switching loaded pads. These should be connected to the VDDX1, VDDX2, and VDDX3 pins.
- To reduce RF emissions and increase the quality of the supply, a pair of 10 nF in parallel with a 1 nF capacitor could be added in the net.

### NOTE

In general, these capacitors should be placed as close as possible to the IC to reduce RF transmission.

## 2.2 VSUP and the CAN regulator VDDC

Unlike the main regulator, the CAN regulator requires an external pass transistor to operate. If the application does not require CAN communications, this regulator can be left unpopulated without affecting the operation of the other peripherals. The pass configuration on the CAN regulator is similar to the pass configuration on the main regulator. A PNP transistor is required, that is, the base must be connected to the BCTL pin which controls the transistor as a linear regulator. The emitter of the transistor goes to VSUP (battery protected) and the collector goes to VDDC. The CAN voltage regulator circuit is also represented in [Figure 2](#).

VDDC is regulated to 5 V and is connected to the power domain for the CAN physical transceiver. In case of a short on this power supply, the rest of the MCU will continue to operate. The VDDC pin requires a 100 nF or larger X7R ceramic or tantalum capacitor to reduce noise in the power supply. The VDDC regulator can be enabled or disabled by software. When the user does not require CAN communications, the VDDC pin must be shorted with VDDX, the BCTL pin must be left floated, and the user must disable the CAN voltage regulator by software (EXTCON bit).

## 2.3 VDD and VDDF

VDDX not only provides 5 V to the peripheral modules, but also powers two other integral voltage regulators, VDDF that powers the NVM and VDD that powers the S12Z core. These two power supplies are bonded out to external pins so that the user adds decoupling capacitance, and they do not require external voltage connections. Connecting 5 V to these pins will cause irreparable damage. VDD and VDDF require a capacitor to ground of 220 nF X7R ceramic.

### NOTE

The VDD and VDDF pins must be used only to add the proper decoupling capacitance. Any external load on these pins will cause damage to the microcontroller's processor or to the memory array.

## 2.4 VDDA and VDDM

As mentioned earlier, not all the peripherals on the S12ZVH are powered from VDDX. The Analog-To-Digital module and the Stepper Motor Controller have independent power domains within the MCU, VDDA and VDDM respectively. Although these modules are normally powered by VDDX, the MCU offers the possibility of powering them from a dedicated power domain. On the usual case, VDDA and VDDM will be powered from VDDX as well, these connections need to be done externally and both power domains require decoupling capacitances on each pin as follows:

- VDDA can be treated as a VDDX pin. This is adding a 100 nF or larger X7R ceramic or tantalum capacitor to ground and connect it to VDDX externally.
- VDDM powers the stepper motors, it can be connected to VDDX but requires larger bulk capacitors to provide instantaneous current for the motors. A 47  $\mu$ F X7R or tantalum capacitor per pin (VDDM1 and VDDM2) is recommended as minimum.

## 2.5 Grounds

As for the grounds, VSS1, VSS2, VSSX1, VSSX2, VSSX3, VSSM1, VSSM2, and VSSC can be shorted together and should be connected to a plane under the MCU for EMC shielding. VSSA, which is the analog ground, should be filtered using an inductive ferrite before connecting it to the rest of the grounds. This will isolate noise caused by the motors and other modules from affecting the measurement accuracy of the ADC module. 50 ohm ferrites at 100 MHz are commonly used for this purpose.

## 2.6 VSENSE

The VSENSE pin is optional and provides the means for direct battery sensing. It should be connected directly to the battery as it has its own reverse battery protection. To avoid over-current damage to the pin and the ADC module, a 10 kilohm series resistor is required.

## 2.7 Pass transistor selection

The maximum current that an external pass transistor can provide depends mainly on the power dissipation capabilities of the transistor packaging. The power dissipated by the transistor can be roughly estimated by the current passing through it multiplied by the voltage applied to it ( $P = V * I$ ).

Consider the following example:

VSUP:: 12 V

Application current: 100 mA

$$P = V * I = (V_{in} - V_{out}) * I_{out} = (12 - 5) * 0.1 = 700mW$$

### Equation 1. Example of pass transistor power dissipation calculation

In this case, the transistor would need to dissipate 700 mW on a best case scenario where the voltage supply is 12 V. Considering a worst case in which the voltage is 18 V, the transistor would need to dissipate 1.3 W. Note that using the external ballast transistor disables the internal voltage regulator. In this particular example, the total available current would be the 100 mA from the transistor.

Thermal behavior and dissipation should be considered before selecting a pass transistor. The junction temperature must never exceed the rated operating junction temperature of the device. The expected junction temperature is calculated with the following equation

$$T_j = T_a + (P * \theta_{ja})$$

### Equation 2. Junction temperature equation

## Reset circuit

Where:

- $T_j$ : Internal silicon junction temperature in °C
- $T_a$ : Maximum expected ambient temperature in °C
- $P$ : Maximum expected power to be dissipated in Watts
- $\theta_{ja}$ : Thermal rating of the package in °C/W

Considering that the previous design is operating at ambient temperature (25 °C) and that the selected transistor has a SOT-223 package [83.3 °C/W], the maximum temperature the transistor would reach is:

$$T_j = T_a + (P * \theta_{ja}) = 25 + (1.3 * 83.3) = 133.29^\circ\text{C}$$

### Equation 3. Junction temperature calculation example

The designer must carefully select a transistor that meets the power dissipation capabilities in the worst case of the design. The BCP53 PNP transistor has been successfully characterized to work as a pass transistor due its high current gain, good power dissipation capabilities, and small form factor.

## 3 Reset circuit

The reset pin is a bidirectional line. It can be used in either of the following ways:

1. External circuits can initiate an MCU reset by pulling this line down.
2. The MCU can initiate a reset in order to trigger external resets.

When the MCU initiates a reset sequence due to a COP (Watchdog Timeout), clock monitor reset, or other internal reset source, it is important that the line is not externally pulled low for more than 24  $\mu\text{s}$ . This is because the reset circuitry within the MCU uses the reset pull time as a way to detect the reset source. If the reset line is held low for more than 24  $\mu\text{s}$ , the MCU would detect the reset as an external PIN reset, instead of the appropriate source of the event (COP or Clock Monitor).

In prototype designs, it is common to add a push-button to manually force a reset. In this case, the designer could choose to add a debounce capacitor to this button. In the event of an internal reset event, the MCU forces the Reset pin low and up again so that other circuits connected to this pin are reset as well. This reset pulse must last less than 24  $\mu\text{s}$ . The debounce capacitance on the reset line must ensure that this timing constraint is met. Capacitors smaller than 10 pF are recommended. If the designer wishes to add a larger debounce capacitor, a diode should be added between the reset pin on the MCU and the button as shown on [Figure 3](#)

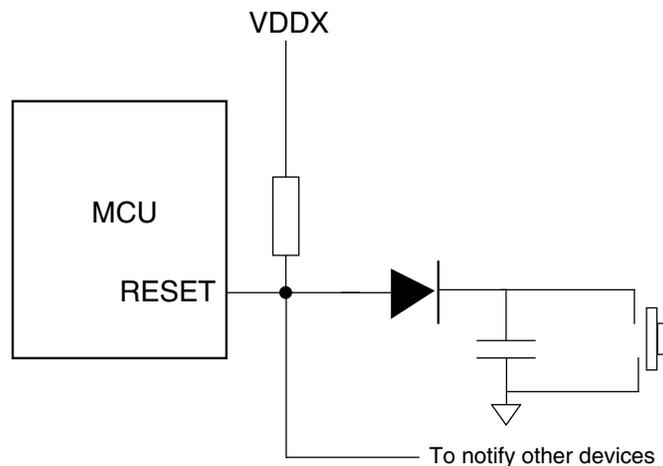
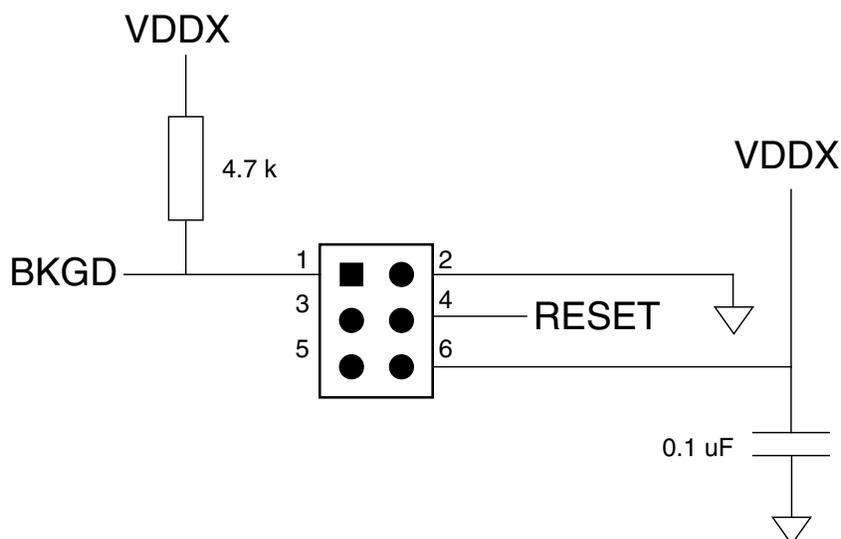


Figure 3. Reset pin with push-button and diode

An external pull up resistor is recommended on the reset line. It can be in the range from 4.7 to 10 kilohm.

## 4 Programming circuit

The S12ZVH family is programmed via the BDM protocol. All the S08 and S12 microcontrollers of Freescale use this protocol and many third party tools are able to program via BDM. The standard BDM connector is a 2 by 3 pin header with 100 mil pitch. [Figure 4](#) describes the BDM connector pinout.



**Figure 4. BDM Connector**

### NOTE

It is assumed that the RESET line already has the pull-up resistor described in [Reset circuit](#).

The BDM protocol is a serial protocol that is transmitted through the BKGD line. This line comes with an internal weak pull-up resistor, so it requires an external strong pull up resistor in the range of 4.7 to 10 kilohm. If a filter capacitor is desired, bear in mind that the BKGD pin is used to serially program the microcontroller so that high capacitances can affect the slew-rate of the signals being transmitted and prevent correct programming.

The BDM connector requires connection to the RESET pin, voltage (VDDX), and ground. It is recommended to add a ceramic capacitor to VDDX near the connector to reduce noise that could be injected by the programming circuitry to the power supply. A capacitor from 100 nF to 220 nF X7R or tantalum is recommended.

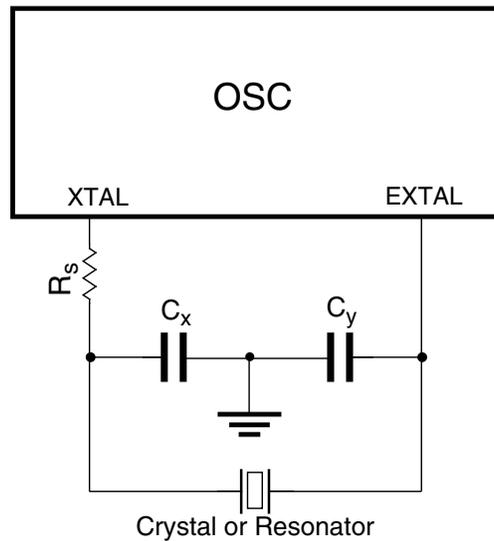
## 5 Clock circuit

Although the S12ZVH family has an internal 1 MHz RC oscillator that can clock the MCU, there is the alternative to add an external crystal. The external main crystal can be anywhere from 4 MHz to 16 MHz. The internal PLL can boost either the internal RC oscillator or the external crystal frequency up to 32 MHz bus clock (64 MHz core clock).

The S12ZVH includes an oscillation circuit capable of supporting either Loop Controlled Pierce (LCP) or Full Swing Pierce (FSP) oscillation mode. The oscillation mode used by the MCU can be configured by software. [Figure 5](#) shows the required oscillator circuit. The Clock, Reset, and Power Management unit on the S12ZVH family is able to drive either on LCP or FSP from the same external circuit. Either when working with the Full Swing Pierce or the Loop Controlled Pierce setup, it is

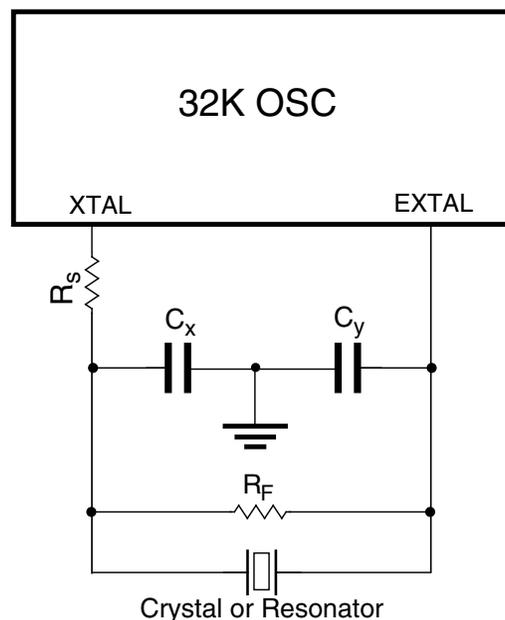
## Clock circuit

necessary for the designer to consult with the crystal vendor to determine the correct  $R_s$ ,  $C_x$ , and  $C_y$  values. Commonly,  $R_s$  is omitted or placed as a zero ohm resistor. For more information on oscillator setups and troubleshooting, refer to application note AN3208 “Crystal Oscillator Troubleshooting Guide” available at [freescale.com](http://freescale.com).



**Figure 5. Main oscillator external circuit for both LCP and FSP configurations**

Besides the main oscillator, the S12ZVH family supports a second smaller crystal used by the Real Time Counter (RTC) module. This smaller crystal must be 32.768 kHz and is used to keep a precise real-time count in the application. The user can select to run the RTC module from the main oscillator although Freescale recommends using the dedicated 32.768 kHz oscillator to achieve the maximum possible accuracy of the module.



**Figure 6. 32 kHz oscillator external circuit**

The 32 kHz oscillator circuit is very similar to the main oscillator. [Figure 6](#) shows the 32 kHz oscillator circuit. The main difference is that the feedback resistor (Rf) needs to be placed externally. The Rs resistor must be 200 kilohm and Rf must be 100 Mohm. The Cx and Cy capacitances depend on the selected crystal or resonator and must be confirmed with the crystal vendor.

When routing the oscillator circuit, it is important to remember that these are high-frequency traces. No other traces (data or power) should be placed under the crystal or load capacitors. The connections from the crystal and the MCU pins must be as short as possible.

## 6 Interrupt pins

The S12ZVH family has certain pins with interrupt functionality. These interrupt-enabled pins are able to wake-up the MCU from STOP and SLEEP when a pulse is applied to the pin. The polarity of the pulse can be configured by software, but pull-resistors need to be placed (or configured) to match this selected polarity. Some pins have internal pull resistors that can be enabled and configured (as pull-up or pull-down) by software. If the user wishes an interrupt to occur on a falling edge or low level then the pin should have an external pull-up. The opposite is required (pull-down) when the user wishes an interrupt to occur on a rising edge or a high level. If the designer wishes to add an external pull resistor, it can be in the range from 4.7 to 10 kilohm. Common modules with interrupt capable pins are the Keyboard Wakeup (KWx), Timer (TIM) modules, the IRQ, and XIRQ pins.

## 7 LCD pins and contrast

The LCD module on the S12ZVH family is able to drive Liquid Crystal Displays (LCDs) with up to 40 frontplanes and 4 backplanes, for a maximum of 160 segments. A single LCD segment is controlled by a specific signal combination of a frontplane (FP) and a backplane (BP). The different waveforms generated by each of the frontplanes and backplanes are not digital, so the designer must avoid adding capacitance to these traces. The LCD is powered and controlled entirely by the LCD module on the MCU. The LCD does not require external power. An external backlight circuit can be used to increase the contrast on the LCD when required.

The LCD module itself is able to control the contrast of the segments on the LCD. This is done by applying an analog signal to the VLCD pin. The VLCD pin internally converts the analog voltage applied to it into signal contrast on the turned-on segments on the LCD. 5 V on the VLCD pin mean the maximum contrast and ON segments are fully black or white depending on the polarity of the display. 0 V on the VLCD pin will fade all the segments, even the ON ones. A potentiometer in a voltage divider setup can be used to manually control the LCD contrast.

## 8 Special and unused pins

Some pins on the S12ZVH MCU are reserved for Freescale internal use only and must not be used on a production level application. These pins are normally marked as NC and must not be grounded or shorted to VDDX, they must be left floating. The TEST pin is the only Freescale's reserved pin that is not marked as an NC pin. TEST line is only used in Freescale factory tests and it must be connected to ground.

Unused digital pins can be left floating. To reduce power consumption, it is recommended that these unused digital pins are configured as inputs and have the internal pull resistor enabled. This will decrease current consumption and susceptibility to external electromagnetic noise.

Unused ADC pins should be grounded to reduce leakage currents. The EXTAL, XTAL, 32K\_EXTAL, and 32K\_XTAL pins default reset condition is to have pull-downs enabled. These pins should be connected to ground if not used.

## 9 High-Current pins

The S12ZVH family is able to directly drive up to four stepper motors. The pins dedicated to the stepper motor controller are rated as high current pins. These pins can drive (or sink) up to 55 mA of instantaneous current. Although the basic use case for these pins is to drive a low-power stepper motor, they can be used to directly drive LEDs without requiring external driving circuitry. The current for these pins is taken from VDDM pins. The VDDM pins need large bulk capacitors to respond to the fast current demands of a typical stepper motor. Refer to section [VDDA and VDDM](#) for more information on powering the Stepper Motor module.

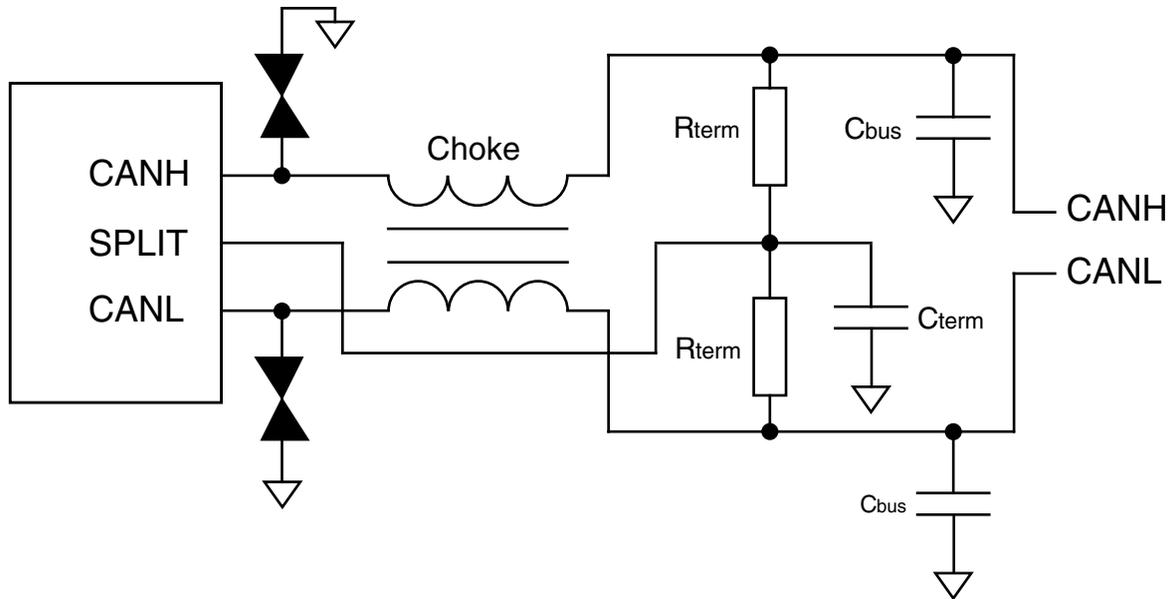
## 10 Analog pins and battery sensing

The ADC module has several channels, some going to external pins and others connected to internal reference voltages. The ADC accuracy is affected if the pin current is larger than  $\pm 2.5$  mA (called disruptive analog input current). The current of ADC pins must be limited by a serial resistor no larger than 10 kilohm. Optionally, the designer could add a filter capacitor to reduce noise on the analog signal. For the best ADC conversion accuracy, the filter added should be larger than 6.1 nF. For more details on the ADC module, accuracy, and conversion timings refer to the S12ZVH reference manual available at [freescale.com](http://freescale.com).

Internally, the VSENSE pin (or VSUP itself) can be connected to an ADC channel after a series of voltage reduction stages. The VSENSE pin requires a 10 kilohm resistor in series.

## 11 CANPHY

The 144-LQFP version of the S12ZVH family has an on-chip CAN physical transceiver and a dedicated power supply for it. Having these modules on-chip helps reduce the total amount of components required to implement communications on a cluster design. As mentioned in [VSUP and the CAN regulator VDDC](#), if the designer wishes to use CAN communications, the dedicated VDDC voltage regulator controller to power the internal CANPHY can be used. As any other CAN physical transceiver, the CANH, CANL, and SPLIT pins are available for the designer to terminate the bus depending on the application. [Figure 7](#) shows an example of a CAN node termination.



**Figure 7. CAN physical transceiver circuit**

Depending on the position of the node within the CAN network the bus might need a specific termination.  $R_{term}$  resistors should assist in having an overall cable impedance of 120 ohm. On a bus implementation of a CAN network, only the two nodes on the two ends of the bus have terminator resistors. In this case each of the  $R_{term}$  resistors must be 60 ohm, so that they maintain 120 ohm of impedance between CANH and CANL. The nodes not placed on the end of the CAN bus do not have termination. A thorough analysis is required to maintain this requirement of the CAN networks.

The SPLIT pin on the transceiver is optional and the designer might choose not to use it. This pin helps stabilize the recessive state of the CAN bus and can be enabled or disabled by software when required. If the SPLIT pin is not used (but CANH and CANL are) it should be left floating. A common node choke on the CANH and CANL lines can help reduce coupled electromagnetic interference. This choke, together with transient suppressors on the transceiver pins can greatly reduce coupled electromagnetic noise, and high-frequency transients.

If the CAN physical transceiver is not used, the CANH, CANL, and SPLIT pins should be connected to ground.

## 12 Printed circuit board design recommendations

The following recommendations are based on the “Effective Printed Circuit Board Design” on-demand webinar available at [freescale.com](http://freescale.com).

When doing a layout try to follow this set of recommendations:

1. Decouple capacitors should be placed as close as possible to the pins of the MCU.
2. The trace that connects power switching devices should be as short as possible. So, these devices should be placed as close as possible to the device they control.
3. Signal traces must be one dielectric away from the return (either adjacent to planar copper or ground trace).
4. When using dual line header connectors (to connect more than one board) prefer a header pin assignment similar to:

Row 1: SSSGSSSGSSP

Row 2: SGSSSGSSSGP

Where S represents a signal, P a power line, and G a ground connection. Following this array ensures that each signal is only one pin away from a ground. Take care to place the most critical signals adjacent to ground pins.

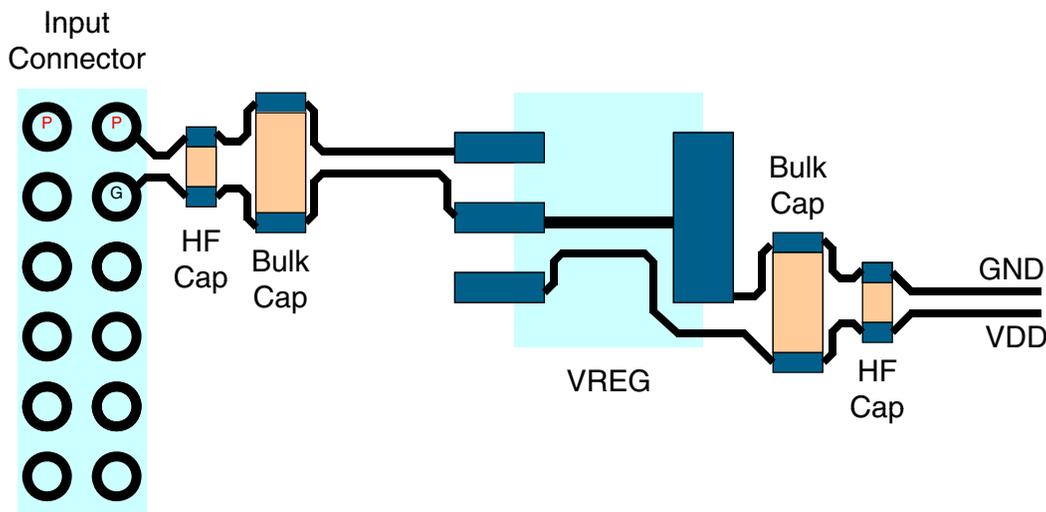
5. Place components to limit signal mixing. Routing power in power realm and sensor lines only where needed. The digital IC connections should belong only to the digital realm.

## Conclusion

6. Prefer largest value capacitors in the smallest package.

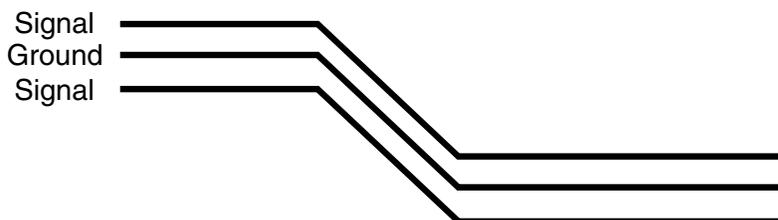
When routing try to follow these recommendations:

1. On low-layer count boards, with no dedicated ground plane, the power lines must be routed in pairs (power and ground). Traces should run side by side spaced as close as manufacturing allows.



**Figure 8. Power line routing**

2. Minimize the volume of the power transmission network.
3. When possible try to route in triplets (Signal, Ground, Signal)



**Figure 9. Routing in triplets**

4. Try to cover all the un-routed space with ground copper.

## 13 Conclusion

The S12ZVH family of microcontrollers includes many analog components on-chip that help reduce the total amount of external components required. Paying special attention to the recommendations on this guideline will ensure a successful design in a very small time-to-market period.

## 14 References

Consult the updated device's reference manual, reference design, and other information at: <http://www.freescale.com/S12ZVH>

The “Effective Printed Circuit Board Design” on-demand webinar can be found in: [http://www.freescale.com/webapp/sps/site/training\\_information.jsp?code=WBNR\\_PCBDESIGN&fsrch](http://www.freescale.com/webapp/sps/site/training_information.jsp?code=WBNR_PCBDESIGN&fsrch)

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