

Space-grade isolated serial peripheral interface (SPI) circuit



Design Goals

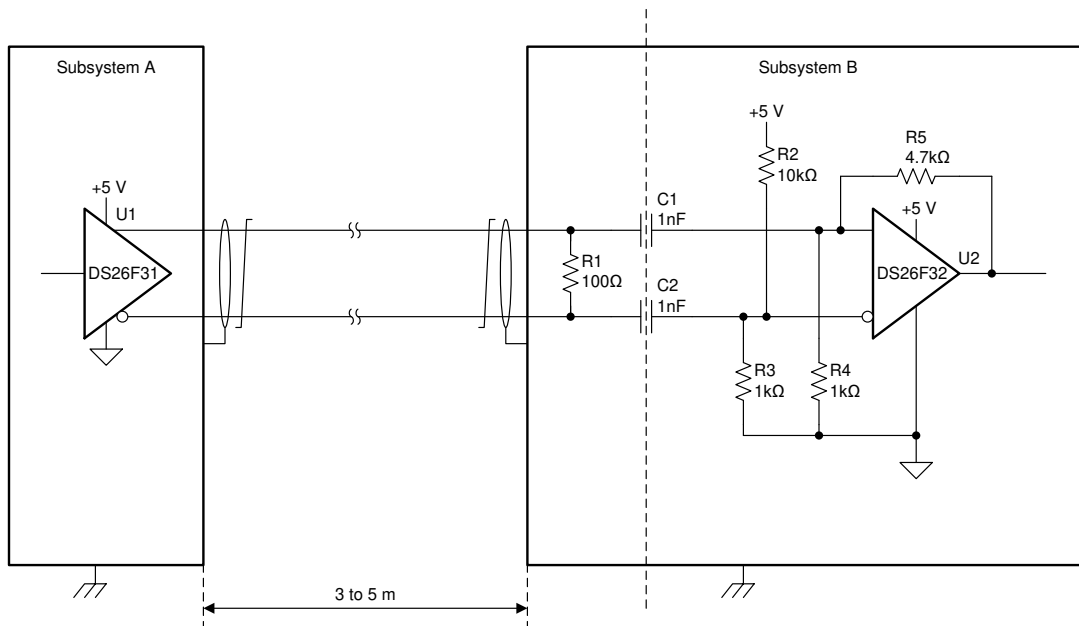
Parameter	Design Requirement
Maximum Bit Rate	$\geq 100\text{kb/s}$
Isolation Voltage	$\geq \pm 100\text{ V}$
Maximum Cable Length	$\geq 5\text{ m}$
Maximum Total Ionizing Dose	$\geq 100\text{krad (Si)}$
Maximum SEL	$\geq 75\text{MeV}\cdot\text{cm}^2/\text{mg}$

Design Description

RS-422-based circuit

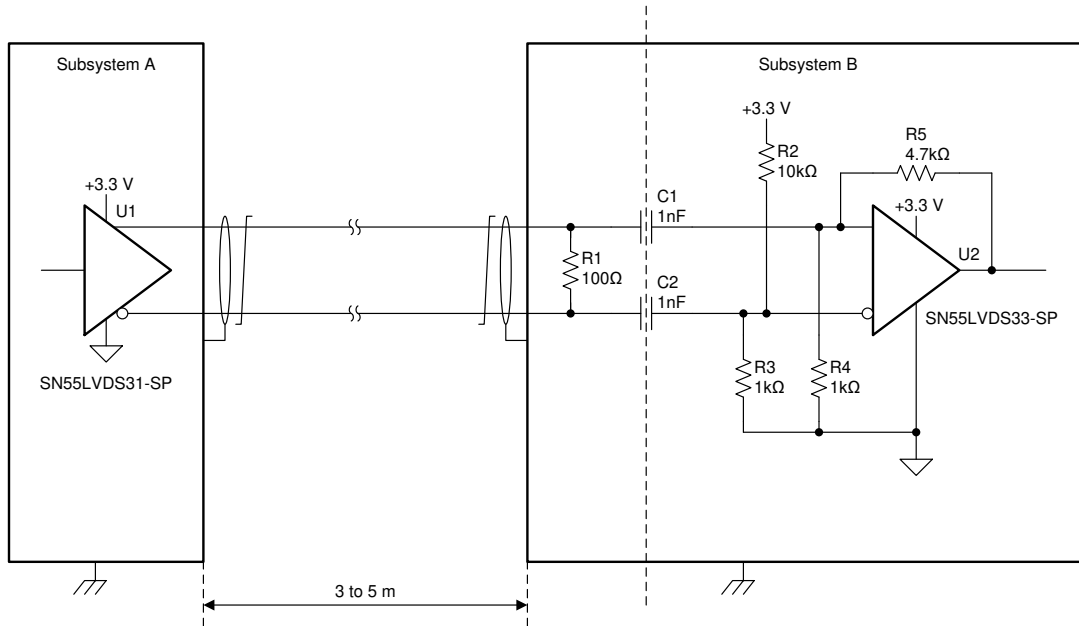
The Serial Peripheral Interface (SPI) is commonly used in embedded systems to connect microcontrollers to peripheral devices such as ADCs and DACs. It is often used in spacecraft applications, and sometimes an isolated SPI implementation is necessary to preserve the spacecraft grounding principles or to support DC offsets.

The following circuit uses the [DS26F31MQML-SP](#) and [DS26F32MQML-SP](#) RS-422 driver and receiver devices to implement one channel of an isolated SPI. Isolation is provided by the AC-coupling capacitors, whose voltage rating determines the level of isolation supported.



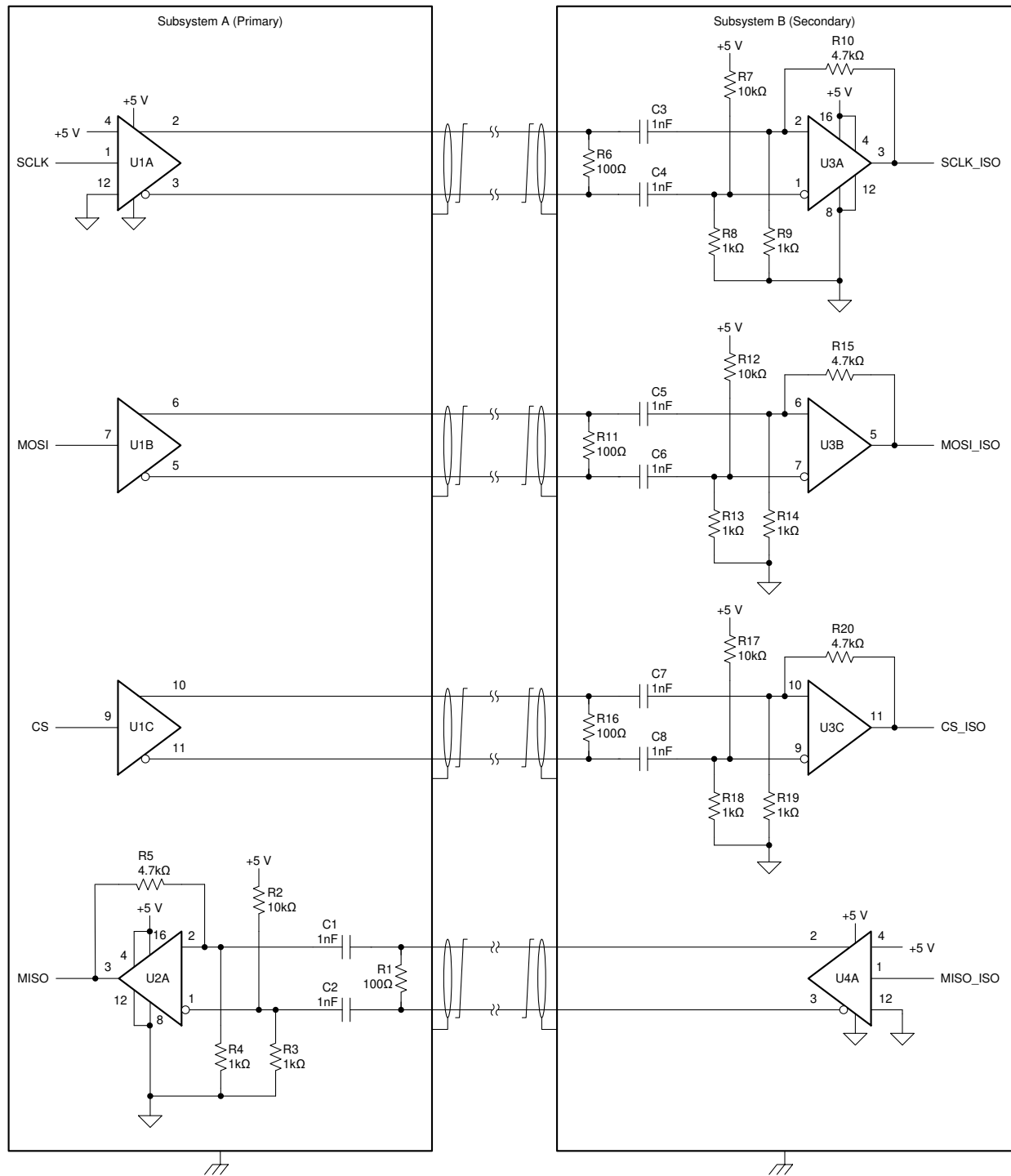
LVDS-based circuit

The previously-described RS-422-based circuit works well, but it needs a 5-V supply to operate. The following circuit uses the same circuit configuration as the previous one, but the RS-422 driver and receiver have been replaced by their LVDS equivalents, the [SN55LVDS31-SP](#) and [SN55LVDS33-SP](#), and the circuit operates from a 3.3-V supply.



Complete SPI Implementation

The following image is a typical four-signal SPI implementation. The circuit shown uses the [DS26F31MQML-SP](#) and [DS26F32MQML-SP](#) devices. The LVDS equivalent is identical except that it uses the [SN55LVDS31-SP](#) and [SN55LVDS33-SP](#) devices and a 3.3-V supply voltage.



U1 = U4 = DS26F31MQML-SP
 U2 = U3 = DS26F32MQML-SP
 Decoupling capacitors and unused gates not shown.

Design Notes

The circuit biases the negative input of each receiver channel slightly above ground. Positive feedback changes the bias point of the positive input depending on the output state of the receiver. When the output is high, the positive input is biased higher than the negative input; when the output is low, the positive input is biased lower than the negative input. In this way, the receiver always remains in the last state that it was actively driven to. The time constant of the AC-coupling circuit is irrelevant, and there is no minimum operating frequency.

Two versions of the same basic circuit are described: one uses RS-422 devices and operates from a 5-V supply, and the other uses LVDS devices and operates from a 3.3-V supply.

Receiver Function Tables

The function tables of the two receiver devices follow. The two devices function identically, but the differential input voltage thresholds are different.

Table 1-1. DS26F32MQML-SP Function Table

Differential Inputs	Enables		Outputs
$V_{ID} = V_{(+IN)} - V_{(-IN)}$	ENABLE	ENABLE	OUT
$V_{ID} \geq 0.2 \text{ V}$	H	X	H
	X	L	H
$V_{ID} \leq -0.2 \text{ V}$	H	X	L
	X	L	L
X	L	H	Z

Table 1-2. SN55LVDS33-SP Function Table

Differential Inputs	Enables		Outputs
$V_{ID} = V_{(A)} - V_{(B)}$	G	\bar{G}	Y
$V_{ID} \geq 50 \text{ mV}$	H	X	H
	X	L	H
$V_{ID} \leq -50 \text{ mV}$	H	X	L
	X	L	L
X	L	H	Z

Isolation

Isolation is provided by the AC-coupling capacitors. These should be chosen with a voltage rating greater than the isolation voltage required. For improved failure tolerance, two capacitors in series can be used; however, *each capacitor must be rated for the full isolation voltage.*

Design Steps

In the following description the component reference designators referred to are those used in the circuit diagram on the first page of this document.

- Choose R1 to match the characteristic impedance of the cable used. In this case, with 24 AWG twisted pair cable, R1 = 100 Ω.
- Choose R2 and R3 so that when the output is low the differential input voltage is ≤ -200 mV. When the output is low the voltage on the positive input is 0 V and the voltage on the negative input is given by the following equation:

$$V_{I(-IN A)} = \left(\frac{R3}{R2 + R3} \right) 5 V = \left(\frac{1 k\Omega}{10 k\Omega + 1 k\Omega} \right) 5 V = 456 mV$$

This yields the following equation for the differential input voltage:

$$V_{ID-} = V_{(+IN A)} - V_{(-IN A)} = 0 mV - 456 mV = -456 mV$$

- Choose R4 and R5 so that when the output voltage is high, the differential input voltage is ≥ 200 mV. When the output is high the voltage on the positive input is given with the following equation: none-numeration

$$V_{I(+IN A)} = \left(\frac{R4}{R4 + R5} \right) 5 V = \left(\frac{1 k\Omega}{1 k\Omega + 4.7 k\Omega} \right) 5 V = 877 mV$$

Therefore, the following equation shows the differential input voltage:

$$V_{ID+} = V_{(+IN A)} - V_{(-IN A)} = 877 mV - 456 mV = 421 mV$$

- C1 and C2 set the time constant of the AC-coupling network. If this time constant is long enough to cause the receiver to change state, the absolute value of the AC-coupling time constant is unimportant. The positive feedback network formed by R5 ensures that the receiver stays in the last state it was actively driven to, and thus the minimum operating frequency is independent of the values of C1 and C2.

The time constant of C2, R2 and R3 is given in the following equation:

$$\tau_{(-IN A)} = \left(\frac{R2 \times R3}{R2 + R3} \right) C2 = 909 ns$$

The time constant of C1, R4, and R5 is given in the following equation:

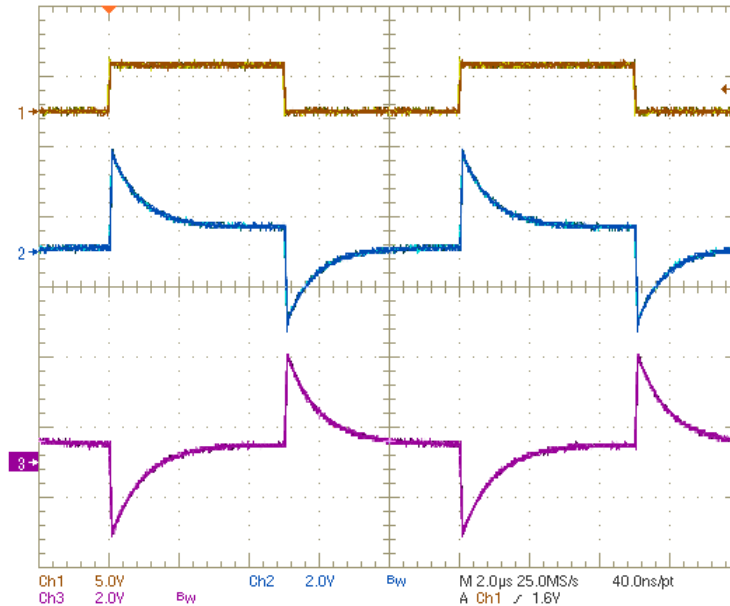
$$\tau_{(+IN A)} = \left(\frac{R4 \times R5}{R4 + R5} \right) C1 = 825 ns$$

- Choose capacitors C1 and C2 with a voltage rating that exceeds the isolation voltage required. For fail-safe circuits, two capacitors in series can be used; however, each individual capacitor must be rated for the full isolation voltage.

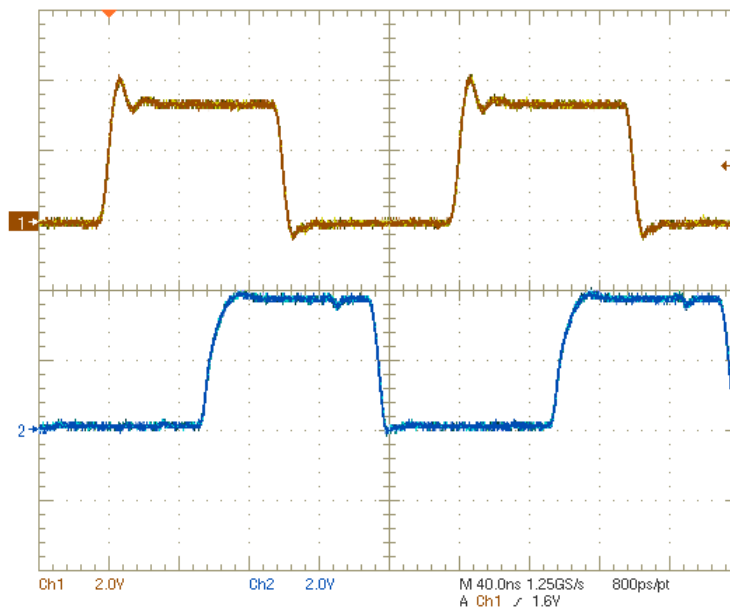
Measurement Results

RS-422-based circuit

The following scope plot shows the input and output signals measured directly at the receiver input pins after transmission over a 5-m length of 24-AWG twisted-pair cable. Channel 1 shows the driver input signal and channels 2 and 3 the positive and negative inputs of the differential receiver. The hysteresis generated at the positive input of the receiver can be seen in the different quiescent levels to which the input returns after the initial capacitive "kick". In contrast, the inverting input, which does not have hysteresis, returns to the same quiescent level. This approach ensures that the receiver output remains in the last state to which it was driven and that the minimum switching frequency is independent of the time constant of the AC-coupling components.

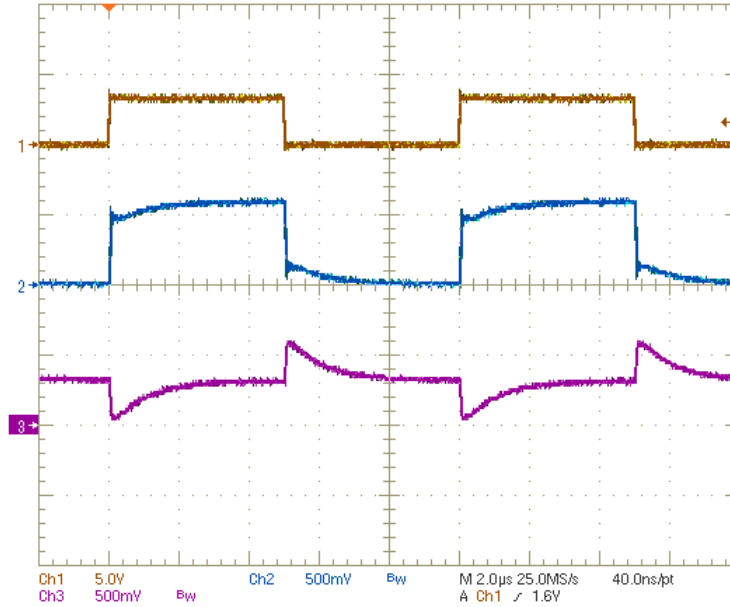


The following scope plot shows the propagation delay from the input of the driver to the output of the receiver. It is about 60 ns.

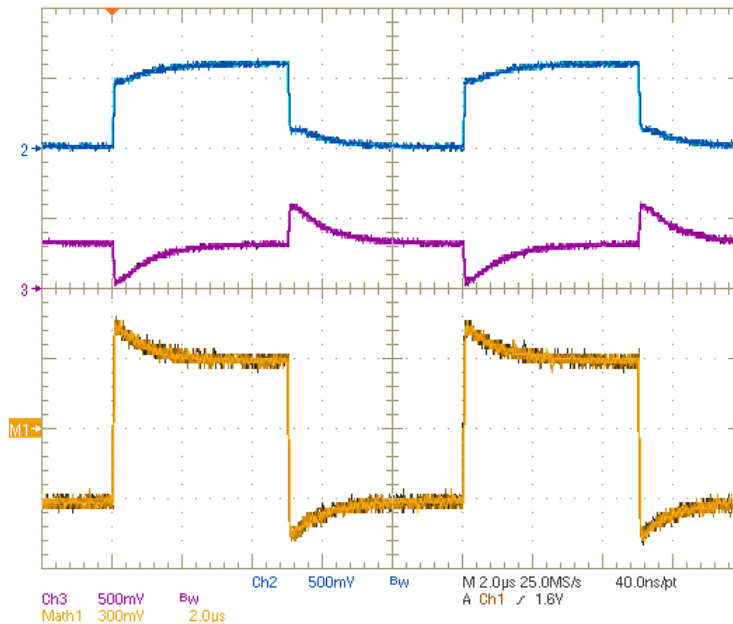


LVDS-based circuit

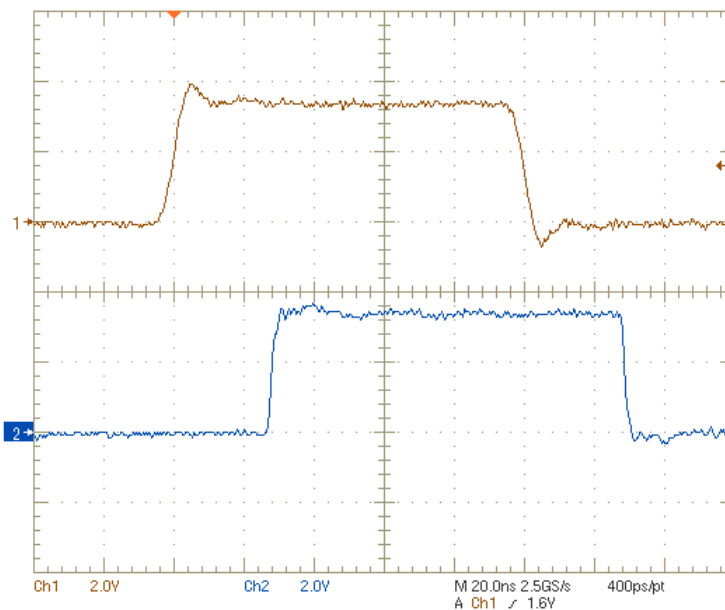
The following scope plot shows the same signals as previously shown, but for the LVDS-based circuit. Note the much smaller amplitude of the LVDS waveforms. Note too, the different shape of the waveform at the positive input of the receiver, which is caused by the much higher hysteresis voltage relative to the signal amplitude.



The following scope plot shows the waveforms at positive and negative inputs of the receiver (channels 2 and 3, respectively) and the differential signal resulting from them (channel M1).



The following scope plot shows the propagation delay from the input of the driver to the output of the receiver. It is about 30 ns.



The following scope plot shows the same signals as previously shown, but for the LVDS-based circuit. Note the much smaller amplitude of the LVDS waveforms. Note too, the different shape of the waveform at the positive input of the receiver, which is caused by the much higher hysteresis voltage relative to the signal amplitude. The following scope plot shows the waveforms at positive and negative inputs of the receiver (channels 2 and 3, respectively) and the differential signal resulting from them (channel M1). The following scope plot shows the propagation delay from the input of the driver to the output of the receiver. It is about 30 ns.

Design References

See the [Analog Engineer's Circuit Cookbooks](#) for TI's comprehensive circuit library.

Design Featured RS-422 Transmitter

DS26F31MQML-SP	
Interface Standard	RS-422
# Transmitter Channels	4
# Receiver Channels	0
Nominal Supply Voltage	5 V
Operating Temperature Range (T _A)	-55°C to 125°C
Maximum Total Ionizing Dose	300 krad (Si)
Maximum SEL	N/A (bipolar)
www.ti.com/product/ds26f31mqml-sp	

Design Featured RS-422 Receiver

DS26F32MQML-SP	
Interface Standard	RS-422
# Transmitter Channels	0
# Receiver Channels	4
Nominal Supply Voltage	5 V
Common-Mode Voltage Range	±6 V
Operating Temperature Range (T _A)	-55°C to 125°C
Maximum Total Ionizing Dose	100 krad (Si)
Maximum SEL	N/A (bipolar)
www.ti.com/product/ds26fmqml-sp	

Design Featured LVDS Transmitter

SN55LVDS31-SP	
Interface Standard	LVDS
# Transmitter Channels	4
# Receiver Channels	0
Nominal Supply Voltage	3.3 V
Operating Temperature Range (T _A)	-55°C to 125°C
Maximum Total Ionizing Dose	150 krad (Si)
Maximum SEL	110 MeV-cm ² /mg
www.ti.com/product/sn55lvds31-sp	

Design Featured LVDS Receiver

SN55LVDS33-SP	
Interface Standard	LVDS
# Transmitters	0
# Receivers	4
Nominal Supply Voltage	3.3 V
Common-Mode Voltage Range	-4 V to 5 V
Operating Temperature Range (T _A)	-55°C to 125°C
Maximum Total Ionizing Dose	100 krad (Si)
Maximum SEL	90 MeV-cm ² /mg
www.ti.com/product/sn55lvds33-sp	

IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATASHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES "AS IS" AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, or other requirements. These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI's products are provided subject to TI's Terms of Sale (www.ti.com/legal/termsofsale.html) or other applicable terms available either on ti.com or provided in conjunction with such TI products. TI's provision of these resources does not expand or otherwise alter TI's applicable warranties or warranty disclaimers for TI products.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2020, Texas Instruments Incorporated