

Technical Notes on using Analog Devices' DSP components and development tools

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Creating A Master-Slave SPI Interface Between Two ADSP-2191 DSPs

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This Engineer-to-Engineer note will discuss how to set-up a Serial Peripheral Interface (SPI) between two ADSP-2191 devices in both the hardware and the software. The master and slave code included in the associated archive can be used as a template for any ADSP-2191 SPI interface.

The hardware for this system was verified using two ADSP-2191-EZ-KITs, and the software was built using the VisualDSP++ 2.0 Tools Suite.

1. Hardware Interface

The SPI is a full-duplex, 4-wire, synchronous interface consisting of two data lines, a clock, and a device-select signal.

The data is transmitted over the MOSI (Master Out Slave In) and MISO (Master In Slave Out) data I/O signals and the clock is the SPI Clock (SCK) signal. These 3 signals are shared between the master and slave devices.

The 4th wire in the interface is the device-select signal. The Programmable Flag pins on the ADSP-2191 can be configured to function as SPI device-selects. Please refer to the data sheet for more information regarding the functional use of these programmable flag pins. On a master ADSP-2191 device, up to seven slave-select signals are available for *each* SPI port. In this example, programmable flag pin 4 (PF4) is

configured as the master-driven output device-select signal.

On the slave side of the interface, PF0 is the multiplexed flag pin assigned to be the SPI0 Slave Select ($\sim$ SPISS0) signal. Figure 2 depicts the hardware connection for a typical master-slave SPI interface. Remember that we are utilizing SPI0 in this interface (SPI1 would use different PFx pins and the SPI1 signals).

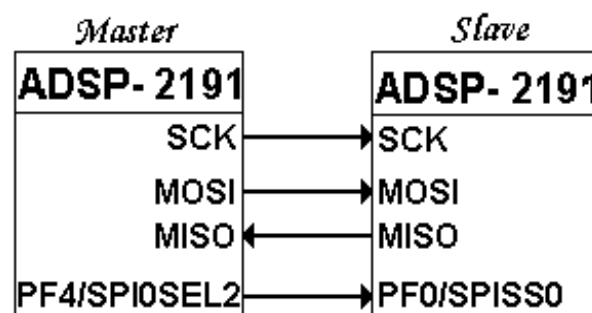


Figure 1: SPI Hardware Connection For 2 ADSP-2191s

2. How The ADSP-2191 SPI Works

The ADSP-2191 features two SPI-compatible ports. An SPI Interface essentially consists of two shift registers that simultaneously transmit and receive one bit of data to and from each other at a fixed bit rate. The following diagram is a general overview of the SPI data buffers and how they relate to each other in an SPI system:

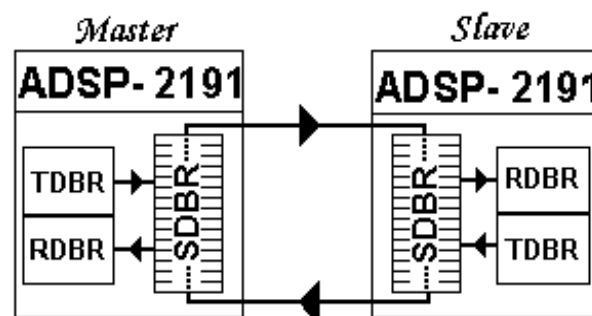


Figure 2: SPI Data Exchange (16-Bit Registers)

The behavior of the SPI depends on how the SPI ports are configured. In this example, transfers are initiated on reads of the receive data buffer register (RDBRx) and interrupts are generated when RDBRx is full. Due to this configuration, the following describes the behavior of the SPI:

Before the SPI transfer takes place, the master and slave devices each places the data to be transmitted in its respective transmit data register (TDBRx).

The master then drives the device-select signal of the slave and supplies the gated SPI Clock (SCK). When the master initiates the transfer, the master's data moves from its TDBRx register to its shift data register (SDBR), where it is shifted out one bit at a time on the MOSI pin on active SCK edges. The master is *also* sampling the MISO pin on inactive SCK edges.

Meanwhile, the slave waits for its device-select input to go active, meaning that the master is about to transmit. When that happens, the slave moves *its* data from *its* TDBRx to *its* SDBR and starts shifting out on the MISO pin on active SCK edges *and* sampling the MOSI pin on inactive SCK edges.

So, *both* devices are transmitting and sampling on each SCK pulse *simultaneously*. This data-shifting scheme continues until one full word has been transmitted *and* received (i.e., the two devices have essentially exchanged SDBR data).

The received data in SDBR then moves to the respective receive data register (RDBRx), which is when the interrupt is generated, informing the DSP that the data can now be read*. When the RDBRx register is read, it is cleared and becomes ready to get the *next* word from the shift register when it arrives.

**Note: The ADSP-2191 core cannot directly access the Shift Data Buffer Register (SDBR).*

3. Programming The SPI Devices

Once the hardware is properly connected, it is time to generate the software to control the two SPI ports so that they will talk to each other. For this to work, software is required to initialize both the master *and* the slave devices.

Please refer to chapter 10 of the “*ADSP-219x/2191 Hardware Reference*” for the various SPI register descriptions and for the “*SPI General Operation*” section, which describes the steps required by both the master and the slave to get an SPI interface running properly.

The code contained in the ZIP archive associated with this Engineer-to-Engineer note will be referenced throughout this section of the text.

3.1. Master Code

The assembly code for the master has been broken into two files, the source code (SPI_Master.asm) and the interrupt handler (SPI_MISR.asm). The numeric super-scripts indicate the corresponding source code line numbers being referenced in the text.

3.1.1. SPI_Master.asm

The very first thing that is *always* required when initializing an SPI interface is the setting of the OPMODE bit (bit 0) in the System Configuration Register⁵⁴⁻⁵⁶ (SYSCR). Setting this bit instructs the DSP to disable SPORT2 and to enable SPI0/1 on those pins. It is also good practice to set bit 4 while you are manipulating SYSCR to ensure that the Interrupt Vector Table (IVT) resides with the rest of your code. There are 3 possible default locations for the IVT depending on the boot mode and whether or not an emulator is present

in the system. Setting bit 4 will prevent jumps to contiguous memory from the IVT when the SPI interrupt occurs.

The next task is to prioritize the interrupts⁶⁵⁻⁷⁰. This step is optional, but, for the purpose of demonstrating this new ADSP-2191 feature, the process will be described here. Because this system will only service the SPI0 interrupt, the interrupts will be prioritized so that the SPI0 interrupt has the highest priority after the 4 fixed-priority core interrupts. This is achieved by setting the appropriate priority values in the Interrupt Priority Registers (IPR0-3). Figure 3 illustrates the alignment of the IPRx registers. Each numeric location in this diagram actually contains a hexadecimal number assigned to be that particular interrupt's priority level.

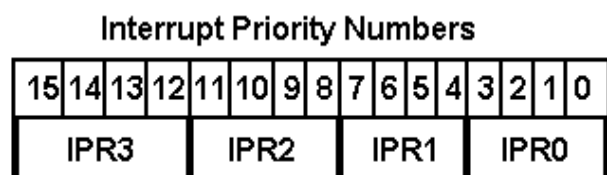


Figure 3: Interrupt Priority Register Alignment

The SPI0 interrupt resides in the 5th location in the priority chain, therefore, we want to assign the highest priority (0x1) to the 5th location, which is actually the *second* location in IPR1. All the other interrupts share the lowest priority value (0xB). Because of this, the hex value 0xB BBB is written to IPR0, IPR2, and IPR3, which sets programmable interrupts 0-3 and 8-15 to the lowest priority. The value written to IPR1 is 0xBB1B, thus setting the SPI0 interrupt at location 5 to be the highest priority of the 16 programmable interrupts.

Once the SPI interface has been enabled and the interrupts are prioritized, the next step is to configure the hardware to use the PF4 pin as a slave-select output signal.

Note: It is best to do this *first* in order to guarantee that the slave device is disabled while the master is being configured. The slave, if properly configured, will do *nothing* until the master enables the slave-select line.

Setting bit 2 (FLS2) of the SPIFLG0 register enables PF4 as an output. Since the slave's select line is active-low, the corresponding FLG2 value (bit 10) is kept high⁸⁹ to ensure that the slave is inactive until the master device is ready to transmit.

After the flag pins have been configured, the next step is to set the bit rate at which the SPI transfer will operate. The bit rate is governed by the equation:

$$SCK = \frac{HCLK}{2 * SPIBAUD0}$$

In this equation, HCLK is the *peripheral clock rate* and SPIBAUD0 is the value that will be written to the SPI0 Baud Rate Register⁹³ (SPIBAUD0). The SPI bit rate will determine the frequency of the SPI Clock (SCK).

After the bit rate has been determined, the final step in preparing the SPI interface is to configure the SPI port itself, which is accomplished by writing to the SPI0 Control Register¹¹⁴ (SPICTL0), shown in figure 4:

Bit #	Name	Value	Result
1:0	TIMOD	00	Transmit on read of RBDR. Interrupt when RDBR is full

2	SZ	0	Send last word when TDBR is empty
3	GM	1	Get more data if RDBR full
4	PSSE	0	Disables slave-select input
5	EMISO	0	Disables slave data output
7:6	Reserved	00	RESERVED
8	SIZE	1	16-Bit Word Length
9	LSBF	0	Transmit MSB First
10	CPHA	1	SCK Toggles Immediately. Software Controls Slave Selects
11	CPOL	1	Active-Low SCK
12	MSTR	1	Device Is Master Device
13	WOM	0	Normal Data I/O
14	SPE	1	SPI Module Enabled
15	Reserved	0	RESERVED

Figure 4: SPICTL0 Register Settings For Master

There are precautions to be considered when choosing the value that will be written to this register. The most important thing to consider here is that certain components of this control register in both the master and slave devices need to be configured *identically* to one another or the interface will not function properly. Since this design utilizes identical master and slave devices, we have identical control registers and it is very easy to have the two sides agree. In the even that your interface utilizes a device other than an ADSP-2191, simply follow these recommendations and the interface should run smoothly.

The critical bit-fields in the SPICTL0 register that *must* match between master and slave are SPI clock phase (CPHA) and polarity (CPOL), data format (LSBF), and word length (SIZE). These descriptors determine when the data is moved to and from the shift register, how that data is coming in and going out, and what size words are going to be transmitted. If this information differs from the configuration of the other SPI devices over the link, there can be data

faults, latch errors, and/or data contention. Since we have identical devices, it is very easy to copy these fields to the slave device's configuration code.

The bit fields that are based on whether the device is a master or a slave are the Master Select (MSTR), the Enable Slave-Select Input (PSSE), and the Enable MISO For Output (EMISO) bits. Since this is the master device, these bits are set accordingly.

The Enable Open-Drain (WOM) bit is needed in the event that you do not wish to have your data-lines connected in a multi-master or multi-slave environment. Since this is a single-master, single-slave design, this feature is not enabled.

The rest of the fields in the register can be configured independently because they deal with internal interrupt and data handling. The transfer initiation mode (TIMOD) instructs the DSP when to have the interrupt occur and when to begin the SPI transfer. The Send Zeros (SZ) and Get More (GM) bits control what the SPI port will do when the Transfer Buffer is empty at the start of a transmission or the Receive Buffer is full when more data is coming in. And, finally, the SPI Module Enable (SPE) bit must be set in order to turn on the port.

After all the set-up code has run, all that is left is to actually do the transfer. The next segment of code sets up the DAG registers for the input and output buffers with a stride of 1 and linear addressing¹²³⁻¹²⁷. The SPI0 Flag Register is written again¹³² to enable the slave on PF4, followed by a dummy read of the RDBR0¹³³ to kick off the transfer. The data is then written to TDBR0¹³⁹ and the loop structure revolves around the SPI interrupt being generated. After the entire 16-word buffer has been transmitted and received, the loop terminates and the

SPIFLG0 register is written again¹⁴⁵ to disable the slave on PF4.

3.1.2. SPI_MISR.asm

This module is the Master Interrupt Service Routine. Because of the way the SPI0 Control Register is configured in the **SPI_Master.asm** module, the SPI0 interrupt will be generated when RDBR0 is full. The interrupt routine uses the secondary set of registers in order to avoid corrupting existing data³³, reads the data from RDBR0³⁷, and stores the read data off to memory in the receive data buffer, RX_Buf_MASTER³⁸. It then reverts to the primary set of registers⁴¹ and returns to the main program⁴².

3.2 . Slave Code

The assembly code for the slave is similar to that of the master and has been broken into two files, the source code (SPI_Slave.asm) and the interrupt handler (SPI_SISR.asm). Again, the referenced line numbers appear as super-scripts.

3.2.1. SPI_Slave.asm

Just as in the master, the first step is to set the OPMODE bit in the SYSCR register. Again, bit 4 of the SYSCR is set to remap the IVT⁴⁷⁻⁵⁰.

The interrupt priorities are then configured as they were in the master device⁵⁹⁻⁶⁴. The port being used is still SPI0, therefore, the same procedure applies.

Since this is the slave device, the SPIFLG0 and SPIBAUD0 registers can be ignored because the master is going to supply all that stuff for the slave. Remember, the master supplies the clock, so the bit rate is only useful in the master

device. The master also supplies the slave-select signal, so the slave doesn't need to configure any output flags.

The only configuration code left to implement is writing the SPICTL0 Register⁹⁸. As was previously stated in the "Master Code" section of this application note, this interface will not work properly unless the critical values in the slave device match those set in the master device.

Figure 5 depicts the values of the bit-fields in the SPICTL0 register and the corresponding result of choosing those specific values:

Bit #	Name	Value	Result
1:0	TIMOD	00	Transmit on read of RBDR. Interrupt when RDBR is full
2	SZ	0	Send last word when TDBR is empty
3	GM	1	Get more data if RDBR full
4	PSSE	1	Enables slave-select input
5	EMISO	1	Enables slave data output
7:6	Reserved	00	RESERVED
8	SIZE	1	16-Bit Word Length
9	LSBF	0	Transmit MSB First
10	CPHA	1	SCK Toggles Immediately. Software Controls Slave Selects
11	CPOL	1	Active-Low SCK
12	MSTR	0	Device Is Slave Device
13	WOM	0	Normal Data I/O
14	SPE	1	SPI Module Enabled
15	Reserved	0	RESERVED

Figure 5: SPICTL0 Register Settings For Slave

As can be seen in this table, the only fields that differ from the configuration of the master device are the 3 fields that determine whether the device is a master or a slave (PSSE, EMISO, and MSTR). Setting PSSE high enables the SPI Slave-Select signal (~SPISS) as an input from a

master device. Setting EMISO enables the MISO data signal as an output. Clearing MSTR indicates that this is *not* a master device.

The slave then initializes the buffers¹⁰⁷⁻¹¹¹ and fills TDBR0¹²² with the data that will be sent back to the master once the master starts transmitting. The loop is set up to receive and transmit 16 words. The slave device sits in idle until the master device drives its SPI slave-select line on PF0. Once that goes low, the slave starts transmitting on MISO and receiving on MOSI at the same time.

3.2.2. SPI_SISR.asm

This module is the Slave Interrupt Service Routine. Because of the way the SPI0 Control Register is configured in the **SPI_Slave.asm** module, the SPI0 interrupt will be generated when RDBR0 is full. This ISR is identical to the master's ISR and was only included because the master and slave portions of this interface were developed as two separate projects.

4. Conclusion

While the SPI hardware interface itself is fairly straightforward, the control code required on both ends can be confusing. Remember that the configuration of the SPI Control Register is what dictates how the ports will behave. For example, the user could choose to change the TIMOD to indicate a transfer on write to TDBRx and interrupt when TDBRx is empty. In that case, the dummy read in the master example would be removed but the interrupt routine would remain the same.

Another alternate scenario could be that the user wants to have the hardware automatically

control the device selects, which is done by setting the CPHA bit of the SPICTLx register to 0. In this case, the writes to SPIFLG0 that control the value of the PF4 pin can be omitted.

Finally, the user may want to use something *other* than an ADSP-2191 to be the master or the slave in an ADSP-2191 SPI system. If that is the case, then there will not be a one-to-one mapping of SPI Control Registers. That means that the user must be careful and know the behavior of this other SPI device in order to appropriately program the control register on the ADSP-2191.