

# Using the LMX5001 Bluetooth Link Controller

National Semiconductor  
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Kenneth Lee  
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## INTRODUCTION

The LMX5001 Link Controller is designed to handle Bluetooth baseband tasks. Combined with National's LMX3162 Radio Transceiver and a Link Management Controller (LMC), it forms a complete physical layer for the Bluetooth application. The first generation Bluetooth solution incorporates three chips, LMX3162 Radio Transceiver, LMX5001 Bluetooth Link Controller (LC), and a third party LMC. It is intended for early adopters to develop a complete system. In this setup, the LMX5001 Link Controller is engaged in two interfaces, one with the radio controller LMX3162 and the other with the LMC. National Semiconductor has refined the interface with LMX3162 and takes the trouble away for you with regards to implementation details on the radio and the LC. As a result, you only need to come up with the LMC controller that interfaces directly with the LMX5001. This application note focuses only on the interface with LMC. The specifications for the LMX5001 Link Controller is detailed in the *LMX5001 Bluetooth Link Controller Datasheet*. This application note describes detail on the interface between the LC and LMC. It looks at a typical system that uses this controller. It also discusses the timing constraints and LMC controller requirements.

## LINK CONTROLLER INTERFACE (LCI)

The interface between the LMX5001 Link Controller and the Link Management controller is a synchronous serial interface specialized in packet transmission. The LC is the master of the LCI. The Bluetooth Specification calls for 16 types of packets, reference *Table 4.2 of the Bluetooth Specification V1.0b*, passed through this interface. To support Bluetooth communication, the LMX5001 Link Controller uses seven signal lines and supports 12 commands from LMC.

### Interface Signals

The LCI is a synchronous serial interface. It contains basic transmit (Tx) and receive (Rx) signals, frame synchronization signals for both transmit (TFS) and receive (RFS), SYSTICK and SYSLOAD signals for Bluetooth link control, as well as SCLK for providing a serial clock. The LMX5001 Link Controller also provides and controls the LMC CPU clock.

The Tx is an input signal. It accepts data transmitted from the LMC. The Rx signal is an output signal. It provides data to the LMC. The data is transferred through these lines using big-endian.

The Tx and Rx lines are used for transferring data packets as well as performing Sysload. When transferring data packets, the LC uses an internal buffer to hold the frame. Each frame transferred through these lines is under the control of TFS and RFS. A Bluetooth packet is broken into many of such frames. One thing to note is that the concept of transmit and receive is relative to the LMC in line with the Bluetooth application perspective, not from the stand point of the LC.

The TFS line is for transmit frame synchronization. It is an output line that enables a frame to be transmitted from the LMC to the LC. The RFS signal is for receive frame synchronization. It is an output signal that enables/disables the LMC to receive data from the LC. Both the TFS and RFS signals are output signals due to the fact that the LMX5001 Link

Controller act as a master of the interface between the LC and the LMC. A frame in this context does not necessarily mean an entire Bluetooth packet. The LMX5001 maintains a one-byte buffer internally so each frame is 8 bits in length. Each data packet is broken down into multiple pieces of 8-bit frames transferred one after another. A Sysload frame, which is discussed below, is not limited to the 8-bit length. The whole Sysload packet is sent in one frame. The LCI is a synchronous interface due to the presence of the TFS and the RFS lines. Please note that the LMC may or may not support full duplex communication. Our typical application described later in this application note uses a micro controller that supports full duplex communication as the LMC. When using that controller, the TFS and RFS signals can be driven simultaneously. In a Bluetooth application, duplex is achieved by using Time-Division Duplex (TDD), called for by the Bluetooth Specifications. No Bluetooth packets are actually transmitted and received simultaneously. They are done during their own slot specified by the Bluetooth Specifications. For a master, it transmits during even slots and receives during odd slots. For a slave, it is the other way around.

The SYSTICK is a pause output signal spaced at half Bluetooth slot, 312.5  $\mu$ s, a specification called for by the Bluetooth Specifications. This signal provides the heart beat for Bluetooth application. Two pauses on that signal line make up one Bluetooth slot.

The SYSLOAD is a pause input signal requested by the LMC to the LC for transmitting commands and receiving status. Due to the fact that the LMX5001 is the master in the LCI, the LMC issues SYSLOAD if and only if the following conditions are satisfied. 1) SYSTICK signal on the half slot is asserted, and 2) current data transfer completes. Sysload is a process that LC and LMC exchange commands and status. It takes place in the "Guard Space", in parallel with frequency hopping. During a Sysload, LMC commands are transmitted to the LC while status for the previous transaction stored in the LC registers is transmitted to the LMC. If the LMC supports full-duplex transmit, as in the example given later as a typical system in this application note, transmit and receive during Sysload can be performed simultaneously to increase system performance.

### Sysload

As mention earlier Sysload is a process between the LC and the LMC to communicate commands from the LMC to the LC and status of the previous slot from the LC to the LMC. All this happens during a special "Guard Space" (<220  $\mu$ s). This usually occurs right between the completion of the previous transaction and the beginning of the next transaction. The SYSTICK following the Sysload signifies the start of the next data transfer. During Sysload, LMC and the LC exchange commands and status. The LMX5001 accepts 12 LMC commands consisting of eight basic commands and four repeating commands for data with encryption. The command code is 5-bit in length. The LMX5001 Link Controller uses hardware to implement Bluetooth encryption engine to achieve the highest order of performance. To do so there needs to have special handshakes between the LMC and the LC when encryption is enabled. This special handshake is also

initiated in the "Guard Space". The eight basic commands performs slave receive and transmit, master receive and transmit, master slave clock interchange, and power saving. During a command transfer, the LMC sends to LC command code, radio program words, number of bits transferred, correlation threshold, access code, GPIO outputs, along with other configuration parameters. During the status transfer, the LMC receives from the LC such information as native clock, master and slave clock difference, maximum correlation achieved, as well as all GPIO inputs.

It should be noted that three program words, each 20 bits in length is passed from the LMC to the LC during the command transfer. These program words are intended for the radio transceiver for its configuration in the next Bluetooth slot. For details regarding these program words, please refer to the *LMX3162 Single Chip Radio Transceiver Datasheet*. PW1, PW2, and PW3 map to N-Counter, R-Counter, and F-Latch respectively.

The following describes the eight basic commands:

**Slave receive with continuous correlation.** Figure 1 illustrates timing for this mode. When waking up from low power mode such as page scan, the slave Bluetooth device must turn on the receiver and correlate Access Code continuously since it is not synchronized with the Master and the time window to correlate Access Code is unknown. If a correlation is successful, a connection is established and slave clock is updated. All consequent slave receive will use windowed correlation to save power. If no correlation is found, it continues to use continuous correlation during the next scan period. Figure 1 illustrates timing for Slave receive with continuous correlation. As you can see, the correlator and the receiver are always on even though the actual correlation and receiving tasks take just a fraction of the time.

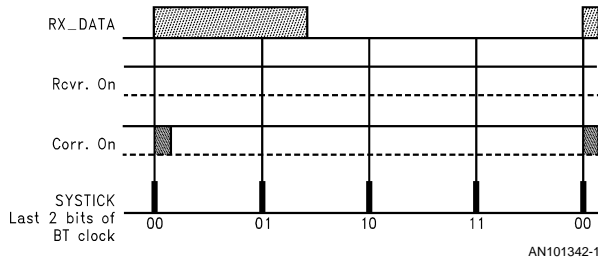


FIGURE 1. Slave Receive with Continuous Correlation

**Slave receive with windowed correlation.** This command is used once a connection is established. Figure 2 illustrates timing for this mode. In this mode, because master and slave are synchronized, the slave knows when to expect the access code from the master. The slave correlation may turn on the receiver and the correlator 10 μs before and 10 μs after that time window. Like the previous command, upon successful correlation, the slave clock is updated to achieve continuous synchronization with the master clock. Both master and slave possess otherwise free running native clocks.

Figure 2 illustrates timing of slave receive with windowed correlation. As you can see, the correlator and the receiver are turned on only during their duty windows.

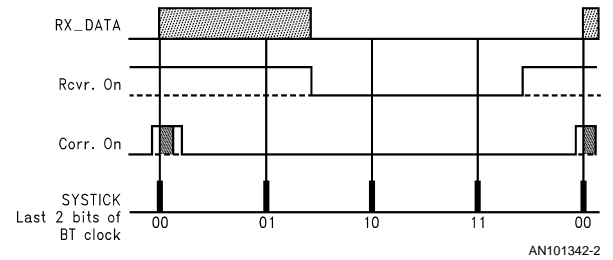


FIGURE 2. Slave Receive with Windowed Correlation

**Slave transmit.** Bluetooth unit transmit using slave transmit slot.

**Master receive.** Unlike slave receive, Master receive does not correlate access code, thus there is no clock adjustment.

**Master transmit.** Bluetooth unit transmit using master transmit slot.

**Change to master clock.** Change Bluetooth native clock to master clock.

**Change to slave clock.** Change Bluetooth native clock to slave clock.

In a Bluetooth scatternet, for instance, a Bluetooth device can act as a master in one piconet and a slave in another. It is necessary sometimes to switch from master to slave and vice versa. These two commands allow the LMC to set the LC to perform as master or slave as needed.

**Power down.** This command instructs the LC to shut down the normal high-frequency crystal and use a much lower frequency crystal to update the native clock. Because the high-frequency crystal provides the LMC clock, in this mode, the LMC is effectively shut off. Most of the functions in the LC are also turned off. When passing the power down command, the LMC also tells the LC when to wake up in as part of the Sysload message. Please note it takes up to 3 SYSTICKs to complete the wake up process. When determining the wake up time, this fact must be taken into account. Figure 3 illustrates the power down timing requirement for the page scan mode. The slave Bluetooth device goes into the power down mode and wake up 18 slots every 1.28 seconds to listen to master for its paging. Due to the power up latency, the power up actually starts 3 SYSTICKs (1½ slots) ahead of the 18 wake up slots.

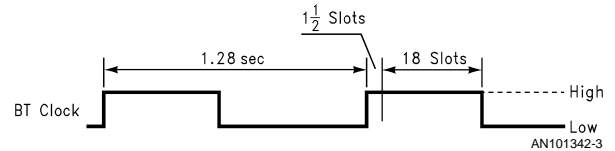


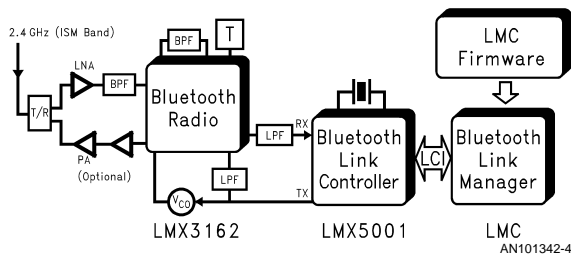
FIGURE 3. Power Down Timing for Page Scan Mode

**ENCRYPTION**

An encryption engine is also implemented in the LMX5001 Link Controller. It takes an encryption initialization stream of 208 bits from the LMC, runs through the encryption engine and generates the encryption stream which is then sent back to the LMC for final packet encryption/decryption. The communication of the initialization stream and encryption stream takes place right after Sysload in the "Guard Space". After data transfer starts, the encryption stream is continued to be sent back byte by byte using the interval between data byte transfers. As mentioned earlier, data packets are broken into 8-bit frames when transferred through the LCI. Because of the relatively fast serial clock (8 MHz), there is enough gap between two frames to transfer an encryption byte.

**A TYPICAL SYSTEM**

Figure 4 shows a typical Bluetooth application using the LMX5001 Link Controller. Combined with the LMX3162 Radio Transceiver and a LMC, it forms a complete physical layer for the Bluetooth application.

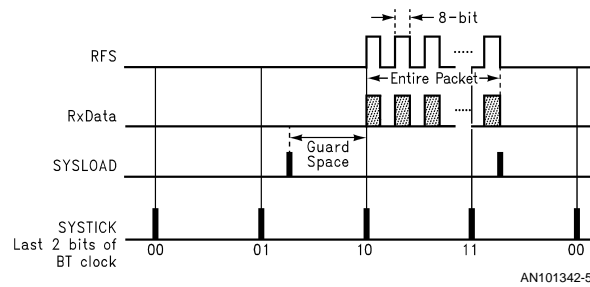


**FIGURE 4. A Typical System**

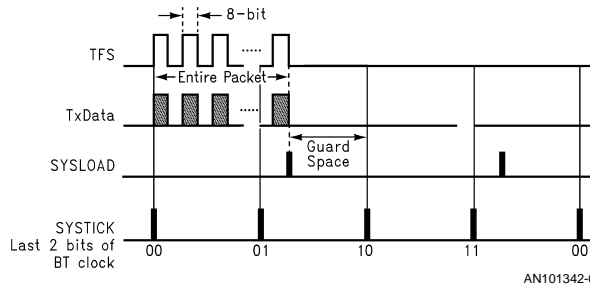
As mentioned in the previous sections of this Application note, The LMX5001 Link Controller is designed to work seamlessly with the LMX3162 Radio Transceiver. It is recommended that this LC only interface with the this radio transceiver via Microwire interface.

**TIMING AND PERFORMANCE**

The Bluetooth Specification requires all Bluetooth devices to use TDD. This is achieved by assigning designated slots for receive and transmit. For a master device, even slots are for transmit and odd slots receive. For slave devices, odd slots are for transmit, and even slots receive. Figure 5 illustrates timing for master receive and Figure 6 transmit. SYSTICK occurs every half slot, 312.5 μs.



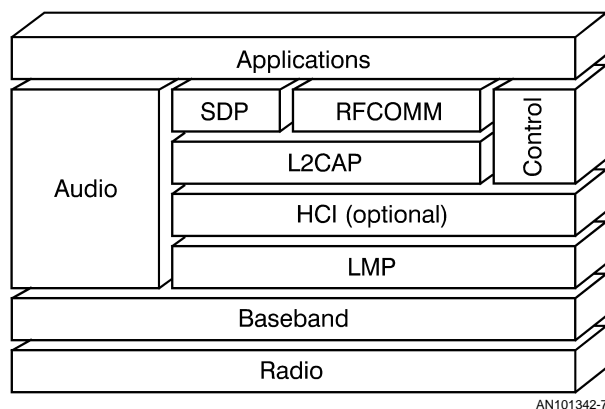
**FIGURE 5. Master Receiving Timing**



**FIGURE 6. Master Transmission Timing**

**LINK MANAGEMENT CONTROLLER REQUIREMENT**

The LMC performs as LMP (Link Management Protocol) in a Bluetooth Device. The LMC acts as the interface between the HCI and the LCI. On one side, It interfaces with the LC through the LCI interface. On the other side, it talks to an optional HCI controller for a connection with the host environment such as a Portable PC. There usually is a Bluetooth Software Stack that communicates directly with the HCI interface from the host PC. Bluetooth Specifications define several HCI devices. The most commonly used ones are USB and UART. The HCI is present solely for Bluetooth devices that require a PC host environment. It is an optional layer in the entire Bluetooth communication stack and may be omitted in an embedded system. Figure 7 shows a Complete Bluetooth Stack.



**FIGURE 7. Bluetooth Communication Stack**

If desired, the LC can also interface with any Link Management Controller. Here are some guide lines in choosing and designing an LMC.

#### Clocks

There are two clock lines in the interface between the LC and the LMC. The 16 MHz crystal oscillator output from the LC for LMC CPU clock and the 8 MHz serial clock in the form of SCLK signal line from the LC for Serial LCI interface. The LMC is not required to use the CPU clock signal. The signal is provided for power management and simplicity in crystal placement.

#### Synchronous Serial Interface

Selections for the LCI interface will have to meet the requirement of a synchronous serial interface. Which means that the frame control signals are needed. The bit order for the serial interface should be big-endian. In our typical system, the LMC uses a synchronous serial interface for the LCI. This interface contains five lines. In addition to DT (Data Transmit) and DR (Data Receive) lines, TFS (Transmit Frame Synchronize) and RFS (Receive Frame Synchronize) lines are used for synchronization. The SCLK (Serial Clock) line provides the serial clock (8 MHz).

#### Full Duplex

Full duplex is not necessary for any data packet transfer. In fact, Bluetooth achieves duplex using TDD. At any given time, the LCI is in either transmit or receive mode. In our typical system, the SPORT interface supports full duplex. The

firmware takes advantage of this feature and uses full duplex for Sysload to increase performance. For normal Bluetooth data transfer, TDD is used.

#### Serial Clock Rate

The Bluetooth data rate is 1 Mbps. This requires the Serial interface to have at least 1 MHz clock rate. Typically this rate is much higher than this. It is not uncommon for the serial clock to reach 4 MHz–8 MHz. The extra bandwidth is needed for activities such as Sysload and encryption stream bytes transfer. In our typical system, the serial clock is 8 MHz.

#### Tx/Rx Buffer Size

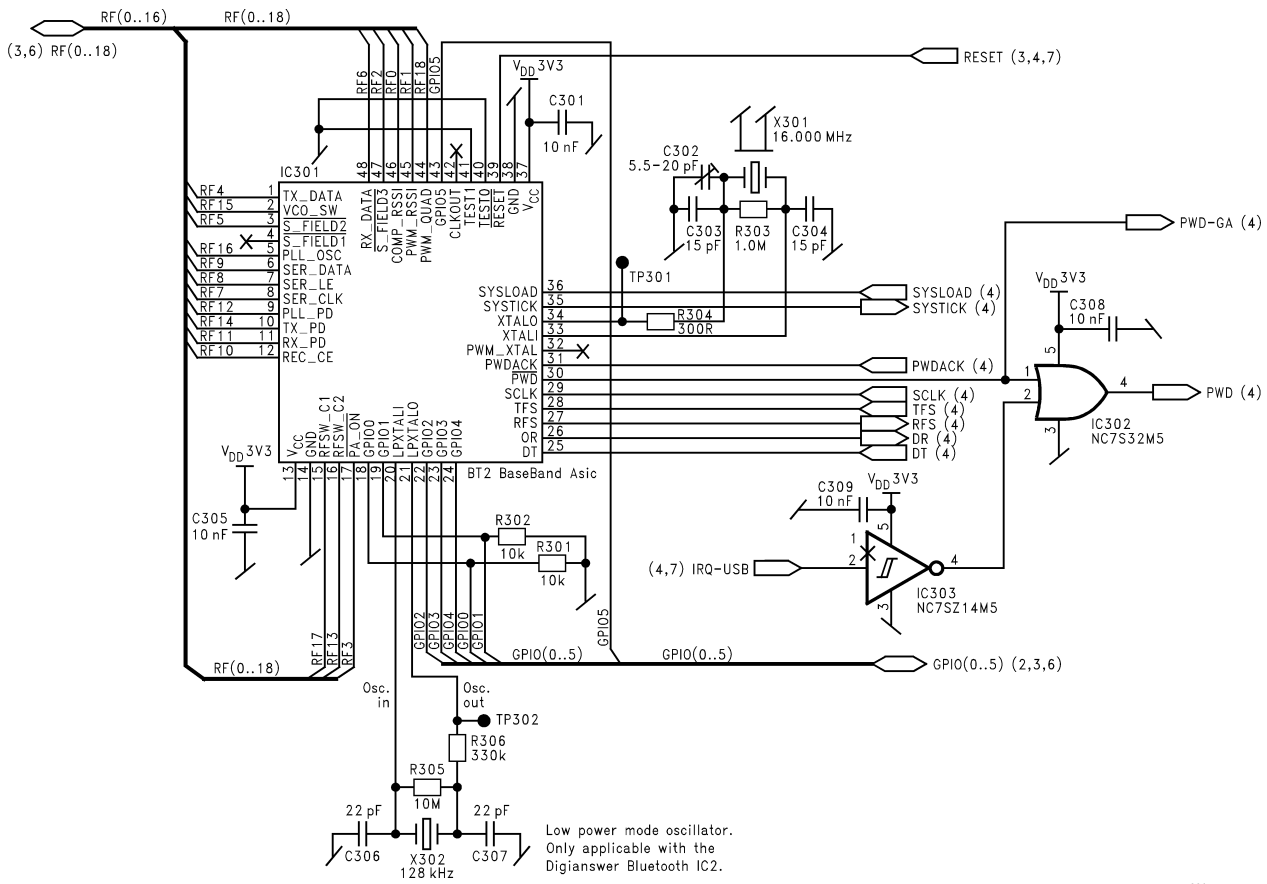
The LMX5001 contains an 8-bit buffer for receive and transmit data. The 8-bit frame size is not restricted for LCI communications during Sysload since the data is transferred directly to/from various LMX5001 registers. In our typical system, Sysload is transferred in one frame.

#### Firmware Consideration

It is most likely that a LMC hardware contains a micro-processor, ROM and RAM, and communication peripherals. The processor needs a software program to carry out all Bluetooth Link Management tasks. This program is called firmware. The firmware controls interfaces with both the link controller and the higher layer protocol, as well as providing packet assembly and disassembly (PAD) required by the Bluetooth Specifications. The PAD tasks include whitening/dewhitening, forward error checking, encryption/decryption, etc. The LMX5001 LC takes care of the encryption/decryption. However, the firmware needs to manage the traffic between the LC and the LMC for encryption initialization words and encryption stream bytes. For our typical system, the ADSP-218x controller interacts with the USB controller as the HCI interface. The firmware for this setup is already available. With other controllers, the task to develop the firmware is left to the users.

#### Processor Speed

The faster the processor speed, the quicker the response. However, too much speed will consume unnecessary precious Bluetooth power. A balance must be selected between the speed and power consumption. The processor needs just enough speed to handle the fastest tasks in the system. It is also true that the more tasks the processor has, the more speed it needs. The LCI requests are usually the most time critical, especially the SYSTICK response. The PAD is also a sizeable factor as far as speed is concerned. This is why the encryption engine is implemented in the Link Controller. In our typical system, the processor speed is 48 MHz.



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## Notes

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**National Semiconductor Corporation**  
Americas  
Tel: 1-800-272-9959  
Fax: 1-800-737-7018  
Email: support@nsc.com  
www.national.com

**National Semiconductor Europe**  
Fax: +49 (0) 180-530 85 86  
Email: europe.support@nsc.com  
Deutsch Tel: +49 (0) 69 9508 6208  
English Tel: +44 (0) 870 24 0 2171  
Français Tel: +33 (0) 1 41 91 8790

**National Semiconductor Asia Pacific Customer Response Group**  
Tel: 65-2544466  
Fax: 65-2504466  
Email: ap.support@nsc.com

**National Semiconductor Japan Ltd.**  
Tel: 81-3-5639-7560  
Fax: 81-3-5639-7507