

Key Design Features

- Synthesizable, technology independent VHDL IP Core
- Separate LVDS Transmitter / Receiver (SERDES) pair
- Up to 8 serial LVDS data lanes + LVDS clock
- Fully configurable clocking (duty cycle + skew)
- Generic parallel data width up to 128 bits wide
- Generic parallel-to-serial mux ratio up to 16:1
- Data rates of up to 1 Gbits per lane
- Integrated asynchronous FIFOs with underflow / overflow detection.
- Bitwise data alignment at the receiver
- No receiver source clock required
- Compatible with a wide range of industry standard protocols including: Channel-Link®, Camera-Link®, FPD-Link®, FlatLink®, MIPI etc.
- Robust and simple to implement using cheap twisted pair cable (e.g. Cat 5E Ethernet)

Applications

- High bandwidth SERDES interfaces
- Serialization of wide buses e.g. 'virtual' ribbon cable
- Direct replacement for many commercial LVDS ICs
- Transport of digital data (e.g. video) over distances of 10m+

Generic Parameters

Generic name	Description	Type	Valid range
dw	Parallel data width	integer	$2 \leq dw \leq 128$
ratio	Parallel-to-serial multiplexer ratio	integer	$2 \leq \text{ratio} \leq 16$
duty	Transmitter clock duty cycle setting	integer	$0 < \text{duty} < \text{ratio}$
skew	Transmitter clock skew setting	integer	$0 \leq \text{skew} \leq \text{ratio}$
lanes	Number of serial data lanes	integer	dw / ratio (8 max)
direction	Serialization/De serialization direction	integer	0: forward 1: backward
polarity	Receiver clock sampling edge	integer	0: -ve edge 1: +ve edge

Block Diagram

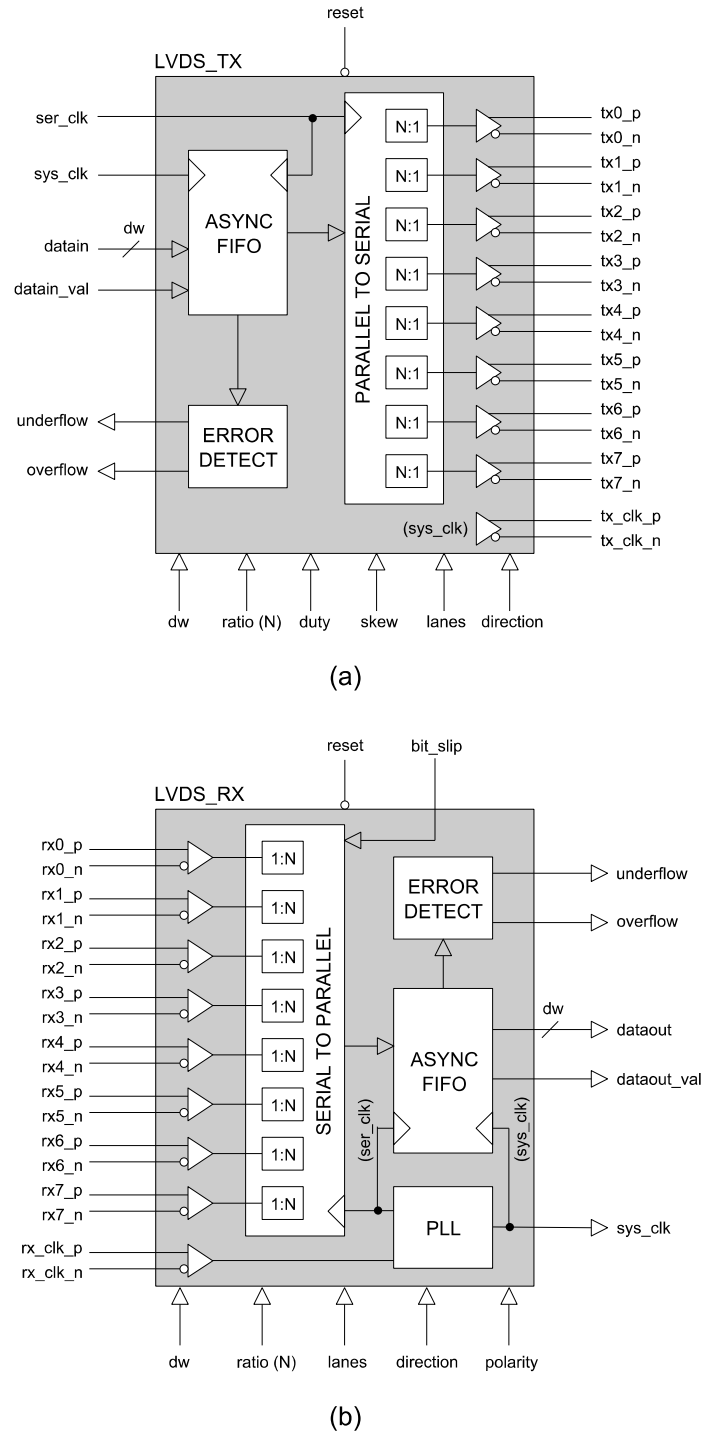


Figure 1: LVDS (SERDES) Transmitter (a) and Receiver (b) architectures

Pin-out Description

LVDS TRANSMITTER

Pin name	I/O	Description	Active state
sys_clk	in	System clock (Synchronous with parallel input data)	rising edge
ser_clk	in	Serial clock (sys_clk multiplied by the mux ratio)	rising edge
reset	in	Asynchronous reset	low
underflow	out	Error flag: indicates starvation of data if: (sys_clk x ratio < ser_clk)	high (sticky until reset)
overflow	out	Error flag: indicates a surplus of data if: (sys_clk x ratio > ser_clk)	high (sticky until reset)
rst_flags	in	Reset error flags	high
datain [dw-1:0]	in	Parallel input data	data
datain_val	in	Parallel input data valid	high
txN_p (max 8)	out	Positive Tx strobe serial data lane 'N'	LVDS
txN_n (max 8)	out	Negative Tx strobe serial data lane 'N'	LVDS
tx_clk_p	out	Positive Tx clock strobe	LVDS
tx_clk_n	out	Negative Tx clock strobe	LVDS

LVDS RECEIVER

Pin name	I/O	Description	Active state
sys_clk	out	System clock (Synchronous with parallel output data)	rising edge
reset	in	Asynchronous reset	low
underflow	out	Error flag: indicates starvation of data if: (sys_clk x ratio < ser_clk)	high (sticky until reset)
overflow	out	Error flag: indicates a surplus of data if: (sys_clk x ratio > ser_clk)	high (sticky until reset)
rst_flags	in	Reset error flags	high
bit_slip	in	Bit shift strobe (Causes parallel data output word to be barrel-shifted by one bit. Used to align output data)	rising edge
dataout [dw-1:0]	out	Parallel output data	data
dataout_val	out	Parallel output data valid	high
rxN_p (max 8)	in	Positive Rx strobe serial data lane 'N'	LVDS
rxN_n (max 8)	in	Negative Rx strobe serial data lane 'N'	LVDS
rx_clk_p	in	Positive Rx clock strobe	LVDS
rx_clk_n	in	Negative Rx clock strobe	LVDS

General Description

The LVDS_SERDES IP Core is a high-speed LVDS Transmitter/Receiver pair suitable for a wide range of serial interface applications. The design is comprised of an independent transmitter and receiver that may be used separately, or together as a single transceiver.

The transceiver can accept parallel data widths of up to 128-bits and features a user-defined multiplexer ratio. By modifying the generic parameters, *dw*, *ratio*, *duty*, *skew*, *lanes* and *direction*, the transceiver can be made compatible with a wide range of third-party LVDS devices such as those from National Semiconductor®, TI®, Thine® and Maxim®.

In total, the transceiver can support up to 8 serial data lanes - each data lane typically handling rates of between 500 Mbits/s and 1Gbits/s. The maximum data rate attained will be dependent on a wide range of factors such as: cable type, cable length, board layout, and the specification of the LVDS buffers. As a general rule, data rates of 350 Mbits/s per lane can be easily achieved on even the most basic FPGA platforms.

In addition to the 8 data lanes, a single clock lane is provided for synchronizing the data between the transmitter and receiver. Figure 1 shows the basic architecture of the transmitter and receiver pair. The following sections explain the individual IP Cores in more detail.

LVDS Transmitter

The transmitter is responsible for serializing the parallel input data into separate data lanes. The input data is partitioned into 'N' groups, where the width of each group is defined by the generic parameter *ratio*. As an example, consider a parallel data width of 21-bits and a mux ratio of 7. The resulting architecture would have 3 data lanes in an arrangement like that shown in Figure 2 below:

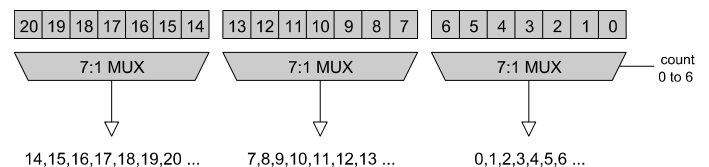


Figure 2: Multiplexer arrangement for a data width of 21-bits and a ratio of 7

The output order of the bits within each multiplexer is controlled by the generic parameter *direction*. With *direction* set to '1' then the serial bits are multiplexed in the order 0, 1, 2, ... etc. When *direction* is '0' then the order is reversed. The *direction* parameter is provided for compatibility with various third party SERDES solutions.

The transmitter requires two separate clocks for correct operation. The signal *sys_clk* is a system clock that is synchronous with the input data. The signal *ser_clk* is the serial clock. The system clock and serial clock do not need to be phase-aligned, but the serial clock must be an exact integer multiple of the system clock with the relationship:

$$\text{ser_clk} = \text{sys_clk} * \text{ratio}$$

After system reset, transmission of data begins on a rising clock-edge of *sys_clk* when *datain_val* is asserted high. The serialization process then begins with parallel data words being read on consecutive system clock cycles.

During operation, the asynchronous FIFO detects the data rate into and out of the transmitter. If at any point the FIFO overflows or is starved of data, then the respective error flags *overflow* or *underflow* are asserted. These flags may also be asserted if the relationship between the system clock and serial clock is not maintained.

Note also that asserting the bit-slip command may cause the error flags to be asserted. For this reason, the flags should only be observed during normal operation when any data-alignment process has been completed. Once set, these flags remain high until a specific reset using the *rst_flags* signal. A system reset will also reset these flags, but any data alignment at the receiver may be lost.

LVDS Transmitter clocking

The LVDS transmitter clock configuration is specified using the generic parameters 'duty' and 'skew'. The parameter *duty* specifies the number of serial clock cycles that the transmitter clock is in the active low state. An example of this is shown in figure 3 below. The *skew* parameter permits the user to skew the transmitter clock (in cycles) relative to the LVDS data. By adjusting these parameters, the IP Core may be used to duplicate the clocking behaviour of most commercial LVDS ICs.

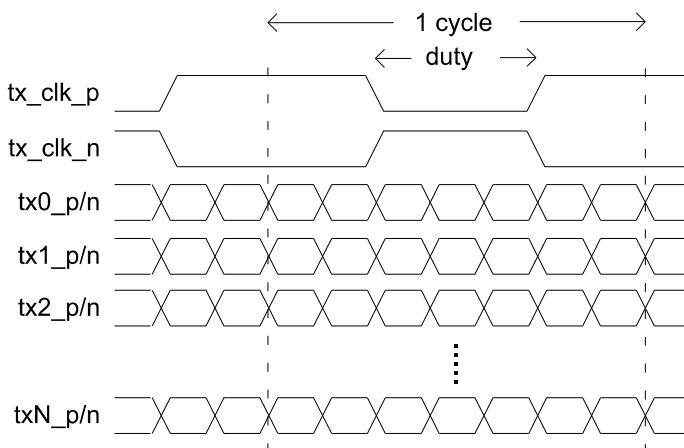


Figure 3: Transmitter clock specification showing a duty cycle setting of 3 serial clock cycles

LVDS Receiver

The receiver performs the reciprocal operation to the transmitter and is responsible for de-serialization of the serial input data. Clock recovery and serial clock generation is performed by an internal PLL. The point at which the data is sampled (point within the data 'eye') may be controlled by the generic parameter *polarity*.

Setting polarity to '0' results in the data being sampled on a falling clock-edge close to the centre of the eye. Setting polarity to '1' results in data being sampled on a rising clock edge. The best setting will depend on the relative skew between the serial clock and data lanes.

After system reset, the de-serialization process begins with parallel data words being output on consecutive cycles of the system clock. Data is valid from the point at which the signal *dataout_val* is asserted high.

As with the transmitter, the asynchronous FIFO monitors the data rate into and out of the receiver. If at any point, the clocks become out of sync, then the respective error flags *overflow* or *underflow* are asserted.

Data alignment at the Receiver

For most situations it's not always practical to perfectly align the parallel data at the transmitter with the parallel data at the receiver. This is because after reset, the input serial data bits could be at any point within an N-bit word. In order to correct this, the receiver employs a *bit_slip* signal that allows the output data word to be barrel-shifted by one bit. The bit slip signal is active on a rising-edge.

For instance, consider the case where the 32-bit pattern '0x44440000' is transmitted with a 4:1 mux ratio. At the receiver end, the 32-bit output word is observed as 0x22220000. In order to align the word correctly, the *bit_slip* signal must be toggled until the correct output is observed.

This is shown graphically in Figure 4 below:

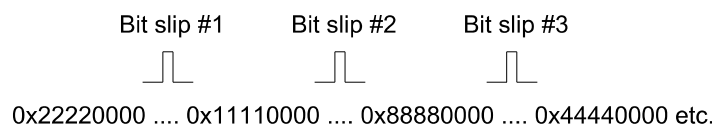


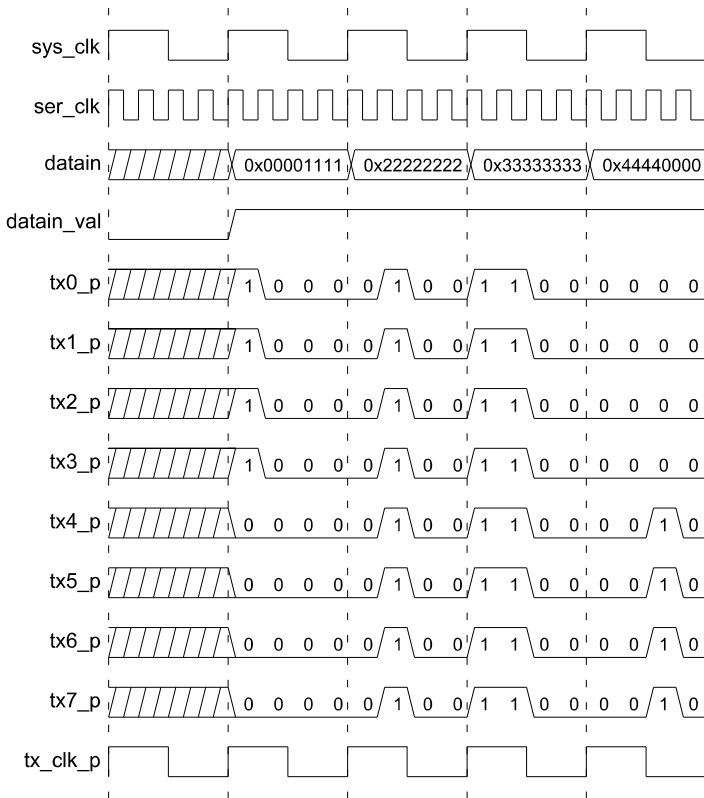
Figure 4: Receiver 'bit_slip' function

Data alignment at the receiver can normally be done quite simply by using a state machine that monitors the receiver output for a special character or pattern. For example, with digital video, this could be a Start of Active Video (SAV) code or an End of Active Video (EAV) code - or some combination of the two.

The state machine would monitor the output for these codes and periodically assert *bit_slip* until the codes are detected and the output data is properly aligned.

Functional Timing

Figure 5 shows the serialization of a 32-bit data word with a mux ratio of 4:1. In this example, all 8 serial data lanes are being used. Note that the frequency of the serial clock is exactly 4 times the frequency of the system clock. The de-serialization process at the receiver has exactly the same timing relationship - but performs the inverse operation.



N.B. Only +ve LVDS strobe signals shown

Figure 5: Example functional timing for the serialization of a 32-bit data word with a mux ratio of 4:1 and all 8 serial data lanes being utilized. The direction is set to '1'.

Source File Description

All source files are provided as text files coded in VHDL.

Source file	Description
pipeline_reg.vhd	Pipeline register
fifo_async.vhd	Asynchronous FIFO
lvds_obuf.vhd	Differential output buffer
lvds_oclk.vhd	Differential output clock generator
lvds_ibuf.vhd	Differential input buffer
lvds_iclck.vhd	Differential input clock buffer
lvds_pll.vhd	PLL for de-skew and serial clock gen
lvds_flow_error.vhd	Overflow / underflow error detector
lvds_deserializer.vhd	Instantiates N x 1:N deserializer
lvds_deserializer_n.vhd	1:N deserializer
lvds_serializer.vhd	Instantiates N x N:1 serializer
lvds_serializer_n.vhd	N:1 serializer
lvds_tx.vhd	Top-level LVDS transmitter component
lvds_rx.vhd	Top-level LVDS receiver component
lvds_serdes_bench.vhd	Top-level test bench

[Note: The components *lvds_obuf.vhd*, *lvds_ibuf.vhd*, *lvds_oclk.vhd*, *lvds_iclck.vhd* and *lvds_pll.vhd* are technology-specific components. These components must be changed for equivalent parts for correct implementation. Please contact Zipcores if further assistance is needed.]

Functional Testing

An example VHDL testbench is provided for use in a suitable VHDL simulator. The compilation order of the source code is as follows:

1. pipeline_reg.vhd
2. fifo_async.vhd
3. lvds_ibuf.vhd
4. lvds_iclck.vhd
5. lvds_obuf.vhd
6. lvds_oclk.vhd
7. lvds_pll.vhd
8. lvds_flow_error.vhd
9. lvds_serializer_n.vhd
10. lvds_serializer.vhd
11. lvds_tx.vhd
12. lvds_deserializer_n.vhd
13. lvds_deserializer.vhd
14. lvds_rx.vhd
15. lvds_serdes_bench.vhd

The VHDL testbench instantiates the transmitter and receiver top-level components in a loop-back configuration so that the output of the transmitter feeds directly to the input of the receiver.

The generic parameters *dw*, *ratio*, *duty*, *skew*, *lanes*, *direction* and *polarity* have been set to 32, 4, 2, 0, 8, 1 and 1 respectively for the test. The user is free to modify these parameters as required to suit their specific test environment.

The simulation must be run for at least 1 ms during which time the LVDS transmitter is fed a random sequence of 32-bit words. Two output text files are generated during the course of the simulation. These files are 'lvds_in.txt' and 'lvds_out.txt' and contain a list of data words captured at the inputs and outputs of the transmitter and receiver. The equivalence of these files proves the correct operation of the test.

Note that at the start of the test, the 'bit_slip' signal is toggled various times in order to align the data correctly at the receiver. If the generic settings are changed, then the user may have to modify the number of bit-slip operations accordingly.

Development Board Testing

The LVDS (SERDES) IP Core was tested in a live demo using the Zipcores HD-video development board. The devboard is based on a Xilinx® Spartan6 FPGA and features a number of general purpose LVDS I/O pins.

An LVDS serial link was used to transmit a high-resolution (1280x800) 24-bit RGB video signal to a Sharp® LQ101K1LY04 LCD display. The connections were set up for the Thine® THC63LVDF84B LVDS receiver IC. Figure 6 and 7 show photos of the general demo setup.



Figure 6: LVDS demo setup



Figure 7: LVDS demo showing Sharp LCD 1280x800 test pattern display

Synthesis

The files required for synthesis and the design hierarchy is shown below:

- lvds_tx.vhd
 - lvds_serializer.vhd
 - lvds_serializer_n.vhd
 - lvds_flow_error.vhd
 - fifo_async.vhd
 - pipeline_reg.vhd
 - lvds_obuf.vhd
 - lvds_oclk.vhd
- lvds_rx.vhd
 - lvds_deserializer.vhd
 - lvds_deserializer_n.vhd
 - lvds_flow_error.vhd
 - fifo_async.vhd
 - pipeline_reg.vhd
 - lvds_pll.vhd
 - lvds_ibuf.vhd
 - lvds_ick.vhd

The VHDL IP Core is technology independent with the exception of the differential LVDS I/O buffers and PLL which must be specific to the FPGA or ASIC process being used. As a benchmark, a Xilinx® Spartan6 FPGA was used to implement the LVDS transmitter and receiver IP cores.

Trial synthesis results are shown with the generic parameters set as follows: dw = 56, ratio = 7, duty = 3, skew = 2, lanes = 8, direction = 1, polarity = 1.

The resource usage is specified after Place and Route.

SPARTAN 6 - LVDS_TX

Resource type	Quantity used
Slice register	129
Slice LUT	91
Block RAM	0
DSP48	0
Occupied slices	49
Clock frequency (approx)	500 MHz

SPARTAN 6 - LVDS_RX

Resource type	Quantity used
Slice Register	325
Slice LUT	174
Block RAM	0
DSP48	0
Occupied slices	102
Clock frequency (approx)	500 MHz

Revision History

Revision	Change description	Date
1.0	Initial revision	12/09/2010
1.1	Added detailed bit_slip section	02/10/2010
1.2	Added development board test setup descriptions	07/01/2011
1.3	New generic parameter 'direction' for compatibility with various commercial LVDS ICs. Added signal to reset error flags	15/05/2011
1.4	Added new generic parameters: clock 'duty' and 'skew' to give further compatibility with commercial LVDS ICs.	09/02/2015