

Design & Test Guidelines

Version 4.0

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Introduction

The following guidelines provide suggestions for improving the testability of circuits using XJTAG. These guidelines should not be taken as a set of rules. The potential advantages in terms of testability should be considered together with all other implications which they may have (e.g. functionality, device cost and board area).

It is assumed that readers of this document have a minimal familiarity with the IEEE standards 1149.1 and 1149.6.

Throughout this document the term 1149.x refers to the IEEE 1149.x (JTAG) boundary scan standards, JTAG devices means devices that implement JTAG boundary scan and are fully compliant with these standards, while non-JTAG devices are those that do not implement JTAG boundary scan.

➤ Specify and use JTAG devices

Although XJTAG is capable of testing the nets between JTAG devices and non-JTAG devices, greater coverage will be obtained by using JTAG devices wherever possible. The more JTAG devices that are incorporated into a circuit the greater the number of nodes that can be fully exercised and tested.

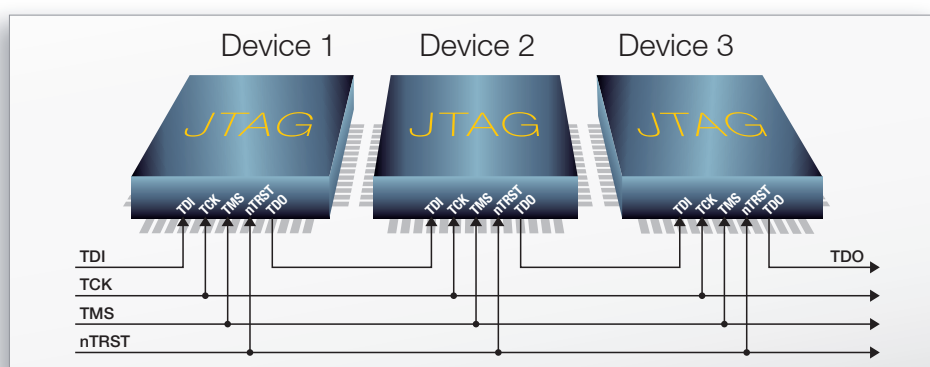
The 1149.6 standard allows the testing of capacitively coupled high speed single ended or differential signals that cannot be tested using 1149.1. In order to use this functionality it is important to ensure that nets to be tested in this way have 1149.6 capable pin on each side of the coupling capacitor.

➤ Check the BSDL files for JTAG devices

Compliance with the 1149.x standards requires that the device must have a BSDL (Boundary Scan Description Language) file. This file describes the device's specific implementation of 1149.x. Ensure that this file is available (usually directly from the device manufacturer's web-site) and that it has been fully validated (BSDL syntax checking is included as an integral part of XJTAG).

➤ Ensure the 1149.1 chain is correctly designed and laid out

JTAG devices can have individual connectors to provide access to the TAP signals; however they can also be connected in a 'daisy chain' format with the TDO signal from one device connected to the TDI of the next.



The TCK, TMS and (optional) nTRST signals must be connected in parallel to all devices connected in a 'daisy chain' format. It is important that nTRST signals are not connected directly to ground as this would completely disable JTAG, not only for an individual device but for the complete scan chain.

If possible route the TAP signals away from other active signals to reduce noise and improve signal integrity. The serial JTAG interface will typically run with a clock rate of 10MHz to 30MHz, and poor layout can induce errors that are very difficult to pinpoint and can require a board re-spin to fix.

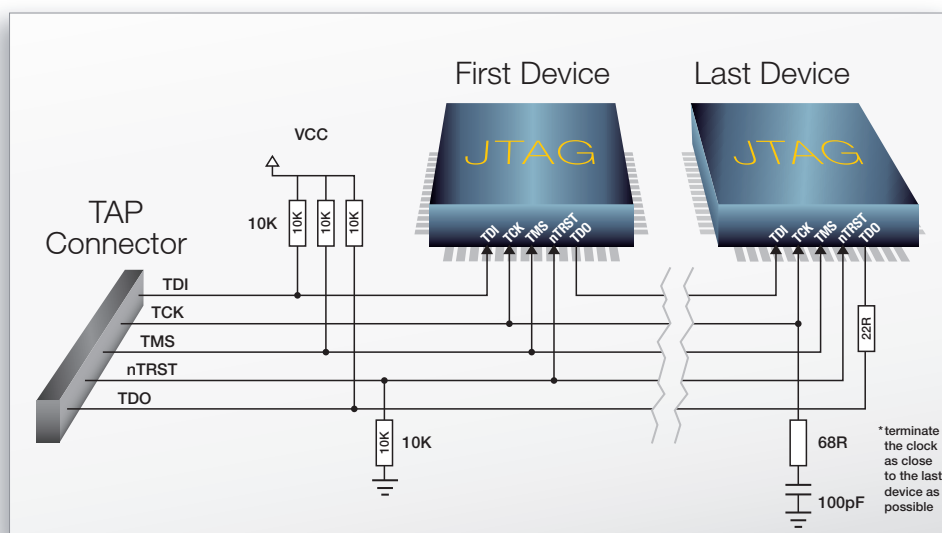
Interleaving TAP signals with power or ground can help diagnose problems with non-functioning JTAG chains; a TAP signal shorted to a constant signal is much more easily diagnosed than two TAP pins shorted together.

➤ Multiple JTAG Chains

It may be necessary to have some devices directly connected to their own connectors for debug purposes during development or programming. Adding the option to link these connectors into a single chain for manufacturing test maybe beneficial and reduce both BOM (Bill of Materials) and handling costs during production. XJTAG's XJLink2 controller can connect to up to four JTAG connectors on a board.

➤ Use correct termination for all TAP signals

TCK should be terminated with a 68 Ω resistor and a 100 pF capacitor in series to ground, placed as close as possible to where the signal enters the final device in the chain. TDI and TMS should be pulled to the power rail with 10 k Ω resistors. TDO should be pulled to the power rail with a 10 k Ω resistor and have a 22 Ω series resistor fitted near to the final device in the chain. It is also recommended that a 10 k Ω pull-down resistor be added to the nTRST line to avoid floating inputs.



➤ Ensure low skew between TAP signals

It is important for correct operation that there is low skew between the TAP signals. The track lengths and buffer delays of the TCK and TMS especially should be kept equal wherever possible.

➤ Provide access to help locate scan chain errors

Allowing physical access between the TDO signal of one device and the TDI signal of the next will allow easy identification of which device is causing a problem in the event of a non-functioning scan chain. This can be from a series termination resistor or a test point.

➤ JTAG mode select

On some devices TAP pins can be configured to have functions other than 1149.x boundary scan so it is important to ensure that the design does not prevent devices being used for JTAG testing. The function of these pins is normally configured by sampling other pins on the device as it is reset. Depending on the requirement of the design this configuration can be achieved in several ways:

- If boundary scan is the only function required on the TAP pins the configuration pins can be tied to the required levels.
- If boundary scan is the dominant function for the pins but it is possible that other functions may be required then optional fit resistors allow the configuration pins to be either high or low with a minor board change.
- If there is a requirement to be able to switch easily between functions then the configuration signals can be brought out to a connector. Pull resistors can be used to define the default state which can then be overridden by a controller such as the XJLink2.

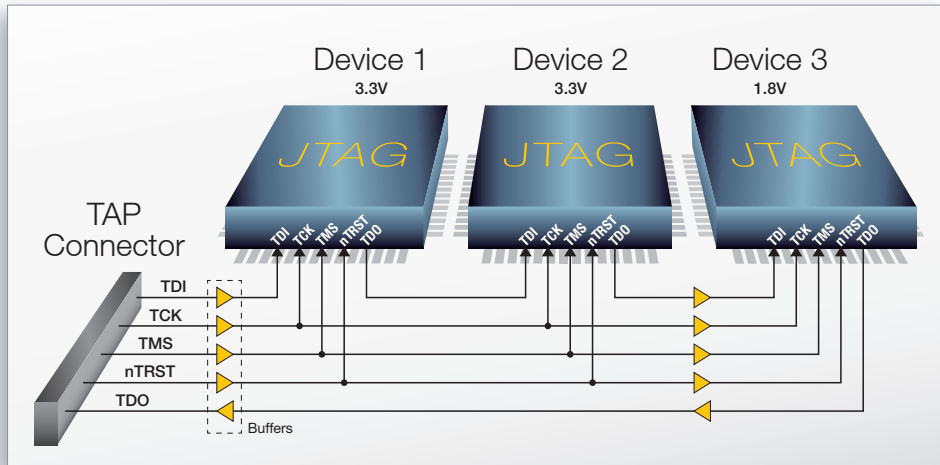
The EMU0 and EMU1 pins on a variety of Texas Instruments processors are one common example of such configuration pins while others include the Mode pins on Freescale processors and the JTAGSEL signal on the AT91 family of processors.

The required values for these pins will be defined in the datasheet/reference manual for the device; however they may also be shown in the COMPLIANCE_PATTERNS section of the BSDL file for the device.

➤ Buffer the TAP signals and voltage level separation

If possible, buffer the primary TAP signals to minimise noise and impedance mismatches and to improve fan-out. Generally if the track lengths are relatively short then it is acceptable to fan out to 4-6 devices, while longer tracks should only fan out to 1 or 2 devices. Ensure TCK, TDI, TMS and nTRST are buffered at board entry and TDO at board exit. It is important to ensure that the buffers are non-inverting.

If there are JTAG devices that operate at different voltages then it is advisable to separate these into chains of devices that operate at the same voltage level. Alternatively group the devices from the same voltage family together in the daisy-chain e.g. 3.3 V and then connect into the devices of the next voltage through a voltage converter to adjust the signal accordingly e.g. 3.3 V down to 1.8 V.



If it is not possible to buffer TAP signals between voltage domains then design the JTAG chain to allow voltages to be translated down e.g. from 3.3 V signals to 2.5 V (for example using resistor divider) as this is easier than stepping up voltages.

It is important that any buffered signals are terminated as previously described. The TCK input to a buffer needs termination close to the buffer while the outputs from any buffers need parallel termination close to the last device on the trace. Any buffered TDO signals should have series termination close to the driver.

» Connector design

When specifying the signal positions on the JTAG connector it is important to consider possible crosstalk/interference issues. Interleaving active signals with ground connections will minimize these effects. If the number of pins available on the connector makes this impractical then prioritise placing TCK next to ground. If this is not possible then use a signal which is unlikely to change during JTAG scans such as reset, nTRST.

It is particularly important to avoid routing any TDO signal adjacent to TCK. TDO transitions occur on the falling edges of TCK; therefore cross-talk from TDO may cause a glitch on TCK, corrupting the data.

It is very important to have a strong ground connection between the JTAG controller and the board under test. If there are any spare pins on the JTAG connector to the board then adding extra ground

JTAG Connector

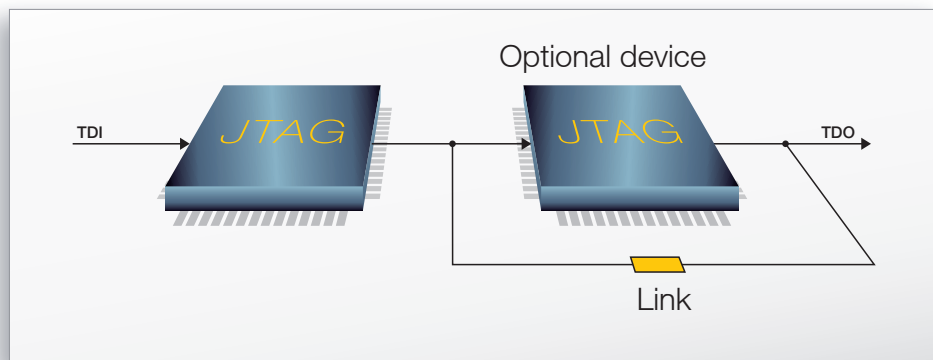
Input	1	2	Input
Input	3	4	Soft GND
TDI	5	6	Soft GND
TMS	7	8	Soft GND
TCK	9	10	Hard GND
Input	11	12	Soft GND
TDO	13	14	Soft GND
High	15	16	Soft GND
Input	17	18	Soft GND
Input	19	20	Hard GND

signals will be beneficial. The XJLink2 has fixed ground connections on pins 10 and 20 so connecting these will improve signal integrity.

Ideally each new design will use the same connector type and signal layout so cables can be reused. Routing the TAP signals to spare pins on other connectors may enable access to the scan chain even if the dedicated test access connector is unfitted or inaccessible.

➤ Bypass optionally fitted 1149.x compliant devices

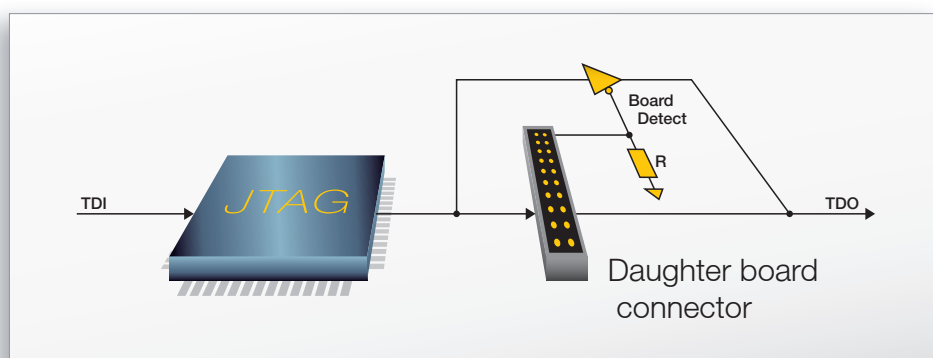
Where JTAG devices are 'optional fit' on a board ensure that a link, normally a 0 Ω resistor, is provided to complete the TAP data chain whenever the device is not fitted.



If this is not done then the broken data path in the scan chain will prevent any testing being done using any other devices in that chain. If a device is unlikely to be fitted then consider placing it in a separate scan chain.

➤ Include add-on and option boards in the 1149.x chain

Where daughter boards are used, route the 1149.x chain through devices on the daughter boards via the board connector. If the daughter board is an option, then use some board detect logic to bypass the TAP data path on the daughter board when it is not fitted as shown below.

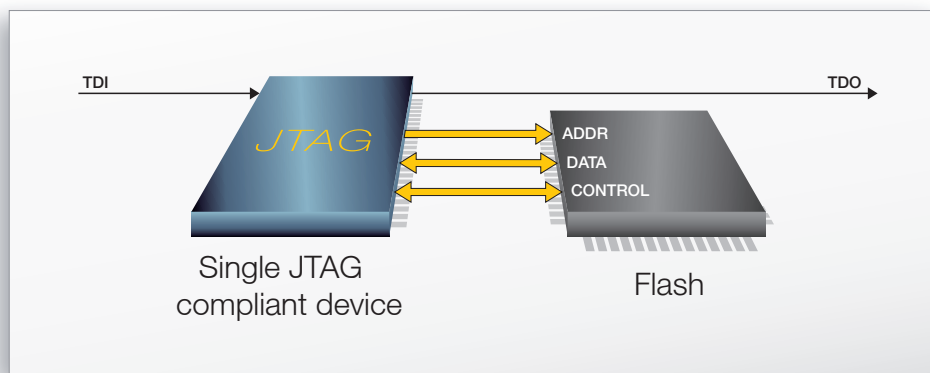


➤ If designing or specifying ASICs include 1149.x compliance

If your design includes ASICs or any other custom designed silicon, you should consider making the custom devices 1149.x compliant as they are otherwise likely to be untestable.

➤ Make programmable parts accessible from the 1149.x chain

If in-system programming of devices such as flash or EEPROM is required, make all the necessary pins of the programmable devices accessible from JTAG devices.



The boundary scan based in-system programming time will depend on both the length of the scan chain and the TCK frequency. For the shortest boundary scan based programming time the TCK frequency must be as high as possible and the scan chain as short as possible.

It is preferable to make all of the required nodes accessible from a single JTAG device. XJTAG will automatically optimise the programming process by putting all JTAG devices that are not required for a particular scan into a mode called CLAMP which shortens the data path through each device to a single bit.

It is advisable to avoid address latch configurations as they will increase the number of scans required to write each byte/word which will significantly increase the programming time.

➤ Provide direct access to programming signals

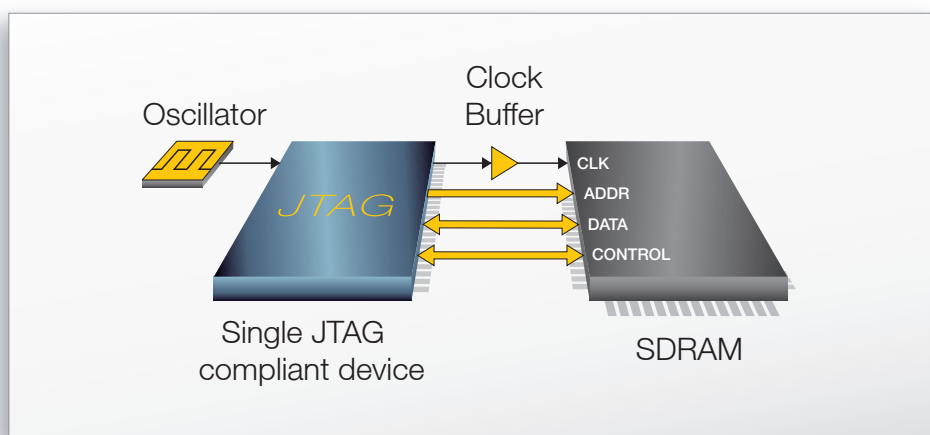
Programming times can be further optimised by directly controlling programming signals such as write enable or even whole protocols such as SPI and IIC. By routing the relevant nets to a connector on the board they can be controlled using spare I/O pins on the JTAG controller rather than through boundary scan. This helps reduce programming times as signals that need to be changed frequently, normally requiring two complete scans, can be toggled independently of chain length and frequency.

To use this functionality it must be possible to disable any boundary scan drivers on these net.

>> Consider the clock to synchronous devices

Many synchronous devices can be tested by boundary scan however this will be dependant on the source of the clock. SDRAM, for example, can only be tested if the clock is controlled by an 1149.x compliant device. If a free-running clock were to be connected directly to the SDRAM then it would not be possible to synchronise the boundary scan test vectors to that clock in real time.

If a configurable JTAG device, such as a CPLD or FPGA, is available then route the clock source through that device to the SDRAM or clock buffers to maximize test coverage as shown below.

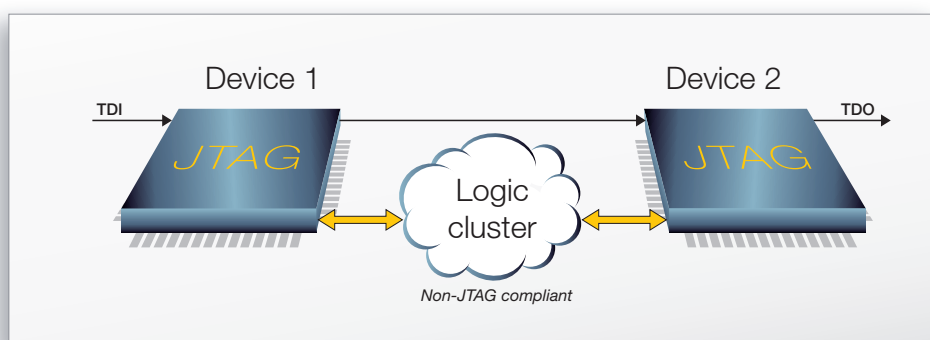


It is also important to ensure that any clock buffers do not have a minimum operating frequency. Some clock buffers have a special control input to allow low frequency signals. Such signals must be accessible from a JTAG enabled pin.

Other devices, such as Ethernet PHYs and switches, require a specific frequency clock input in order to function. In these cases it is important to make sure the clock is not provided by an 1149.x enabled pin. A crystal or oscillator should be connected to the non-compliant device either directly or via a clock buffer.

While it will not be possible to use boundary scan to interact with the non-compliant device at these speeds; providing a suitable clock will often allow some level of testing that would not otherwise be possible.

>> Surround logic clusters with JTAG devices

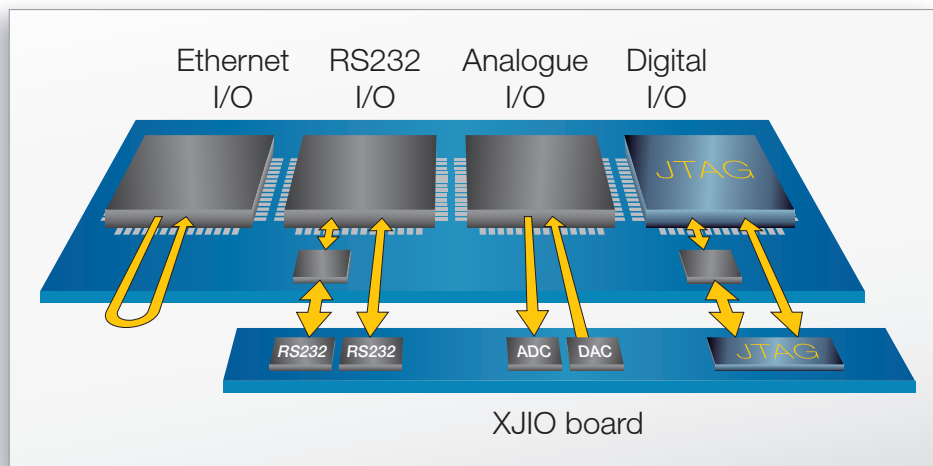


Arrange non-JTAG logic into clusters surrounded by JTAG devices which can control all the inputs and monitor all the outputs to and from the cluster. Try to ensure that sufficient access to nodes within the cluster is available in order to test the operation of the cluster as fully as possible. If necessary, add additional JTAG connections to gain access to the required cluster nodes. Alternatively it may be beneficial to have the logic system in a programmable logic device which supports boundary scan.

➤ Extend 1149.x testing through connectors

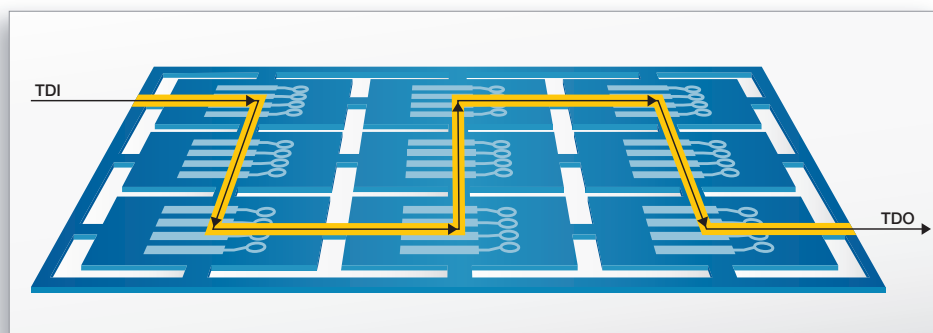
Test coverage is greatly increased if external connectors can be attached to additional 1149.x accessible nets. Testing of connector pins directly attached to nets with a single 1149.x pin can be extended to include open circuit testing if connected to external 1149.x controllable I/O, such as the XJIO board.

This form of testing is only possible for standard digital signals. Where such testing is not possible, for signals such as Ethernet and RS485, design I/O ports so that loopbacks can be used.



➤ Consider testing multi-board panels as one unit

Where multiple boards are constructed on a single panel, consider routing power and TAP signals through some or all of the boards on a panel to enable simultaneous testing of all the boards before separating them.



➤ Consider watchdog operation

Provide links or 1149.x controllable logic to ensure watchdog operation can be disabled during test. Reset events generated when a watchdog fails to receive a regular input during testing can produce unexpected test result or even prevent tests from completing.

➤ Test analog circuits

Although 1149.1 and 1149.6 do not include any explicit functionality for testing of analog circuits, many tests can be performed with careful design. Consider connecting using 1149.x compliant outputs to pull comparator or amplifier inputs to fixed states and use the outputs from these devices to provide known inputs to JTAG devices. The addition of low cost DACs and ADCs can provide supplementary controls for, and monitoring of analog clusters by connecting the digital side of the ADC and DAC to devices in the boundary scan chain. With a small amount of appropriate additional circuitry large amounts of analog testing can be performed.

➤ Do not rely on programmable pull resistors

Try not to use the programmable pull-ups which are provided in the I/O pads of some processors and FPGAs to enable external logic to operate. If the pull-ups required on an IIC bus were only provided by programmable pull-ups then any devices attached to the IIC bus may not be testable by boundary scan. If this cannot be avoided then make the IIC bus pins available at an external connector so pull-ups can be added externally for testing purposes.

➤ Consider using the functionality of JTAG devices

There will always be some parts of every circuit that cannot be tested using standard 1149.x techniques, while other parts of the design may require 'at speed' testing. In these situations it may be possible to use programs loaded into devices in the JTAG chain to exercise the functionality of the board.

Configurable devices such as CPLDs and FPGAs can be programmed by running SVF or STAPL files. For processors it may be possible to use the flexibility of XJTAG's programming language XJEase to load the configuration.

➤ Use test functionality in non-JTAG devices

Some non-JTAG devices have special test features that can be used to increase test coverage. These features, such as NAND tree or test pattern generation, allow testing of nets connected to signals that cannot be tested by using boundary scan to interact with the devices functionality. They can be invoked by writing to registers using interfaces such as SPI, IIC and MDIO that can be controlled through boundary scan.

>> Interactive tests

A number of tests can only be done with the aid of the test operator. Visual devices can be tested by having the operator observe their function and input their results; switches by having a JTAG device monitor the state of the switch whilst being actuated by the operator. Other devices such as stepper motor controllers and speaker systems can also be tested in a similar way.

>> Program non-volatile memory devices

XJTAG may be used to program many devices such as NOR and NAND flashes with both serial and parallel interfaces. This is useful for loading application images or just storing configuration options, serial numbers, Ethernet MAC addresses etc. as part of the test procedure.

>> Fast flash programming

In circuit programming of flash devices via boundary scan can be very slow because each net can only be switched once with each JTAG scan and each scan can be several thousand bits long. One solution to this problem is to use either FPGA-assisted or processor-assisted programming routines. These routines first load the FPGA or processor with a programming engine that controls the flash programming. The JTAG port is then used to transfer data to the programming engine.

FPGA assisted programming can be implemented using XJTAG's XJFlash technologies. As a result, flash devices can be programmed at speeds close to their theoretical maximum. If your design contains a flash device that is not connected to an FPGA but the design does have an FPGA with spare pins, then by connecting up the flash device to these additional pins you can gain the flexibility to use XJFlash.

Processor assisted programming, while slower than XJFlash, is still significantly quicker than using boundary scan. The debug interface provided on many processors use JTAG as their communication protocol. Such processors can be configured through JTAG to use their flash controllers to program an image into the flash.

For more information about implementing fast flash programming please contact support@xjtag.com.

>> Test with unconfigured FPGAs and CPLDs

Configurable devices such as FPGAs and CPLDs have a high proportion of I/O signals that are ideal for high levels of test coverage. However, when these devices are configured many of these signals do not provide their full I/O capability as the input or output functionality that is not needed in the application is "switched off". Using boundary scan does not re-enable this functionality, and so test coverage is reduced.

There is an **application note** on the XJTAG web-site describing the best strategy for testing boards containing these types of devices.

Glossary

ADC	Analog to Digital Converter
ASIC	Application Specific Integrated Circuit
BSDL	Boundary Scan Description Language
CPLD	Complex Programmable Logic Device
DAC	Digital to Analog Converter
DFT	Design for Testability
EEPROM	Electrically Erasable and Programmable Read Only Memory
FPGA	Field Programmable Gate Array
IEEE	Institute of Electrical and Electronics Engineers
1149.x	IEEE Standard 1149.x: 1149.1: Test Access Port and boundary scan architecture 1149.6: AC coupled and differential signals (see www.ieee.org)
IIC	Inter-Integrated Circuit (I2C)
I/O	Input / Output
JTAG	Joint Test Action Group
nTRST	Test Reset (Active low TAP Signal)
PCB	Printed Circuit Board
STAPL	Standard Test And Programming Language
SVF	Serial Vector Format
TAP	Test Access Port
TCK	Test Clock (TAP Signal)
TDI	Test Data Input (TAP signal)
TDO	Test Data Output (TAP Signal)
TMS	Test Mode Select (TAP Signal)
XJTAG	A suite of tools aiding the development and test of electronic systems