

# Understanding ISP Wiring

With the high bit rates of today's In-System Programming protocols, careful wiring between the programmer and the programming/testing fixture must be considered.

## Fewer Wires, Higher Speeds

In-System Programming (ISP) is becoming the programming solution preferred by small and big OEM/EMS alike. Since each silicon manufacturer implements its own programming protocol(s), every device family has its own particular programming interface. Nonetheless, the lines needed to program a typical device have decreased during the years. Modern devices only need very few lines to be programmed; in some cases, just one line is needed (Fig. 1).

At the same time, the devices' non-volatile memory is rapidly increasing (Fig. 2). To keep programming times low, the ISP lines must therefore be capable of sustaining higher communication bit rates. Higher bit rates mean that the wiring of the ISP lines inside the programming/testing fixture has to be carefully thought.

## Fixture Wiring

Usually, an Automatic Test Equipment (ATE) performs parametric and functional tests on the Unit Under Test (UUT) that is placed inside a custom, unit-specific test fixture. The test fixture routes several ATE control lines to the various test points on the UUT. The same fixture is used to in-system program the target device(s) (or DUP, Device Under Programming) in the UUT that needs to be programmed. In-system programming usually takes place after the component parametric test and before the functional test. Multi-PCB panels add to the complexity of the wiring inside the fixture; fixtures with hundreds of nails are not uncommon (Fig. 3).

While the vast majority of connections required for board testing are low-speed transmission lines, the wiring of the lines dedicated to programming must take into account the high speed of modern ISP.

## ISP Wiring Issues

One of the most important parameters to take into account for ISP wiring is connection length. Usually (but this is not always known to the test engineer), ISP signal integrity starts to degrade with connections longer than 40-50cm. For this reason the programmer should be placed as near as possible to the fixture, better yet inside the fixture.

The 50cm limit should not be taken as an absolute maximum: it depends on the ISP protocol. Asynchronous protocols such as UART, for example, allow for longer connections; Freescale's BDM protocol, due to the high bit rate and driving characteristics, requires shorter wiring.

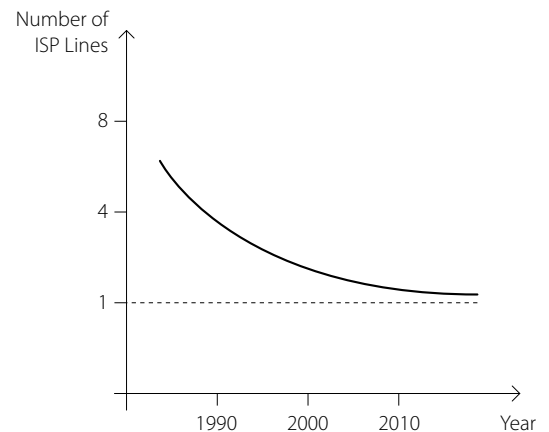


Fig. 1

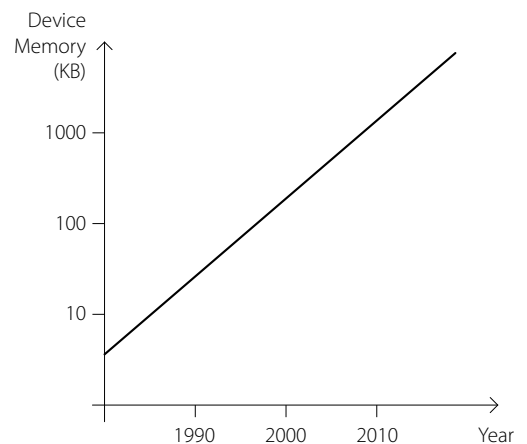


Fig. 2

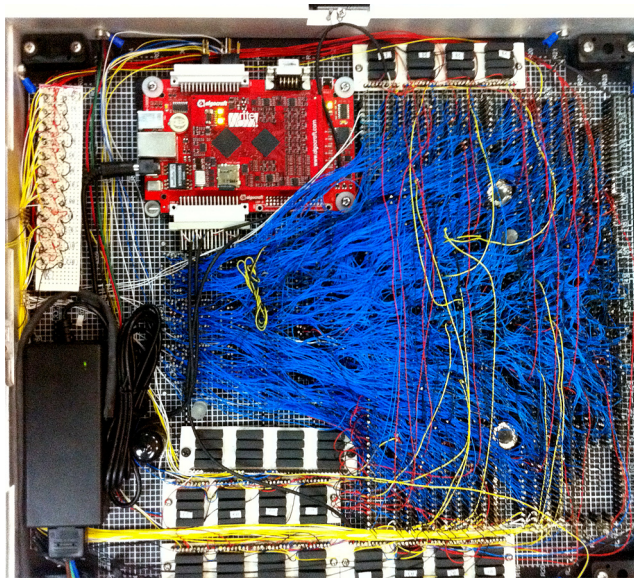


Fig. 3

An important role in an electric communication is played by the transmission line. Due to the high number of wires and to their connection typology (usually wire wrap, making solderless connections of wires to terminals), fixture wiring is typically done with single-core, isolated wires with AWG from 20 to 30.

Since almost all programmable devices (serial memories, microcontrollers, etc.) feature single-ended, CMOS lines, almost all In-System Programmers in the market feature single-ended, CMOS driving of ISP lines (Fig. 4).

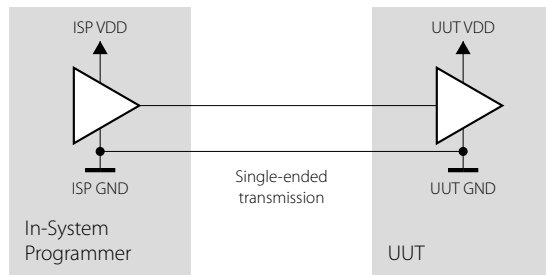


Fig. 4

This transmission line is easier to implement than a differential line, but it offers less immunity to common-mode noise. Programmer and DUP usually share the same ground potential and, with the simultaneous activity of several digital lines, electric noise will add both on the transmitter and receiver end—possibly corrupting the transmission. Fig. 5 shows a signal affected by common-mode noise.

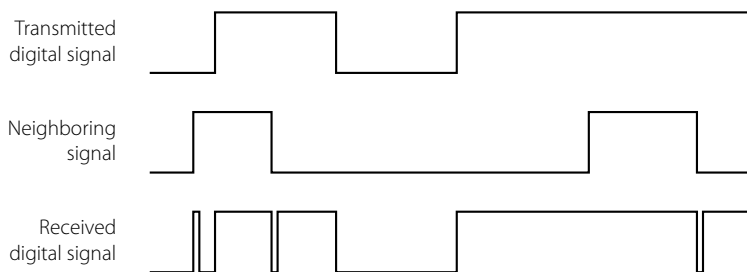


Fig. 5

Another source of noise can be the crosstalk phenomenon. Crosstalk arises when a signal affects another nearby signal. Usually the coupling is capacitive, and to the nearest neighbor, but other forms of coupling and effects on signal further away are sometimes important.

Fig. 6 shows an example of crosstalk between two conductors inside a fixture. The CH1 signal is affected by the CH2 signal. The steeper the edges of the CH2 signal, and the higher the CH1 line impedance, the higher the crosstalk. ISP protocols such as I<sup>2</sup>C, ICC, etc., where the high logic state is obtained through open-drain driving, are more subject to the crosstalk phenomenon.

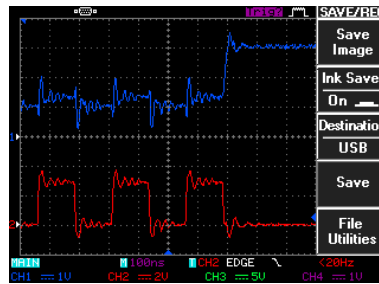


Fig. 6

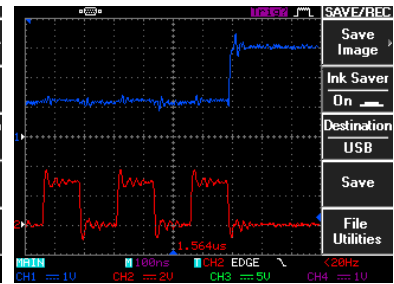


Fig. 7

In order to reduce crosstalk, twisted pair cabling should be used, where a “shielding” conductor (only one end of which is connected to ground, usually on the programmer side) is twisted together with the main conductor (alternatively, a coaxial cable can be used). Fig. 7 shows the benefits of such a cabling. Fig. 8 shows how cable twisting should be implemented.

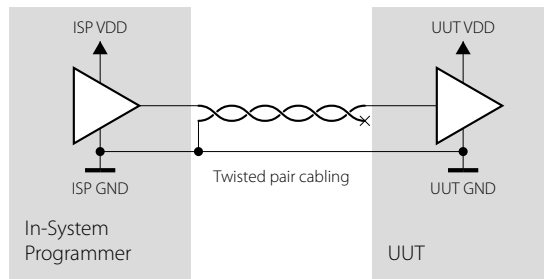


Fig. 8

### High-Speed Signals

Crosstalk effects are empathized by modern In-System Programmers since, in order to reach the higher bit rates of today’s ISP protocols, they employ high-speed single ended line driving. To help avoid crosstalk, the fixture should have a ground plane on the plate hosting the nails.

Additionally, ground connections should be redundant; all the ground pins of the programmer should be individually connected to ground nails on the fixture, and these should be connected to each other, as shown in Fig. 9.

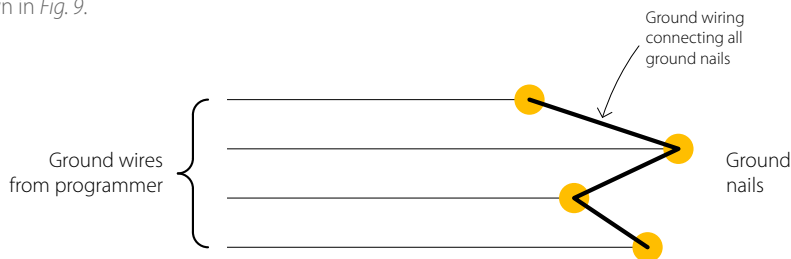


Fig. 9

### Impedance Matching

Impedance matching is another factor that improves signal transmission. A transmission line is said to be “matched” when its characteristic impedance ( $Z_0$ ) is equal to that of the transmitter ( $Z_{OTX}$ ) and to that of the receiver ( $Z_{ORX}$ ). When the transmission line is matched, signal reflection and interferences are null (Fig. 10).

Perfect impedance matching is impossible to obtain in real-world conditions. In particular, the output impedance of a programmer line ( $Z_{oTX}$ ) is typically in the order of hundreds of Ohm, while the input impedance of a microcontroller line ( $Z_{oRX}$ ) is usually in the order of hundred thousands of Ohm. Additional circuitry on the UUT tied to the transmission line may make things worse.

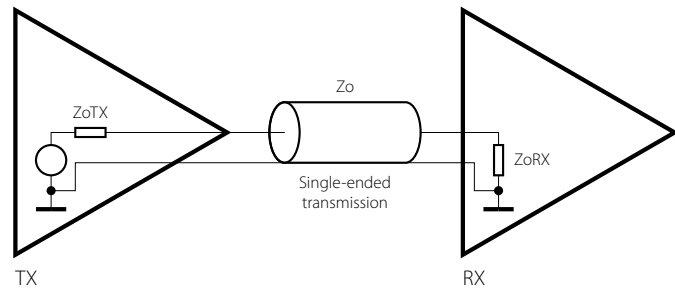


Fig. 10

As an example of unmatched transmission line, see Fig. 11. A strong undershoot is present on the signal. A pull-down resistor between signal and ground reduces this phenomenon. The resistor, whose value of 390 Ohm has been empirically found, has been placed between the contacting nail and the fixture's ground plane. Fig. 12 shows the effect of the pull-down resistor.

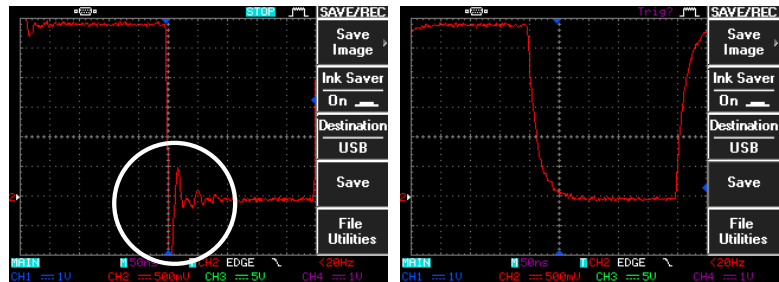


Fig. 11

Fig. 12

The pull-down resistor, however, draws a significant amount of current from the transmitter. For a 5V CMOS signal, the current drawn is

$$I = 5V / 390\Omega = 13mA,$$

which is comparable with the maximum source current of a CMOS line. It is suggested to use non-inductive resistors, such as carbon resistors.

## Eye Diagram

An eye diagram allows to evaluate the quality of a transmission line. An eye diagram is an oscilloscope display in which a digital data signal from a receiver is repetitively sampled and applied to the vertical input, while the data rate is used to trigger the horizontal sweep. An open eye pattern corresponds to minimal signal distortion. Distortion of the signal waveform due to crosstalk interference and noise appears as closure of the eye pattern.

Fig. 13 shows the eye diagram captured on the MOSI signal of a SPI protocol, one of the various protocols used in In-System Programming.

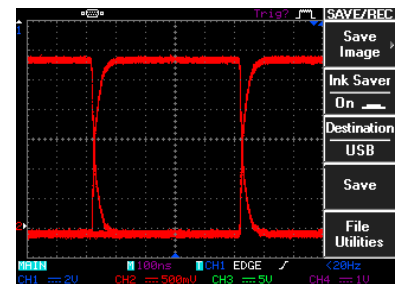


Fig. 13

If the signals are too long, too short, poorly synchronized with the system clock, too high, too low, too noisy, or too slow to change, or have too much undershoot or overshoot, this can be observed from the eye diagram.

While the analysis of the eye diagram is suggested for advanced signal troubleshooting, it is by no means mandatory. Traditional scope captures of the signals involved in ISP are enough to evaluate the quality of the fixture connections.

## About Algocraft

Algocraft Srl ([www.algocraft.com](http://www.algocraft.com)) is a high-tech company whose core business is to design, develop and market a wide range of professional systems dedicated to the manufacturing and testing of electronic boards. Algocraft team includes high-skilled engineers with over 10 years of individual design experience in the Industrial Programming field.