“Tails Code Key” technology
For
Maintenance Enhancment of serial bus communication

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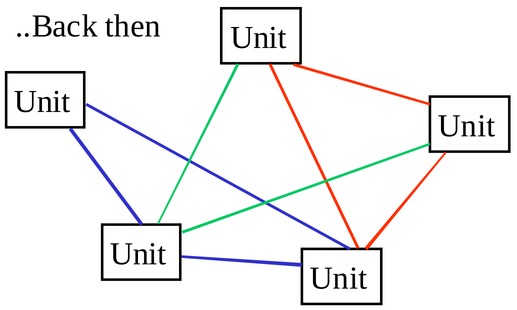
www.sitaltech.com

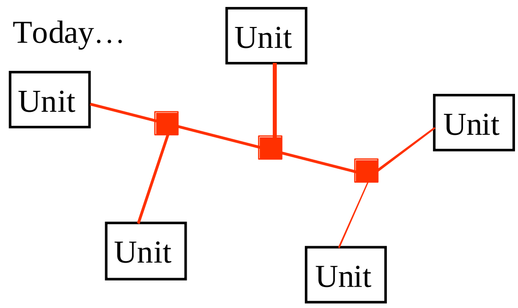
This article presents a method of enhancing bus maintenance quality by means of performing real time parametric testing on the bus.
“Tail Key Code” gives an early warning that there is a problem before functionallity is damaged.
“Tail Key Code” is the result of fault isolation test, thus pin points an exact physical location of the damage, saving hours of maintenance time.
“Tail Key Code” picks up a single failure event, and allows fixing the problem without the need to recapture this problem later on.

Forward

Electronic systems, such as avionics systems, fulfill their mission by performing repeatedly data interchange between electronic units. Each electronic unit, sometimes called sensor, contributes its findings to other units by sending its data.
Older systems had dedicated electronic wires to connect each unit with the other units that needed its data. As Systems grew in size, the wiring became big & complex. Electronic buses were developed to reduce the number of wires in those systems.

An Electronic bus, or just bus, is a network topology that uses a common electric wires pathway between all devices. Not all the devices have to interchange data between them, yet when one device sends information on the bus, all the devices receive this data.

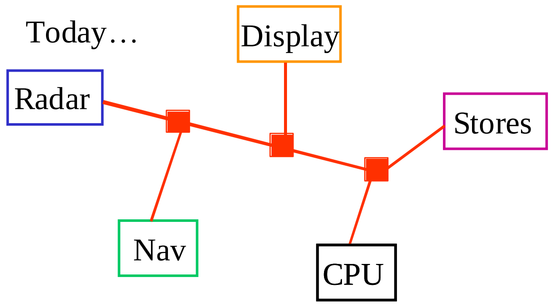


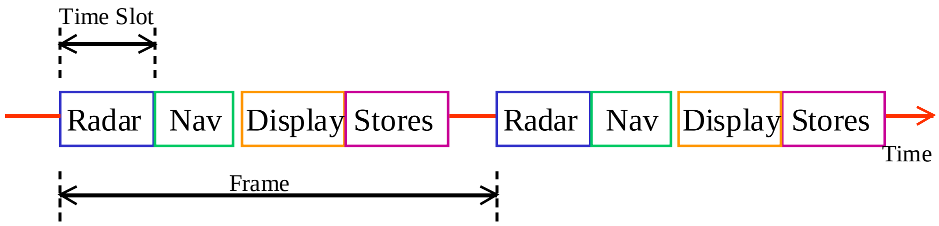


In most buses on a particular time, T, only one unit can transmit data to other units because the electronic wires can have only one electronic value at a given time. As a result these buses need rules that make sure only one unit transmits data to the bus at a particular time.
Typically buses are either time division multiplexed which means that the time axis is divided into time slots, and each time slot is dedicated to the transmission of a different unit, or use carrier sense, meaning that a unit, prior to transmit data to the bus, must sense if no other unit is transmitting at the same time.

In Time Division Access busses, in a particular time slot, only the transmitting unit and the receiving unit (or units) benefit from the bus, other units wait for their time slot.

In order for all units to communicate, many time slots are arranged one after the other. When all time slots are completed, the system typically starts a new sequence of time slot all over again. A set of time slots ordered one after the other is typically defined as a frame.
For example, real time control systems, such as Avionic Systems, repeat the frame 50 times a second. This rate is higher than human brain computation, thus a human that monitors the system's displays feel as if all units were connected to all other units constantly and not in time slots as it actually is. Avionic systems, for example, perform complex computations to eventually position a round viewfinder that moves smoothly on the pilot's head up display based on radar, navigation system, and orientation sensor unit's data.



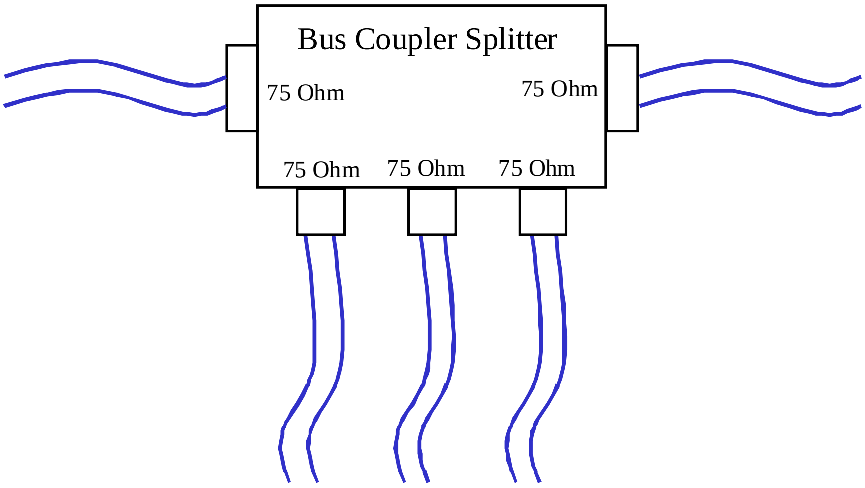


This smoothness in motion is easily achieved if each of the units were connected to each other with dedicated electronic cables. It is somewhat more complex to achieve this smoothness when all of these units are connected via a single pair of electronic wires that serves as a time multiplexed data bus.

Bus coupling

The bus is physically built of electric wires, typically a twisted pair of wires. The wire's physical structure presents input impedance for a driver that transmits electronic waves on to the wires. The transmitter's output impedance has to match the wire's input impedance; otherwise some of the transmitted energy would be bounced back from the wire onto the transmitter and would eventually distort the signal on the wires.
The electronic wave on the electric wire travels at ~4/5 the speed of light.

When the transmitted signal reaches the end of the wire, which typically is an electronic unit, the input impedance of the unit has to match the wire's impedance to prevent back waves. This phenomenon is called coupling.
Since more than two units are connected to the bus, a bus split has to be designed such that signal coupling is maintained. This split is typically referred to as a "coupler". There are 3 way, 4 way, 5 way, and so on bus couplers. These couplers balance the impedance such that an electronic wave coming from one of the branches splits into all other branches and sees matched impedance. Without a coupler, simple connection of more than 2 branches together will result in a non-matching impedance and part of the energy bouncing back to the transmitting branch.
Bus couplers are usually built from resistors or transformers or both.



A well-balanced system bus would have all units present the bus wire's impedance as input impedance, and all transmitters' matched with the wire's impedance, and all couplers well balanced to the wire's impedance.

Bus Problems

Buses reduce the number of wires in systems. All units communicate through the single bus, but

What happens when the bus fails?

Possible bus failures can be wires disconnection, couplers components failures, and connector's degraded connection.
Buses, especially for automotive, military & space, suffer from extreme usage conditions that can produce any of the above failures.

A bus failure has its direct affect on the impedance. A bus connector miss-connected, for example, would present infinite impedance to the signal that crashes into it. The arrived signal has no other option but to return back to sender. This signal return should not have occurred had the connector been properly connected. This signal return can be viewed as a transmission of a new transmitter on the bus. So now there are two transmitters, the unit that transmits to the bus along with the echo that bounced back from the connector.
The echo is the same data as transmitted by the transmitter, but delayed in time. The amount of delay depends on the distance between the transmitter, the bad connector and the speed of light.
An example of this phenomenon was very common in television broadcasting when receiving a station through an antenna, and seeing the picture with its shifted watermark ghost. The ghost arrived from a big building that echoed the broadcast and was picked up by the antenna. The distance from the broadcasting station to the antenna is smaller than the distance from the broadcasting station to a building and then to the antenna. The extra distance accounts for the shift between the original picture and its ghost.

Wires short circuit or open circuit present zero and infinite impedance, but any damage to the bus would present an impedance different from the wire's impedance in the range between these two extremes. For example humidity between the wires could be seen as a resistor in parallel to the wire's impedance lowering its impedance. Bad contacts on a connector could be measured as a resistor in series thus presenting higher impedance than the matched impedance.

Any bus fault has its affect on the bus impedance. So any fault becomes a transmitter transmitting a delayed signal. The amplitude of that echo transmitter depends on how much that faulty impedance is different from the wire's impedance.

To make the complexity of analyzing the bus signal even harder, one should keep tracking the echo signal (…although it's traveling almost at speed of light). That echo signal along with the original unit's transmission now arrives at a well-balanced load. But this load is designed to absorb the energy from the original transmission only, and the extra echo gets bounced back once again. The echoes decay over time because of coupling ratio, resistance of wires and components. For example if you through a stone into a pool similar effects can be seen. The waves go to all directions until they crash into the walls and bounce back to the other walls and so on until the waves decay completely.

Current maintenance capabilities

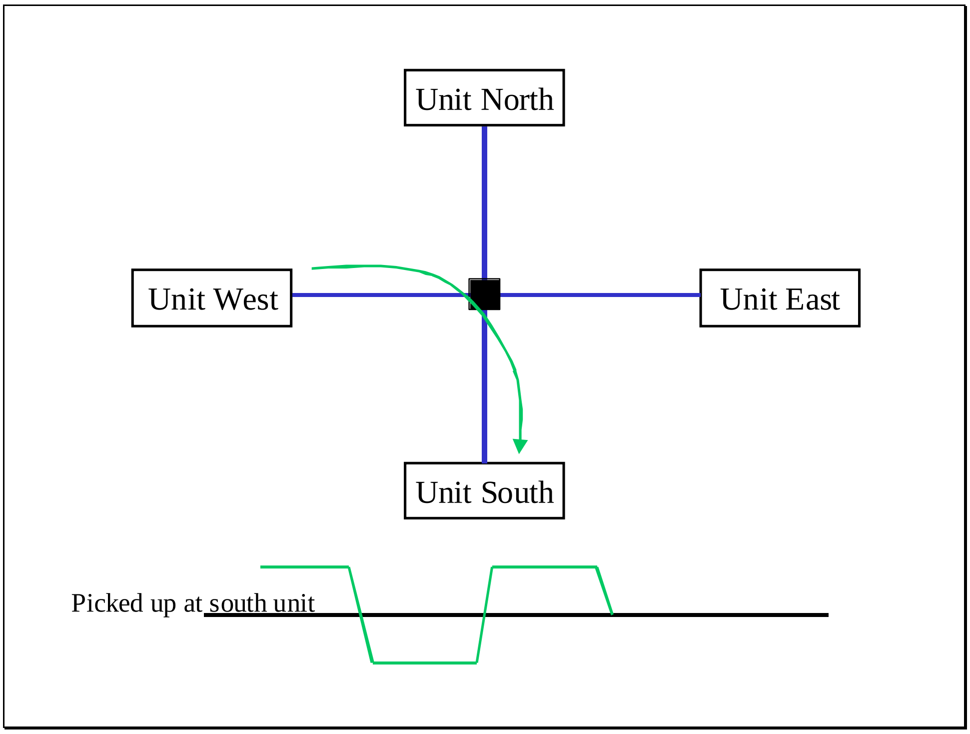
Most systems perform functional testing for verifying bus functionality. The functional testing is usually a test that verifies that all units can receive and transmit to the bus. These tests are usually performed after the systems powers up or after operator request.
Functional testing will most likely have a go / no-go result.
If the bus has some damage that forces a marginal bus condition that do not impair functionality, the test would pass. This marginal condition could easily impair functionality when the bus is introduced with field conditions. This behavior, for

example, might create single event failures which are much more difficult to debug than constant functional failure.

Proposed maintenance capabilities with

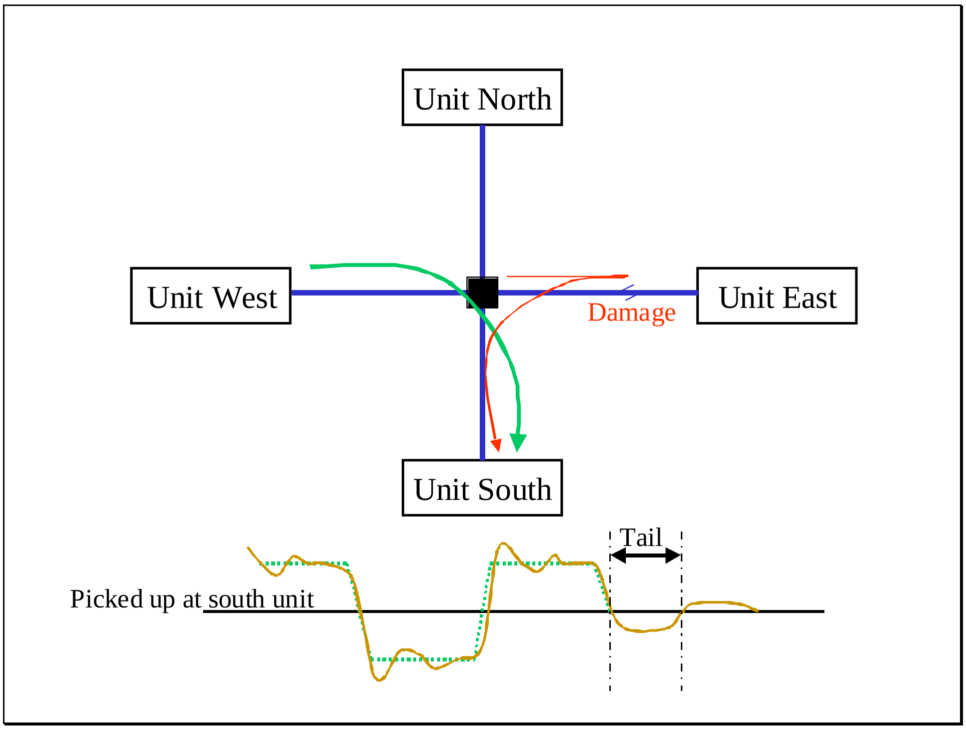
"Tails Code Key" Technology

In a perfect bus coupling condition the receiver unit that is listening to a transmitter unit, receives the transmitter's message as transmitted. Actually, that transmission is spread to all bus units. Since the units, wires and couplers are in perfect condition, the loads absorb the energy that arrives and no echo is produced.



When there is a bus problem somewhere in the bus topology, that damage echoes part of the energy that hit back to all other units. The listener receives the original transmission, plus that echo skewed in time by the extra distance from the transmitter to the damage and from there to the listener.

The echo is assumed to be of lower amplitude than the original transmission. This lower level does not hurt the normal message transmission. Assuming the listener accepts the original transmission and assuming it knows when the original transmission starts and ends due to its adherence to bus standard, such as MIL-STD-1553, that is words of 20 microseconds, the listener can measure the signal that is left on the bus after the ideal transmission length. That left over echo is referred to as "tail". The length of the tail is proportional to the extra distance between the transmitter, the damage and to the listener.



Each transmitting unit is located at a different distance from a given bus fault that changes the coupling. Each unit's transmission will have a different tail length for a given bus fault.

If one unit on the bus measures the tail from all units' transmissions, this unit can hold a list of all tail lengths. This list is referred to as "Tails Code Key". In perfect bus condition this list should be all zeros because no tails are monitored. However, once the bus is damaged somewhere in the bus topology, a non-zero "Tails Code Key" is produced.

A simulation example list of tail lengths measured at center coupler of the above bus:

Unit name	Perfect bus	East bus fault	North bus fault	West bus fault
North	0 ns	50 ns	10 ns	50 ns
South	0 ns	50 ns	50 ns	50 ns
East	0 ns	10 ns	50 ns	50 ns
West	0 ns	50 ns	50 ns	10 ns

Formal definition of the algorithm

Let Li be the listener unit that composes the "Tails Code Key" by measuring the tail of all units on the bus.
Let L*n* (Length *n*) be the distance between unit *n* and the Li.

Let E1*n* (Error1 *n*) be the distance between unit *n* and bus fault.

Let E2*n* (Error2 *n*) be the distance between bus fault and Li.

Let D*n* (Delta *n*) be $Dn = (E1n + E2n) - Ln$.
Let TD*n* (Time Delta *n*) be the length of the tail for unit n. $TDn = Dn / (4/5*C)$.
Distance divided by 4/5 speed of light.

Let $K_{1..N}$ (Key 1 to n) be a set of time figures: $K_{1..N}$ = TD1, TD2, TD3...TD*n*.
$K_{1..N}$ is a list of tail lengths in seconds for all units.

For an ideal bus, $K_{1..N} = (0,0,0,\ldots 0)$
For each bus fault positioned in a unique place on the bus a unique, non-zero $K_{1..N}$ is measured by Li.

Using "Tails Code Key" Technology

One of the units on the bus, called "Algorithm Executor" (AE) should be able to measure the tails of all units on the bus. This unit should maintain a list of all tails. This list is the "Tails Code Key".

Since buses are not ideal, the "Tails Code Key" is expected not to be zero. The AE unit should be able to perform calibration task, initiated by the system's operator, which will measure the "Tails Code Key" and keep this code as the master reference code.

During operation of the system, the AE unit should constantly measure the "Tails Code Key" and check if that code is within a tolerated distance from the reference code. When an un-tolerated "Tails Code Key" is measured, this code should be registered.

The un-tolerated "Tails Code Key" is in fact a signature of a specific bus fault somewhere in the bus topology. A technician should be able to pin point the exact physical location of the bus fault based on the values of the "Tails Code Key".

Online knowledge databases can maintain a record of all known signatures for a specific bus. Searching in that database with the measured "Tails Code Key" will result with the location of the bus problem.

If the bus fault is not severe, bus functionality would probably persist, however, technicians would be able to locate the fault thanks to the code, and replace or repair whatever needs to be repaired before functionality is hurt.

The AE unit also records bus problems that occur only once, or occur for a limited period of time, such as when aircrafts perform intense maneuvers. The recorded code defines the physical location of the problem. Technical crews get a physical location of the problem even though they cannot, and need not, reproduce the problem.

Summary

"Tails Code Key" enhances maintenance of system buses infrastructure.

"Tails Code Key" is a technology that measures bus signals that are normally considered noise and filtered out by most bus units.
"Tails Code Key" looks for the left over signal on a bus and measures it. The distances between the bus fault and the transmitters directly affect the left over signal length in time. "Tails Code Key" produces a list of tails from various transmitters on the bus, and derived from that list, a precise geometrically location of the bus fault can be found.

By comparing the list of tail lengths to a reference list of a particular bus, a system implementing "Tails Code Key" technology would be able to warn about a bus problem before it fails functionality, deliver a physical location of that problem on the bus even if it happened only once during the operation of the system.

The "Tails Code Key" technology is patent pending and is available with Sital Technology's IP cores.

Listen to the echoes, they have something to ~~tell~~ tail us…

Appendix A: Simulations

This Appendix includes simulation results of a bus.
The simulations were performed on Mentor Graphics Hyperlynx LineSim signal integrity simulation tool Version 7.7.

The bus was built from 4 units that are connected with 6 meters bus from a central coupler. The bus topology is symmetric in all directions, to make the analysis easier to comprehend.

The bus cables are standard Z_0 = 50 Ohm.
The bus monitoring was done on the center coupler (red arrow).
Each of the units, north, south, west and east, present a 50 Ohm input impedance, and matched transmitter impedance.
All bus faults were imposed on the east branch as can be seen in the following pages.

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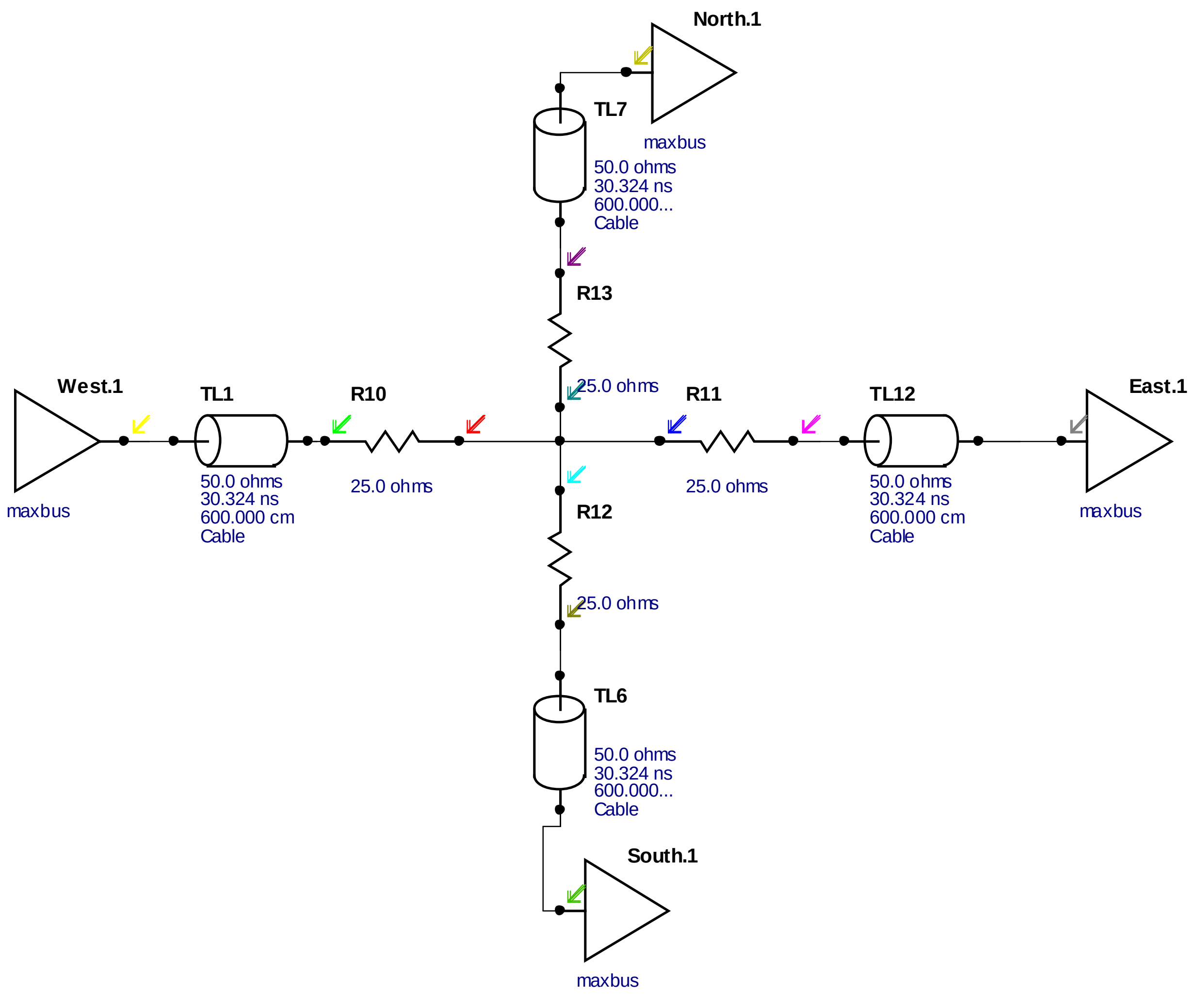
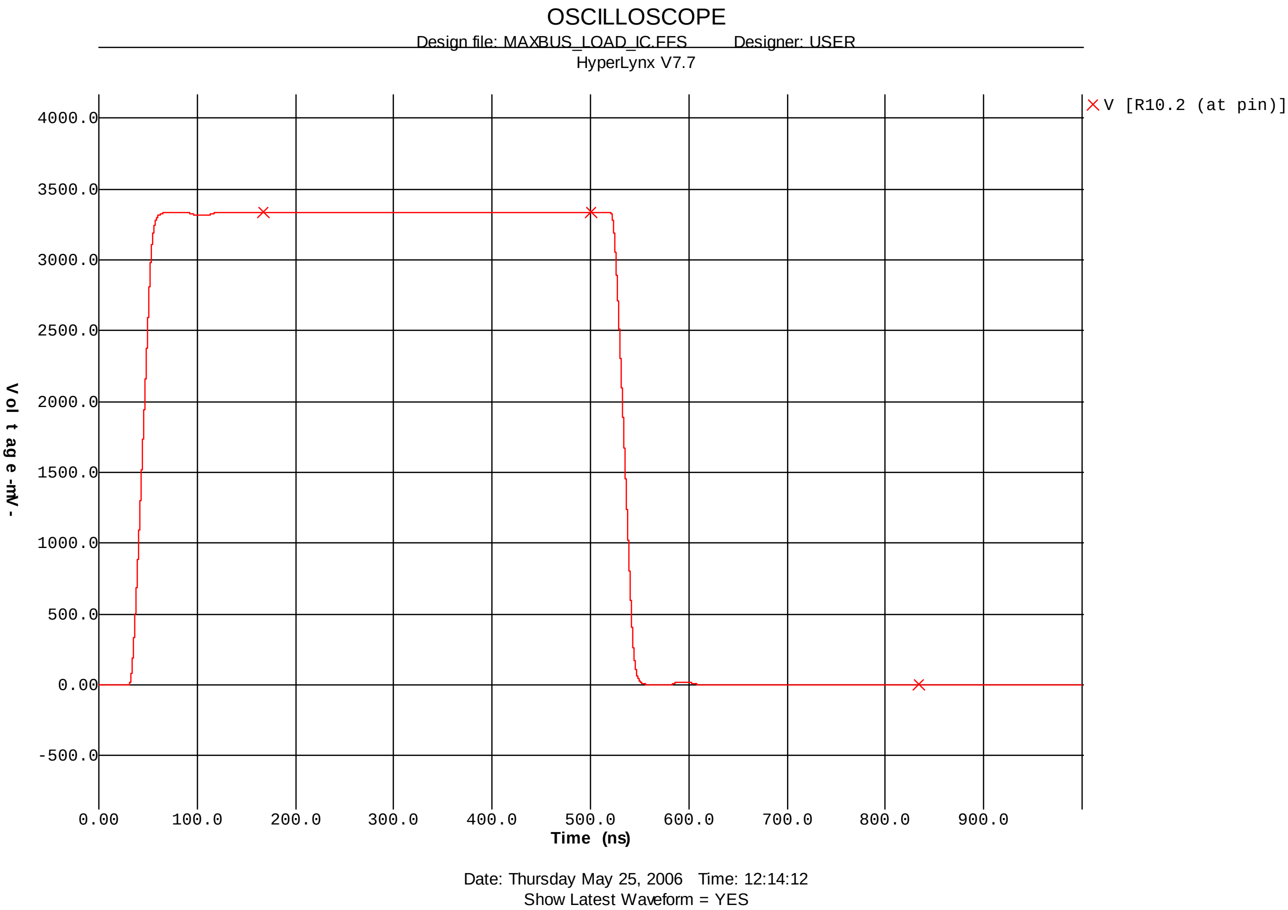
HyperLynx LineSim V7.7

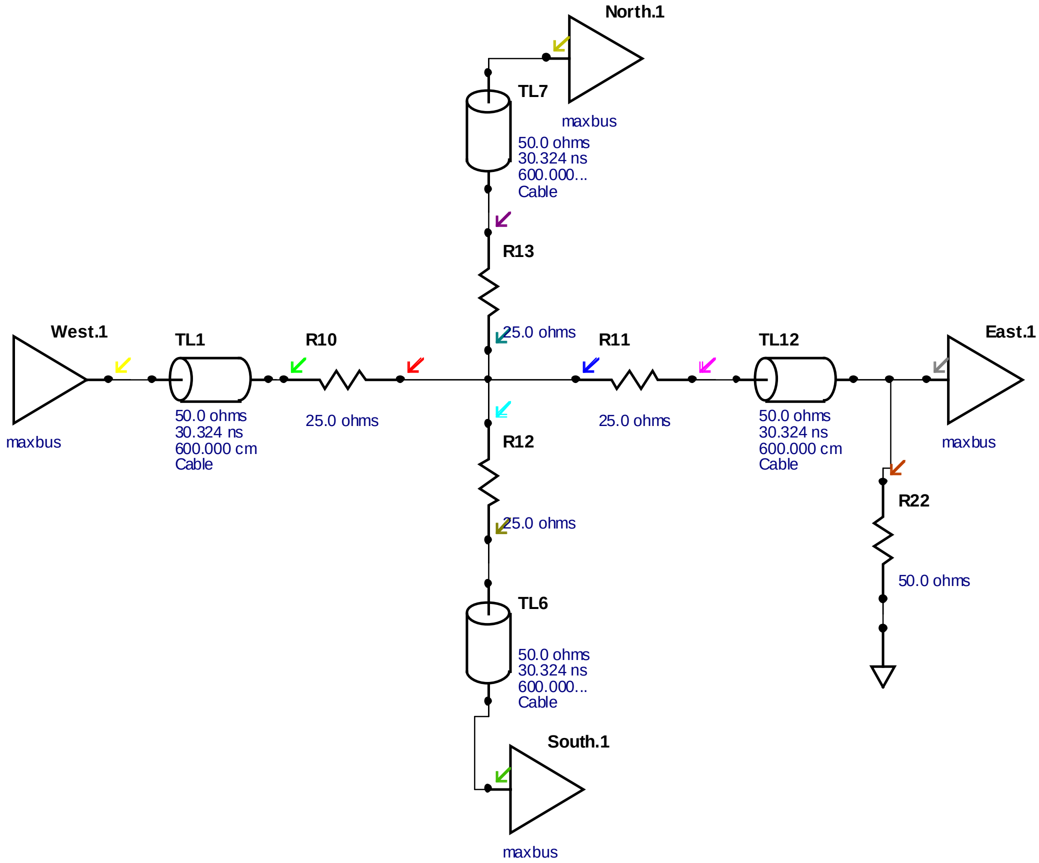


The wave detected on the coupler center in ideal bus condition is:

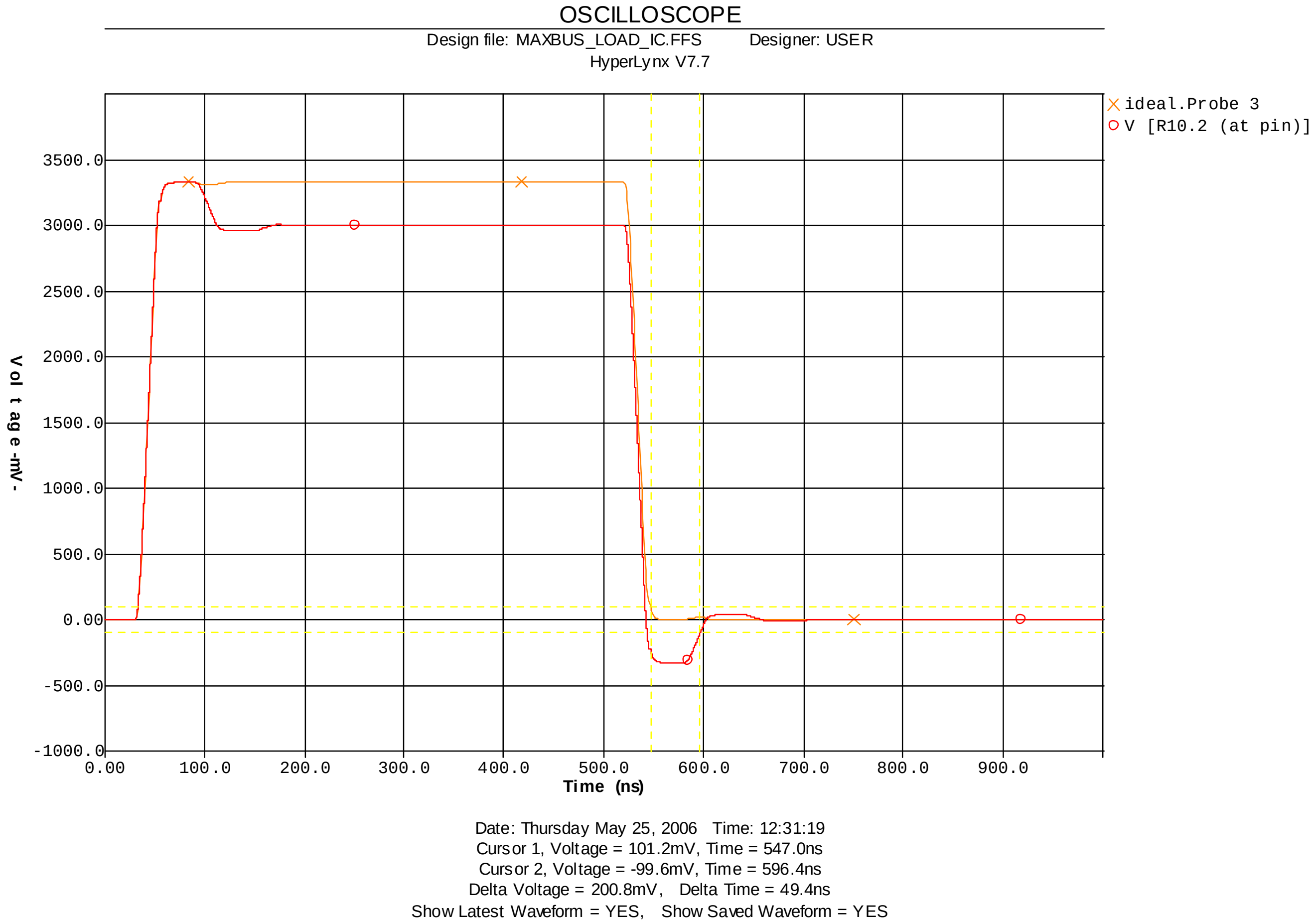


Bus defect #1:
The bus defect is an additional input 50-Ohm load in the connection with east unit.
The input impedance is now 25 Ohm.

Design File: maxbus_load_ic
HyperLynx LineSim V7.7



The signal detected in the coupler center is:



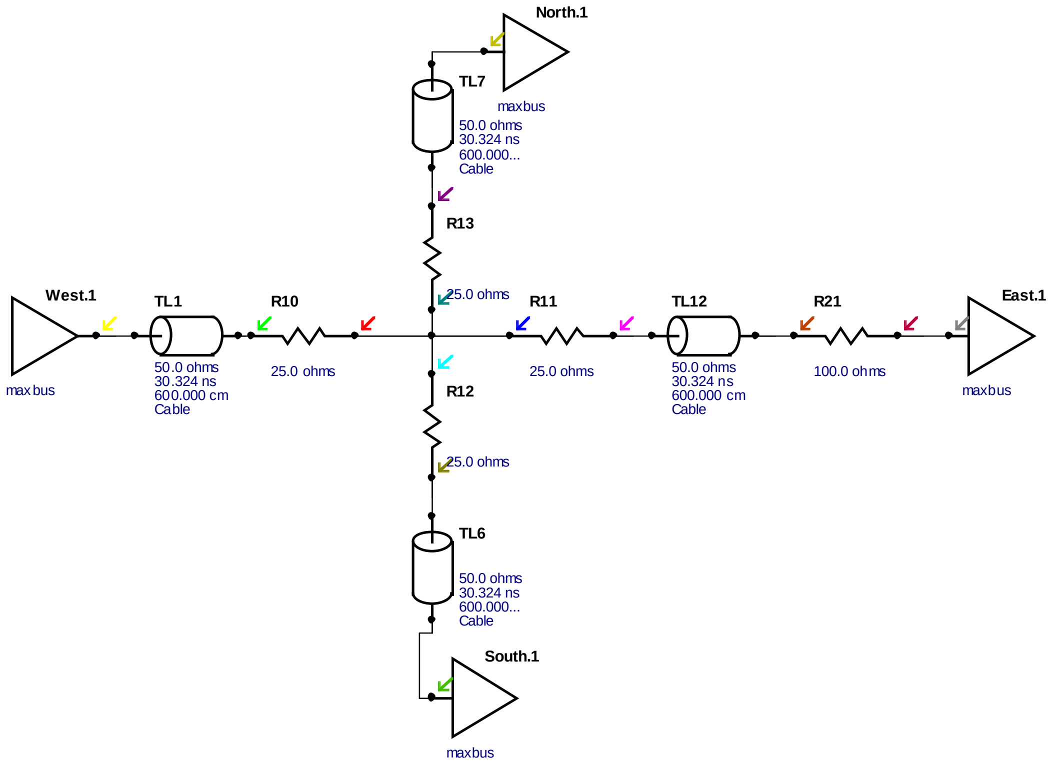
The orange line is the ideal bus signal.
The red line is the signal detected when the fault is introduced.

Results analysis:
As seen, after about 49 ns the echo signal with polarity opposite from the transmitted energy is added to the original transmission. The result is a step down in voltage in both time 100 ns and in 550 ns.
The tail is the energy that exists on the line from the ideal end point at about 550 ns, and stays at the same negative value for 49 ns (till 600 ns).
In this simulation the bus fault's impedance (25 Ohm) is lower than the wire's impedance (50 Ohm), thus the echo is of opposite polarity of the original transmission.
The length of the tail is ~50 ns, and is due to a fault with 12 meters (6+6) extra travel distance. The speed of the signal is 4/5 speed of light.
When the east unit transmits, the bus fault 50-Ohm impedance lowers the signal that goes to the bus, but does not create any echo because the rest of the bus is well coupled.
The "Tails Code Key" for this fault is 49 ns tail length for North South and West units, but 0 ns for east unit. So the fault is 12 meters/2 away from North South and West, but 0 meters from East unit.

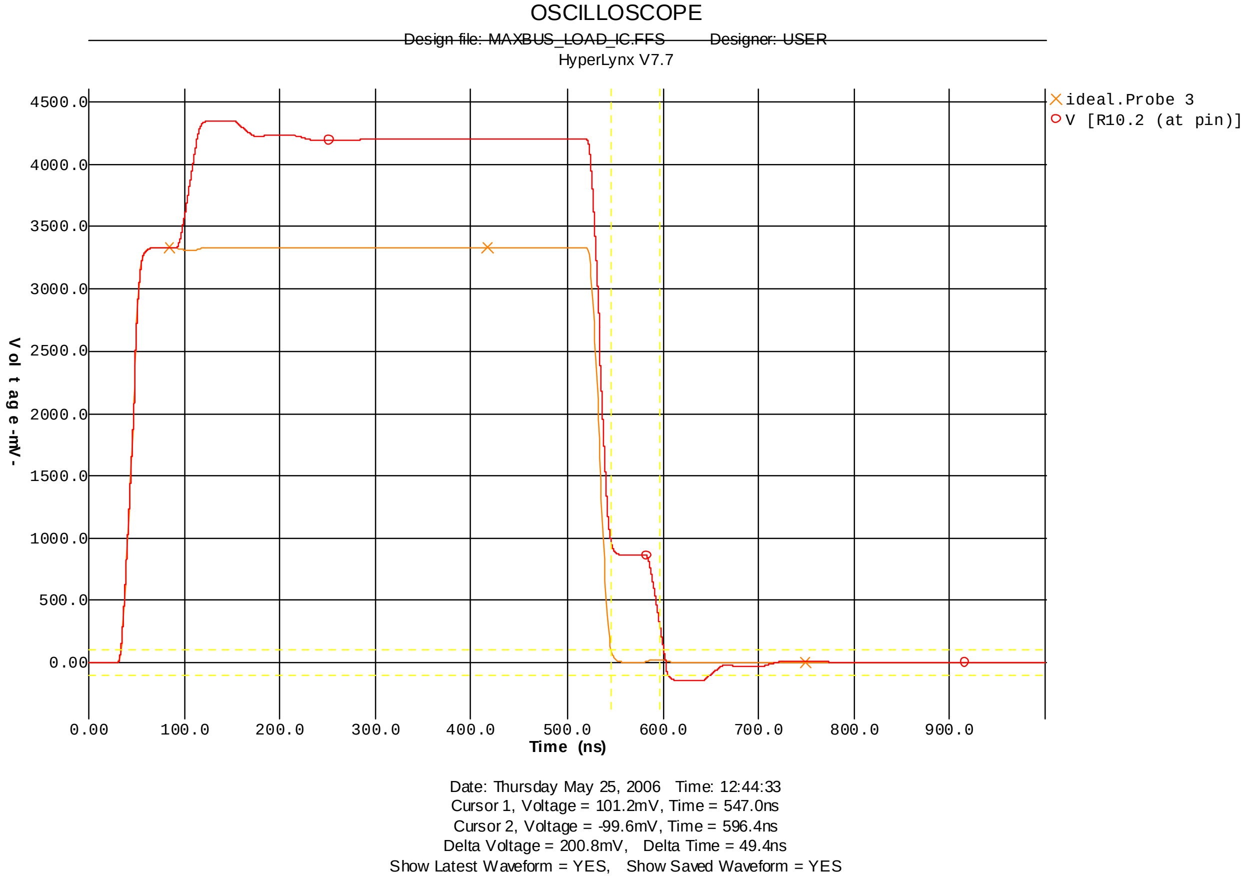
Bus defect #2:

The bus defect is an additional serial resistor of 100 Ohm in the connection with east unit. The input impedance is now 150 Ohm.

Design File: maxbus_load_ic
HyperLynx LineSim V7.7



The signal detected in the coupler center is:

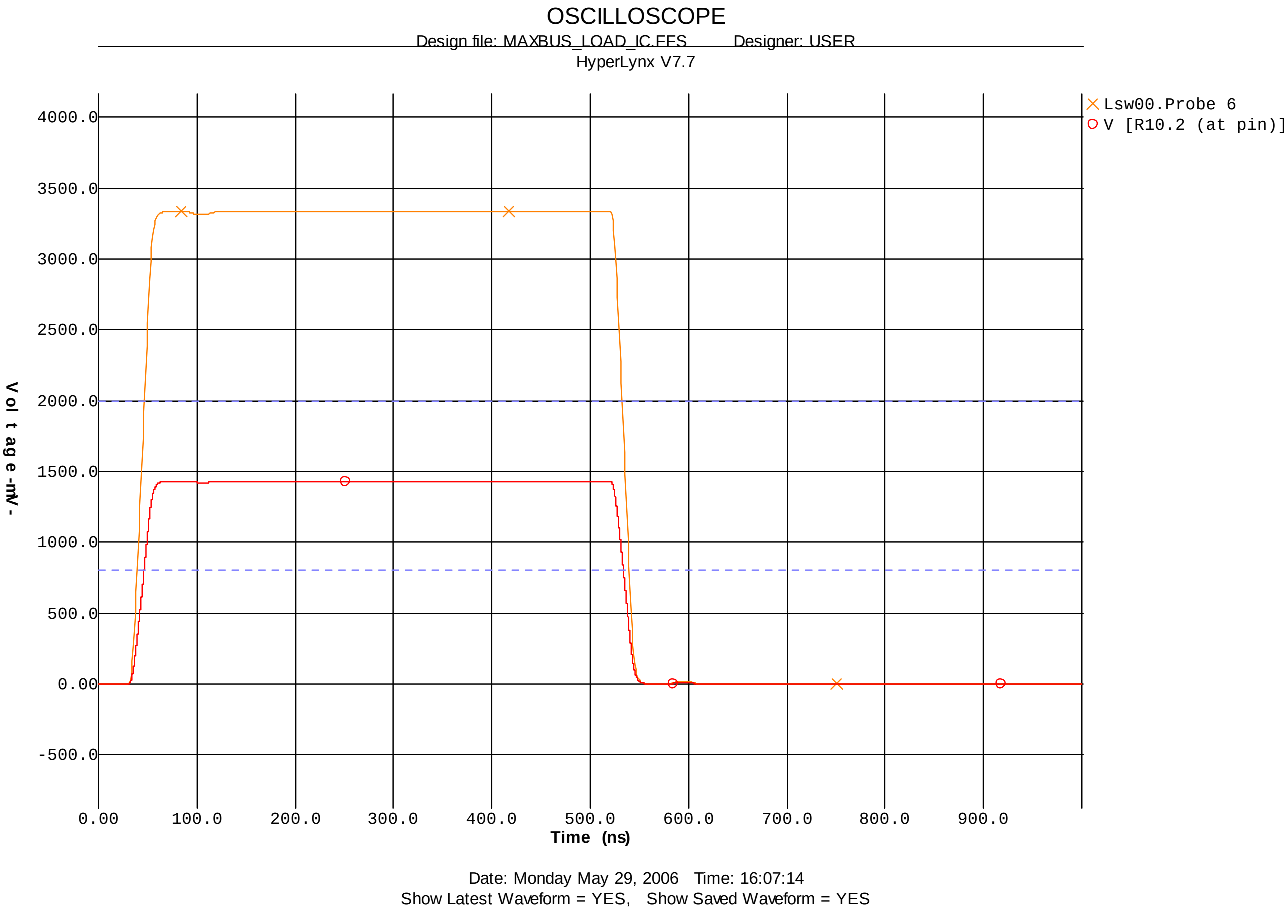


The orange line is the ideal bus signal.
The red line is the signal detected when the east resistance is higher.

Results analysis:
As seen, after about 49 ns the echo signal with polarity equal to the transmitted energy is added to the original transmission. The result is a step up in voltage in both time 100 ns and in 550 ns.
The tail is the energy that exists on the line from the ideal end point at about 550 ns, and stays at the same positive value for 49 ns (till 600 ns).
In this simulation the bus fault's load (150 Ohm) is higher than the wire's impedance (50 Ohm), thus the echo is of the same polarity of the original transmission.
The length of the tail is ~50 ns, and is due to a fault with 12 meters (6+6) extra travel distance.

When the east unit transmits, the bus fault 100-Ohm serial resistance lowers the signal that goes to the bus, but does not create any echo because the remainder of the bus is well coupled.

East transmitting:

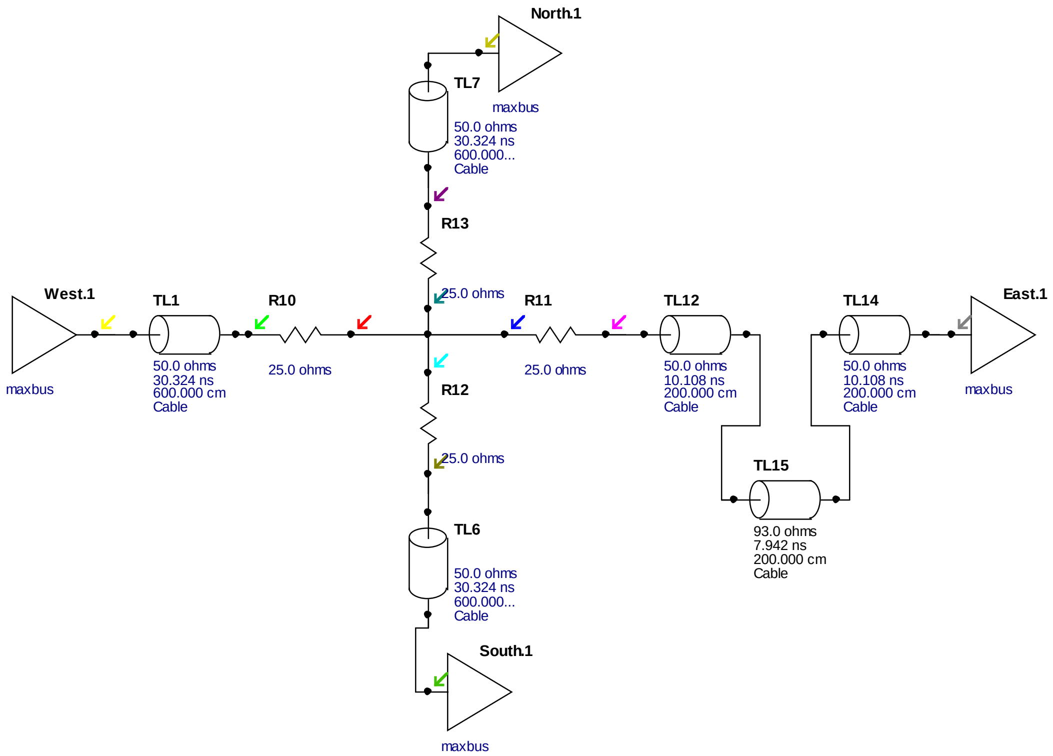


The “Tails Code Key” for this fault is 49 ns tail length for North South and West units, but 0 ns for east unit. So the fault is 12 meters/2 away from North South and West, but 0 meters from East unit.

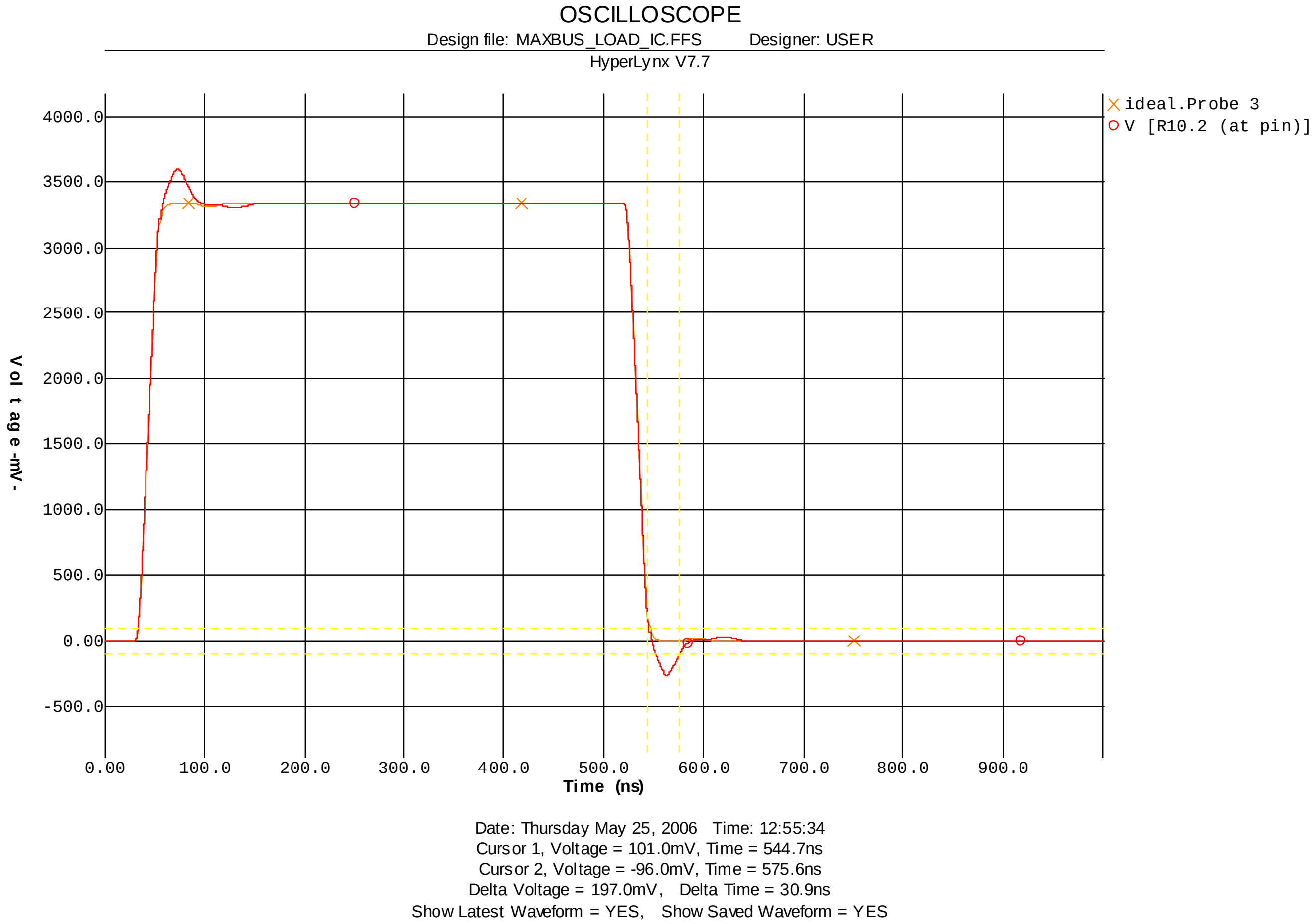
Bus defect #3:

The bus defect is 2 meters of the wrong cable (Z_0 = 93 Ohm) after 2 meters or correct (matched) cable, and after it, an additional 2 meters of correct cable. This fault represents a bad or damaged cable.

Design File: maxbus_load_ic
HyperLynx LineSim V7.7



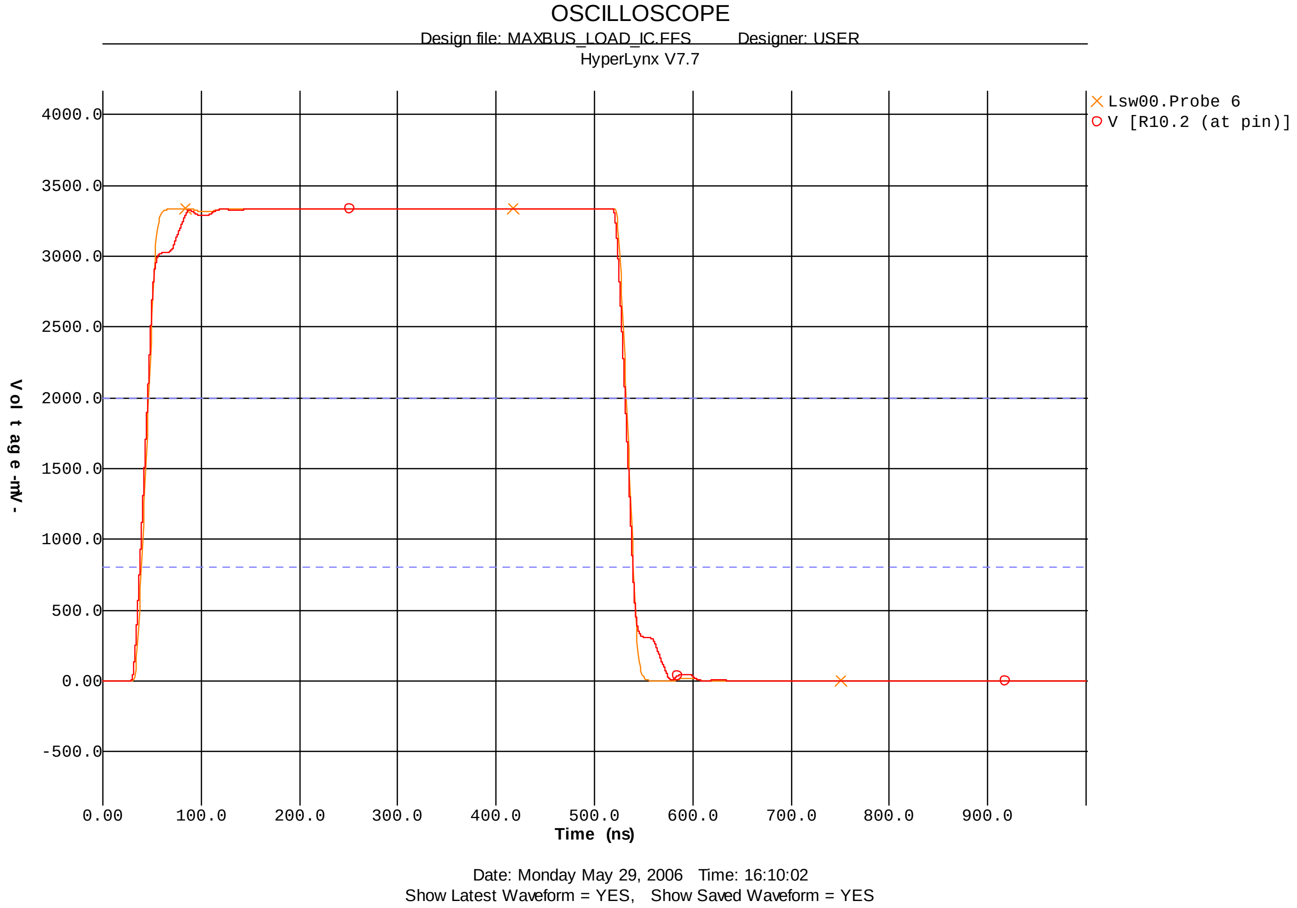
The signal detected in the coupler center is:



The orange line is the ideal bus signal.
The red line is the signal detected when the east cable is faulty.

Results analysis:
As seen, the cables now present a higher resistance than the 50-Ohm, thus the signal rises above the ideal orange signal. However that extra signal reaches the east unit's 50-Ohm load that sends an echo back with inverse polarity. The resulting signal measured on the bus is a tail of about 30 ns with inverse polarity is seen on the bus.

When the east unit transmits the reaction to the same bus fault is different. The resulting diagram can be seen in the attached diagram:



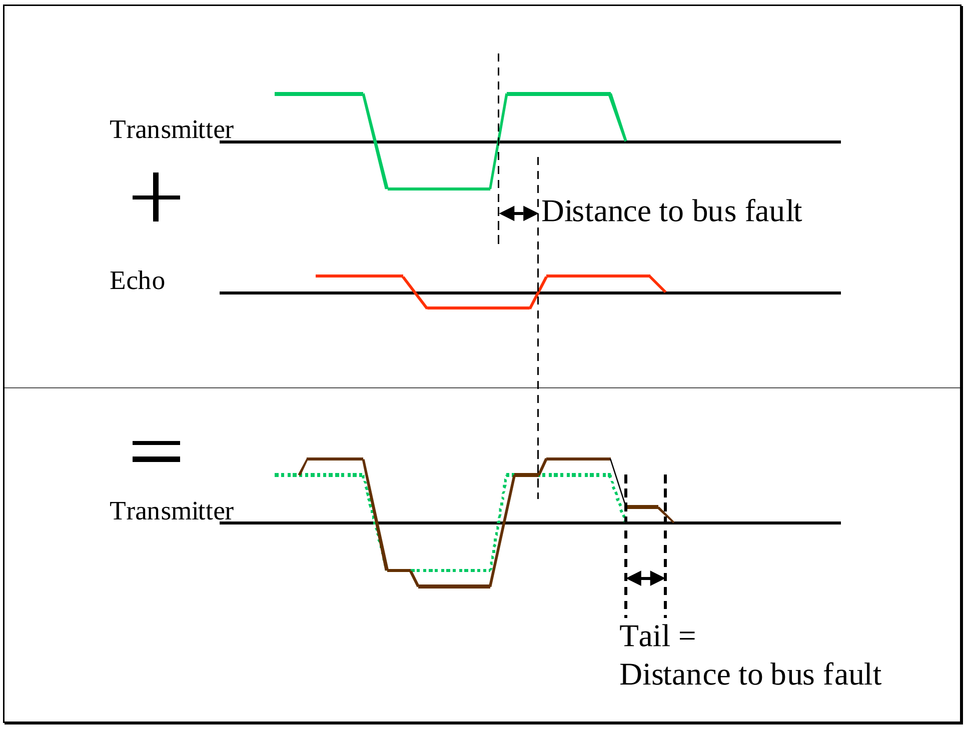
The same 30 ns tail is measured, however its polarity is positive value, i.e., added to the original transmitter.

Simulation conclusion:
"Tails Code Key" found a tail of 30 ns for all transmitters because the fault is located 2 to 4 meters away from all units.
In this case "Tails Code Key" found the same lengths of tail for all transmitters. If the same bus fault were in the west or north or south, the same "Tails Code Key" would be measured, which would be a problem. However, in most cases, buses are not symmetric as in this demo, so the "Tails Code Key" would be unique for all four faults.
If the bus is symmetric, it is possible to measure the polarity of the tail. When the fault is in the east, the east's transmission tail is in the same polarity as the original transmission, but the tail of all three other transmitters is of opposite polarity.

Appendix B: Tail analysis

This Appendix explains the wave results seen in Appendix A.

Fault's impedance higher than bus wire impedance:



Fault's impedance lower than bus wire impedance: