



Guide to the Last Mile

A Benchmark for VDSL Testing

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Introduction

Telephone companies (telcos) have been generating increasing levels of revenue out of their twisted-pair copper outside plant (OSP) cables by offering high-speed data services. These services are, in most cases, delivered from the telco's central office over fiber to a remote terminal and, from this remote terminal, to the customer over what is called the "last mile," a/k/a twisted-pair copper cable. The latest of these services is VDSL2. The stringent demands that VDSL2 place on this copper cable require specific tests to "qualify" it as being able to carry VDSL2. Test equipment has been designed to qualify this last mile of twisted-pair copper for VDSL and to fix the VDSL service if something goes wrong with it.

This booklet is written as a guide to assist the telecom technician in qualifying and maintaining twisted pair cable for VDSL service.

Factors that a technician may want to consider when selecting a piece of test equipment for qualifying twisted pair for VDSL service are addressed in the Appendix.

What is VDSL?

VDSL is the acronym for Very high-speed Digital Subscriber Line. It provides faster data transmission over twisted pair, which allows for the provision of high-bandwidth applications such as Internet Protocol Television (IPTV), Voice over Internet Protocol (VoIP), and very-high-speed internet access. VDSL works over twisted pair.

The first version, VDSL1, with its 1.2 MHz bandwidth and asynchronous data rates of up to a theoretical 16 Mbps upstream and 52 Mbps downstream, did not allow telcos to offer all the features that cable television companies offer, such as the ability to simultaneously view several HDTV programs. VDSL2, on the other hand, utilizes bandwidth up to 30 MHz to provide theoretical data rates up to 100 Mbps both upstream and downstream. While VDSL2 works on twisted-pair, it has to be **very good** twisted-pair. The challenge that telcos face is to ensure that the twisted pair in their system is capable of supporting VDSL2 service.

How does Triple Play (television, voice telephone and internet access) work on VDSL2? The International Standards Organization's (ISO) open system interconnection (OSI) 7-layer protocol stack defines a hierarchy of duties or tasks for establishing and maintaining a communications link across a network so that the applications that reside at the top layer (email, IPTV, VoIP, etc.) will work. We do not have to worry about what these are called and the differences between layers and the different methods of achieving the task of a particular layer. What we need to know is that each layer communicates with the layers directly above and below it and, through this, with its corresponding layer at other points in the network to establish a communications path.

Why the Old Ways Won't Work with VDSL

This section will cover why the old ways of testing and installing services are not conducive to having satisfied VDSL subscribers.

Telcos have deployed services on twisted-pair for years that required them to make alterations to their POTS (plain old telephone service) lines. In the 1970s they had to remove load coils to accommodate analog subscriber carrier. In the 1980s they had to remove bridged taps and load coils to offer a service called ISDN (Integrated Services Digital Network). Frame Relay debuted and the telco installer became involved not only in making sure that the twisted-pair (the physical layer) was very clean, but he or she might have to "go up the protocol stack" to install and troubleshoot the service. Finally ADSL came along which further tightened the rules about what kind of twisted pair was required. Despite all these changes in technology, telcos could select from available vacant plant a twisted pair that would work for these applications.

VDSL service is much touchier about what kind of twisted pair it will work over than any of the above services. Most ADSL1 service had the "blazing" data rate of 1.5 Mbps and telcos still had some trouble conditioning the twisted pair to handle it. VDSL2, as deployed in the U.S., has data rates of approximately 50 Mbps, or, about thirty times faster than ADSL1.

Telcos have been successful with these older services by having a reactive approach to maintenance. In simple terms, they try to install the service and if it doesn't work or if the subscriber complains, they look for another pair to use. As a last resort, they try to fix the problem. Now they have to become proactive when they implement VDSL for IPTV. As we'll discuss below, with the older services, a subscriber may not even be aware that the service is substandard. However, with real-time, very high speed services, the subscriber is aware of the smallest degradation of service. Consequently, the pair should be thoroughly tested (qualified) before this real-time, very high speed service is installed on it. The tech or the telco can't merely install it on a likely pair and, if the subscriber complains, switch pairs and hope that the subscriber doesn't complain again. If the tech finds a fault when conditioning a pair for VDSL2, he or she doesn't merely look for another pair. Rather, the tech finds and removes the fault.

Basic Testing Procedure

What are the elements of the VDSL network that we need to test? Basically, VDSL works by having a DSL modem or, for "Triple Play," a DSL router at the customer's premise connect to and communicate with a digital subscriber line access multiplexer (DSLAM) at the telco's central office or, more likely, at a remote cabinet that is connected to the central office via fiber. From our discussion above of the 7-Layer protocol stack, this DSLAM is a Layer 2 device. Layer 1 (the copper physical layer) must be in good condition for the Layer 2 DSLAM to work and the DSLAM must work before Layer 3 can work. A DSLAM is a large group of modems that combines the Ethernet signals received from the subscriber modems and multiplexes them into a single, in this case, Internet Protocol (IP) network and transmits this to the Broadband Remote Access Server (BRAS).

The BRAS is a Layer 3 device located at the center of the telco's IP network and combines the traffic from many DSLAMs. It routes this IP traffic to other BRASs in the telco's network or outward in the Internet to Internet routers. It is the BRAS that assigns the subscriber's IP address.

We'll cover specifics later but to outline the basics of the testing process for a VDSL2 circuit that does not work at all, the first step is physical-layer testing which determines whether or not the Layer 1 (twisted-pair copper OSP) is capable of handling a very high-speed digital service such as IPTV. The pair must be more rigorously tested than if it merely were going to be used

for voice-grade POTS. When a tech investigates trouble on a circuit with a DSL service, he or she must make sure that the copper, the physical layer, is in excellent condition before testing the service. If there is a physical-layer problem, it doesn't matter what condition the DSL equipment is in, because the service won't work properly. Once the technician is certain that the physical-layer is in good shape, he or she then goes on to test the service.

The second step is to verify that there is Layer 2 connectivity. Does the (subscriber premises) DSL modem work? Will it communicate with the (remote cabinet) DSLAM? Will they "sync"? This is accomplished by replacing, in turn, the modem and the DSLAM with known-good ("golden") modem and DSLAM and trying to sync. The tech also verifies that these devices are configured properly.

The next step is to verify that there is Layer 3 connectivity to and through the Internet. Does the BRAS connect to other BRASs in the network? Will it "surf"? The tech can determine this by trying to ping an IP address of a known server that is "on the other side" of the internet. If this is successful, the tech is said to be able to "surf."

The key to testing is to make sure it is done one layer at a time and that the technician works his or her way from the lowest layer (physical layer) upward. If a circuit won't surf, the tech does not start the trouble-shooting process by testing Layer 3 connectivity (trying to ping an IP address across the Internet). After all, it might not surf because it doesn't sync.

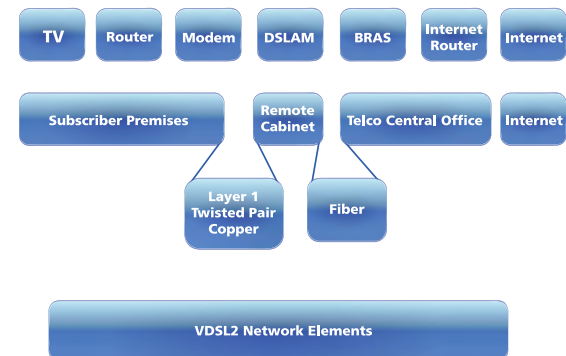


Figure 1: VDSL2 network elements

Characteristics of a Perfect Pair for Installing VDSL2 Service

Measured wire-to-wire (tip-to-ring or A-to-B) and each wire to the cable's shield (ground), a pair should have no DCV but ≤ 10 DCV is acceptable. If it has > 10 DCV, it could be crossed with a working pair.

Measured wire-to-wire (tip-to-ring or A-to-B) and each wire to the cable's shield (ground), a pair should have no ACV but ≤ 10 ACV is acceptable. If it has > 10 ACV, it might be dangerous and it is a source of noise.

Measured wire-to-wire (tip-to-ring or A-to-B) and each wire to the cable's shield (ground), the resistance should be close to the test set's reading of infinity but $> 3 \text{ M}\Omega$ is acceptable. The pair has a fault if the wires are shorted to each other or one of the wires is shorted to the shield by $\leq 3 \text{ M}\Omega$ because it is unbalanced and is susceptible to noise. It is also susceptible to corrosion.

A pair cannot have any load coils because they kill any signal above 4 KHz such as VDSL.

A pair should be balanced. Put simply, tip (A) should be a mirror image of ring (B). If it is not, the pair will be susceptible to noise which will reduce the data throughput, sometimes to the point of making the signal unintelligible.

The noise on the pair, measured across the spectrum used by the VDSL2 being tested (8, 12, 17 or 30 MHz) should be ≤ -60 dBm. Noise above this power will cause diminished data throughput or, in some cases, loss of signal.

Telcos sometimes state power levels in "decibels above reference noise" (dBrn) instead of "decibel above one milliwatt" (dBm). Using dBrn avoids the use of negative numbers. If noise specifications are stated this way, the conversion is:

$$0 \text{ dBm} = 90 \text{ dBrn}$$

$$-90 \text{ dBm} = 0 \text{ dBrn}$$

For measuring the power of noise and power influence on POTS (voice-band or < 4 KHz) circuits, telcos in the U.S. further refine dBrn by using a filter that mimics what the human ear can hear. As is discussed elsewhere, they don't want to measure noise that does not adversely affect the ability of the receiver to understand the information that was transmitted. This filter is called a "C Message" or "C" filter. The power level of noise so filtered is measured in "dBrnC". Places other than the USA use a slightly different filter to accomplish this by using what is called a psophometric filter.

There should be no impulse noise hits above -35 dBm on the pair. This is measured across the spectrum used by VDSL2 during a five-minute test. Impulse noise spikes cause pixelization errors and, when there are enough of them, dropouts.

VDSL2, as implemented following ITU G.993.2, has length limits. Data throughput of 50 Mbps can be achieved over a distance of 3,300 ft (1,000 meters) on a good copper pair and data throughput of 30 Mbps can be achieved at a distance of 3,500 ft (1,066 meters) on a good copper pair.

A pair cannot have bridged taps because they cause a decrease in data throughput.

There should be a very minimum of impedance changes along the pair. Impedance changes cause some of the signal to be bounced back toward the transmitter. This adversely affects the length over which the signal is intelligible.

Factors That Can Cause a Pair to be Ineffective for VDSL Service

There are several characteristics that would cause a pair to not qualify for VDSL2.

Breakdown of insulation resistance

As stated elsewhere here, the insulation on the conductors has to be good enough to prevent high-resistance faults. Insulation resistance can be compromised by:

- Being pierced with even a bed-of-nails connector can allow moisture to penetrate to the copper which causes corrosion and high-resistance faults.
- Water in the cable will cause not only a breakdown of insulation resistance but also changes the impedance of the pairs which causes reach and data throughput to be adversely affected.
- Not being careful when handling the pairs can cause the insulation of the conductors to be degraded. It can get nicked, abraded and otherwise damaged. The advantage of going to "ready access plant" as telcos did years ago is that any tech can access it. The disadvantage is that any tech can access it. It is not uncommon for technicians to be a source of trouble in the cable plant.

Grounding

Good grounds deteriorate over time allowing noise that would have otherwise gone to ground to enter the pairs.

- The actual grounding conductors (usually ground rods) can degrade by corroding, coming loose in the earth, or from tampering.
- The ability of the earth to conduct (resistivity) can change as the soil dries out such that a once-adequate ground in the wet season is no longer adequate in the dry season. Changes in topography such as grading, etc. can also cause this.
- It is even possible that an adequate ground was removed either accidentally or in a misguided attempt to reduce noise.
- Ground rods at the subscriber's location: the station protector or network interface device (NID) are part of the protection against lightening and power surges. They are tested to assure that they provide adequate safety protection. A maximum resistance value of 25Ω is considered low enough to assure safety. However, adequate noise reduction is not achieved unless that ground rod is bonded to the incoming power neutral. Also, safety is not assured unless the incoming power neutral is bonded to the subscriber's ground (station ground). Dangerous voltages can be present on the station ground if it is not so bonded to the incoming power neutral.
- Ground rods along a cable path, bonded to the cable shield, are effective for lightning protection, but frequently do not provide a low enough resistance path to be effective in reducing power influence or broadband noise (both discussed below) on cable pairs. This creates the need to periodically bond the cable's shield to the power company's multi-ground neutral (MGN) as described below.

Bonding

The bonds that electrically connect the cable shields together at a splice and may also connect the shields to a ground rod or to the power company's MGN can be degraded which, again, allows noise to enter the pairs that would otherwise have gone to ground. (Bonds can be installed incorrectly or not at all but the assumption here is that they were adequate at one time.)

A properly bonded cable shield keeps noise away from the cable pairs.

How does it do that? This properly bonded shield requires a low resistance conduction path from one end of a section of shield back to the other end of that section through a path outside the cable. This connection effectively shorts out voltage on the cable shield and allows a current to flow along the shield that is induced by magnetic fields from a near-by power cable or other noise sources. That induced current creates a magnetic field that opposes the magnetic field coming from power, this cancelling out longitudinal voltages on the cable pairs.

A ground rod bonded to the shield at each end of a cable section creates a shorting path between the ends of that shield. But, resistance on the ground rods can allow voltage to be present between the ends of the section. This voltage appears on the pairs that are in the cable. Consequently, a very low-resistance ground is required at each end of the section which is usually provided by bonding the shield to the power MGN. Since induced power varies along the length of the cable, it is important to divide the cable into shorter sections so that the shield is bonded to the MGN at least every 1,000 ft (300 meters) and also at each point where the exposure to power changes, such as where it branches.

Properly installed bonds deteriorate because:

- Over time mechanical bonds may loosen due to thermal changes and corrosion.
- Bonds are removed in order to use a cable locator. Sometimes they are not replaced.
- Bonds may be removed to check ground resistance. Sometimes they are not replaced.
- Bonds may be removed accidentally or in a misguided attempt to reduce noise.

Bridged tap

A section of cable pair that has been added between the "normal" ends of the pair is known as a bridged tap. Another pair has been "T"ed onto the original pair. This is very common and, in fact, it was standard operating

practice to use them in POTS. The dilemma is that they cause problems with services such as DSL. In VDSL2, bridged taps as short as 3 ft (1 m) reduce data throughput.

Load coils

On copper circuits in excess of 18,000 feet, capacitance of the pair causes high loss to voice frequency signals. The solution was to put load coils on these long circuits in standard locations along their length. Load coils are series inductors that reduce capacitance loss up to 4 KHz (voice band) but that also kill frequencies above 4 KHz. This was great for POTS circuits but it kills ISDN and DSL. While load coils are rarely installed today, there are LOTS of them left out there and they must be removed before any of the above-mentioned services will work.

Excess length

VDSL2 data throughput deteriorates quickly from a theoretical maximum of 100 Mbps at the source to about 50 Mbps at 3,300 ft (1,000 meters) and to about 30 Mbps at 3,500 ft (1,066 meters) over a good pair.

Impedance changes

Too many changes in impedance cause loss of range and data throughput problems. In addition to the changes caused by wet cable mentioned above, impedance changes are also caused by anything that changes the distance between the tip and ring (A and B) conductors such as:

- Single-wire splice connectors such as “B” connectors or Scotchlok® that, rather than splicing the wires of a twenty-five-pair group at once, would almost invite the tech to untwist the pair because he or she had to splice one wire of the pair at a time. The tech may have tried to squeeze the two wires of the pair together when the splice was complete. The tech may or may not have re-twisted them and, if he or she did, it is not likely that the twist was the same as in the rest of the pair.
- The connecting wires in a cross connect are the pairs that connect the two sides of a cross connect cabinet which might be untwisted or not sufficiently twisted. In addition to causing data throughput problems

because of the impedance change, these pairs are not only susceptible to crosstalk; they are a source of crosstalk in other pairs. When we think of crosstalk, we usually think of it as an audible signal in the voice frequency range. This crosstalk, however, is at VDSL frequencies. Telcos have programs to retrofit these cabinets with data-grade wire.

Unbalanced pair

This occurs when the tip (A) conductor is not a mirror image of the ring (B) conductor. It makes the pair intermittently susceptible to noise which inhibits data throughput. It is caused by:

Tip and ring (A and B) are not the same length which might, at first glance, seem improbable. After all, both conductors go from the transmitter to the subscriber. Consider an unbalanced bridged tap. This is where one of the conductors of the bridged tap has been removed but the other one was not removed.

Tip and ring (A and B) are not the same resistance which is caused by a high resistance fault on one of the conductors. The insulation of only one conductor may have been nicked which, over time, allowed it to corrode. Or, some corrosion occurred on one conductor at a splice point where the connector was improperly crimped.

The pair is being recombined. This is a splicing error where one of the pair's conductors, e.g. the tip (A), was spliced to the tip (A) of another pair, allowed to go on some distance and then spliced back to the original pair. Not only is there a length difference because of the different twist ratios of the two pairs, but there is an impedance mismatch.

Power company

Even with good grounding and bonding, a problem with the power company having a phase imbalance, inadequate grounding or a faulty transformer can cause so much induction that the circuit will be noisy.

Tests to Effectively Deliver VDSL Service

With a volt/ohmmeter, the following measurements are made:

- Wire to wire – tip-to-ring or A-to-B
- Each wire to shield - tip-to-shield [ground] and ring-to-shield [ground] or, A-to-shield [earth] and B-to-shield [earth]

AC volts

This is a major cause of noise. There should be almost no AC voltage on any cable pair that is not ringing. (Ringing voltage is between 70 ACV and 110 ACV.) If there is more than about 10 ACV on a line when it is not in ringing mode, check for bonding problems on the cable shield and for ground problems. In rare cases the pair may be crossed with AC. In any case, the AC needs to be removed. (Some telco-specific volt/ohmmeters provide a user-selectable option of a 100 K Ω or a 3 M Ω termination. Select 3 M Ω .)

DC volts

A non-working pair ideally should have no DCV. If it has over 10 DCV, it could be crossed with a working pair.

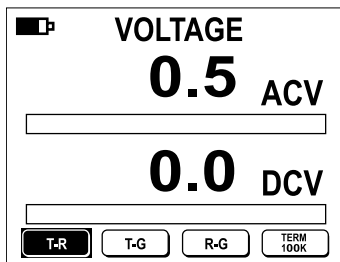


Figure 2. Sample of volt/ohmmeter test display

Resistance

The insulation on the wires of the pair that is being qualified for VDSL ideally would have no shorts; the tip-to-ring (A-to-B) and tip-or-ring-to-shield (A-or-B-to-shield) resistance would be infinite.

- Tip-to-ground (A-to-earth) and ring-to-ground (B-to-earth) would be completely open.

- The conductors of the pair (tip and ring or A and B) would not be shorted to the cable's shield or to any other ground.

As a practical matter, however, resistance readings >3 M Ω are acceptable.

There are two ways to measure insulation resistance; the first is with a standard low resistance ohmmeter (found in multimeters).

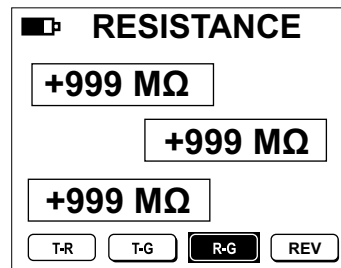


Figure 3. Sample of resistance test display

The second way to measure insulation resistance is by a "leakage test." This tests insulation resistance at 150 DCV which is higher than the normal operating voltages in order to determine the likelihood of a future breakdown in insulation (a high resistance fault) and/or to bring about such an impending failure while the tech is on site and can locate and repair the problem.

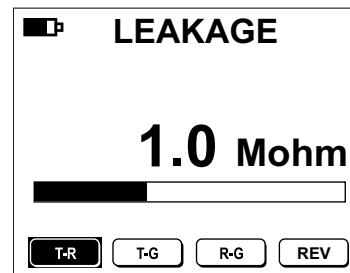


Figure 4. Sample of leakage test display

As with the volt/ohmmeter insulation resistance test discussed above, if there is ≤ 3 M Ω insulation resistance, there is a fault.

While these insulation resistance tests will determine if there is a high-resistance fault, they will not locate it. A resistive fault locator will locate the fault.

Resistive fault locator (RFL)

A multimeter can find hard, or “metallic”, faults. These are dead shorts and wide opens. Because, at a given temperature, the resistance per foot of each gauge of wire is known, distance to hard faults can be calculated.

Other faults, resistive faults, are high resistance. Metal does not touch metal. These resistive faults make up the majority of faults in OSP. They are what we are looking for with the leakage test; an insulation resistance test. While the leakage test can indicate that we have one of these high resistance faults and its severity, it doesn’t help us locate it. A TDR won’t find it either, however, an RFL will find faults of <2 MΩ on a pair or a single conductor.

If a tech has at least one good wire (preferably a pair of good wires) in the same cable as is the faulted pair, he or she can determine the location of the fault. Because resistance of metal varies with the temperature and the size of the conductor, the tech must know the gauge of the conductors and the temperature of the cable. The test requires that a strap be used at the end of the cable away from the test set. Modern RFL sets have diagrams showing the tech how to set up and perform the test as shown in Figure 5.

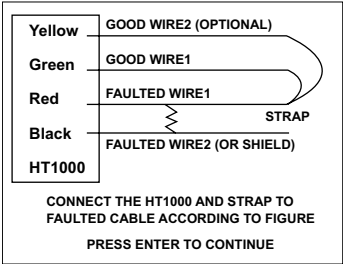


Figure 5. Sample of RFL test display

Figure 6 shows a result screen when the RFL test is complete. The abbreviations are:

- DTS – distance to strap (from the test set to the other end)
- DTF – distance to fault (from the test set)
- FTS – Fault to strap

The screen in Figure 6 shows the fault-to-strap distance was calculated by subtracting distance-to-fault from distance-to-strap. This is done when only one good conductor is used. If a pair of good wires (instead of a single wire) had been used, the fault-to-strap distance is actually measured electrically and the display would indicate the result was “verified.” This latter method allows the tech to know whether the readings make sense: does distance-to-fault added to fault-to-strap equal distance-to-strap?

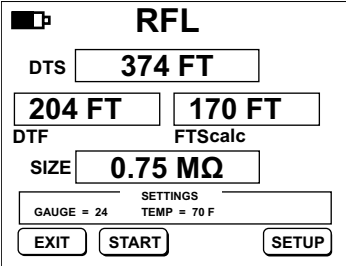


Figure 6. Sample of completed RFL test display

Load coil detection

The requirement for a DSL circuit is that it have no load coils. Presence of ACV or DCV on the pair can inhibit the ability of a test set to detect the correct number of load coils so, if relevant, it is recommended that central office battery be removed before testing.

A load-coil-detecting function in a test set display will show the number of load coils detected. A waveform graph also may be displayed. The number of dips in this waveform corresponds to the number of load coils. The waveform does not, however, indicate the distance to the load coils. A TDR will give the distance to the first load coil (covered in the next section).

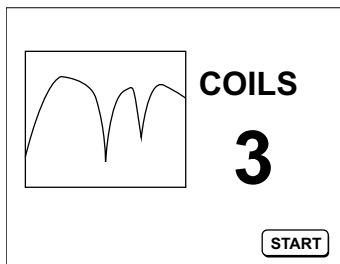


Figure 7. Sample of load coil test display

Balance

The pair should be balanced. Tip (A) should be a mirror image of ring (B). The tech determines the extent to which a pair is balanced by looking at the symptom of imbalance; the level of noise on the pair. We will consider:

- Voice-band noise
- Voice-band power influence
- Longitudinal balance
- Stress

While the need to measure the first three is largely replaced by the stress/super stress test, we still need to understand them.

Voice-band noise

From the field, a tech connects to a quiet termination line, (by dialing a special number) in the central office, that produces dead silence. Noise on the circuit is then measured between tip and ring (A and B). Any noise that the tech measures has to be from the OSP portion of the circuit under test. Since vacant pairs are not connected to the network, this measurement cannot be made on vacant pairs because of the need to have a working pair to access a quiet termination number. Passing noise measurements are ≤ 60 dBm.

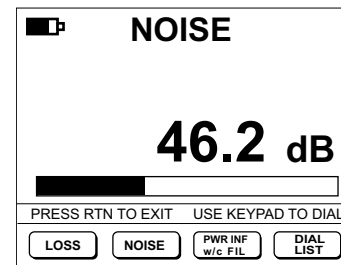


Figure 8. Sample of noise test display

Voice-band power influence

Power influence is the noise that is caused by AC induction on a cable or pair. If the cable's shield is bonded together and periodically bonded to ground, this induced AC goes to ground and does not find its way onto tip and ring (A and B). To perform the power influence test, tip and ring (A and B) are shorted and the noise is measured to the shield. In a "balanced pair," tip and ring (A and B) are mirror images of each other. In such a balanced pair, the noise due to power influence is not audible. In an unbalanced pair, the noise is audible. Acceptable power influence readings for VDSL are ≤ 90 dBmC. Unacceptable levels of power influence are typically caused by poor bonding and grounding of the cable shield.

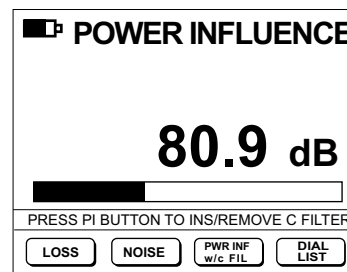


Figure 9. Sample of power influence test display

Longitudinal balance

As previously discussed, if tip and ring (A and B) of a cable are not alike (if they are “unbalanced”), the pair is susceptible to having noise induced onto it. Telco engineers have, therefore, long been on a quest to be able to easily determine how balanced a cable pair is; how alike tip and ring (A and B) of that cable pair are. Longitudinal balance, dating from the 1970s, gets at this. It is a calculated number arrived at by measuring power influence (discussed above) on a circuit and then measuring circuit noise (discussed above) on the same circuit. Circuit noise is subtracted from power influence. A passing longitudinal balance number is ≥ 60 dB or as high as possible while passing the power influence and noise tests.

But, the point is that longitudinal balance does not really give an indication of how alike or how balanced tip and ring (A and B) are. They merely provide an indication of how noisy a pair is only at the time the measurements are made.

Longitudinal balance varies by time of day and season of the year because power influence does. Therefore, a tech might get a passing longitudinal balance number one time and a failing one another time. Longitudinal balance tests are not repeatable. An unbalanced pair may only be noisy when the garage door goes up or when the air conditioner is running while the washing machine is running or when a light with a bad ballast is turned on. If the tech doesn't do the longitudinal balance test while that condition exists, the circuit will not fail the test.

Stress test

Very simply, the stress test puts a known constant amount of power influence on the pair and then measures the resultant noise. Stress provides a very good indication of the extent to which tip and ring (A and B) are mirror images of each other; the extent to which they are balanced.

Stress overcomes the disadvantages of the longitudinal balance test:

- The stress test results do not vary when power influence changes. It is repeatable.
- The stress test can be used on vacant pairs because there is no need to dial into a quiet termination line to use it.

Readings for stress vary from telco to telco so the following thresholds are a guideline:

Good: < 20 dBm

Marginal: 20 to 30 dBm

Bad: > 30 dBm

If the pair fails the stress test, it is unbalanced. Tip (A) is not a mirror image of ring (B). Reasons why the pair fails include:

- One conductor of the pair may be longer than the other. If the open meter test (discussed below) were performed, tip-to-shield (A-to-shield) length would be different than ring-to-shield (B-to-shield) length.
- A split pair will cause the pair to be unbalanced. A TDR will show where the split is. Use a tone and probe to identify the actual wires involved. Listen for tone carry-over on adjacent conductors. The tone on the split conductor will be louder than the tone on adjacent conductors.
- A series resistance fault in tip or ring (A or B) will cause an imbalance. Short and ground the pair at the far end. Using a multimeter test, measure the resistance of each side to ground. The highest reading is the series fault. The fault can be located using a TDR (discussed above).
- A short between the conductors is a fault but it does not cause an imbalance because tip and ring (A and B) are equally affected; they are still mirror images of each other. This short will not cause a stress/super stress test to fail. These faults can be located with a TDR.
- One of the conductors being shorted to the shield (called a “ground”) will, however, cause an imbalance which will cause the stress/super stress test to fail. An RFL will locate a ground.

Noise

The noise on the pair, measured across the spectrum used by VDSL2 (up to 8, 12, 17 or 30 MHz), should be < -60 dBm. We have discussed noise as the symptom of an unbalanced pair. There are some other helpful ways to look at noise. But, there are several questions to consider when tackling noise.

- Is it relevant? Is its frequency such that it will interfere with the signal?
- How powerful is it? Is it powerful enough to interfere with the signal?
- Is it constant or intermittent? If it is intermittent, is it extremely short duration spikes?
- Where is it coming from? How do we get rid of it?

Voice-band spectrum analyzer

This is the first test tool we'll consider. When noise or power influence is measured, the result is a reading of the power (dBm) of that noise. In trying to find the source of that noise, knowing its power level is not much help. The tech needs to analyze that noise to find its frequency in order to determine whether the noise comes from AC and/or its harmonics (outside the cable) or from crosstalk (inside the cable). That is what a spectrum analyzer does. It is a graphical representation of the noise with the frequency of the noise on the horizontal axis and the amplitude of these frequencies on the vertical axis.

Before further discussing the spectrum analyzer, let's review the two ways of measuring noise from above. The first is "Power Influence" (PI). This is measured by shorting tip and ring (A and B) and measuring them to ground or "longitudinally". The second is "Noise Metallic" (NM) or simply "Noise". It is measured between tip and ring (A and B) and is done on a voice-band spectrum analyzer by connecting the analyzer's leads to tip and ring (A and B) of the pair.

When there are high power influence (PI) readings, the cause is almost certainly bad grounds and bonds or noise from the commercial power ground getting into the telco ground. A telco practice of tying the cross-connect cabinet's ground to the power-pole MGN might cause high power influence if the MGN is open, causing power neutral current to travel back toward the substation on the telco neutral. If there is high PI, the tech looks at the power influence spectrum analyzer to verify that it is 60 Hz or a harmonic. This is done on the analyzer by connecting the black lead to tip (A) and the red lead to the cable shield and leaving the green lead, if the analyzer has one, disconnected.

As we've said, a good circuit will have ≤ 30 dBm of noise. If there is high NM, the spectrum analyzer is used to look at the frequency of the noise to see if it is from PI (60 Hz and its harmonics) or from something else; something that is coming from within the cable itself such as crosstalk. Remember that NM is between tip and ring (A and B). It is inside the cable.

If the pair being measured is well-balanced, the NM should be low no matter how high PI is. However, if there is high PI (on this well-balanced pair) and low noise, there will be problems with VDSL2 because the high PI number indicates problems with grounds. This means that there is likely to be impulse noise (more later).

The tech can compare information from both spectrum analyzer graphs (Power Influence and Noise Metallic) to determine the cause of noise problems.

A voice-band spectrum analyzer screen displaying approximately a -45 dBm noise source at 1,344.1 Hz is shown in Figure 10.

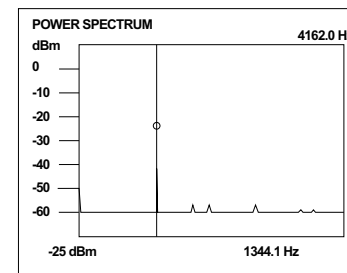


Figure 10. Sample of voice-band spectrum analyzer display

Wide-band spectrum analyzer

A wide-band spectrum analyzer is used much like a voice-band spectrum analyzer. The latter is useful in determining if commercial AC noise is present but it doesn't show noise across the frequency band occupied by VDSL. The wide-band spectrum does that. (Unlike ADSL2, VDSL2 does not have a fixed bandwidth. VDSL2 has different "band plans". The bandwidth can be 8, 12, 17 or 30 MHz. Even within these bandwidths, there are different versions [8a, 8b, 12a...].) The point is that the tech wants to look for noise within the frequencies relevant to the VDSL2 that he or she is working with.

The shape of that noise on the wide-band spectrum analyzer can help identify its source. In general, if the noise is spread widely across the spectrum, it is likely from crosstalk which is from inside the cable. If there are spikes or if the noise is concentrated at the low end of the spectrum, it is from outside the cable and is caused by bonding and grounding problems.

A wide-band spectrum analyzer showing noise up to 33.2 MHz with about a -32 dBm noise spike at 1.42 MHz and a noise floor at about -75 dBm appears in Figure 11.

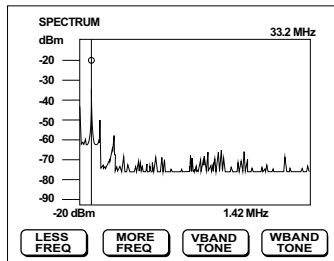


Figure 11. Sample of wide-band spectrum analyzer display

Impulse noise

When we were outlining the questions with respect to noise above, one of the questions dealt with whether the noise was extremely short duration spikes. These very short duration spikes of noise are called “impulse noise.” This impulse noise poses a special threat to a digital communication system. If a spike of noise could make the receiver of such a system not understand whether a plus or a minus had been transmitted, the whole string of digital information might have to be retransmitted. There are algorithms that can correct one or two such errors. But as bit rates increase, the “time” or “space” of a single bit gets smaller and smaller and the same size impulse noise spike can knock out more information. This makes it more likely the whole block of information will have to be retransmitted. In the world of data communications technology such as ADSL, the result of this is that the subscriber merely sees a slowdown in effective data rate.

While impulse noise caused problems to data services such as ADSL, that service is structured so that such problems only cause the effective data rate to be reduced. Consequently, the subscriber may not be aware of the problem.

With telcos introducing very-high-speed real-time services such as IPTV, impulse noise becomes very important for two reasons. The first is that these services have very small bit times so a relatively small impulse-noise spike would knock out more data. The second is that these services are real-time. In other words, the data cannot be retransmitted so the effect is not masked by merely having the effective data rate go down. The subscriber immediately sees the effect of the impulse noise spike in the form of pixelization or even picture dropout. Sometimes the transmission equipment even has to “reset” itself by retraining.

Background

These very-high-speed services use modern video protocols that “compress” data to get more and more video channels out of the same bandwidth. To perhaps oversimplify it, they make every bit carry more and more information. This makes the loss of a few bits have a disproportionately large impact.

While a growth industry recently has been in mitigating the effects of impulse noise, telcos have known for over a hundred years that shielding their cables and grounding these shields will eliminate noise on a balanced pair. Some telephone people are relearning this fact.

What is an impulse noise test?

An impulse noise test detects and counts noise spikes or “hits” over a period of time and displays the results numerically

How impulse noise is measured

There are several variables for the tech to determine and, in some cases, set when measuring impulse noise. Among them are:

Measurement filter

When we want to measure the noise that affects what our ears hear, we use a filter that behaves as our ears do; one that does not pass anything below about 400 Hz or above 4,000 Hz. Basically, it rejects noise that our ears cannot hear. We would not want to say that an audio circuit was bad because it had noise in the 50 KHz range; noise that we cannot hear. So, we disregard noise that we cannot hear. When we measure impulse noise we are

concerned only with noise that will adversely affect the service on the circuit under test. So, test sets that measure impulse noise use different filters to reject this noise.

"F" – for HDSL – from 5 KHz to 245 KHz

"G" - for ADSL – from 20 KHz to 1.2 MHz

"J" – for ADSL2 – from 20 KHz to 2.2 MHz

"Max" – for VDSL2 – from 20 KHz to 30 MHz

Test time

How long do we want the test to run? Back in "the day" ('70s and '80s) impulse noise tests for such things as radio remote-broadcast circuits and circuits that carried TV broadcasts for the networks were run for hours and even days. After all, impulse noise varies over time like other power-influence noise. A common standard for VDSL now is that there are no hits during a 5 minute test.

Trigger level

Impulse noise test sets automatically set power thresholds for impulse noise detection. This is called the "trigger level." Some test sets have additional trigger levels at both 3 dB above and below the "main" trigger level and then separately count hits that reach all three of these. This allows the impulse noise hits to be "qualified." A threshold of -35 dBm is generally accepted.

There should be no impulse noise hits during a five-minute test. If the pair fails the impulse noise test, the likely culprit is bad grounding or bonding that is allowing the noise spikes into the pair instead of taking them to ground.

Figure 12 shows a sample of an impulse-noise-test screen for a test with a "G" filter (20 KHz to 1.2 MHz) that has been running for 29 seconds and has recorded 5 hits at the main trigger level of -45 dBm with 7 hits at -48 dBm and 1 at (the noisier) -42 dBm.

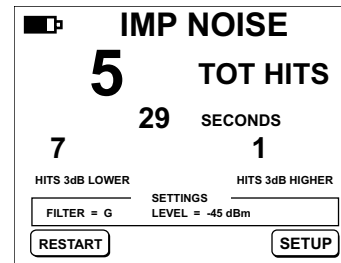


Figure 12. Sample of impulse noise test screen display

Length measurement

Data throughput on VDSL2 of 50 Mbps can be achieved over a distance of 3,300 ft (1,000 meters) on a good copper pair and data throughput of 30 Mbps can be achieved at a distance of 3,500 ft (1,067 meters) on a good copper pair. So, there is a limit on the length of a pair being qualified for VDSL2.

Length of a cable pair can be measured electrically in three ways:

- Resistance – Discussed above in "RFL" section
- Impedance – Discussed later in "TDR" section
- Capacitance – Discussed below in "Open Meter" section

Open meter

A capacitor is two conductors separated by an insulator. So, a pair of wires, as well as one wire and the cable shield, are both capacitors. In other words, there are three conductors: tip (A), ring (B) and shield. Therefore, there are three capacitors:

- Tip-to-ring (A-to-B)
- Tip-to shield (A-to-shield)
- Ring-to shield (B-to-shield)

The capacitance of OSP cable in the USA is engineered to have values of:

- Tip-to-ring = 0.083 $\mu\text{F}/\text{mile}$ (microfarads per mile) or, A-to-B = 0.0516 $\mu\text{F}/\text{km}$ (microfarads per kilometer)
- Tip-to-shield and ring-to-shield = 0.125 $\mu\text{F}/\text{mile}$ or, A-to-shield and B-to-shield = 0.078 $\mu\text{F}/\text{km}$

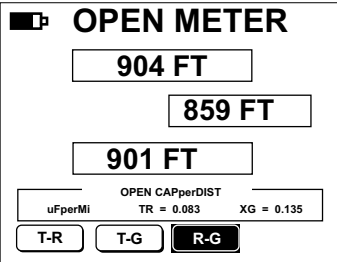


Figure 13. Sample of open meter screen display

(Note that drop wire, inside wire, etc. is not engineered to have this capacitance and their length cannot be measured with an open meter unless their capacitance per foot (meter) is known and the open meter allows that capacitance to be input.)

The amount of capacitance of two conductors is proportional to their length. An open meter simply measures the capacitance and does the arithmetic to convert that to length. It is able to measure the length of any one of these conductors against any other. The tech does not need to know the temperature or gauge of the wire or how fast an electrical signal moves along the pair so the open meter is easier to use for length measurements than are the other two methods discussed that are based on resistance and impedance.

The tech is not so much interested in tip-to-ring (A-to-B) length as he or she is in tip-to-shield (A-to-shield) length and ring-to-shield (B-to-shield) length and making sure that they are the same. If they are not, the shorter one is open. (The shield goes as far as the longest wire does.)

Therefore, the tip-to-shield (A-to-shield) length and the ring-to-shield (B-to-shield) length must be almost equal and less than 3,300 ft (1,000 meters) for a data throughput of 50 Mbps and less than 3,500 ft (1,066 meters) for a data throughput of 30 Mbps.

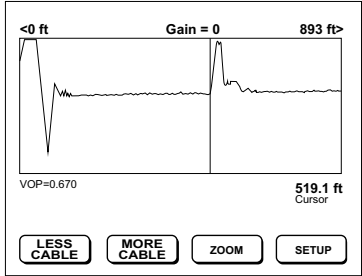


Figure 14.

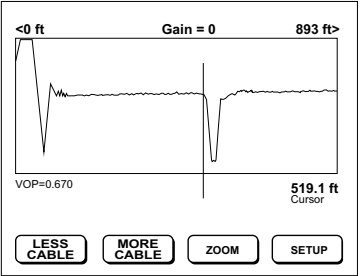


Figure 15.

Time Domain Reflectometer (TDR)

The impedance of a pair changes when the distance between tip and ring (A and B) changes or when the material (air, water, jelly) that fills the cable changes. A TDR detects these changes in impedance and, without going deeply into how, gives the distance to the impedance changes. Very simply put, a TDR operates by sending pulses of energy down the wires and timing how long it takes for them to get back after being reflected by an impedance change. The TDR knows how fast these pulses travel because the tech has input that speed. By knowing how long a pulse has been gone and how fast it is moving, the distance covered by the pulse can be calculated. A simple rule for interpreting a TDR trace is that the impedance and the trace go up as tip and ring (A and B) move apart, as seen in Figure 14, and they go down as tip and ring (A and B) move closer together, as seen in Figure 15. In order to qualify the last mile of copper for VDSL2, a tech isn't using a TDR to locate shorts, opens, splits and wet cable at long distances. That tech is now looking for changes in impedance that didn't cause problems for POTS. And, while those "old" faults do cause the impedance to change, the tech is now looking for different kinds of "faults" that also cause a change in impedance and a reduction in data throughput in VDSL2. The tech is now looking for the following conditions:

Bridged tap

In the past, long-range TDRs were the ones that sold most because they helped locate the faults that caused problems for the OSP of that day; opens, shorts and wet cable at a relatively long distance away. Those TDRs did show bridged taps but because of the nature of the TDR-trace dead-zone, short ones were masked by the dead zone that follows the splice that created the bridged tap. A TDR for conditioning twisted-pair OSP for VDSL would need a very short pulse width so as to minimize the dead zone.

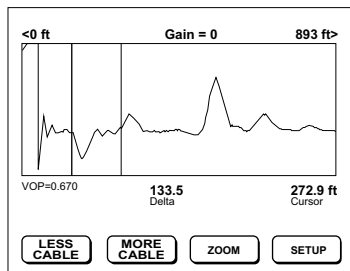


Figure 16. Sample of bridged tap

A TDR trace of a bridged tap is shown in Figure 16. The location of the splice that makes the bridged tap is marked by the downward movement of the trace. The next upward movement of the trace is considered to be the end of the tap. A pair with an open at the end of the bridged tap and an open at the end of the main part of the pair would have two of these upward movements of the trace. This is the only time a TDR can see two actual opens on a single pair.

Single-wire splice connectors

These may not actually need to be located but if they are, the TDR trace may be described as: tip and ring (A and B) are untwisted to begin the splice so the trace goes up and then immediately down because the wires are brought together to be inserted into the connector. The height of the trace can be manipulated by changing the gain and pulse width. However, a good splice, one with very little impedance change, will be harder to find than one with a larger impedance change.

The connecting wire in a cross connect

These are easy to locate by opening the cabinet and visually inspecting the wires. On a TDR trace, however, they may be described as: tip and ring (A and B) are separated, increasing the impedance which causes the trace to go upward a bit but not as high as the complete open at the end of the pair.

Damp or wet pairs

Moisture decreases the impedance causing the TDR trace to go downward as illustrated so the beginning of the wet section can be located. But, as it also changes the speed with which the TDR's pulses of energy travel on the wires, the length of the wet section cannot be determined unless the tech goes to the other end and tests from that direction. In Figure 17, the wet section is between the two cursors.

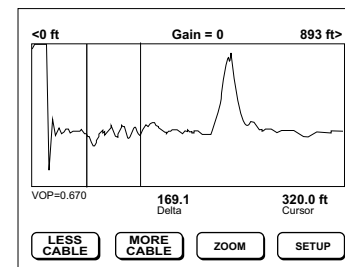


Figure 17. Sample of wet section

Split and re-split pair

Figure 18 shows the trace for a recombined pair. The trace goes up at the first cursor which is the point where the pair was split because the impedance goes up when the wires are separated. The trace then goes down at the second cursor which is the point of the re-split where the wires are rejoined.

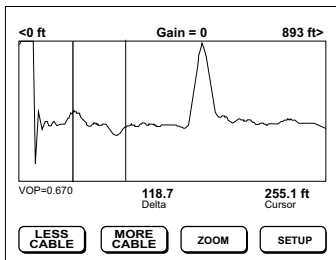


Figure 18. Sample of recombined pair

Since most TDR traces don't look like illustrations in user manuals with the horizontal part of the trace being nice and flat before they change to a well-defined event, a dual-trace TDR allows the comparison of the trace of a good pair with that of a problem pair by showing the differences in the two fairly bumpy traces.

Steps to Turn Up a VDSL Circuit

Step 1

Identify the VDSL circuit appearance at the DSLAM and note the upstream/downstream data rate using a VDSL test set in the VDSL-remote-terminal emulation-mode.

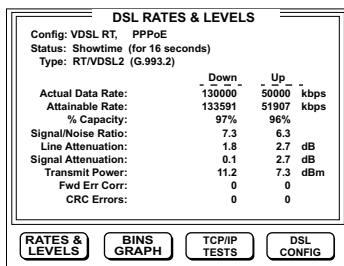


Figure 19. Sample VDSL test set screen

The actual data rate may be lower than the attainable rate due to circuit design or company sales strategy. If it won't sync at the DSLAM, the tech confirms that he or she is on the right circuit and it has been provisioned.

Step 2

Using the auto-test capability of some VDSL test sets, test the physical copper pair (Layer 1) for the following:

- DC volts tip-to-ring (A-to-B) and tip/ring to-ground (A/B to-earth) = <.5 DCV is ideal but ≤10 DCV is acceptable.
- AC volts tip-to-ring (A-to-B) and tip/ring-to-ground (A/B to-earth) = <1.0 ACV is ideal but ≤10 ACV is acceptable.
- Stress = <20 dBrn is good, 20 to 30 dBrn is marginal.
- Leakage tip-to-ring (A-to-B) and tip/ring-to-ground (A/B to-earth) = infinity is ideal [no leakage] but >3 MΩ is acceptable.
- Resistance tip-to-ring (A-to-B) and tip/ring-to-ground (A/B to-earth) = infinity is ideal [no leakage] but >3 MΩ is acceptable.
- Open meter tip-to-ring (A-to-B) and tip/ring-to-shield (A/B to-earth) = <3,300 ft (1,000 m) for 50 Mbps data throughput and <3,500 ft (1,066 m) for 30 Mbps data throughput.
- Load coils = none.

If the test set does not have an auto test capability, test these parameters individually.

Step 3

Run a TDR trace looking for bridged tap. The distance to the open at the end of the pair should match the open meter distance reading. A typical trace with an open at 2245 ft is shown in Figure 20.

If a bridged tap is identified as in the trace shown in Figure 21, locate and remove it. They are normally found at a spliced lateral or left-in drop. In the trace below, the first cursor from the left is at the beginning of the bridged tap and the next cursor is at the end of the lateral.

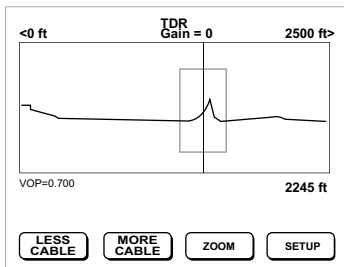


Figure 20.

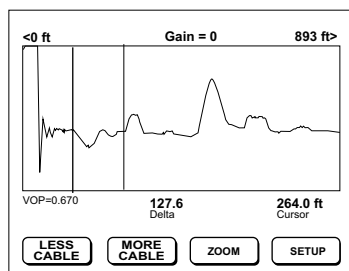


Figure 21.

Step 4

Check the noise floor on the spectrum analyzer to 8, 12, 17 or 30 MHz (depending on the VDSL2 band plan used). The noise floor should be ≤ 60 dBm across most of the spectrum as in Figure 22.

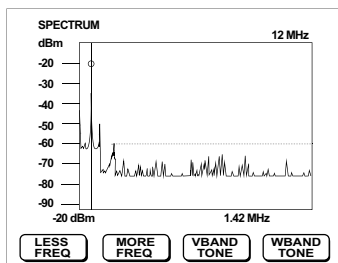


Figure 22.

Step 5

Verify that there is no impulse noise. Connect the circuit to the pair.

Step 6

Go the customers premise. Connect to the pair with a VDSL test set. Note the actual upstream/downstream rates. A typical screen is shown previously in Figure 19.

Troubleshooting VDSL

Slow service/reduced data throughput

We have discussed the faults on the copper pair (Layer 1) that could cause reduced data throughput. VDSL test sets have capabilities of measuring the

Layer 2 digital data throughput that give the tech some hints at which Layer 1 faults may be causing the data throughput to be reduced. Among them are:

Bit-per-tone

Without going too deeply into it, the VDSL signal is broken up into sub-channels or tones. Depending on the band plan and profiles used (mentioned earlier), the number of these tones varies. Each of these tones can carry a maximum of fifteen bits. If all is well, they do carry fifteen bits and the maximum data throughput is achieved. If all is not well, some of the tones may carry no bits while others do carry fifteen bits. At what frequencies this happens can help the tech determine the cause. In other cases, the number of bits carried in most of the tones is reduced.

Signal-to-noise ratio

This is simply the ratio of the power of the usable signal being transmitted to that of an undesired signal (noise). The goal is to have high signal power and low noise power; a high signal to noise ratio. If data throughput is reduced, is the cause low signal power or high noise power or, perhaps, both? The answer can help the tech find the source of the reduced throughput.

VDSL test sets typically display these in what is called a “Bins Graph” as seen in Figure 23. The screen shows that each of the tones (also referred to as “bins”) is carrying 15 bits and that the signal to noise ratio is about 50. This is not likely unless the tech is right at the DSLAM.

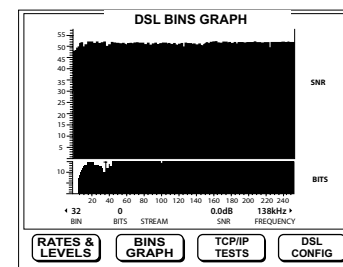


Figure 23. Sample of “bins graph”

Consider the screen in Figure 24. It shows signal-to-noise ratio falling as the frequency increases. The tones-per-bin number is less than 15 in many places. This is a circuit that is likely too long. (If tones are empty [no bits] the tech can determine if it is in the upstream or downstream band by referring to the band plan. Some empty tones will not affect the overall circuit performance.)

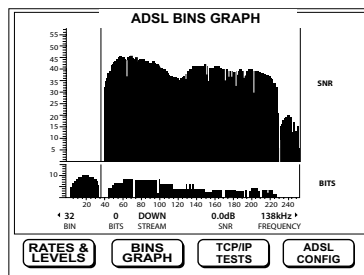


Figure 24. Sample of signal-to-noise ratio

Dips in bits-per-tone indicate interference. Checking the frequency of the interference often makes it possible to identify its cause. If the bits-per-tone numbers are reduced and it is determined that noise is not the cause, the cause could be DC faults such as bridged taps, wet sections or other impedance changes.

Very low or non-existent bits-per-tone in the high frequency band indicate the presence of a long loop. If there is a major dip in bits-per-tone, the most likely troubles are bridged taps, wet sections or other changes in impedance.

If bits-per-tone numbers are low across the entire bandwidth, the cause is likely DC faults such as shorts or grounds.

A major dip in bits-per-tone indicates AC trouble on the loop. To verify the type of AC trouble, the tech compares the signal-to-noise to bits-per-tone. If they occur at the same frequency, the degraded throughput is most likely due to a transmission influence.

Important Factors in Selecting a VDSL Test Set

- Fast processor to speed up (reduce/quicken) individual and overall testing times.
- Lightweight unit for ease of use and transport.
- Rechargeable batteries, ac or dc power.
- Simple menus, intuitive design.
- Comprehensive test suite to reduce the number of required test sets.
- Complete range of testing for physical layer verifications (POTS) through VDSL signal transmissions.

Many of the advanced requirements are:

- To check and display both AC and DC volts simultaneously for instant assessment of potentially hazardous and acceptable voltage limits.
- A stress test to reveal pair imbalances or intermittent conditions that disrupt voice or digital signals.
- Single- and dual-trace TDR with a zero (0) dead zone to locate the various conditions indicating impedance mismatches: shorts, opens, splits and recombined pairs, wet cable, bridged tap, single-wire splice connectors, connecting wire in a cross connect. Dual-trace TDR allows comparison of traces from good and faulted pairs to improve pinpoint fault locating.
- Resistive Fault Locator to display distance readings of pair or single conductor faults <2 MΩ.
- Spectrum analyzer (voice band and wide band up to 30 MHz) to identify the frequencies and potential sources of noise that affect services.
- Auto tests, user-defined test sequences, to simplify and standardize basic testing, and store for reference.
- Incremental pair test that uses auto test function to incrementally record each test result with pair ID, date and time stamp; has the ability to store a large number of tests for later recall and follow-up testing; monitor pair's condition over time.
- VDSL2+ golden modem to verify DSLAM connectivity and internet connection via multiple data points: actual and attainable data rate, percent capacity and signal to noise ratio up and down stream, S/N ratio and bits-per-bin graph, ping statistics, and more.

Available from Megger

HT1000/2 Copper Wire Analyzer

- Noise finder via a 30 MHz spectrum analyzer
- 7 user selectable auto tests
- Incremental pair test program
- 200 pair pre-post test storage
- AC or DC power
- USB port downloads updates and uploads test results

The HT1000/2 is a high performance, full feature, hand held instrument designed to provide copper wire provisioning and maintenance technicians with the most critical tests at the touch of a button. Durable and water resistant, it is equipped with a highly effective 1/4 VGA LCD screen and a powerful backlight designed to make testing and troubleshooting easier in all work environments.



The HT1000/2 is the ideal fully-featured instrument on the market today for physical layer and VDSL testing

The on-screen menu launches most tests with a single keystroke.

Super Stress™ reaches beyond standard longitudinal balance testing, identifying even hard-to-find short loop unbalances.

Dualtrace TDR is standard, with 12 trace storage and intermittent fault location.

The HT1000/2 has user-selectable auto tests with an incremental pair testing process.

Test for DC and AC volts at the same time, no need to switch between separate screens.

Download updates and upload test results quickly and easily via the integrated USB port.

Megger is your source for testing needs

Megger offers the following high-quality instruments for testing telecommunication systems.

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