Marvell White Paper

Virtual Cable Tester™ (VCT) Technology For Gigabit Networks

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1.0 Executive Overview

To ease and facilitate the rapid deployment of Gigabit Ethernet to the desktop and throughout the enterprise network, Marvell has introduced an innovative new feature for its Alaska® family of Gigabit Ethernet Physical Layer (PHY) devices, called Virtual Cable Tester™ (VCT) technology. Built into the latest generation of Alaska PHYs, the VCT feature utilizes Time Domain Reflectometry (TDR) technology to remotely and non-evasively diagnose the quality and characteristics of the attached cable plant. Using this technology, the Alaska devices detect and report potential cabling issues such as cable opens, cable shorts or any impedance mismatch in the cable and accurately report--within one meter--the distance of the fault. Additionally, VCT technology will also detect pair swaps, pair polarity reversal and excessive pair skew.

Marvell's VCT technology is truly revolutionary in that it enables the IT manager or end user to remotely diagnose the attached cable plant, quickly identifying the failing mechanism, and isolating the source of the problem. Essentially, VCT technology integrates, on a single chip, the functionality of a several thousand-dollar cable meter system typically required by IT professionals to handle corporate network service and support issues. Moreover, with VCT technology integrated onto the Alaska PHYs, each device port can independently detect and report cabling issues without the need to unplug cables, connect cable testers and install loop-back modules at the far end.

Perhaps the best way to highlight the value of Marvell's VCT technology is through an example. Consider a case where a corporation has been slowly upgrading their clients/PCs to Gigabit (10/100/1000 Mbps) connectivity and is now ready to upgrade the entire network with the purchase and installation of Gigabit switches. Upon installation of a Gigabit switch, the IT manager finds that all Gigabit ports are functioning with the exception of the fourth port. He/she then sees through the switch software interface a "pop-up" message that reads:

> *"Network connection has failed on Port 4. Pair 2 (typically pins 3 and 6, orange color) of your CAT 5 cable is discontinuous ("open") approximately 68 meters from the switch."*

The IT manager is then able to make the repair to the cabling plant and all ports of the switch operate flawlessly at Gigabit speeds. The engine behind the above software pop-up message is Marvell's VCT technology. In this example, due to integrated VCT technology, it is very likely that the switch systems manufacturer was spared the burden of receiving a phone call to their support line, or even a returned product. VCT technology is key to reducing the costly support issues experienced by manufacturers of networking equipment as well as improving customer satisfaction levels. Major systems manufacturers have estimated that by deploying VCT technology they would be able to eliminate 80% of received support phone calls.

2.0 Introduction

Like its predecessor (Fast Ethernet), Gigabit Ethernet is enjoying quick market adoption due to its ability to offer a significant increase in network bandwidth -- ten times more bandwidth -- while maintaining backward compatibility to the installed base of Ethernet networking systems, and maintaining an aggressive cost structure. As a testament to the rapid adoption of Gigabit Ethernet, Gigabit Ethernet connectivity is now offered as a standard feature on mainstream desktop PCs and laptop computers, and the price of a Gigabit NIC is now equal to or less than the price of a Fast Ethernet NIC. Additionally, Gigabit switch systems are now available with densities as high as 48 ports -- the same port density offered by Fast Ethernet switch systems.

One of the key features of Ethernet technology that has led to mass deployment is the "plug-and-play" aspect of installing and configuring the network. The legacy of Ethernet is that when end-users or IT personnel purchase and install Ethernet equipment, it simply works properly and transparently. With the Marvell Alaska PHY products, this "ease-of-use" concept has been extended to Gigabit Ethernet networks through the integration of advanced features and state-of-the-art DSP technology, resulting in superior performance beyond that required by the IEEE 802.3ab standard. The advantages of the Alaska family of Gigabit PHYs are discussed in detail in a separate white paper [1]. The use of the

Alaska PHYs maximizes the probability that when Gigabit Ethernet is deployed, it simply works.

3.0 Gigabit Ethernet Transmission Over CAT 5 Cable

The IEEE 802.3ab Gigabit Ethernet standard represents truly extraordinary technology in that the standard defines 1000 Mb/s data transmission over the same copper media defined for Fast Ethernet at 100 Mb/s – CAT 5 Unshielded Twisted Pair (UTP) cable. An important distinction, however, is the fact that Gigabit Ethernet transmission requires four twisted-pairs where Fast Ethernet transmission requires only two twisted-pairs. Additionally, it is noted that Fast Ethernet transmits over one twisted-pair and receives over the other twisted-pair, where Gigabit Ethernet utilizes full duplex transmission, simultaneously transmitting and receiving over all four pairs.

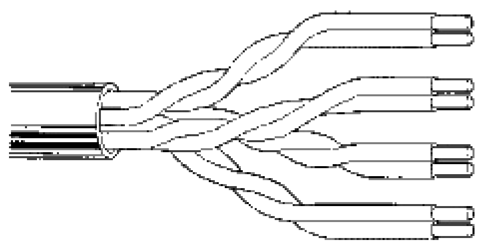

Figure 1: Graphic of Typical Category 5 Cable

4.0 Cable Plant Issues

Standard CAT 5 cable contains four twisted-pair lines or eight conductors in total. Thus, as the current installed base of Fast Ethernet systems require only two twisted-pairs, the third and fourth pairs of the CAT 5 cable have, more than likely, been unused. The availability of the third and fourth pairs is what made the transition to Gigabit Ethernet possible as this technology requires the use of all four pairs. This fact, however, is also a potential source of failure as Gigabit Ethernet systems are deployed. As the third and fourth pairs have not been required, and likely have been dormant for years, there is a probability that these pairs will require some attention from IT personnel. Some of the potential problems are as follows:

- **Open** – Lack of continuity between the pins at each end of the twisted-pair cable.
- **Short** – Two or more conductors are short-circuited together.
- **Crossed pair** – When a twisted-pair is incorrectly connected at one end. For example, pair 3 is connected to pins 4 and 5 on one end and pins 7 and 8 on the other end.
- **Reversed pair** – When the two conductors in a twisted-pair are connected with reverse polarity. For example, one conductor in pair 3 is connected

to pin 1 on one side and to pin 2 on the other, while the second conductor is connected between pin 2 and pin 1.
- **Improper termination** – As the characteristic impendence of CAT 5 cable is 100 ohms, to prevent waveform reflections and potential data errors, the cable terminations at each end must also be 100 ohms.

There are many additional scenarios related to the cabling plant that could result in down network links. These issues could arise during installation of the network or can be random events throughout the life of the network. The following are some examples:

- **"Oops, I forgot to connect that cable."** The Ethernet connection from the user (i.e., networked PC) to the switch located in the wiring closet, consists of many discrete cables and connectors – all of which are potential sources of fault (see figure 2). In a typical installation, the fewest number of RJ45 connectors used in a single network link is six (6). The most common form of a fault, or disconnection (also called an "open"), is an unconnected cable somewhere in the infrastructure. This problem is easily rectified but can also be frustrating as it may take significant time to isolate the problem (find the disconnected cable).
- **Faulty RJ45 connectors**. Opens may be created by faulty RJ45 connectors as the connectors can degrade with frequent use. This problem is more difficult to isolate as it is less obvious to the eye.
- **Cable damage.** Inadvertent damage to the cabling plant may occur during an upgrade of the cabling infrastructure or other construction near the cabling plant. Failure sources in this case are typically the result of cable opens or shorts of one or more twisted-pairs of the cable bundle. For example, one or more pairs may be inadvertently cut open by a nail or stapler gun. This type of accident could also result in cable shorts as the two conductors in the twisted are smashed together, severing the insulation material and creating a short.

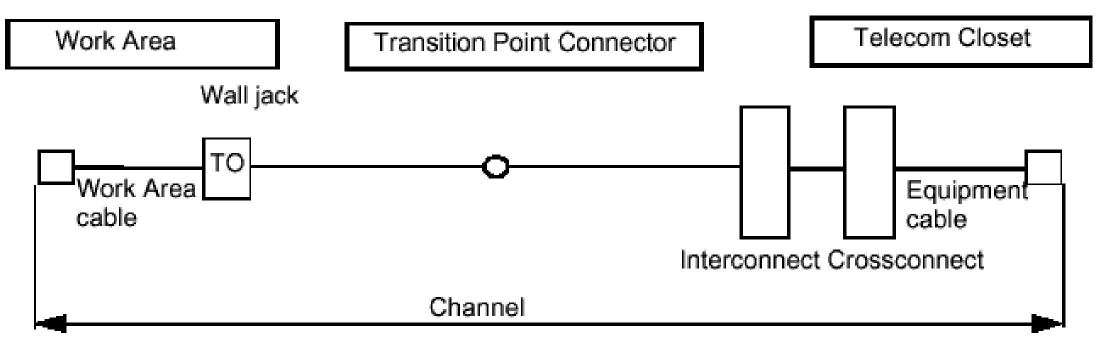

Figure 2: ANSI/EIA/TIA Horizontal Cabling Subsystem

5.0 Cost of Ownership

The scenarios described above will prevent a proper Gigabit Ethernet connection from being established. Typically, when an end-user or IT manager purchases and installs new networking equipment, the burden of the equipment working properly is on the system manufacturer, even when the source of the problem may lie in the cabling plant. The fact that systems manufacturers do not necessarily have control over the end-user's cabling plant/infrastructure makes this an interesting issue to resolve.

When networking systems fail to function properly upon purchase and installation, the systems manufacturer is exposed to the following disadvantages:

- Increased cost for customer support, resulting in decreased product profit margins. Support includes phone calls into the support line as well as the potential for field visits.
- Negative impact to the systems manufacturer's quality and customer satisfaction level.
- Potential for lost business/revenue. The end-user or IT personnel may decide to return the product to the manufacturer or replace the non-working systems with equipment from a competing supplier.

Network reliability is a top priority. If the network equipment is unstable or unreliable in any given installation, there is higher probability of network downtime. For the end-user, network downtime directly translates to lost productivity/revenue.

After introducing VCT and TDR technology in the next section, we later return to the issues raised in this section and review how Marvell's VCT technology adds significant value to the end-user and the IT manager.

6.0 VCT and TDR Technology

Marvell's VCT feature utilizes Time Domain Reflectometry (TDR) to diagnose the attached cable plant. Similar to the principle of radar, TDR is the analysis of a conductor by sending a pulsed signal into the conductor, and then examining the reflection of that pulse. When the transmitted pulse reaches the end of the cable, or a fault along the cable, part or all of the pulse energy is reflected back to the source. Marvell's VCT algorithm measures the time it takes for the signal to travel down the cable, see the problem and reflect back. This measured time is converted to distance and made available through an internal register in the Alaska PHY.

Figure 3 shows some example waveforms for various conditions of an open cable. Referring to the waveforms in Test 1 (100 meter open cable), the first waveform shown is the called the "source waveform." The second waveform shown is called the “reflected waveform,” and as its name implies it is the reflection of the source waveform after it has traversed the cable, reflected at the end of the open cable and returned. The “smoothing” of the reflected waveform is due to the low-pass filter characteristics of CAT 5 cable.

As shown in Tests 2 and 3, the reflected waveform is closer to the source waveform as the round-trip propagation distance is shorter. Tests 3 and 4 show that for very short cable opens, the energy of the reflected waveform is “added” to the source waveform. Essentially the round-trip propagation is shorter than the width of the source waveform. VCT technology is very precise and can measure these slight propagation delays, and hence the distance to the fault (or open in this case).

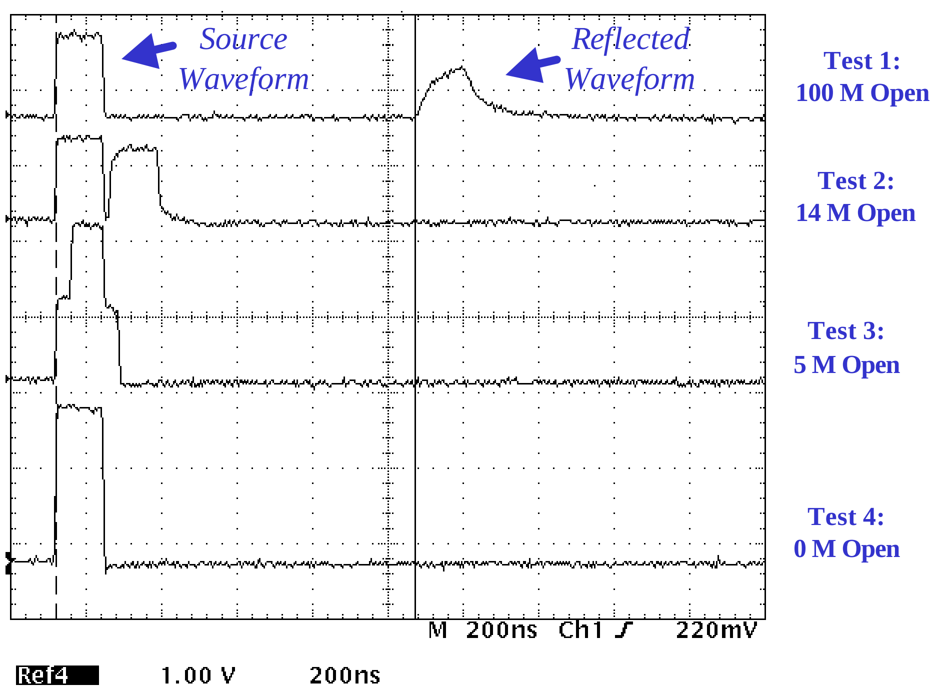

Figure 3: Example Waveforms With Cable Open (Disconnected Cable)

6.1 Impedance In Transmission Lines

Any time two metallic conductors are placed close together they form a cable impedance. A correctly terminated line is defined as a line or cable with impedance that is equal to the source’s impedance as well as the impedance of the load. For a perfectly terminated line, the reflected waveform is zero. In this case, the load absorbs all the energy of the source waveform. When the cable is disconnected (or open) at the far end, the load impedance is infinite and the reflected waveform is equal to the source waveform. The following equation defines this dynamic further; it is a calculation of the Reflection Coefficient, p_L:

$$p_L = \frac{V\text{ (Reflected waveform)}}{V\text{ (Source waveform)}} = \frac{Z_L - Z_0}{Z_L + Z_0}$$

Where Z_L is the load impedance, Z_0 is the cable impedance, and the impedance of CAT 5 cable is 100 ohms (see Figure 4).

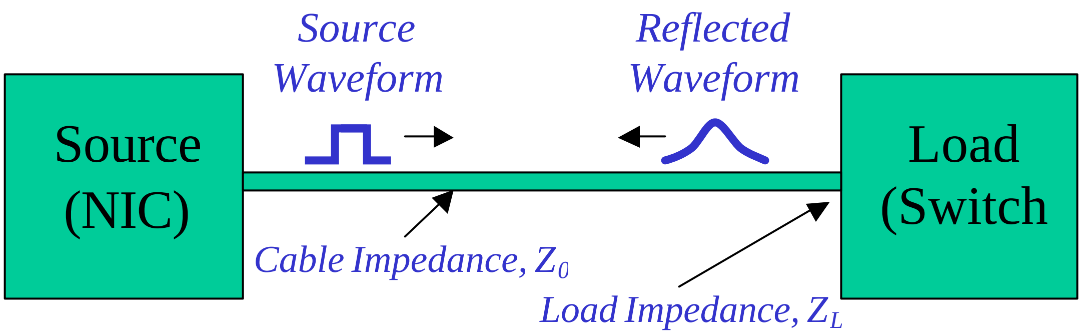

Figure 4: Source and Reflected Waveforms

The table below shows the Reflection Coefficient for several load conditions.

Load Impedance,Z_L (Ohms)	Reflection Coefficient (p_L)
Infinite (open)	1.0
300	0.5
150	0.25
125	0.17
100	0
75	-0.17
50	-0.25
33.3	-0.5
0 (short)	-1.0

Table 1: Calculated Reflection Coefficient for Various Load Impendances

Several observations may be made from the above data:

- When the load impedance is greater than the cable impedance, a positive reflection results, and conversely, when the load impedance is less than the cable impedance, a negative reflection occurs (i.e., the reflected pulse is of a magnitude below zero). VCT technology uses this information to help determine the load impedance.
- When the load impedance is 300 ohms, the reflection coefficient is 0.5, which implies that the reflected waveform is one-half the magnitude of the source waveform. VCT technology uses the polarity and magnitude of the reflected waveform to precisely calculate and report the load impedance.

Figure 5 shows the examples of a short-circuit (zero ohms load impedance) and a 50 ohm load impedance.

- When the load impedance is 100 ohms, the reflection coefficient is zero, which implies that the load absorbs 100% of the energy of the source waveform, and there is no reflected waveform. In the absence of a reflected waveform, the VCT algorithm knows that no cable faults exist. This is a good thing.

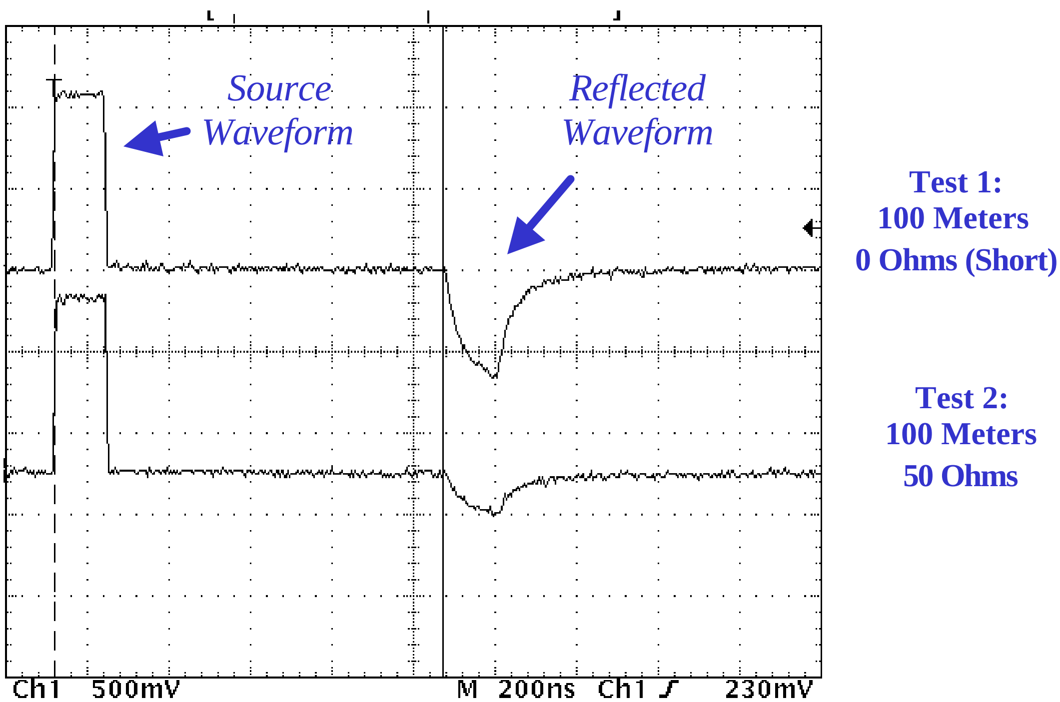

Figure 5: Example Waveforms Showing Negative Reflections

6.2 Calculating Distance; Velocity of Propagation

The Velocity of Propagation (VOP) is a specification of the cable indicating the speed at which a signal travels down the cable. Different cables have different VOPs. The VOP is defined relative to the speed of light in a vacuum, which is 186,400 miles per second. This speed is represented by the number 1 (100%) -- all other signals are slower. For example, a cable with a VOP of 0.71 would transmit a signal at a velocity 71% the speed of light. CAT 5 twisted-pair cabling has a VOP of 0.71, which translates to a propagation delay of 4.7 ns/meter.

Using TDR technology to measure the propagation delay of the reflected waveform, and by knowing the calculated VOP of CAT 5 cable, it becomes a relatively simple exercise to calculate the length of the cable, or the distance to the cable fault.

6.3 The 2-Pair Problem of Gigabit Ethernet

As reviewed in prior sections, the Gigabit Ethernet standard requires four CAT 5 pairs for Gigabit transmission. However, in actual cabling systems, there are cabling installations that contain only two CAT 5 cables. Typically, cabling bundles include four twisted-pair conductors; however, in many cases, IT personnel have routed only two twisted-pair conductors to an end-user. For example, consider a case where a 4-pair bundle is split between two users (or a user and a networked printer) in order to reduce installation costs. This may be common practice particularly in environments of employee expansion (expansion beyond the existing cable infrastructure), or in environments where end-users are consolidated in a single office/cubicle.

Prior to Gigabit Ethernet technology, splitting a four-pair bundle into two sets of two twisted-pairs could be viewed as acceptable, as the Ethernet technology at the time (both 10BASE-T and 10/100BASE-T) required only two twisted-pairs for transmission. Today, deploying Gigabit Ethernet systems in a two-pair cabling environment would result in a problem – a link or connection would not occur. In this environment, the Auto-Negotiation process would be carried out successfully as this scheme involves transmission on only 2 twisted-pairs. Further, the Auto-Negotiation process would inform the Gigabit systems at each end of the link that the other is Gigabit ready. Data transmission would proceed; however, this will result in failure, as Gigabit data transmission requires four pairs. The data link would then go back into Auto-Negotiation mode, and this process will continue infinitely.

Marvell recognized this issue and, as a result, designed a feature into the Alaska PHY devices that will automatically detect this 2-pair environment and downshift operation to 100 Mb/s. Downshifting to 100 Mb/s enables the network to properly link. Under similar conditions, competing devices cannot link and the network would go down. As reviewed in the next section, the downshift mode and status may be controlled through Marvell's VCT software GUI interface.

7.0 VCT's Software Interface

The preceding sections discussed how TDR and VCT technology is used to extract information from the attached cable plant. Using this technology, pertinent data regarding the cabling plant is stored in internal registers of the Alaska PHY. Marvell also offers a software package that extracts and interprets this data and presents it to the user in an easy-to-use GUI interface. The Marvell GUI shown in Figure 6 offers a superset of data available to the user. As the source code is made available, systems manufacturers may customize and choose to present a subset of this data. The data may be presented in a diagnostic mode or in a mode presentable to the end-user, such as "pop-up" messages.

Using VCT technology and a software GUI interface, the potential cable problems discussed in section 4.0 are quickly diagnosed, enabling appropriate action to be taken. Below, some examples of wiring faults are presented, as well as "pop-up" messages that could be generated using the Marvell VCT engine.

> A technician inadvertently staples through a CAT 5 cable bundle:
> *"Network connection has failed on Port X. Pair 2 (typically pins 3 and 6, orange color) of your cable is open approximately 68 meters from the switch."*
>
> During a switch upgrade, a cable at the patch panel has been left unconnected:
> *"Network connection has failed on Port X. There is a disconnection in the cable at approximately 88 meters. You may want to check the patch panel or switch in the wiring closet."*
>
> A client upgrades to a Gigabit NIC; however, the CAT 5 cable was previously split to accommodate two users, and thus the connection was made with only two twisted-pair wires:
> *"FYI: You are currently operating at a 100 Mbps data rate. Gigabit transmission is possible by upgrading to a cable that contains four (4) twisted-pairs."*

In the examples above, note that the messages to the user or IT manager may be from the vantage point of the client or the switch. VCT technology is currently being deployed at both ends of the network, enabling maximum flexibility in the diagnosis of cabling faults.

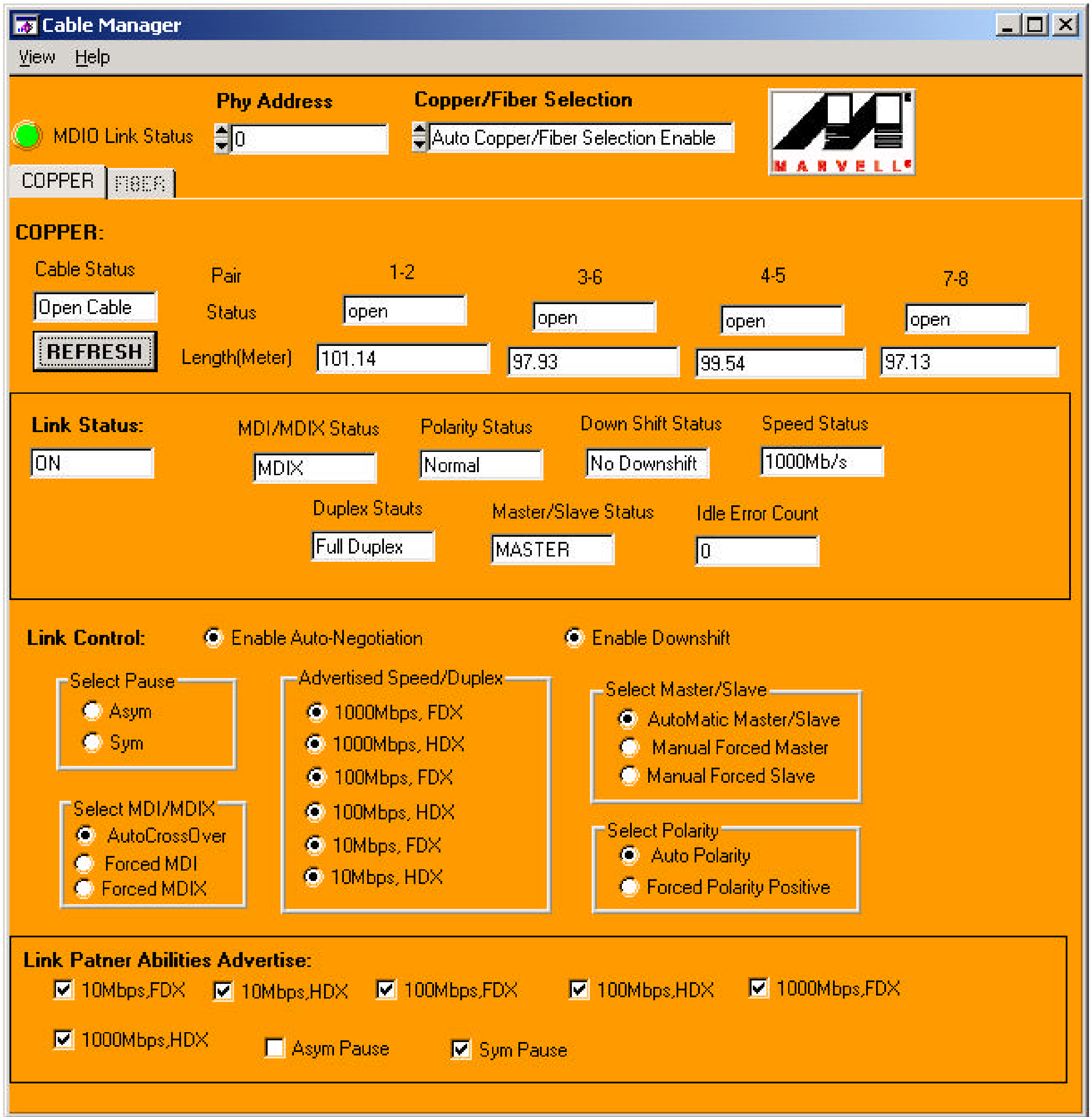

Figure 6:_Marvell's VCT GUI Interface

8.0 Conclusion

The networking industry is currently in the midst of the next major LAN upgrade cycle – enterprise networks are upgrading from 100 Mbps Fast Ethernet networks to 1,000 Mbps Gigabit Ethernet networks. During this transition, it is critical that Ethernet maintain it's ease-of-use, "plug-and-play" qualities that have led to its mass adoption. Through the integration of superior DSP technology and an advanced feature set, the Marvell Alaska family of Gigabit Ethernet PHYs meets and exceeds this requirement [4]. Additionally, through Marvell's VCT technology, cable faults may now be quickly diagnosed, thereby reducing the total cost of ownership.

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