The ATM Controversy

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The question of whether the 155 Mb/s ATM interface is properly supported by category 5 cabling has been a topic of some disagreement. Unfortunately for the end user of ATM, the importance of the channel bandwidth above 100 MHz has, on occasion, been misrepresented so as to promote systems and test equipment unspecified above 100 MHz.

Category 5, as specified, does not satisfy the requirements of the 155 Mb/s ATM network This fact is supported by theoretical analysis and by experiment[1]. However, in the interest of allowing the existing standards to become established, the physical layer requirements of this network have sometimes been presented from the "best case"[2] perspective.

This paper analyzes the channel bandwidth requirements of a few widely used 155 Mb/s ATM products in the context of the best and worst case conditions defined by the ATM Forum AF-PHY-0015.000 and TIA-568 standards and demonstrates that typical ATM products rely on the channel bandwidth beyond 100 MHz for proper operation.

The Main Points

Those opposed to characterizing category 5 systems beyond 100 MHz present the following arguments.

1. Percentage of energy above 100 MHz

   Argument:

   The percentage of spectral energy generated by a 155 Mb/s ATM device between 100 and 155 MHz varies as a function of rise time and could be as low as 2.5% .

   Since Attenuation to Crosstalk Ratio (ACR) of a worst case category 5 installation becomes negative above 115 MHz, the 155 Mb/s ATM receiver cannot use the energy above 115 MHz and must, therefore, filter this energy.

   Based on the slowest transmit rise time of 3.5 ns[3] and based on a receive filter with a cut-off frequency of 115 MHz, the energy available at the receiver between 100 and 155 MHz is only 1.5%. Such a low amount of energy does not warrant any changes in the standards.

   Response:

   The conclusion that only 1.5% of spectral energy is available to the ATM receiver represents a theoretical best case. It is based on the slowest allowable symbol rise time and the most severe receive filtering possible. This conclusion does not represent real implementations.

   This paper will demonstrate that, in reality, the amount of transmit and receive energy above 100 MHz varies from product to product and that the ATM receiver often recovers close to 5% of spectral energy above 100 MHz.

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[1] See Scope Communications papers, "155 Mb/s Bit Error Rate Experiment" and "Analysis of Physical Layer Requirements for 155 Mb/s Twisted Pair ATM"

[2] In the context of this paper, "best case" channel bandwidth requirements are the requirements of the ATM products with the narrowest allowable transmit and receive spectrum. "Worst case" channel requirements are the requirements of the ATM products with the widest allowable transmit and receive bandwidth.

[3] The ATM Forum standard, AF-PHY-0015.000, specifies symbol rise and fall times of 1.5 ns minimum and 3.5 ns maximum (Sec. 3.5). The slower the rise time, the less energy is generated between 100 and 155 MHz.

Ironically, the argument that the ACR of a category 5 system could be negative above 115 MHz is presented in opposition to extended frequency testing when it really should be used in support of extended frequency testing. Since ATM products rely on the energy above 115 MHz for proper operation, the channel should be characterized above 115 MHz, particularly in view of the fact that the category 5 specification does not guarantee adequate operation in that frequency range.

2. Negatives to changing the ATM Forum standard

Argument:

There are no cabling standards defining system performance above 100 MHz that AF-PHY-0015.000 could reference.

There is no standard that would control the accuracy of field testers above 100 MHz and no standard to guarantee the quality of cabling components that claim extended frequency performance.

Response:

Extended frequency operation of category 5 systems could be guaranteed through extended frequency testing. Field test equipment with guaranteed accuracy up to 160 MHz is available and TIA-568-A test limits are easily extendible beyond 100 MHz.

At the June, 1996 meeting of the ATM Forum, the work of defining the extended frequency operation of category 5 systems has been directed to the TIA and the ISO committees.

The ATM Standard

When determining how much energy an ATM service uses between 100 and 155 MHz, we need to consider the widest transmit and receive filters allowable by the AF-PHY-0015.000 standard.

The ATM channel specification should be based on the widest possible signal spectrum, not on the narrowest possible signal spectrum because the ATM service is expected to work under the worst case conditions, instead of being marginal under the best case conditions.

The portion of AF-PHY-0015.000 dealing with the channel requirements is unsatisfactory and should be changed. Even under the best case conditions – the conditions no industry standard should be based on – the 100 MHz category 5 channel provides insufficient support for the 155 Mb/s network.

Boundary conditions aside, let us at least analyze the channel requirements of some real ATM products that are being installed today.

Transmit Spectrum

A 155 Mb/s ATM transmitter typically consists of a driver followed by a transmit filter. The driver produces an unfiltered NRZ spectrum having sharp rise/fall times and a broadband spectrum. The spectral lobes beyond 155 MHz are not required for signal recovery and can be filtered out.

The transmit filter characteristics vary from implementation to implementation. Typically, this filter is designed to attenuate the spectral energy above 155 MHz.

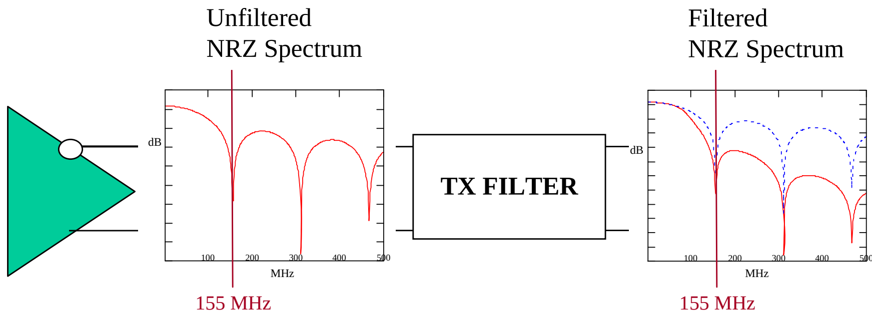

Figure 1: *155 Mb/s ATM transmitter; the spectral lobes above 155 MHz are attenuated by the transmit filter; the energy of the first lobe, extending to 155 MHz, may or may not be attenuated by the filter*

The characteristics of the transmit filter effect the symbol rise time. The wider the bandwidth of the filter, the shorter the rise time. The rise/fall time ($T_{r/f}$) of the NRZ signal is determined by the 3 dB cut-off frequency (Fc) of the transmit filter

$$F_c = \frac{3.5}{T_{r/f}}$$

The widest allowable transmit filter would be the filter that produces the shortest allowable symbol rise/fall time, $T_{r/f}$, of 1.5 ns. The 3 dB cut-off frequency of such a transmit filter is 233 MHz. Depending on the shape of the transmit filter with a 3 dB point at 233 MHz, the energy in the first lobe between 100 and 155 MHz can be as high as 4.9%[4].

In order to determine the amount of the transmit energy real products generate between 100 and 155 MHz, we have measured the characteristics of three different filter modules used in three different shipping products. Two out of three transmit filters had practically no attenuation up to 155 MHz.

[4] If a Butterworth filter with a cut-off frequency of 233 MHz is used, the percentage of the energy between 100 and 155 MHz is 4.9%.

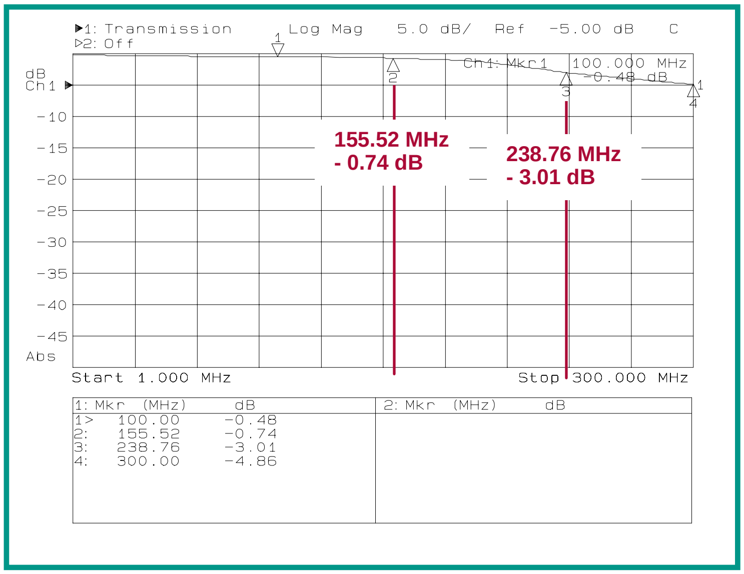

Figure 2: *Transmit filter response of Vendor A; magnetics used: VALOR PT4172. There is less than 1 dB of attenuation at 155 MHz and the cut-off frequency appears to be around 238 MHz. Such a filter produces a waveform with the shortest allowable rise time and more than 4% of first lobe energy between 100 and 155 MHz.*

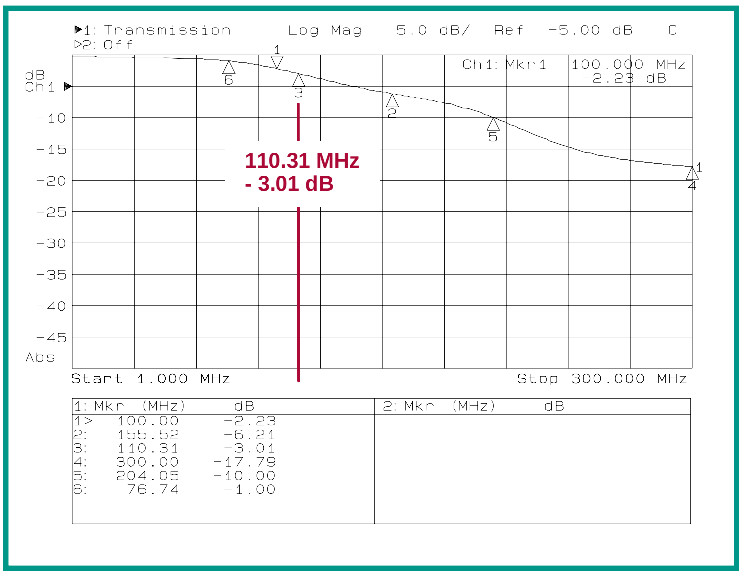

Figure 3: *Transmit filter response of Vendor B; magnetics used: VALOR SF6035. This filter has a cut-off frequency at 110 MHz and, therefore, produces a waveform with maximum allowable rise time. This device produces about 2.5% of spectral energy between 100 and 155 MHz.*

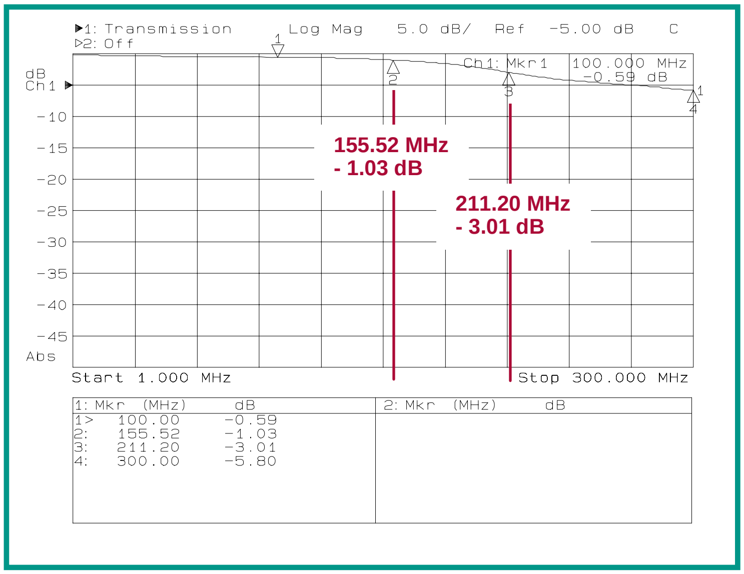

Figure 4: *Transmit filter response of Vendor C; magnetics used: Pulse Engineering PE-68517. There is about 1 dB of attenuation at 155 MHz and the cut-off frequency appears to be around 211 MHz. Such a filter produces a waveform with a rise time close to 1.5 ns and more than 4% of first lobe energy between 100 and 155 MHz.*

Figures 2, 3 and 4 show that the responses of standard magnetics used in the 155 Mb/s ATM products vary, producing the transmit energy between 100 and 155 MHz ranging from about 2.5% to more than 4%.

But does the receiver "see" all of the energy above 100 MHz?

Receive Spectrum

The spectrum of the signal at the receiver is determined by the receive filter and by the receive equalizer. The equalizer counteracts the channel attenuation response and restores the first spectral lobe to its original transmit shape, as shown in the following figure.

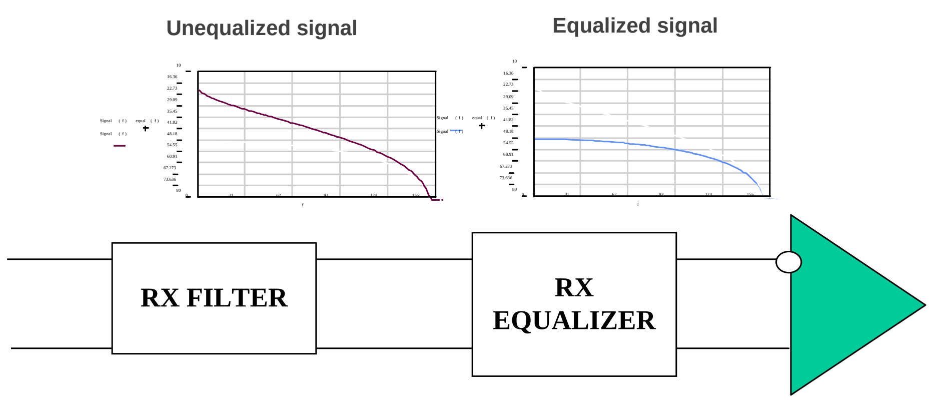

Figure 5: *155 Mb/s ATM receiver. The energy of the first lobe between 100 and 155 MHz is a function of both the receive filter and the receive equalizer.*

In order to evaluate the spectral energy at the ATM receiver, we need to look at the combined response of the receive filter and the receive equalizer.

Following are the responses of receive filters used in the products from Vendors A, B and C.

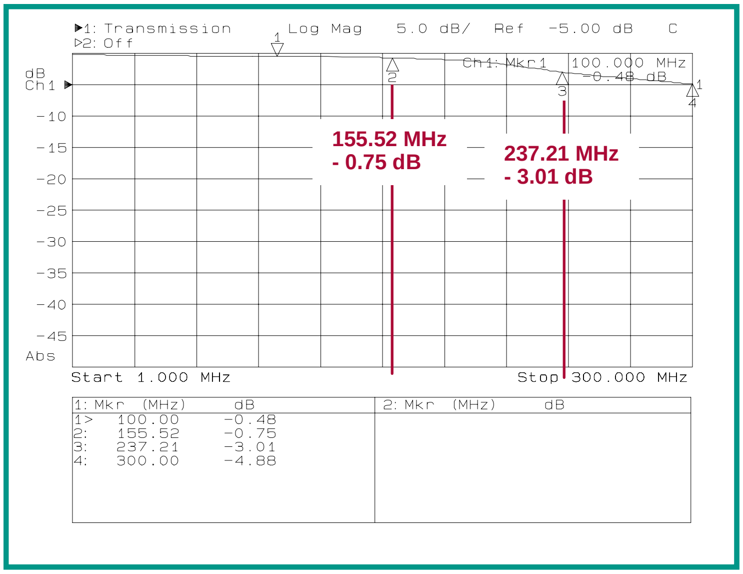

Figure 6: *Receive filter response of Vendor A; magnetics used: VALOR PT4172. There is less than 1 dB of attenuation at 155 MHz and the cut-off frequency appears to be around 237 MHz. Such a filter leaves more than 4% of spectral energy between 100 and 155 MHz.*

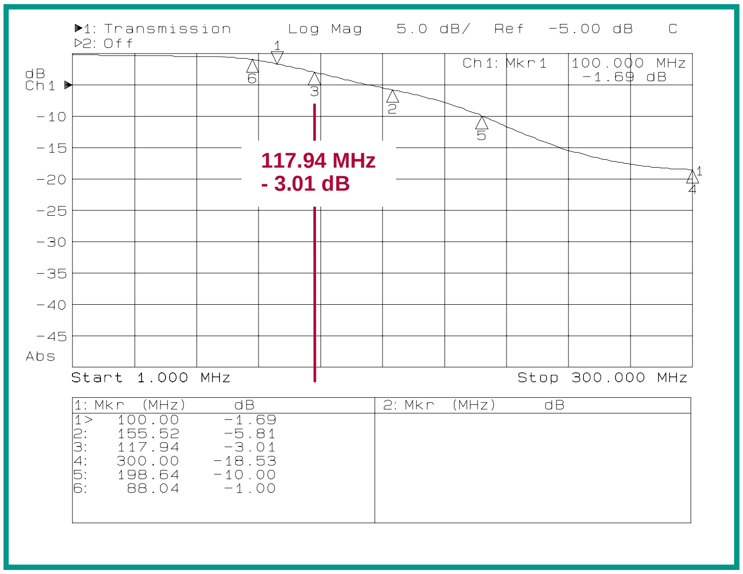

Figure 7: *Receive filter response of Vendor B; magnetics used: VALOR SF6035. This filter has a cut-off frequency at 117 MHz and produces about 2.5% of spectral energy between 100 and 155 MHz.*

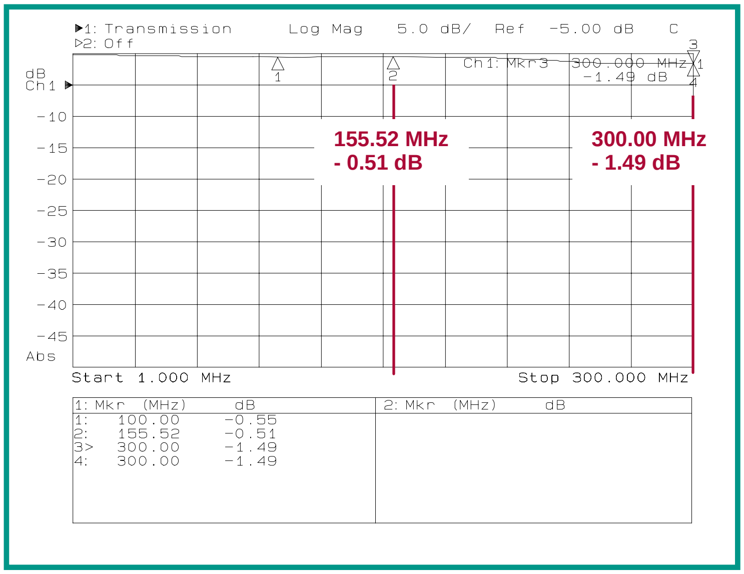

Figure 8: *Receive filter response of Vendor C; magnetics used: Pulse Engineering PE-68517. There is about 0.5 dB of attenuation at 155 MHz and the cut-off frequency is beyond 300 MHz. Such a filter produces more than 4% of first lobe energy between 100 and 155 MHz.*

Based on Figures 6 to 8, it is obvious that standard magnetics used in the ATM products do not necessarily reduce the receive energy above 100 MHz. **Two out of three products examined had practically no filtering in the transmitter and practically no filtering in the receiver below 155 MHz.**

Let us now examine a typical equalizer response.

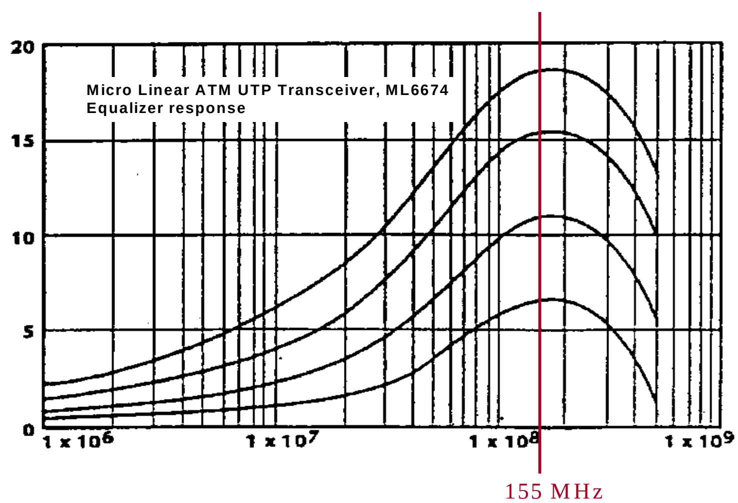

Figure 9: *Equalizer curves from the specification for Micro Linear ATM UTP transceiver, ML667. The equalizer response slopes upward, compensating for the channel attenuation all the way up to 155 MHz. This means that the equalizer restores all the energy between 100 and 155 MHz without filtering it.*

From Figure 9, it is clear that a commonly used 155 Mb/s ATM equalizer does not suppress the energy above 100 MHz, allowing most of the energy at the output of the filter to enter the receiver.

Energy Above 100 MHz In Real Products

The above analysis of three 155 Mb/s twisted pair ATM products reveals that the typical magnetics and transceiver components produce systems which allow more than 4% of signal power at the receiver to reside between 100 and 155 MHz. The products examined here are all compliant with the ATM Forum standard, AF-PHY-0015.000.

The conclusion that an ATM receiver can only use of 1.5% of energy above 100 MHz is based on the assumption of the best case system – a system employing the narrowest possible transmit and receive filters. Our examination of three ATM products selected at random has revealed that two out of three products employed wide transmit and receive filters, resulting in more than 4 % of energy at the receiver above 100 MHz.

ACR Above 115 MHz

The worst case category 5 channel exhibits negative ACR above 115 MHz. This means that above 115 MHz the receiver could, theoretically, see more Near End Crosstalk (NEXT) noise than signal. For this reason, it would seem appropriate that the receiver should suppress the energy above 115 MHz. But is this, in fact, being done in real products?

Two out of three products we have examined employed receive filters considerably wider than 115 MHz and allowed practically all of the first lobe energy up to 155 MHz to enter the receiver. How do these products work without filtering the energy above 115 MHz? They work because on the outer pairs of the Modular Jack (pins 1, 2 and 7, 8) used by the ATM network there is plenty of NEXT margin and, for this reason, the ACR on these outer pairs almost never becomes negative all the way up to 155 MHz. The energy above 115 MHz is not filtered by the ATM products because it is needed to ensure the robustness of the ATM network.

The fact that ATM products do not suppress the energy above 115 MHz even though category 5 ACR could be negative above 115 MHz, is just another point in evidence that the currently shipping 155 Mb/s ATM products use the category 5 systems beyond specification. The only reason these products work is that most category 5 systems deliver the needed performance up to 155 MHz.

However, major performance degradation can be expected if the channel response of a category 5 system exhibits any kind of a flaw or a discontinuity above 100 MHz.[5]

Extended Frequency Test Tools

Because the 155 Mb/s ATM service relies on the channel response beyond 100 MHz, it is a good idea to characterize category 5 installations expected to carry 155 Mb/s ATM traffic beyond 100 MHz. TIA-568-

[5] See Scope Communications paper, “155 Mb/s Bit Error Rate Experiment”. This paper describes a BER test that was witnessed by Inchcape Testing Services NA Inc., ETL Testing Laboratories. The test demonstrates that even the best 155 Mb/s ATM systems rely on channel performance above 100 MHz.

A and TSB-67 category 5 limits are easily extendible to 160 MHz. Even the TSB-67 accuracy model for hand held tools can easily be extended to 160 MHz.

The accuracy of every WireScope 155 and every Dual Remote 155 manufactured by Scope Communications is fully certified to TSB-67 and a report is shipped with every product. This report shows all six parameters of the TSB-67 accuracy model and the overall accuracy of the unit, measured and plotted up to 160 MHz. The WireScope 155 is guaranteed to perform accurate measurements up to 160 MHz. Our manufacturing process has been verified by Inchcape Testing Services NA, Inc., ETL Testing Laboratories.

The typical NEXT and attenuation accuracy of Scope's products is shown in the following figure.

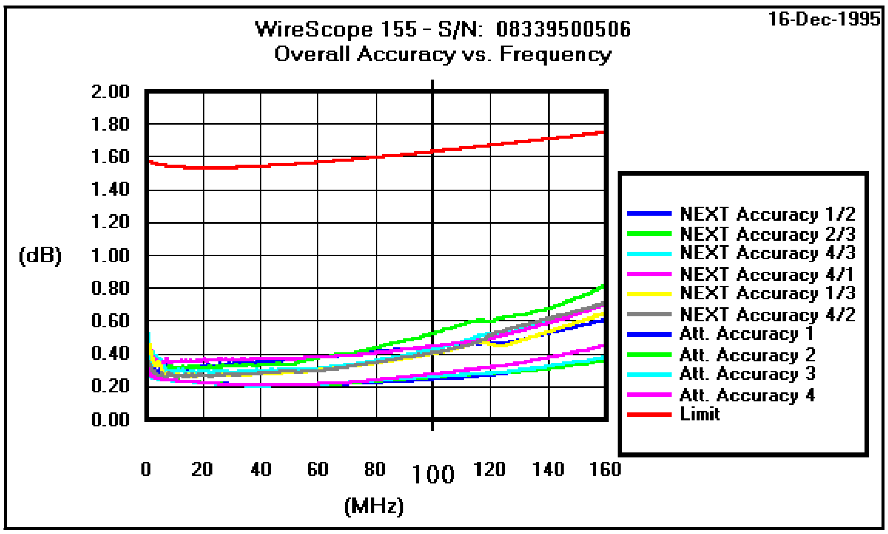

Figure 10: ***Actual production measurement of the WireScope with S/N 083395005006. This is a plot of the overall accuracy computed per the accuracy model in the TSB-67 and extended to 160 MHz. The TSB-67 Level II accuracy limit, the most stringent accuracy limit, is plotted as a red line. The required Level II accuracy at 100 MHz is 1.6 dB. Typical NEXT accuracy of the WireScope 155 is better than 0.6 dB at 100 MHz. Typical NEXT accuracy at 160 MHz is about 0.8 dB – twice as good as the required Level II accuracy at 100 MHz.***

Plots, similar to the one shown above, are available for all six accuracy parameters with every WireScope 155 / Dual Remote 155 kit manufactured by Scope.

Summary

This paper has critiqued the arguments offered in opposition to characterizing category 5 installations beyond 100 MHz. The measurements presented here demonstrate that real shipping AF-PHY-0015.000 compliant products use practically no filtering of the transmit and receive spectrum up to 155 MHz. As a result, the energy entering the 155 Mb/s receiver often extends to 155 MHz with over 4% of this energy located above 100 MHz.

Earlier Scope Communications papers, "Analysis of Physical Layer Requirements for 155 Mb/s Twisted Pair ATM" and "155 Mb/s Bit Error Rate Experiment" have presented theoretical and experimental studies demonstrating that the 155 Mb/s twisted pair ATM network relies on the channel response above 100 MHz for delivering the required Bit Error Rate performance.

Based the bandwidth requirements of this most commonly installed twisted pair ATM network, there is a need for a field tester with guaranteed Level II accuracy up to 160 MHz. WireScope 155 is such a tester. It can be used to characterize the cable response up to 155 MHz and to verify that category 5 installations will properly support 155 Mb/s ATM traffic.

A typical ATM system, with practically no filtering at the transmitter and no filtering at the receiver relies on more than 4% of signal energy between 100 and 155 MHz for the robustness of its physical layer. The arguments leading to the conclusion that only 1.5% of energy above 100 MHz enters the receiver are based on the best case system.

But international standards, such as the ATM Forum AF-PHY-0015.000, should never be based on the model of a best case system and they should not even be based on the model of a typical system. International standards should guarantee proper operation of a worst case system, preferably with some degree of margin[6].

[6] As of this writing (July, 1996), the ATM Forum has resolved to re-open the issue of the physical layer requirements for the 155 Mb/s ATM interface once the ISO and TIA committees define specifications for extended frequency cabling systems. But regardless of when this issue will be discussed by the ATM Forum, the category 5 systems being installed today should be characterized beyond 100 MHz if they are expected to properly support 155 Mb/s ATM traffic.

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