Technical Report

TR-285
Broadband Copper Cable Models

Issue: 2 Amendment 1
Issue Date: February 2023

Issue History

Issue Number	Approval Date	Release Date	Issue Editor	Changes
1	23 February 2015	16 March 2015	Andre Holley TELUS Communications Inc.	Original
1cor1	9 November 2015	11 November 2015	Andre Holley TELUS Communications Inc.	Correct Cable transfer function
1amd1	13 March 2017	5 May 2017	Andre Holley TELUS Communications Inc.	New Cable reference models added.
2	2 September 2019	2 September 2019	Andre Holley TELUS Communications Inc.	Add New Cable Models
2amd1	24 February 2023	24 February 2023	Andre Holley TELUS Communications Inc.	Add Australian Cable Models

Comments or questions about this Broadband Forum Technical Report should be directed to info@broadband-forum.org.

Editor:	Andre Holley	TELUS Communications Inc.
Physical Layer Transmission Work Area Director(s)	Herman Verbueken	Nokia

Table of Contents

Table of Figures

Table of Tables

Executive Summary

See Executive Summary / TR-285 Issue 2 [1]

New reference cable models deployed by Australian operators are added in Annex G:

1. 0.57mm Annealed copper solid polyethylene insulated 2 pair lead-in cable (HT57)
2. CPFUT 0.4mm. Cellular polyethylene insulation, grease filled, 10 twisted pairs in a unit or binder.
3. PEIFLI 0.4mm. PE insulated, grease filled, single quad lead-in cable.
4. HT57 0.57mm. High twist lead-in cable, solid PE insulated, grease filled, 2 twisted pairs – Blue-White with higher twist rate and Red-Black with lower twist rate.
5. Cat 3 Building Cabling. 25 or 100 twisted pairs with 10 and 5 pair subunits, PE insulated. Air core.

1 Purpose and Scope

1.1 Purpose

The purpose of this Technical Report is to support the development of testing capabilities at frequencies above 30 MHz by providing detailed models of copper cables. This work complements emerging specifications for G.fast access technology and FTTdp transmission deployment.

1.2 Scope

This Technical Report focuses on the subject of modeling copper cables at frequencies above 30 MHz. This Technical Report provides models that can be used in Broadband Forum specifications for testing of G.fast implementations.

These models include the single line parameters, the transfer function of the direct path, the transfer function of the FEXT coupling, and the input impedance of the line.

This Technical Report addresses the cable that extends from the Distribution Point (DP) to the Network Interface Device (NID) at the Customer Premises.

2 References and Terminology

2.1 Conventions

In this Technical Report, several words are used to signify the requirements of the specification. These words are always capitalized. More information can be found be in RFC 2119 [2]

MUST	This word, or the term "REQUIRED", means that the definition is an absolute requirement of the specification.
MUST NOT	This phrase means that the definition is an absolute prohibition of the specification.
SHOULD	This word, or the term "RECOMMENDED", means that there could exist valid reasons in particular circumstances to ignore this item, but the full implications need to be understood and carefully weighed before choosing a different course.
SHOULD NOT	This phrase, or the phrase "NOT RECOMMENDED" means that there could exist valid reasons in particular circumstances when the particular behavior is acceptable or even useful, but the full implications need to be understood and the case carefully weighed before implementing any behavior described with this label.
MAY	This word, or the term "OPTIONAL", means that this item is one of an allowed set of alternatives. An implementation that does not include this option MUST be prepared to inter-operate with another implementation that does include the option.

2.2 References

The following references are of relevance to this Technical Report. At the time of publication, the editions indicated were valid. All references are subject to revision; users of this Technical Report are therefore encouraged to investigate the possibility of applying the most recent edition of the references listed below.

A list of currently valid Broadband Forum Technical Reports is published at www.broadband-forum.org.

Document	Title	Source	Year
[1] TR-285 Issue 2	Broadband Copper cable Models	BBF	2019
[2] RFC-2119	Key words for use in RFCs to Indicate Requirement Levels	IETF	1997
[3] N. A. Marlowe,	A normal limit theorem for power sums of independent random variables, Vol. 46, pp. 2081-2089	Bell Syst. Tech. J.,	1967
[4] I. Nasell	Some properties of power sums of truncated normal random variables. Vol. 46, pp. 2091-2110	Bell Syst. Tech. J.,	1967

2.3 Definitions

See Definitions / TR-285 Issue 2.

2.4 Abbreviations

This Technical Report uses the following abbreviations:

TR	Technical Report
CPUFT	Cellular polyethylene insulation, grease filled
PCIFLI	PE insulated; grease filled

3 Technical Report Impact

3.1 Energy Efficiency

TR-285 Issue 2 Amendment 1 has no impact on energy efficiency.

3.2 Security

TR-285 Issue 2 Amendment 1 has no impact on security.

3.3 Privacy

.
TR-285 Issue 2 Amendment 1 has no impact on privacy.

Annex G: Australian Cable Models

.
Telecommunications companies in Australia have been deploying twisted pair cables since the early in the 20th Century. Today there is a large deployment of this cable which may be usable for modern and emerging twisted pair communications protocols. This annex provides attenuation and crosstalk models for common cables in the Australian context.

G.1 Cable selection and setup

The following cable types have been identified as potential carriers of modern and emerging twisted pair communications protocols in the Australian network of distribution cables, lead-in cables and building cables.

1. CPFUT 0.4mm. Cellular polyethylene insulation, grease filled, 10 twisted pairs in a unit or binder.
2. PEIFLI 0.4mm. PE insulated, grease filled, single quad lead-in cable.
3. HT57 0.57mm. High twist lead-in cable, solid PE insulated, grease filled, 2 twisted pairs – Blue-White with higher twist rate and Red-Black with lower twist rate.
4. Cat 3 Building Cabling. 25 or 100 twisted pairs with 10 and 5 pair subunits, PE insulated. Air core.

Lead-in cables are commonly called “drop” cables outside of Australia. They are essentially a combination of twisted pair and two pair quad cables.

Measurements were taken over a frequency range extending to 500 MHz.

The measurements for HT57 cable were taken using the cable farm illustrated in Figure 1

Figure 1 - Cable farm used for taking HT57 measurements.

Figure 2 shows an example of common lead-in / drop (PEIFLI and HT57) and in-home (CAT3) Australian cables.

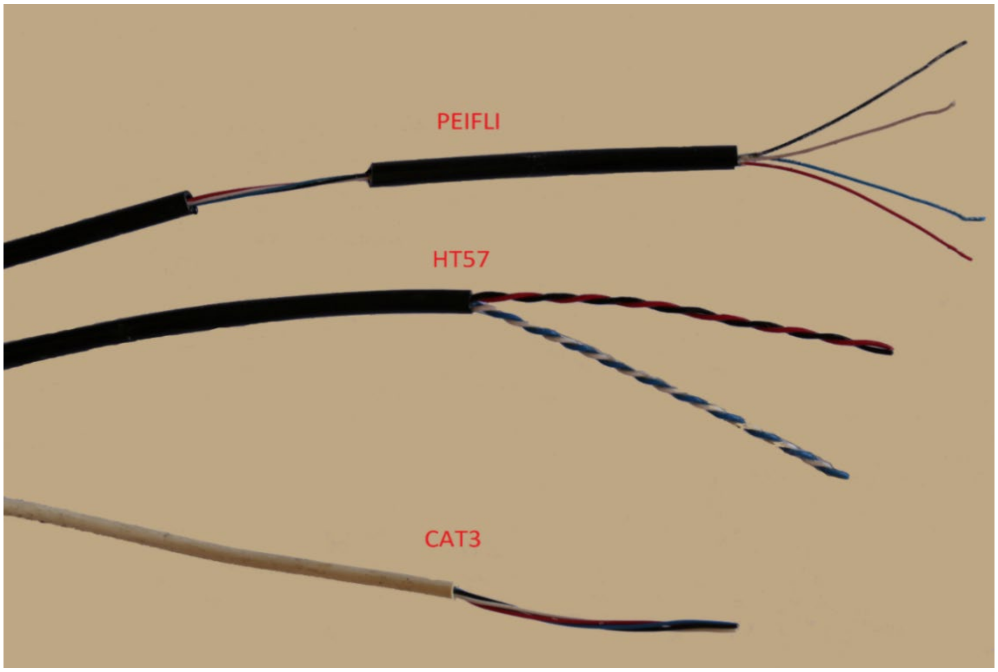

Figure 2 - Common lead-in / drop (PEIFLI and HT57) and in-home (CAT 3) Australian cables

Figure 3 illustrates a sample test setup for measuring CPFUT 10pr cable, where 2 pairs under test are connected to a 4-port VNA via a pair of baluns. This arrangement is repeated at the other end of the cable.

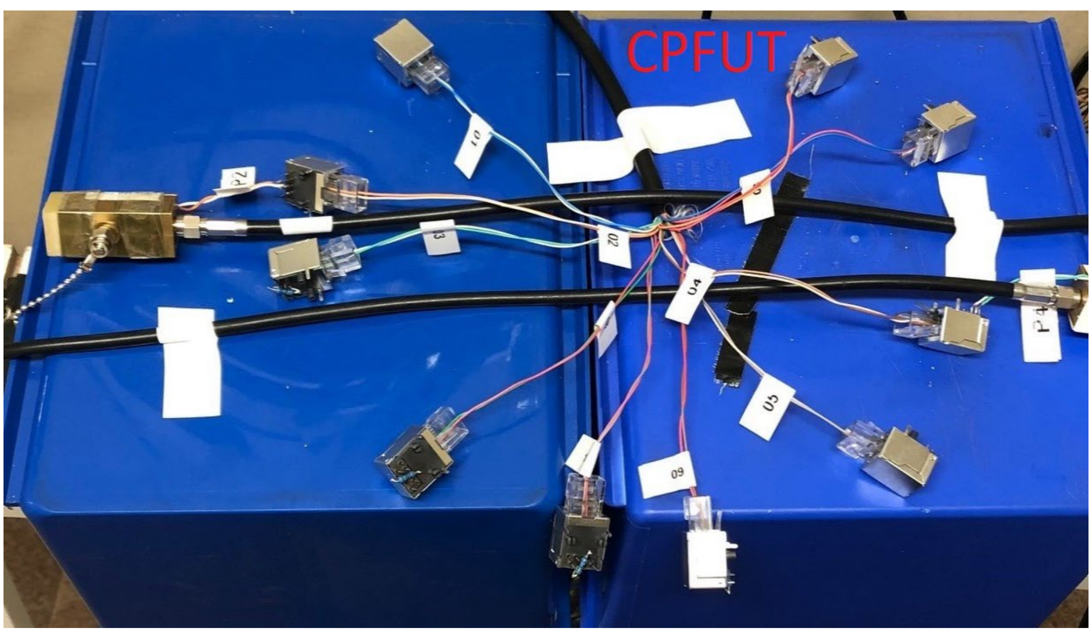

Figure 3 - Test setup for CPFUT 10pr cable

Figure 4 shows and example of a common CAT3 Australian multi-pair multi-dwelling unit riser cable.

Figure 4 - CAT3 multi-pair riser cable.

G.2 Cable Models

Existing methods for modelling twisted pair cables needed extension to effectively model the behaviours of Australian cables diverged at higher frequencies. The key observations were:

- Additional loss in transmission path due to crosstalk
- Changes in crosstalk behaviour beyond the two-slope model
- Crosstalk behaviour in intra-binder and intra-cable crosstalk with pairs of the same twist ratio has a significantly different signature compared with other pair combination with non-integer twist lengths

Models for attenuation and mean pair to pair FEXT and NEXT of 100m of each of a range of Australian cables are tabulated here. The basic attenuation model presented below accounts for losses due to crosstalk using a $K'f^2$ factor however it is worth noting that this effect is superseded at higher frequencies by crosstalk self-returning into the original pair and this model does not account for this effect. The basic models are as follows with f in MHz:

$$Attenuation\ (f) = \mathrm{Attenuation(1MHz)}\sqrt{f} + K'f^2 \qquad \text{(A1)}$$

$$FEXTR\ (f) = \mathrm{Max}\{0, \mathrm{FEXTR(1MHz)} - 20 * \log_{10}(f) - pf\} \qquad \text{(A2)}$$

$$NEXTA\ (f, 100m) = \mathrm{NEXTA(1MHz, 100m)} - \mathrm{Slope}_N * \log_{10}(f) - \left\{\mathrm{if}(f > f_T) then\ Slope_2 * \log_{10}\left(\frac{f}{f_T}\right) else\ 0\right\} \qquad \text{(A3)}$$

In addition, the Australian Communications Alliance codes characterise crosstalk using the 1% worst case FEXT power sum ratio and NEXT power sum attenuation from M disturbers at 1MHz. These power sums over M disturbing pairs may be obtained theoretically from the basic FEXTR and NEXTA models using the Wilkinson approximation (see the classic BSTJ papers by N. A. Marlowe,[3] and by I. Nasell,[4].

$$FEXTPSR\ (f, M) = \mathrm{FEXTPSR(1MHz, M = 4)} - 6 * \log_{10}\left(\frac{M}{4}\right) - 20 * \log_{10}(f) - pf \qquad \text{(A4)}$$

$$NEXTPSA\ (f, M) = \mathrm{NEXTPSA(1MHz, M = 4)} - 6 * \log_{10}\left(\frac{M}{4}\right) - \mathrm{Slope}_N * \log_{10}(f) - \left\{\mathrm{if}(f > f_T) then\ Slope_2 * \log_{10}\left(\frac{f}{f_T}\right) else\ 0\right\} \qquad \text{(A5)}$$

The Model parameters are derived from measurements that were performed on individual cables and on groups of cables within a 50mm PVC access pipe. Individual cable measurements include within unit (WU). Measurements between cables sharing a pipe are designated within pipe (WP). The mean attenuation and crosstalk parameters in dB for 100m of various cable types with full overlap are tabulated below, along with 1% power sum crosstalk adjusted to 4 disturbers:

Table 1 - Attenuation and Crosstalk model parameters for some Australian cables

Cable type	Pair Comb	Atten 1MHz	K'	FEXTR 1 MHz	FEXTPSR 1 MHz,4d	p	NEXTA 1MHz	NEXTPSA 1MHz,4d	$Slope_N$	f_T	$Slope_2$
CPFUT .4 10pr WU	45	1.9	.00085	63	46.6	.053	56	40.5	15	N/A	0
CPFUT .4 10pr WP	100	1.9	.00085	92	75.4	.21	91	75.5	15	7	10
PEIFLI .4 quad WP	6	1.9	.00007	79	61.6	.01	77	57.6	15	N/A	0
HT57 2pr WP bw-bw	28	1.8	.000009	85	69.5	0	93	77.4	10	N/A	0
HT57 2pr WP rb-rb	28	1.56	.00001	79.5	55.3	.015	83	67.5	10	N/A	0
HT57 2pr WP rb-bw	28	1.68 mean	NA	108	92.4	0	114	98.5	15	N/A	0
Cat3 Riser 25pr WU	45	1.9	.00012	70	50.9	.016	68	49.6	15	100	10

G.3 Cable measurements

This section shows the measurements performed and the mapping of the derived parameter model on the various cable types.

G.3.1 CPUFT cable

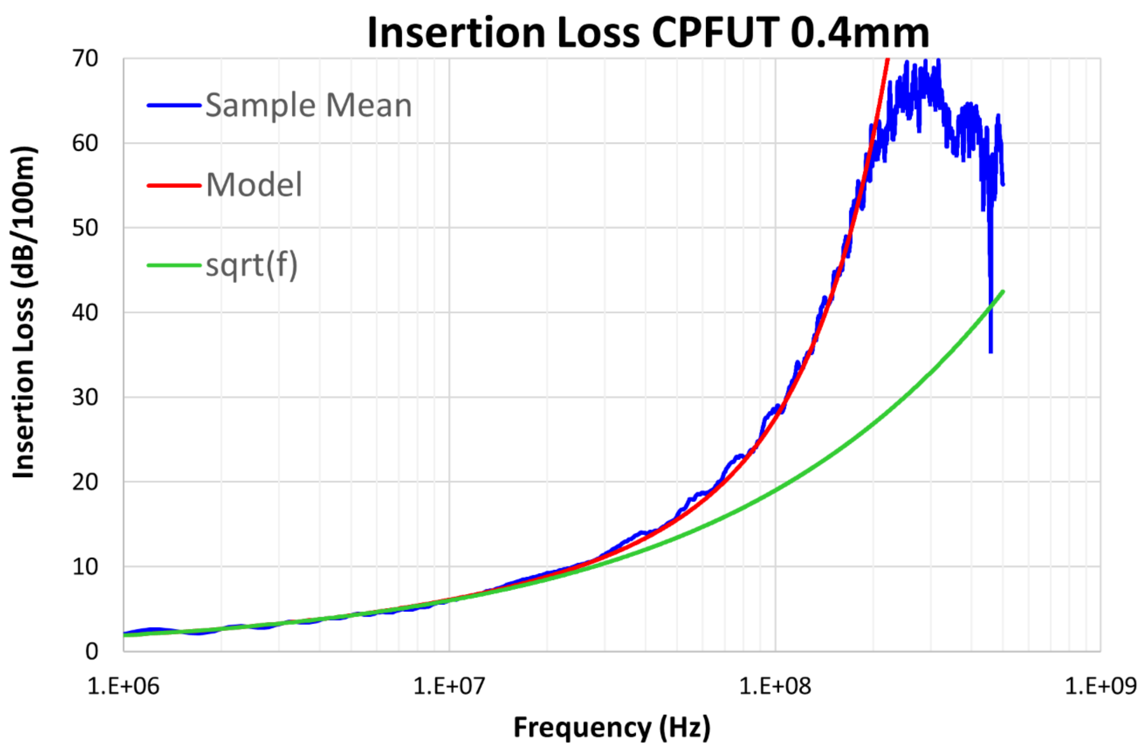

Figure 5 - Comparison of measured attenuation of 0.4mm CPFUT with fitted √f and the proposed √f + constant x f2 model.

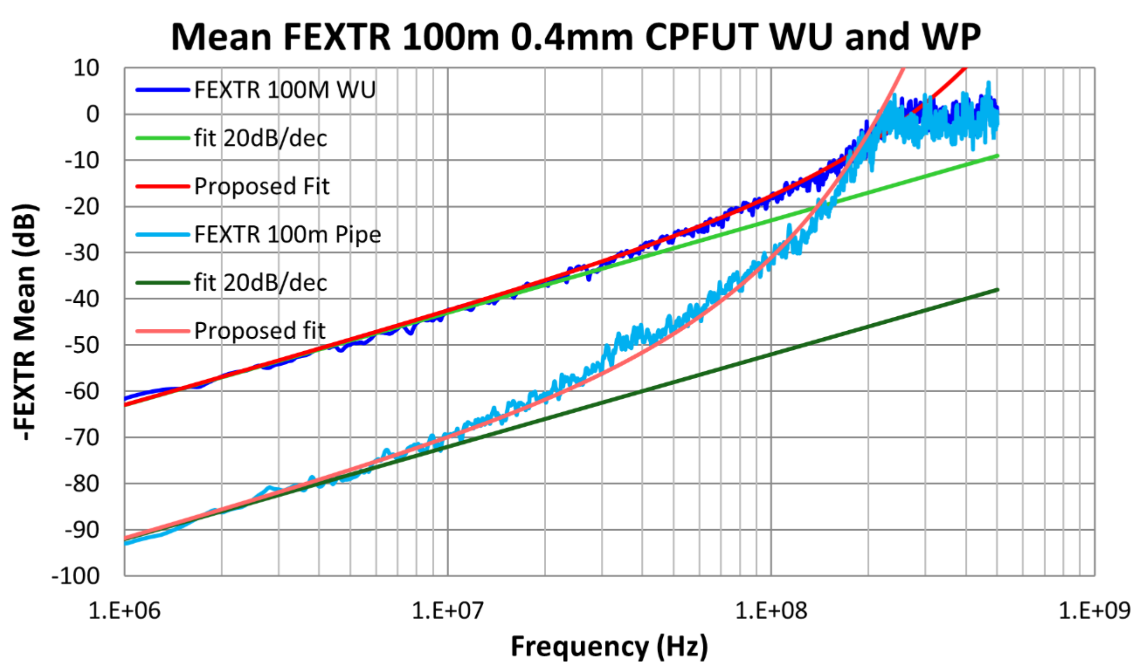

Figure 6 - Comparison of mean FEXTR vs f for CPFUT within pipe and within unit ensembles

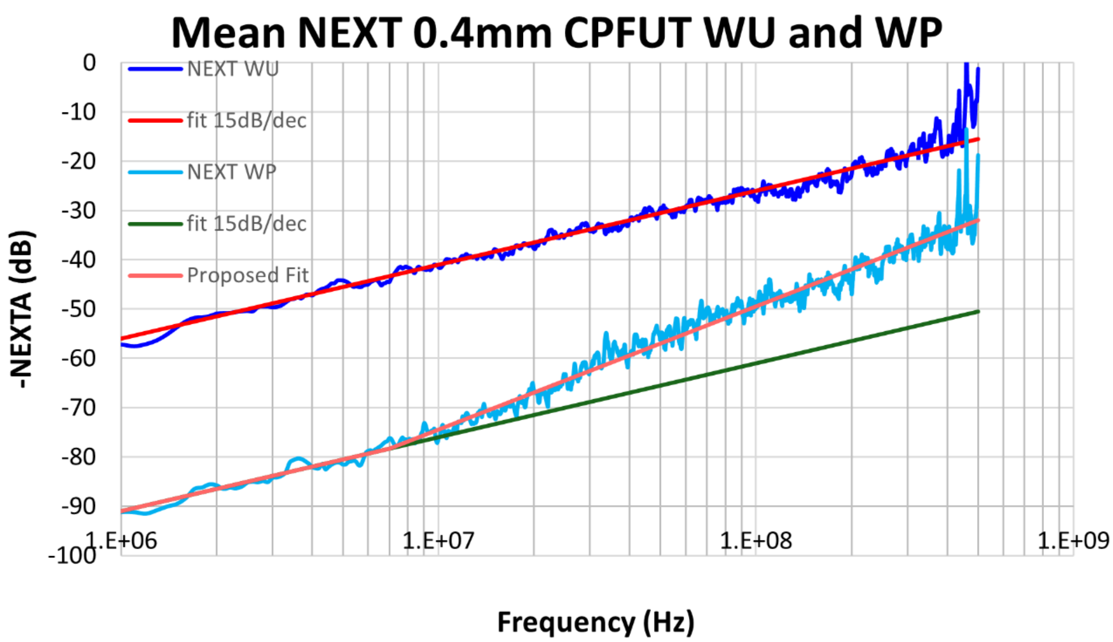

Figure 7 - Comparison of mean NEXTA vs f for CPFUT within unit and within pipe ensembles

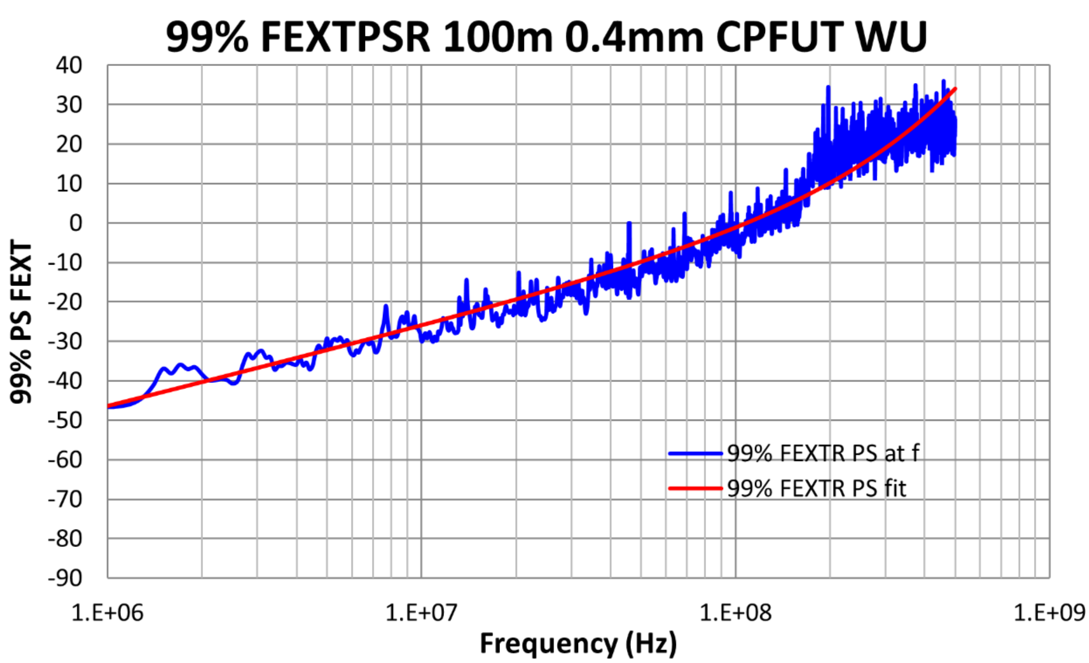

Figure 8 - Comparison of sample mean FEXTPSR with calculated mean from FEXTR statistics using Wilkinson Approximation for CPFUT within unit ensemble

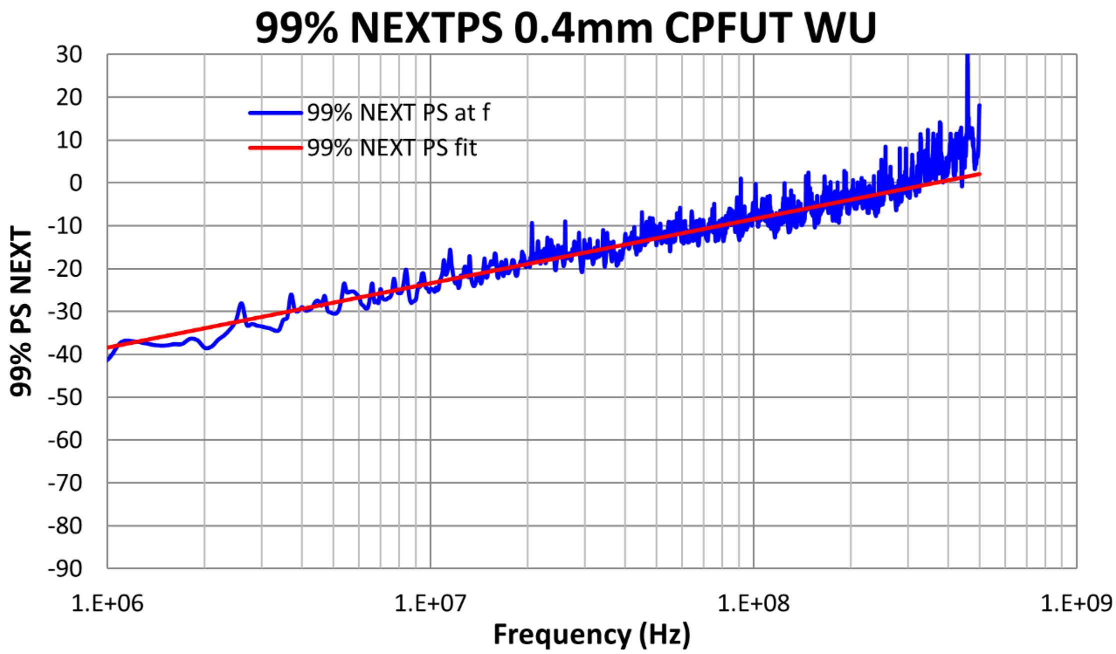

Figure 9 - Comparison of sample mean NEXTPSA with calculated mean from NEXTA statistics using Wilkinson Approximation for CPFUT within unit ensemble

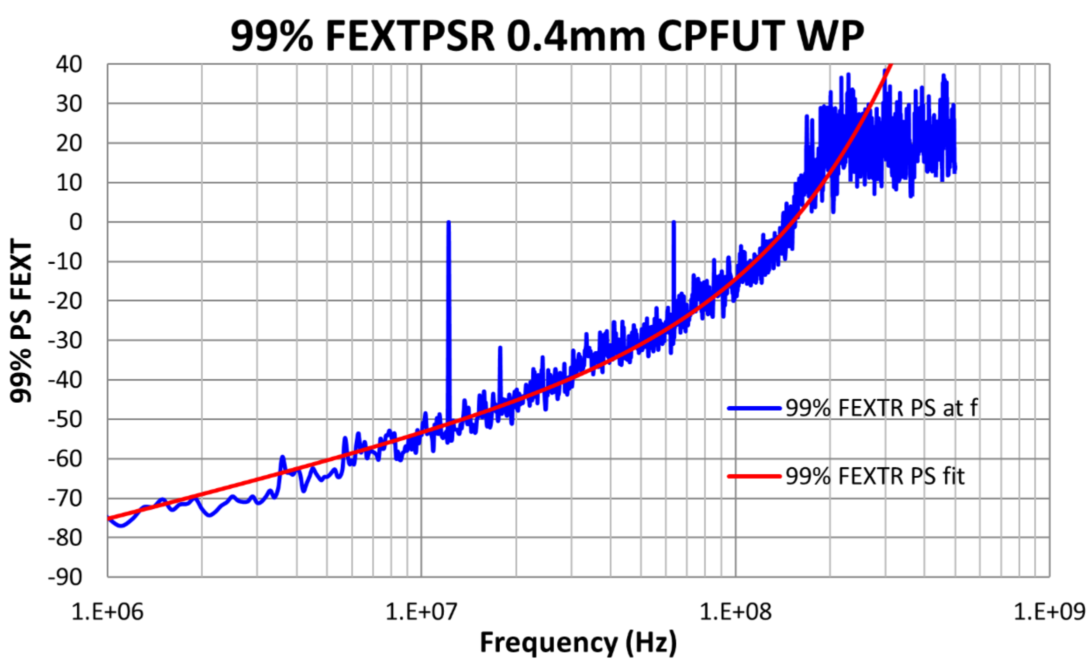

Figure 10 - Comparison of sample mean FEXTPSR with calculated mean from FEXTR statistics using Wilkinson Approximation for CPFUT within pipe ensemble

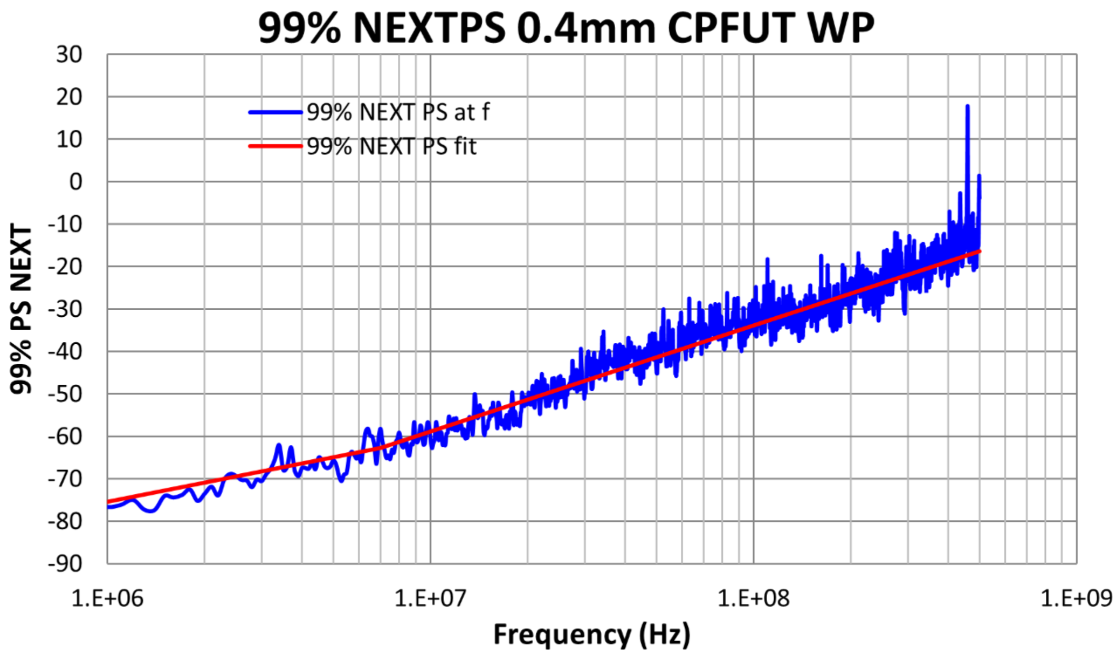

Figure 11 - Comparison of sample mean NEXTPSA with calculated mean from NEXTA statistics using Wilkinson Approximation for CPFUT within pipe ensemble

G.3.2 PEIFLI cable

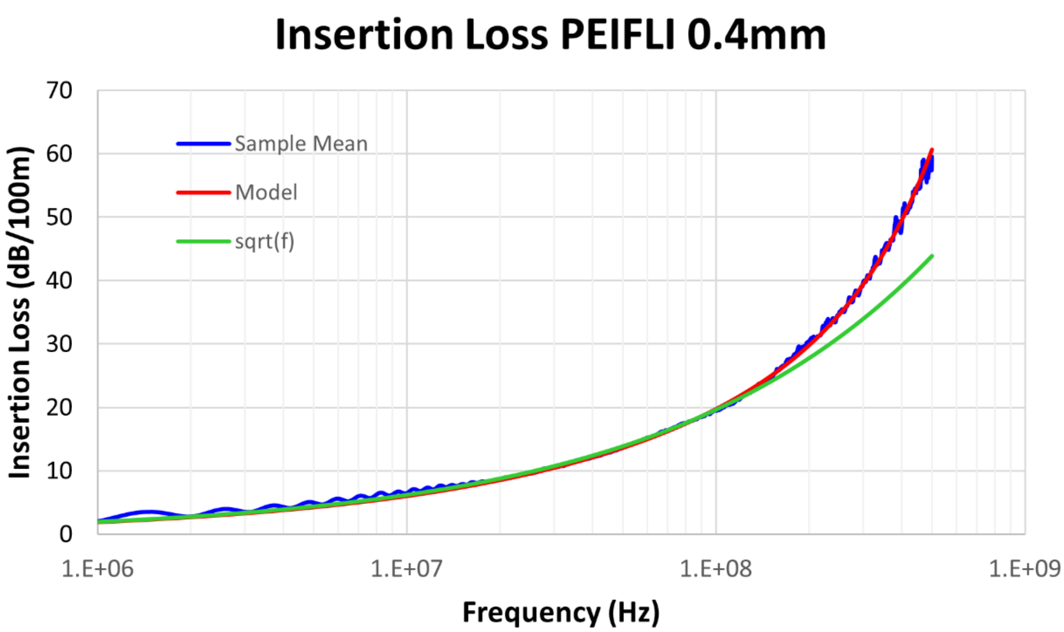

Figure 12 - Comparison of measured attenuation of 0.4mm PEIFLI with fitted √f and the proposed √f + constant x f2 model.

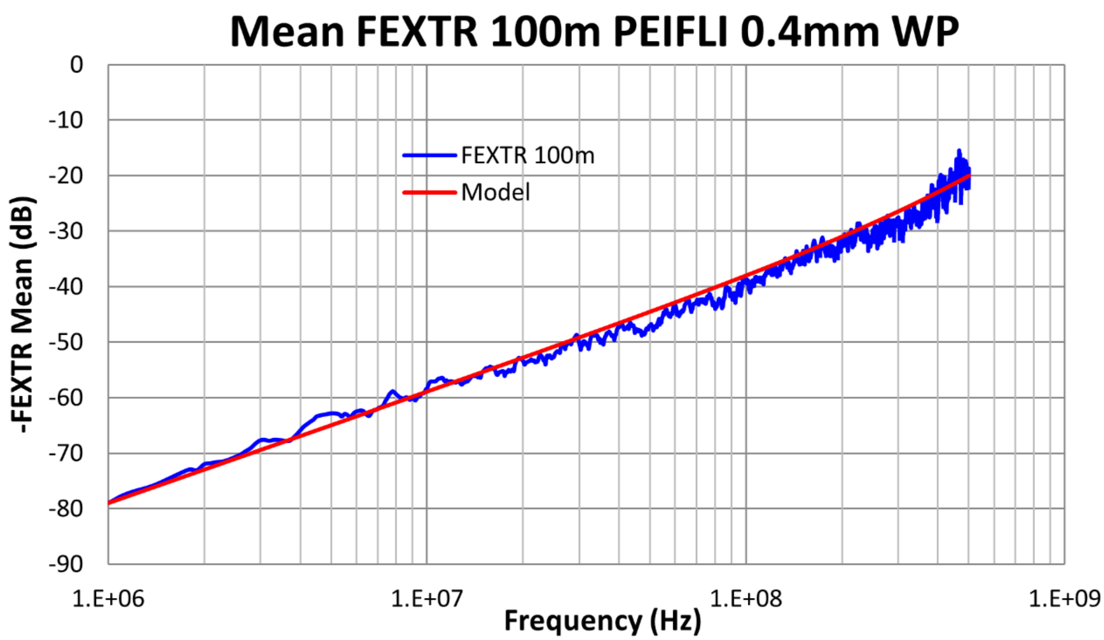

Figure 13 - Comparison of mean FEXTR with model for PEIFLI within pipe ensembles

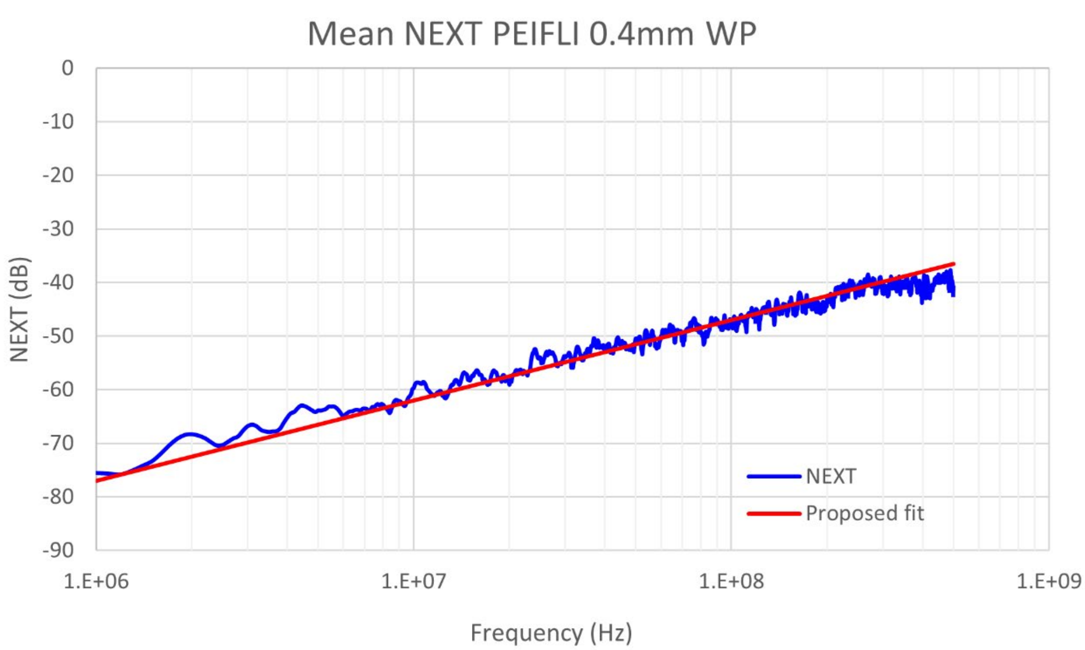

Figure 14 - Comparison of mean NEXTA with model for PEIFLI within pipe ensembles

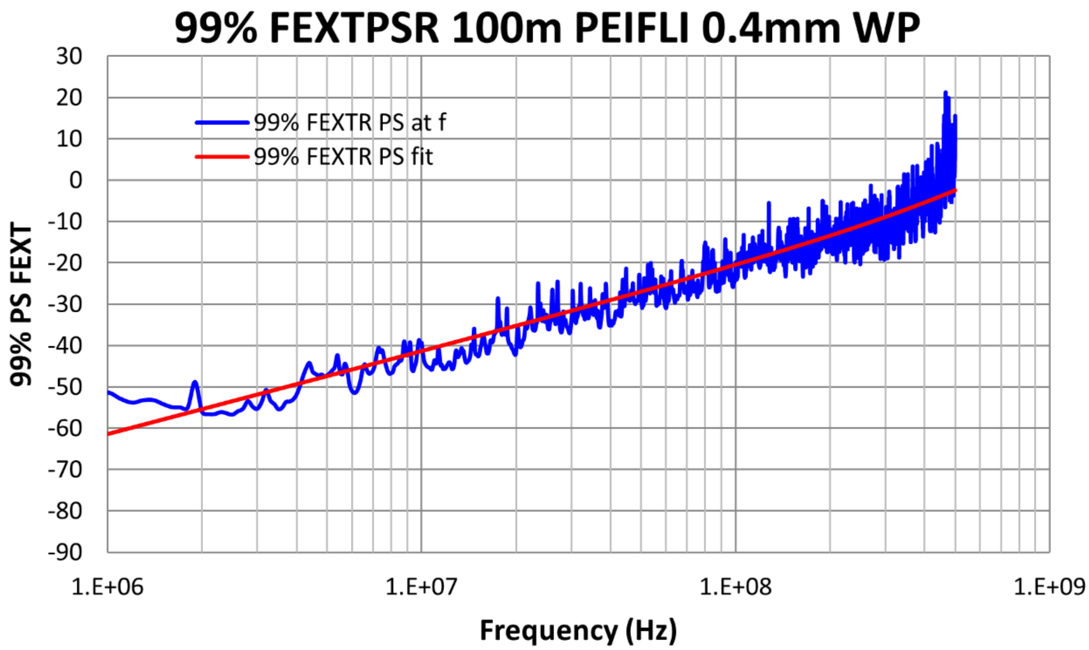

Figure 15 - Comparison of sample mean FEXTPSR with calculated mean from FEXTR statistics using Wilkinson Approximation for PEIFLI within pipe ensemble

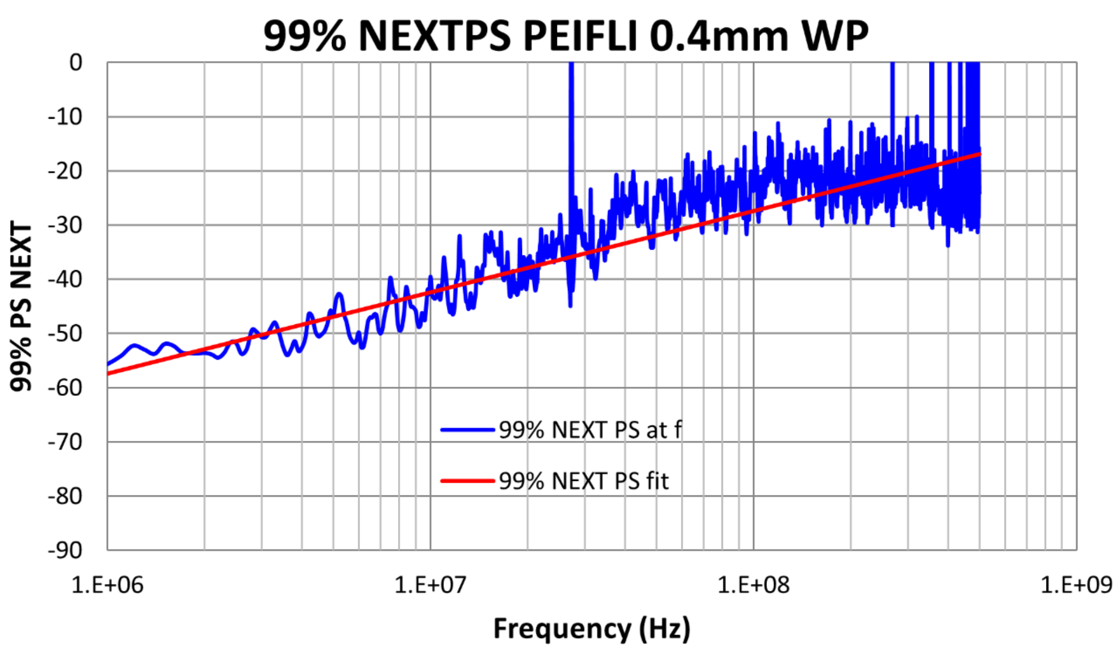

Figure 16 - Comparison of sample mean NEXTPSA with calculated mean from NEXTA statistics using Wilkinson Approximation for PEIFLI within pipe ensemble

G.3.3 HT57 lead-in cable

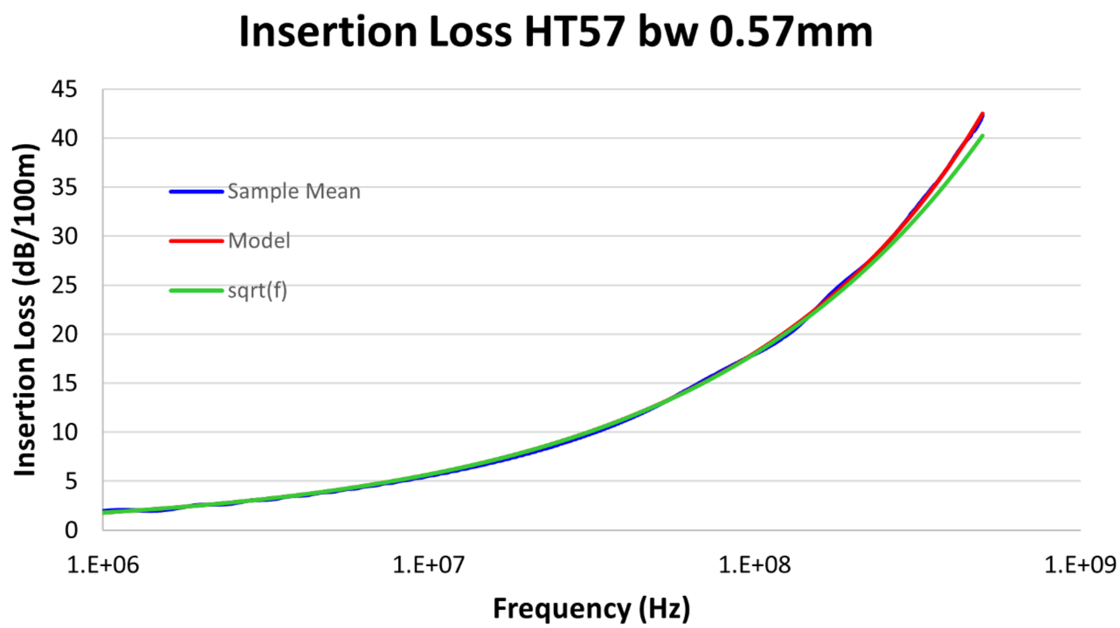

Figure 17 - Comparison of measured attenuation of 0.57mm HT57 bw with fitted √f and the proposed √f + constant x f2 model.

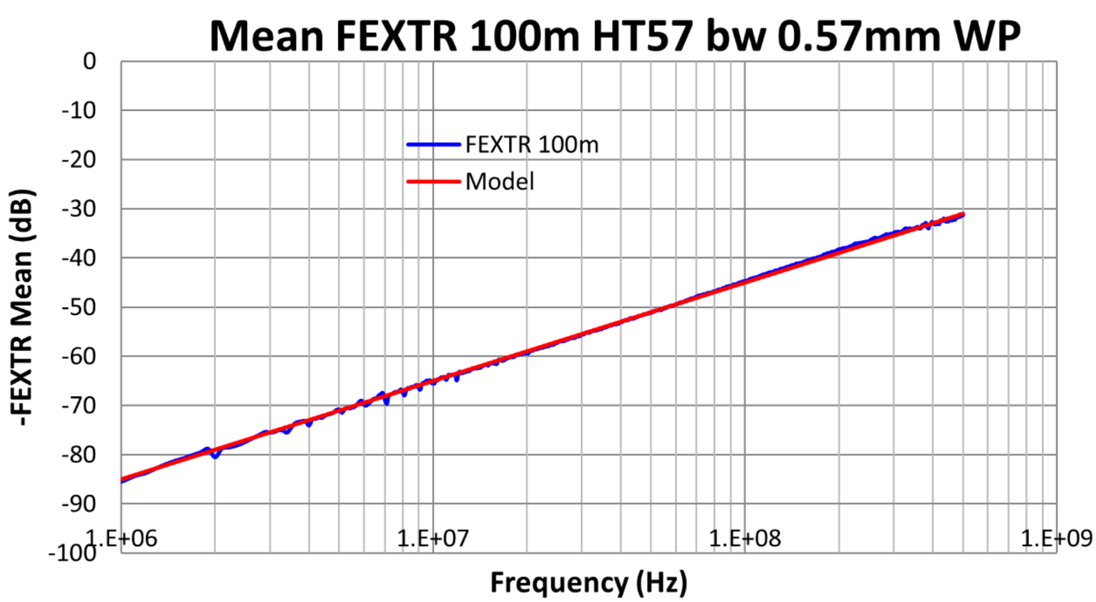

Figure 18 - Comparison of mean FEXTR with model for HT57 bw within pipe ensembles

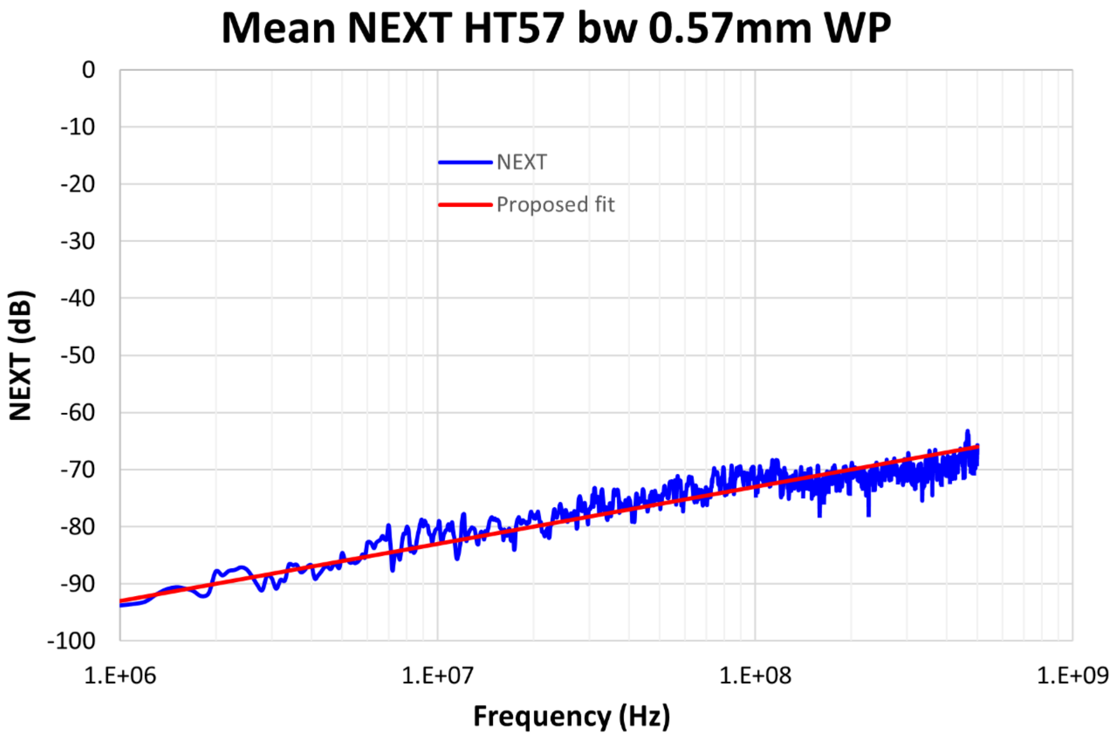

Figure 19 - Comparison of mean NEXTA with model for HT57 bw within pipe ensembles

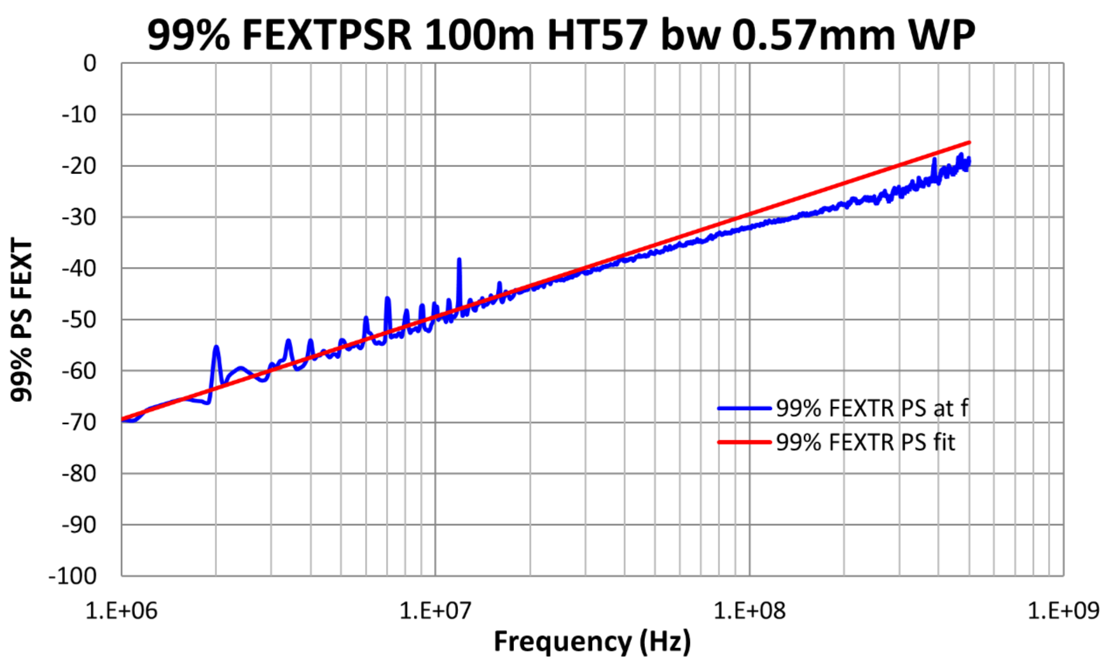

Figure 20 - Comparison of sample mean FEXTPSR with calculated mean from FEXTR statistics using Wilkinson Approximation for HT57 bw within pipe ensemble

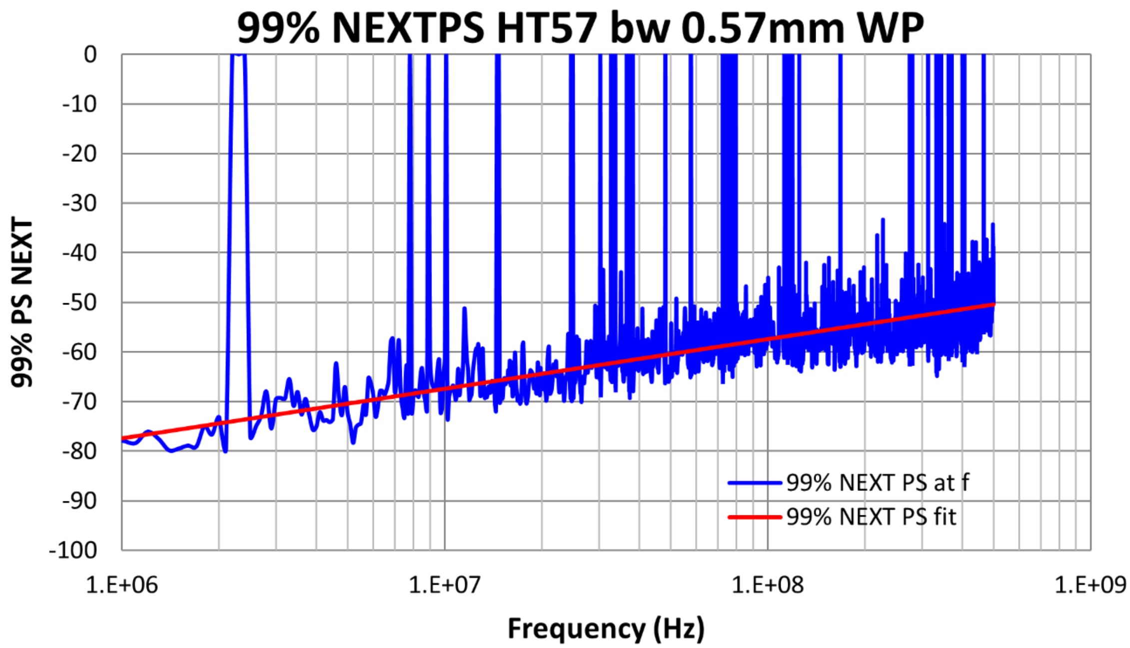

Figure 21 - Comparison of sample mean NEXTPSA with calculated mean from NEXTA statistics using Wilkinson Approximation for HT57 bw within pipe ensemble

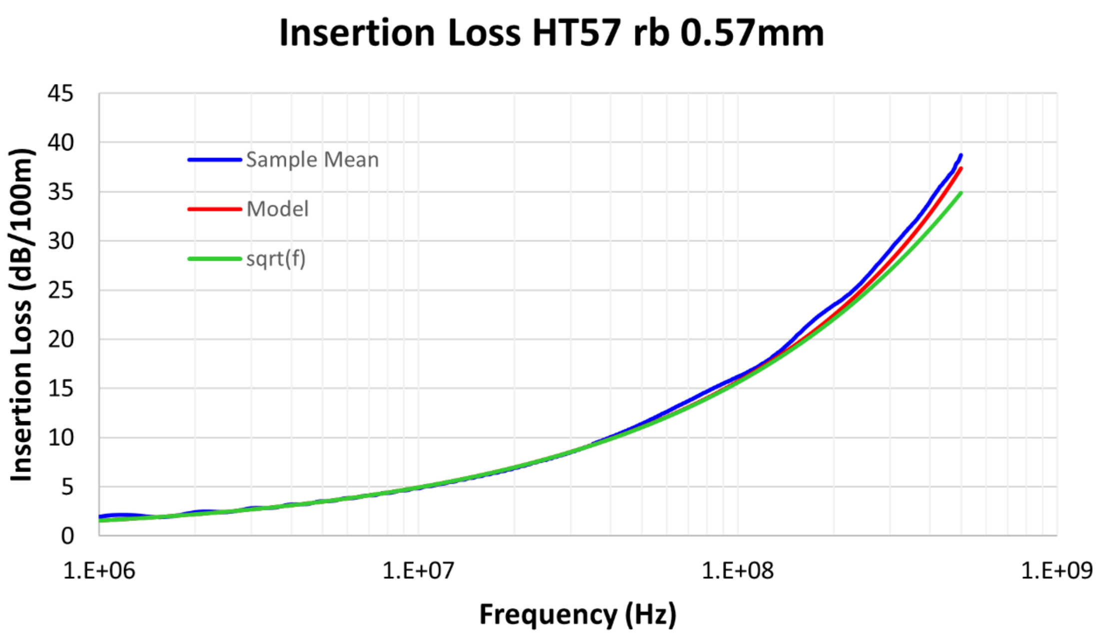

Figure 22 - Comparison of measured attenuation of 0.57mm HT57 rb with fitted √f and the proposed √f + constant x f2 model.

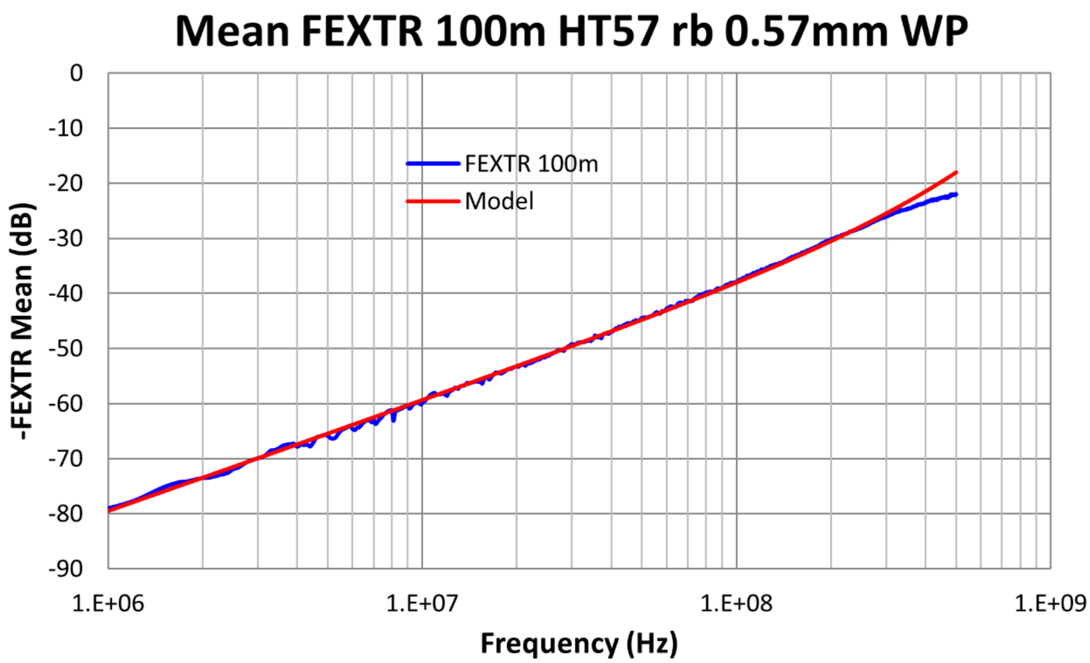

Figure 23 - Comparison of mean FEXTR with model for HT57 rb within pipe ensembles

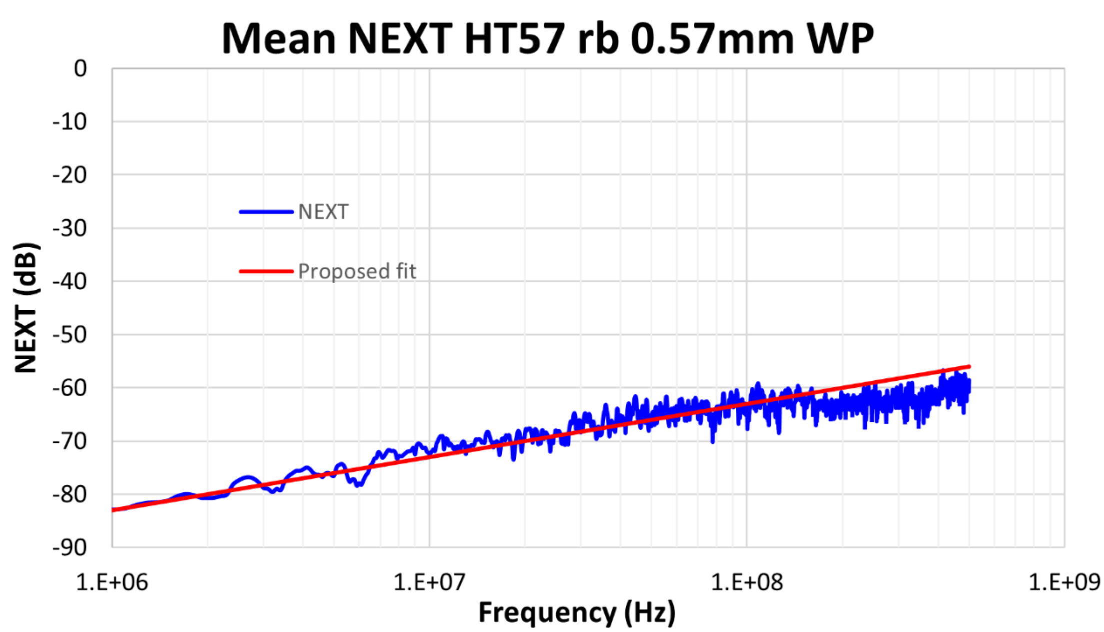

Figure 24 - Comparison of mean NEXTA with model for HT57 rb within pipe ensembles

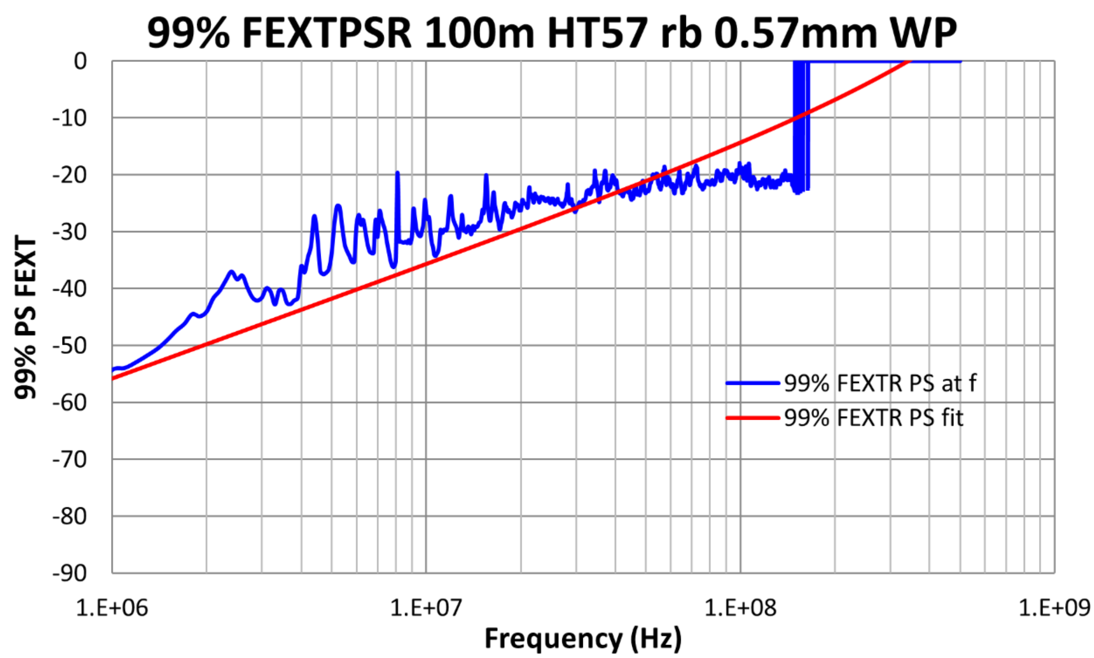

Figure 25 - Comparison of sample mean FEXTPSR with calculated mean from FEXTR statistics using Wilkinson Approximation for HT57 rb within pipe ensemble

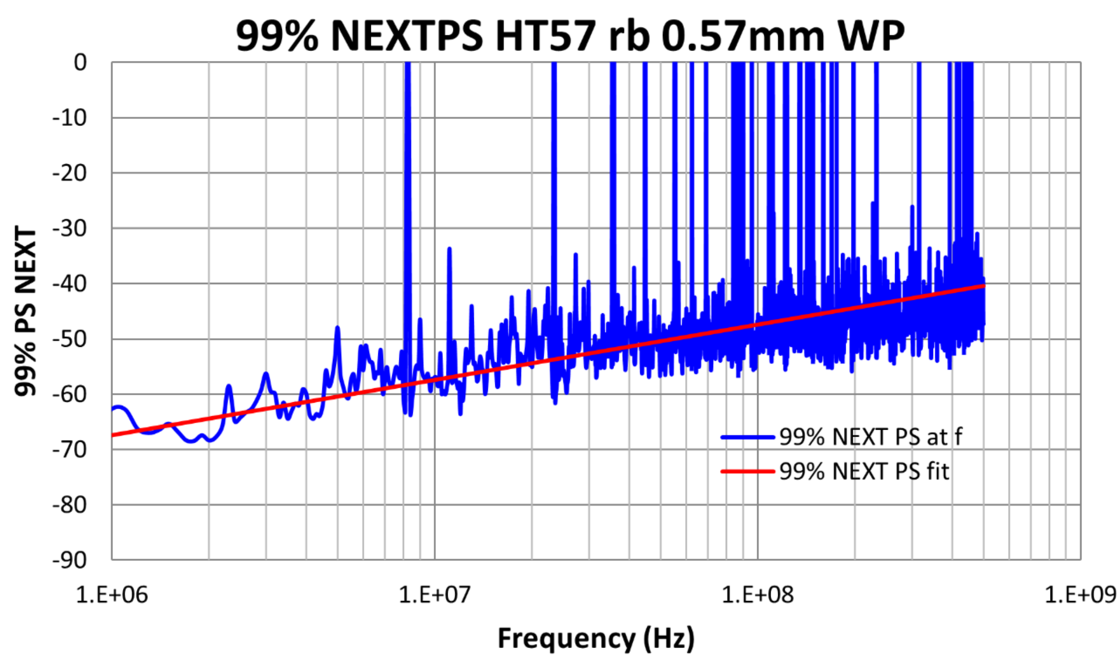

Figure 26 - Comparison of sample mean NEXTPSA with calculated mean from NEXTA statistics using Wilkinson Approximation for HT57 rb within pipe ensemble

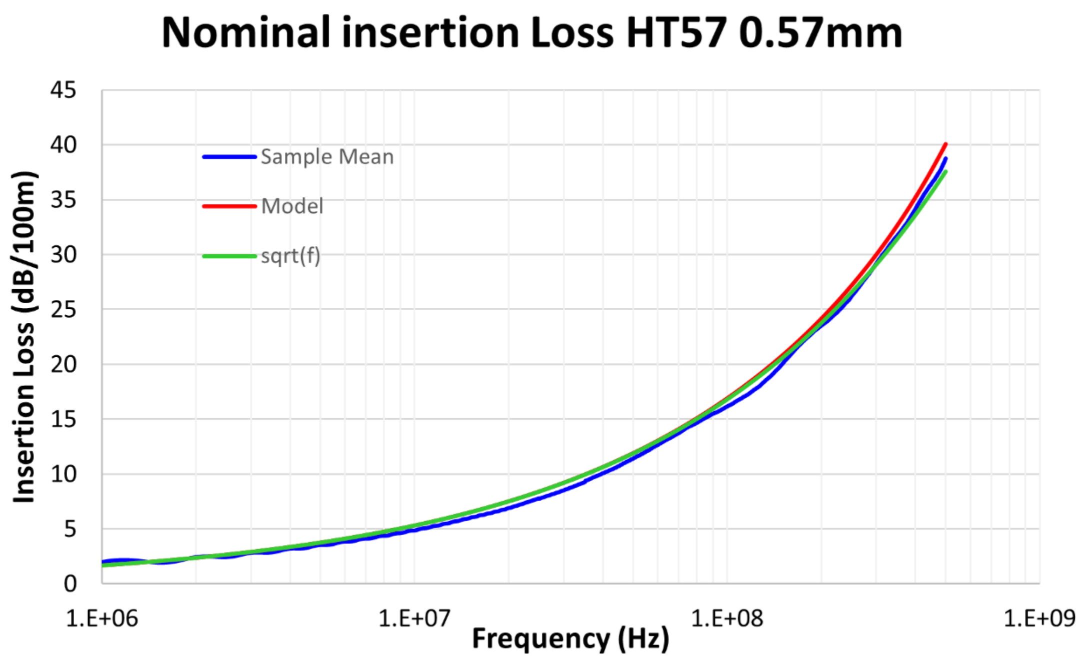

Figure 27 - Comparison of measured attenuation of 0.57mm HT57 with fitted √f and the proposed √f + constant x f2 model.

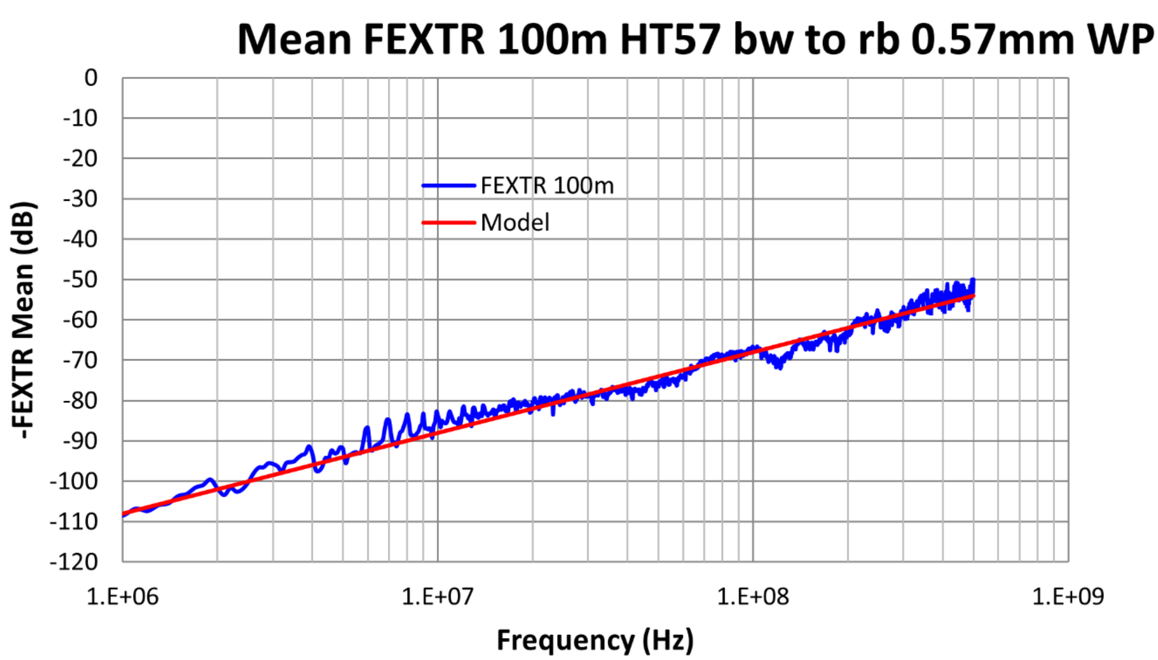

Figure 28 - Comparison of mean FEXTR with model for HT57 bw to rb within pipe ensembles

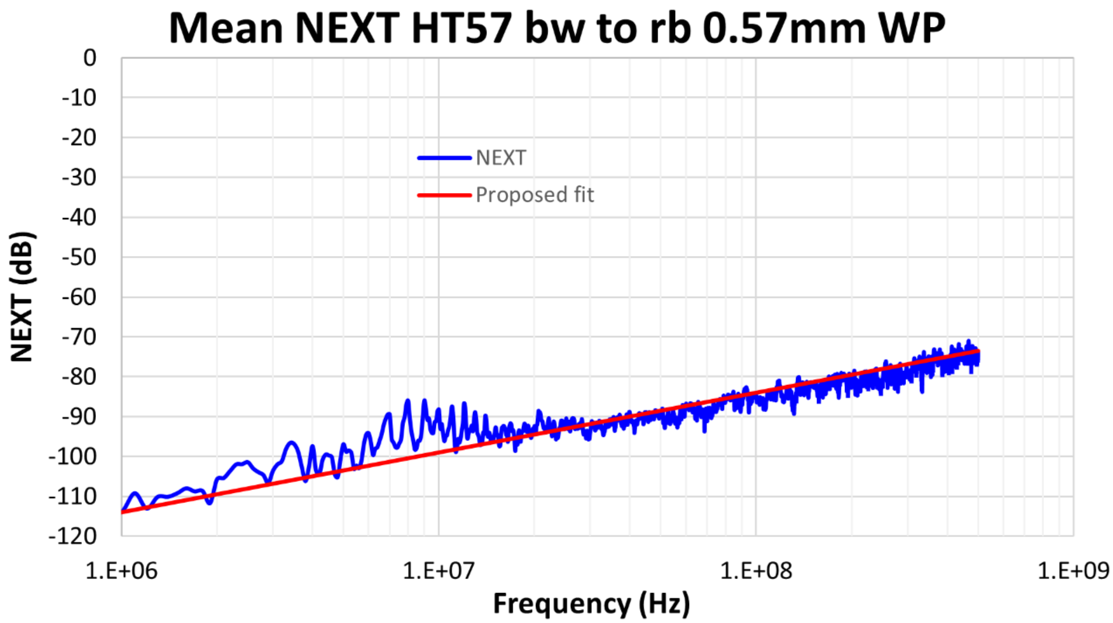

Figure 29 - Comparison of mean NEXTA with model for HT57 bw to rb within pipe ensembles

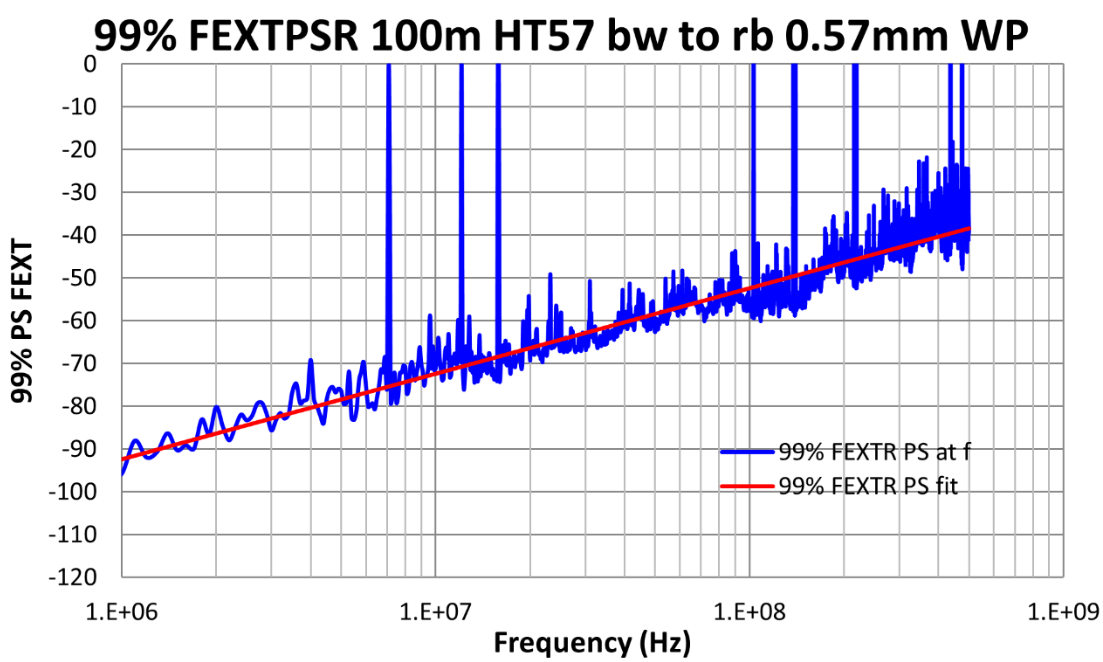

Figure 30 - Comparison of sample mean FEXTPSR with calculated mean from FEXTR statistics using Wilkinson Approximation for HT57 bw to rb within pipe ensemble

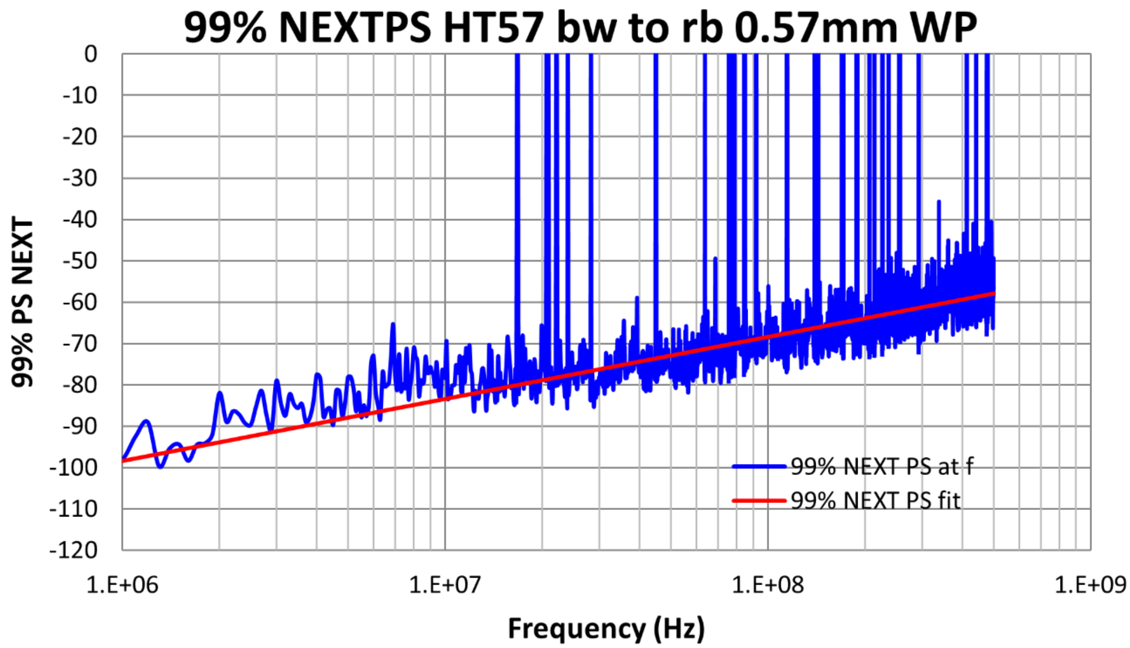

Figure 31 - Comparison of sample mean NEXTPSA with calculated mean from NEXTA statistics using Wilkinson Approximation for HT57 bw to rb within pipe ensemble

G.3.4 CAT3 mult-pair riser cable

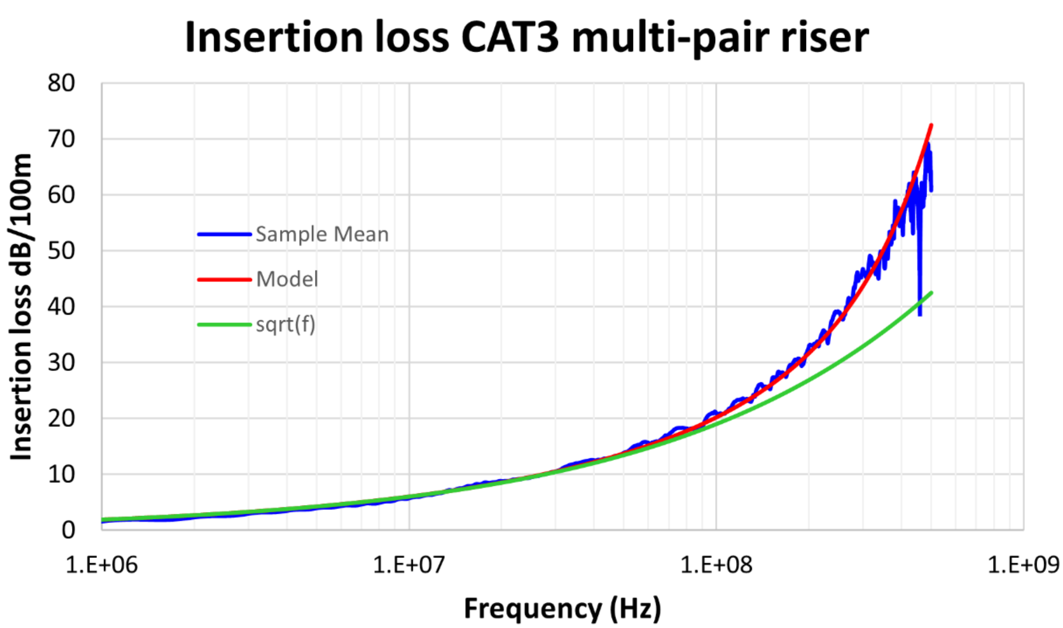

Figure 32 - Comparison of measured attenuation of CAT3 multi-pair with fitted √f and the proposed √f + constant x f2 model.

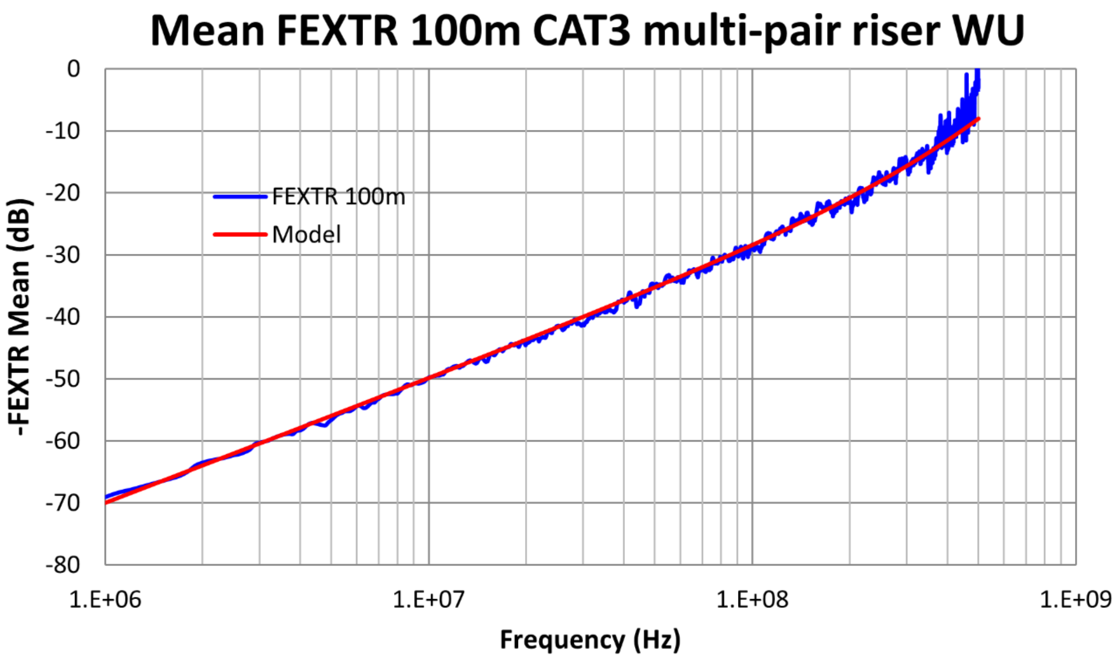

Figure 33 - Comparison of mean FEXTR with model for CAT3 multi-pair within unit ensembles

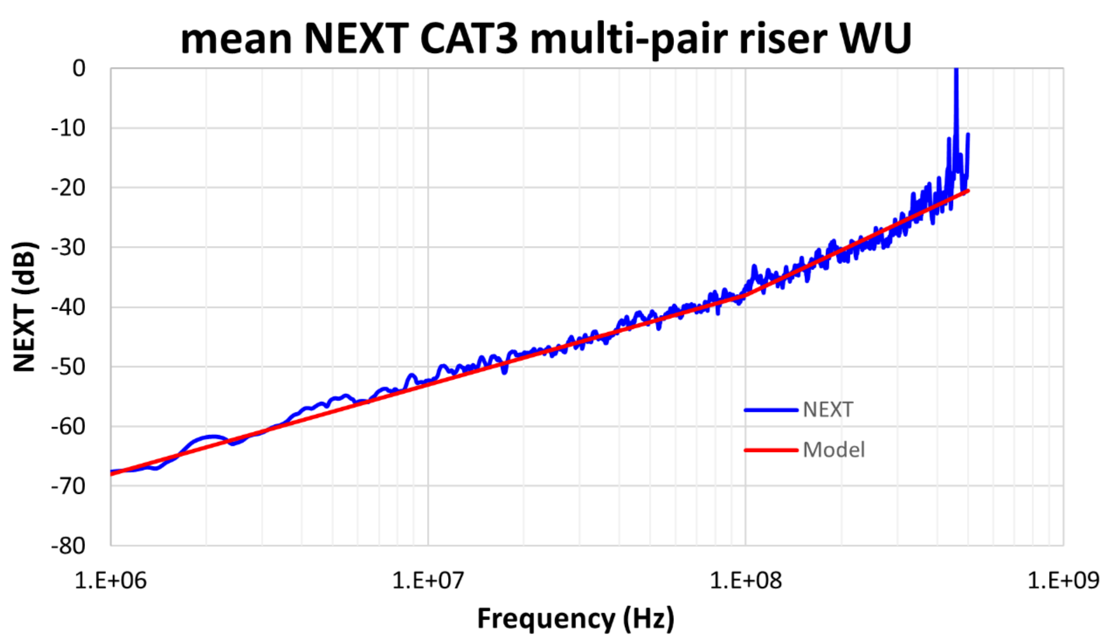

Figure 34 - Comparison of mean NEXTA with model for CAT3 multi-pair within unit ensembles

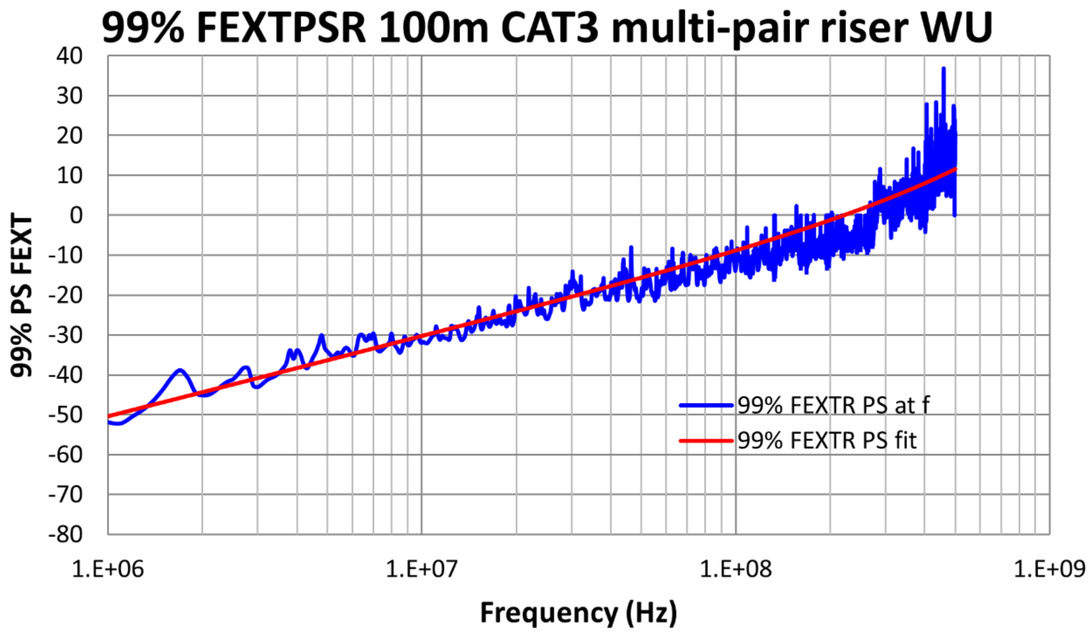

Figure 35 - Comparison of sample mean FEXTPSR with calculated mean from FEXTR statistics using Wilkinson Approximation for CAT3 multi-pair within unit ensemble

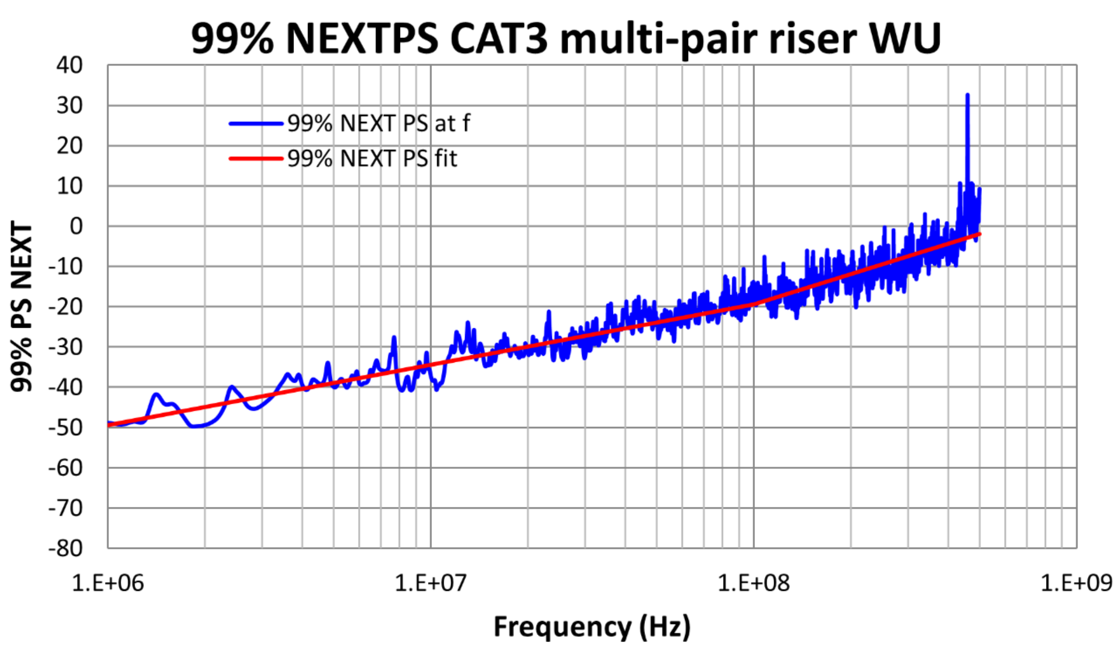

Figure 36 - Comparison of sample mean NEXTPSA with calculated mean from NEXTA statistics using Wilkinson Approximation for CAT3 multi-pair within unit ensemble

End of Broadband Forum Technical Report TR-285 Issue 2 Amendment 1

