IEEE P802.3at Task Force
Power Via MDI Enhancements
Midspan Adhoc

Midspan/Channel Requirements below 1MHz – Final Report

Yair Darshan / Microsemi Corporation, May 15, 2008

Meeting Participants in May 14, 2008 ad hoc

Terry Cob	Systemax / Commscope
Wolfgang Knitterscheidr	Eurocomp
Rick Frosch	Phihong
Bertro Simon	Microsemi
Raul Lozano	Juniper Network
Stefan Landau	Eurocomp
George Zimmerman	Solarflare
Pavlik Reimboim	Microsemi
George Eisler	Solarflare
Sreu Kleausuitzv	Eurocomp
Keith Hopwood	Phihong
Sterling Vaden	SMP DATA COM
Gianluca Sanita’	NSN
Iris Shuker	Mirosemi
Tamir Reshef	Microsemi

Previous meetings participants.

- Previous meetings participants.
- David Law 3COM
- Rick Frosch Phihong
- Mick Mccormack T.I
- Gaoling Zou Maxim
- Keith Hopwood Phihong
- Christian Bia
- Peter Johnson Sifos
- Frank Yang Commscope
- Christophe Gouwy AMIS
- Randy K Rannow Tyco Electronics
- Mlaggiolino Joseph Broadcom
- Thuyen Dinh Pulse
- Eran Bello Microsemi
- Sanita' Gianluca NSN
- Stephen Sedio Foxconn
- Reshef Tamir Microsemi
- Pavlik Reimboim Microsemi
- Larry Shorthill NXP
- Mo Saboori Pulse (*)
- Steve Sedio Foxconn
- Thong Huynh Maxim
- Harmik Singh Maxim
- Geoff Thompson Nortel
- Clay Stanford LT

Ad Hoc meeting May 8 and May 14, 2008 - Report

- 3RD BER tests results
- Finalizing Operating Bandwidth
- Final results of SCM with and w/o Midspan
- Worst case analysis results
- Evaluating the design margins in the system
- Midspan TF including test setup for compliance.
- Reviewing, Discussing and updating Remedy for comments addressing 33.4.8.2 Draft D3.0
- Q&A

BER test sensitivity analysis

- Setup:
- A standard 100BT system tested at 100BT w/o Midspan by using 100BT standard equipment generator.
- Generator Transmitter inductance reduced to 350uH by adding external parallel inductance for total equivalent inductance of 350uH. (It is not known for sure if test equipment is not using BLW tracking)
- Results:
- BER tests results showed ZERO lost packets with and w/o Midspan ALT A when BLW data were inserted.
- Two Midspan devices were tested with different implementations
- Conclusions:
- The above results together with the other two UNH tests confirms that the addition of 3rd Inductance (that meets the requirements) in parallel is not affecting the data integrity under BLW conditions.
- *See transfer function derivation for understanding why it is not affecting the results from mathematical/physical point of view .*

Finalizing Operating Bandwidth

- The reason for our work was the fact that 350uH was defined only for 100BT.
- BLW effects are relevant only for 100BT
- The 350uH was defined at lower frequency (100KHz) then the data bandwidth minimum frequency (1MHz) which imply that the relevancy of the operating worst case bandwidth under BLW conditions is not lower then 100KHz.
- Hence there is no need to address lower frequencies then 100KHz in the System Channel Model with or without Midspan according to the current specifications (ANSI X3.263-1995 (TP-PMD) subclause 9.1.7).
- As a result
  - Operating frequency range of TF: 100KHz<= f < 1MHz.
  - Confirmed by PHY experts (Dan Dove and others)

Analysis Model Parameters

	Parameter	Units	Min	Max	Comments
	Transformer				
1	Inductance	uH	350		At Ibias maximum
2	Rwp	Ω		0.5	
3	Rws	Ω		0.55	
4	Transformer insersion loss at 100MHz	dB		1	
5	Transformer insersion loss at 1MHz	dB		0.5	Typical value is 0.2dB
6	**Connectors** Rdc	Ω		0.2	
7	Total **Channel** Resistance	Ω		25	For 100m
8	100BT **transmitter** signal	Vpp	2		Data from Dan Dove
9	100BT **receiver** minimum signal to detect at worst case	Vpp	0.045		Data from Dan Dove
10	Source and Load **Terminations**	Ω	95	105	Data from Steve Sedio, Dan Dove and Randy Rannow
11	**Test Equipment** Gain Measurements **errors**	dB		0.1	Test equipment vendors to comment
12	**Switch** Design Margin	dB		>20	See detailed calculations in next slide
13	**Midspan** Design Margin	dB		<1	See detailed calculations in next slide

Termination min/max value considerations

- Inputs from Steve Sedio, Dan Dove and Randy Rannow
- Source and load accuracy: +/-5%.
- The spec is driven by the Return Loss criteria. With an 85-110 ohm line impedance, we have to meet return loss.
- This limits the capacitance and resistance of the port. Typically some use 100ohms with +/-1%, but many IC vendors are implementing internal terminations which may not be as tightly specified.
- Conclusions:
- Model: Using +/-5% is practical than using +/- 1%.
- Test setup: Use +/- 1% resistors.

Worst Case Analysis conditions

- Worst Case Gain Attenuation operating conditions in the System Channel Model w/o Midspan.
  - RL ➔ Min (RL=Termination at the Receiver side)
  - RS➔ Max (RS=Termination at the Transmitter side)
  - Rwp, Rws ➔ Max (Primary and Secondary Transformer windings)
  - Connector ➔ Max (Connector contact resistance)
  - LM ➔ Min (=350uH, Happen at Ibias max.)
  - Rc ➔ Max ➔ (length=100m, Cable resistance)
  - Number of connectors ➔ Max=6, i.e. Channel= 4, Equipment= 2

Acceptable System Channel w.c Gain=Insertion Loss=Attenuation at 100MHz for 100m.

	Parameter	Units	Value	Source	Comments
1	Transmitter Minimum output	Vpp/dB	2 / 6	Dan Dove and others	
2	Channel Insertion Loss	dB	24	ANSI/TIA/EIA-568-B.1-2001	
3	Source Load termination attenuation	dB	6.02	100/(100+100)= 0.5=6.02dB	
4	Data Transformer worst case insertion loss	dB	2	In reality the number is lower	Two Data transformers
5	Minimum signal at Receiver input	dB/Vpp	6-24-6.02-2= -25.97dB =0.05Vpp	Calculated based on the data in this table	Dan Dove: 0.045Vpp.
6	PHY to PHY minimum requirement to support 100BT at worst case conditions at 100MHz.	(V/V)/ dB	0.05/2=0.025 -32	Calculated based on the data in this table	

Acceptable System Channel w.c Gain=Insertion Loss=Attenuation at **1MHz** for 100m.

	Parameter	Units	Value	Source	Comments
1	Transmitter Minimum output	Vpp/dB	2 / 6	Dan Dove	
2	Channel Insertion Loss	dB	2.2	-ANSI/TIA/EIA-568-B.1-2001	
			4	ISO/IEC 11801:2002	
3	Source Load termination attenuation	dB	6.02	100/(100+100)= 0.5=6.02dB	
4	Data Transformer worst case insertion loss	dB	~1	Actually is ~0.2dB at 1MHz. 0.5dB was used as worst case	Two Data transformers
5	Minimum signal at Receiver input	Db/Vpp	6-4-6.02-1= -4.97dB =0.563Vpp	Calculated based on the data in this table	
6	PHY to PHY minimum requirement to support 100BT at worst case conditions at 1MHz.	(V/V)/ dB	0.563/2=0.281 -11	Calculated based on the data in this table	

Our interest is frequencies below 1MHz.

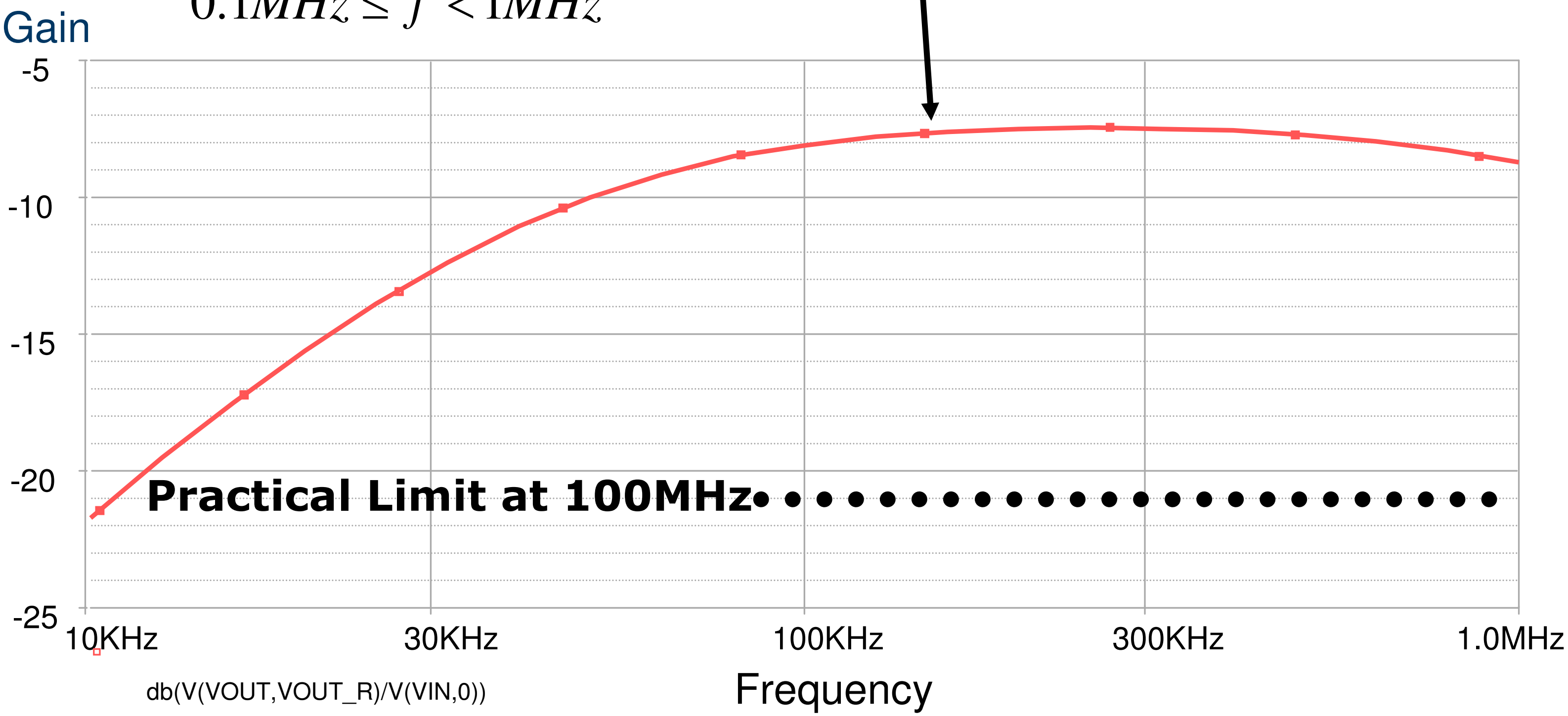
Hence we have **21dB design margin** (0.05Vpp @100MHz/0.563Vpp @ 1MHz)

SCM: without Midspan at 350uH,100m. W.C analysis

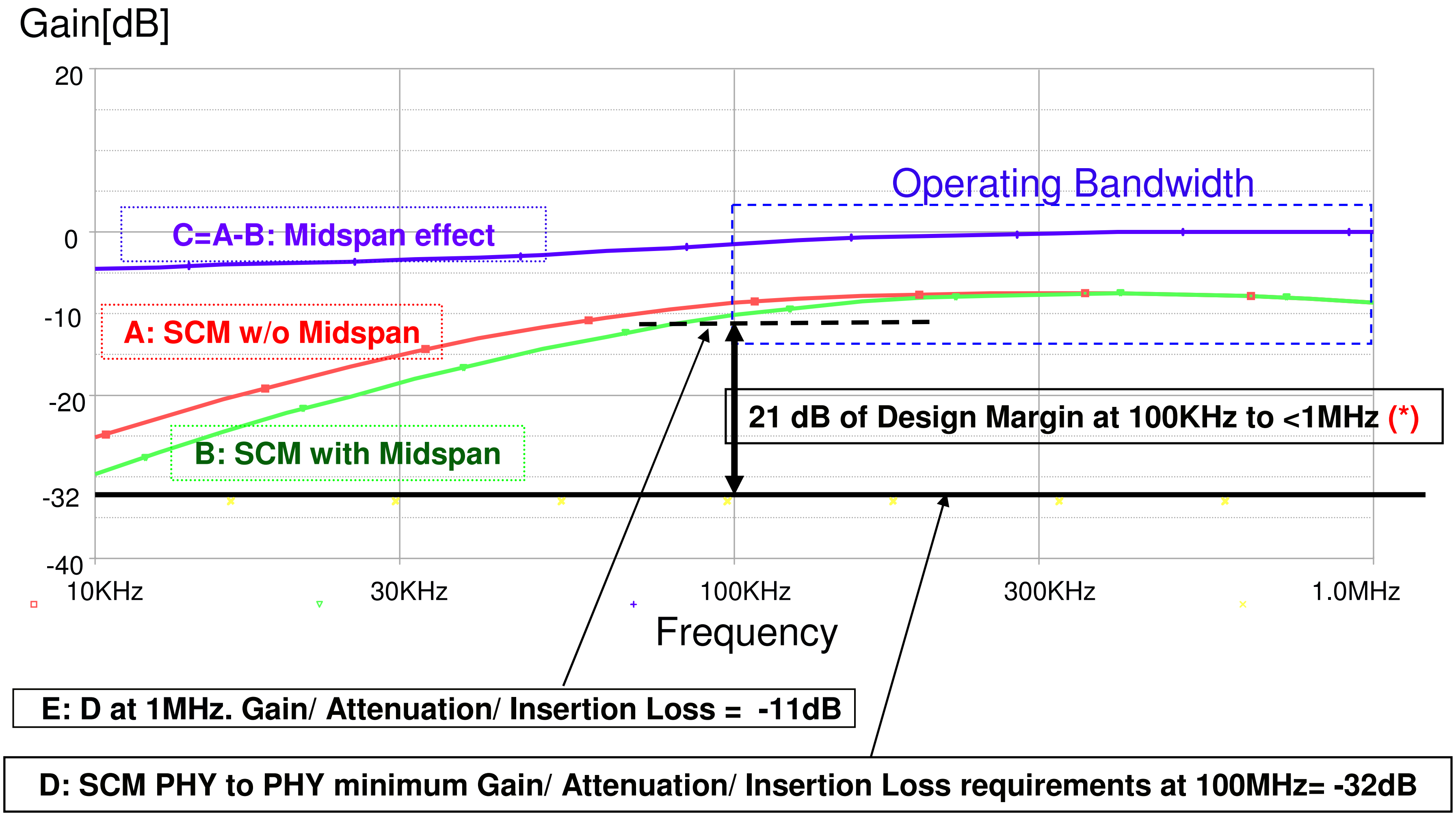
- A compliant System Channel Model Gain w/o Midspan, must be higher than this curve per current standards and standard components specifications

$$Gain = -9.075 + 14.419\cdot f - 41.781\cdot f^2 + 45.759\cdot f^3 - 18.075\cdot f^4$$

$$0.1MHz \le f < 1MHz$$



SCM: with and without Midspan at 350uH,100m. W.C analysis



(*) Actually margin is higher by additional 3dB due to the fact that Channel IL is ~1dB at f<1MHz and not 4dB

How to distribute the design margins that we have in the system at frequencies below 1MHz?

- At 100KHz, the system gain is:
  - ~-8dB w/o Midspan (-8.7dB at 1MHz, -7.5dB at 300KHz)
  - ~ -9dB with Midspan (-8.7dB at 1MHz, -7.5dB at 300KHz)
  - Which is practically negligible difference.
- The SCM is required by various system components specifications to work with gain as low as
  - -32dB at 100MHz
  - -11dB at 1MHz
  - Hence the PHY is capable to work with Gain as low as -32dB
  - But the inductance issue is relevant at the low frequency range which is 21dB higher then the worst case conditions.
- Since the Midspan has negligible effect on the SCM it is recommended to assign most of the Margin to the Switch according to the following ratio:
  - Midspan: 1dB max. as function of frequency from 100KHz to 1MHz
  - Switch: 20dB min. as function of frequency from 100KHz to 1MHz

Generating Midspan TF

- Steps:
- 1. Generating System Model w/o Midspan, **SCM**.
- 2. Generating System Model with Midspan ALT A, **SCMM**.
- 3. Finding w.c analysis results and update the model. Done.
- 4. Finding Midspan TF=SCM -SCMM (Gain[db] vs Frequency plot)
- 5. Finding the best regression function structure to build the TF.
  (3, 4 and 5 order polynomial regression vs. Logarithmic regression were evaluated.)
- 6. Logarithmic structure showed best accuracy for the operating bandwidth under discussion (100KHz to 1MHz) for Midspan.
- 7. Adding margin function to cover Test Equipment errors and design.
- 8. Getting Final Equation.

Midspan TF and test setup for compliance.

Including w.c analysis, Test Equipment Error and design Margin

$$\left\{ -c + 37.5 \cdot LOG_{10}\left(\frac{a \cdot f}{\sqrt{1 + b \cdot f^2}} \right) \right\}$$

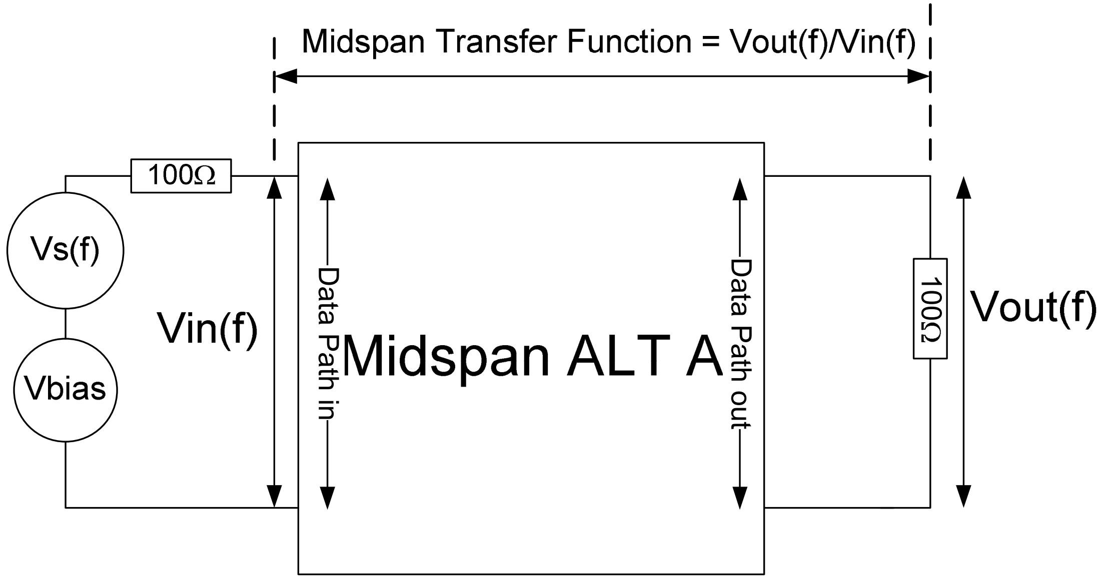
$$Updated\ \ Equation\ \ 33-14$$

$$a = 22.40$$

$$b = 520.5$$

$$c = 0.1000$$

$$0.1MHz \le f < 1MHz$$



- Vin(f) is the Sine wave signal to be used to measure the Midspan TF.
- Vbias is the DC offset voltage to be superimposed on the Sine wave in order to generate Ibias. Ibias=TBD (8mA?) +Iunb/2. Iunb is specified in Table 33-9.
- Vout (f) is the Midspan response to Vin(f)

Q&A

- Discussion

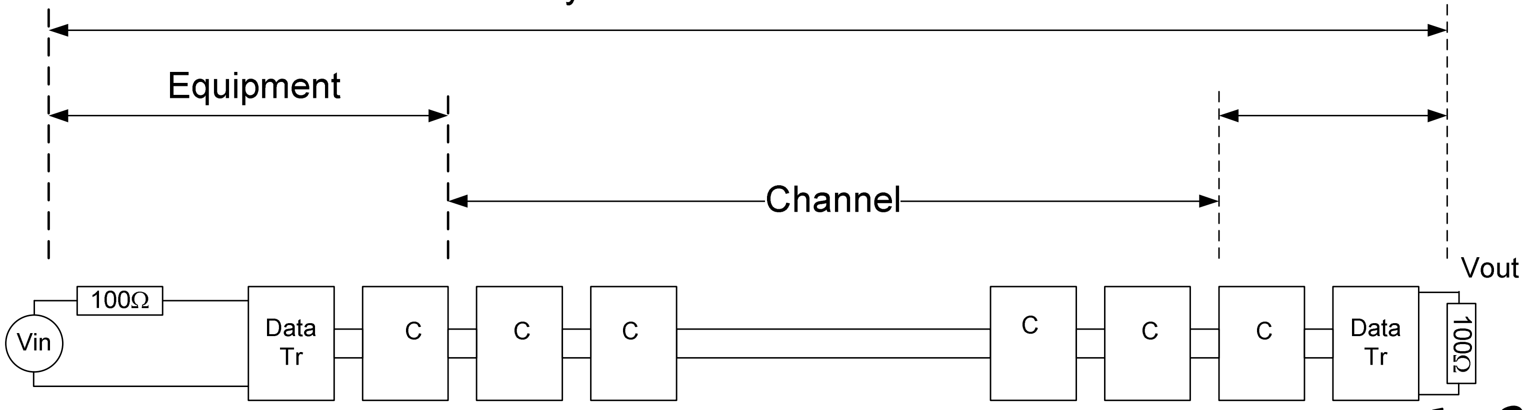
Previous Discussions and Material

Agenda

- Terms and abbreviations
- Reviewing 1st ad hoc summary from Jan 2008 interim meeting
- Reviewing 2nd ad hoc summary from Feb 2008 ad hoc meeting
- Objectives
- Background
- Proposed solution
- Key data used in this work
- Progress from Last meeting
- Channel Model with and w/o DC bias effects
- Measurements/Simulations/Calculations for single data transformer
- Signal Bandwidth

Terms and abbreviations

- **Channel Model =CM :** Cable + 4 Connectors forming 25 Ohms at 100m round loop on data pairs
- **System Channel Model = SCM:** Channel + 2xData 100BT Transformer connected to signal source with 100 ohm series impedance and loaded with 100 ohm termination
- **Transfer Function =TF:** The ratio between the voltage at the load termination to the signal source as function of frequency. The TF includes the effect of the source and load impedance for simulating the droop effect as function of the inductance of the data transformers
- **Low Frequency Model=LFM:** The System Channel Model used for derivation of the Transfer Function is limited to frequencies <1MHz
- **LM, Magnetizing Inductance:** Data transformer inductance
- Idc=The total dc bias current that the transformer is exposed too as a results of the data and the channel imbalance during PSE operation.

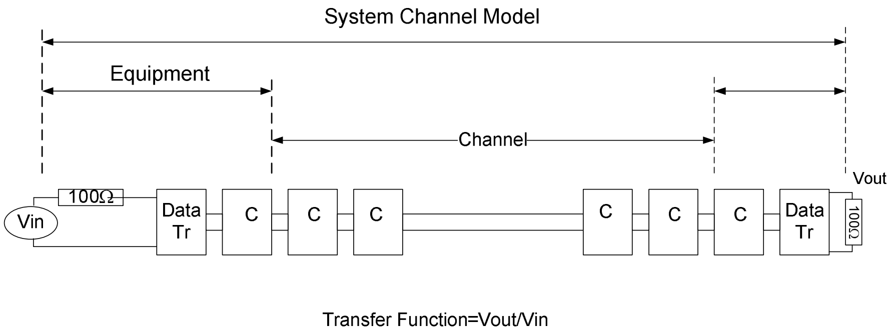


Add hoc agree

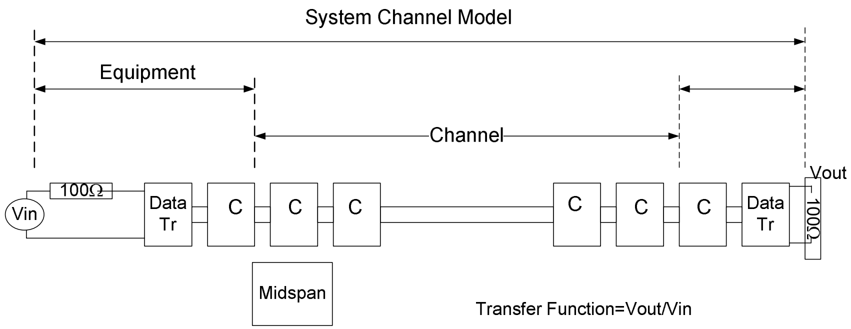
Transfer Function=Vout/Vin

Objectives

- (1) To define the requirements for a System Channel Model at the signal path for 100BT operation at frequencies below 1MHz



- (2) To define the requirements for a Midspan at the signal path for 100BT operation at frequencies below 1MHz as a result of (1)



Add hoc agree

1st adhoc meeting Discussions/Summary – Jan 2008

See: http://www.ieee802.org/3/at/public/jan08/darshan_5_0108.pdf

- Three groups are working on the project: TF function group and two BER tests groups.
- Preliminary model and lab test results were presented.
- We discuss the differences between the preliminary model and the expected final model.
  - Model parasitics (Leakage, winding capacitance) has negligible effect at the low frequency band under discussion.
  - Current model and lab test results are w/o DC bias and magnetic non-lineary effects which expected to change the TF at very low frequencies
- There is no difference in low frequencies between transformers and auto transformers with the same inductance. The differences appear at high frequencies (above 1MHz).
- Tests and simulations shows negligible differences in TF gain/frequency at well below 100KHz. Final results will be presented with the DC bias as planned.
- **BER tests Results and Conclusions:**
  - Preliminary BER tests shows similar behavior for channel with and without Midspans in most tested equipment.
  - In general, it seems that if a device passes a BLW test without a Midspan in-line, it will pass with the addition of the midspan.
  - There are a few cases where the addition of the Midspan caused the device to go from passing to failing.
  - If the device fails the test without the Midspan, the addition of a Midspan introduces minimal error.
  - For the handful of devices tested it seems that if the device can handle BLW packets properly, the addition of a Midspan will not introduce enough error to cause significant packet loss.
  - All tests done for 100BT for 100BT equipment in different OCLs for 10 random equipment samples and different length. No knowledge if the equipment under test had BLW compensation.
- Ad hoc acknowledge preliminary results as similar to the current knowledge and experience from the field.
- Ad hoc is OK with continuing the proposed concept of TF definition and compliance criteria
- Next steps as proposed

Add hoc agree

2nd ad hoc meeting Discussions/Summary – Feb 27, 2008

- Comparison between Measurements, Simulations and Calculations shows good match for single data transformer model.

- Next steps:
- Verify the above for the whole channel (Receiver transformer + Channel).
- Need to determine TF lower frequency limit
- To specify maximum Midspan Gain deviation from the reference System

  Channel Model vs frequency

Add hoc agree

3rd ad hoc meeting Discussions/Summary – March 12, 2008

- 2nd BER tests group preliminary test results shows similar results to the results of 1st group.
  - 1st group report will be presented at the March IEEE meeting
  - 2nd group report will be presented in next meetings.
- Single Transformer TF derivation – Done.
- Next Steps
- To present two transformer TF measurements vs simulation
- To preset full System Channel measurements vs Simulation
- To present to the group the two options for setting the bandwidth low frequency. To get PHYs experts opinion.
- Finalize synchronizing System Channel Model measurements with Simulation.
- Present BER tests of 2nd group
- Continue as planed

Add hoc agree

Background

- The IEEE802.3at task force approve using ALT A Midspan.
  - Powering the PD through the signal path
- The IEEE802.3 requires that when a Midspan is inserted in the channel it shall not alter the channel performance.
  - The channel performance is defined from 1MHz and up by 33.4.8
  - The 802.3 doesn't not define requirements for the channel below 1MHz.
- In addition, there is the inductance requirements as specified in ANSI X3.263-1995 (TP-PMD) subclause 9.1.7 which may be affected when a ALT A Midspan is sued in the channel for 100BT
- As a result, the droop of the signal may increased which may affect the BER
  - In addition, the effect of BLW on the BER may increase as well
- All of the above may further affected by the presence of DC bias due to the cabling imbalance

Add hoc agree

Additional Information

- BLW is relevant for 100BT operation
- Channel has to work at worst case BLW conditions
- Modern PHYs have BLW tracking hence keep BER un changed
- Modern PHYs can handle down to 150uH inductance and lower
- In case of lost packets due to BLW, Transmitter re-transmit data, hence end user is not affected
- All of the above may help us to generate cost effective requirements for system channel with and without Midspan and with or without DC bias
- In addition the results of this work may be used to replace the 350uH requirement in transmitter side with implementation independent TF

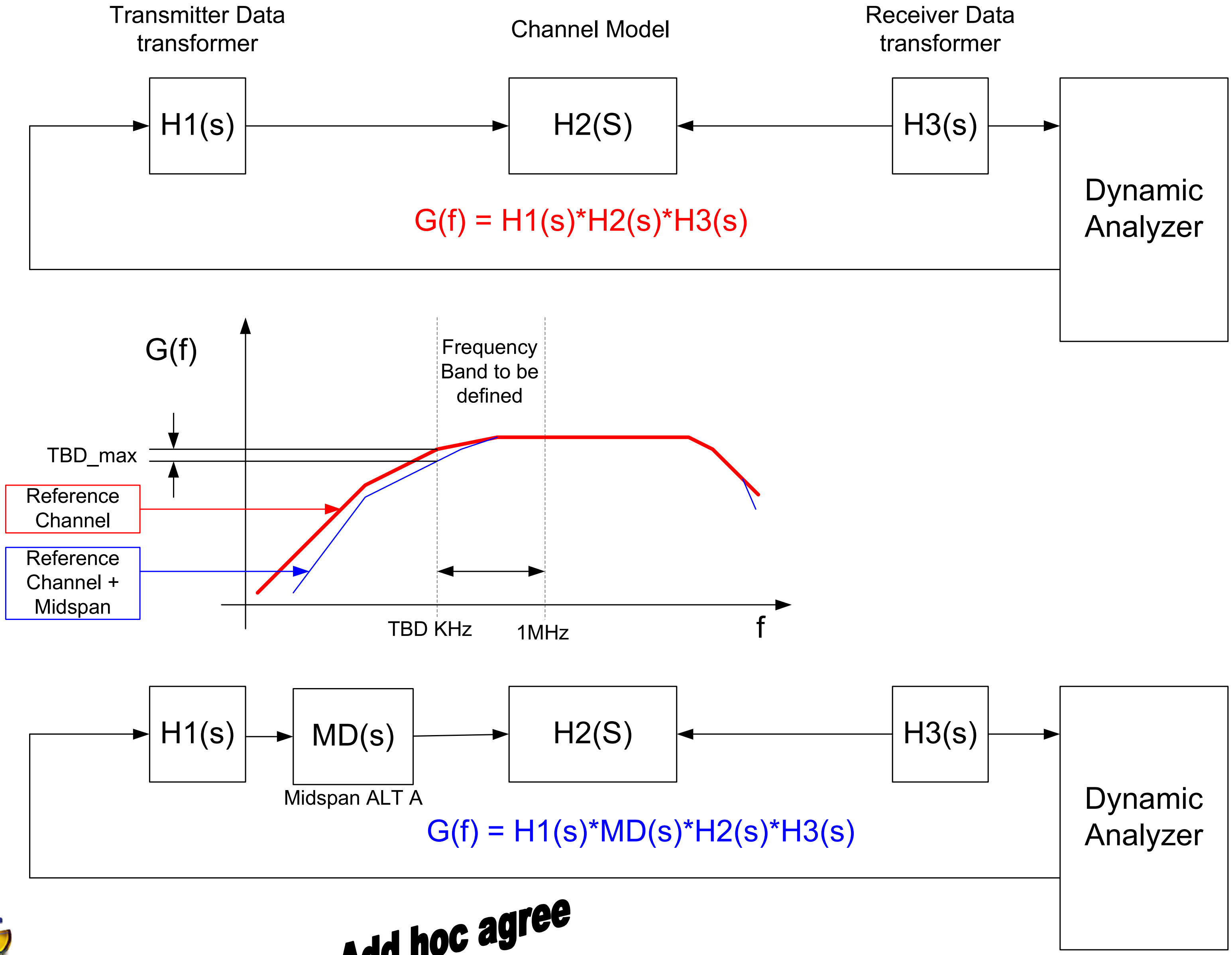
Add hoc agree

Proposed Solution

- Defining a transfer function for the Midspan at the signal path from 100KHz up to 1MHz (not include 1MHz. Channel is already specified from 1MHz and up)
- Step 1:Measuring the transfer function of standard compliant channel with out Midspan and without DC bias
- Step 2:Building channel model for frequencies below 1MHz with out Midspan and without DC bias
- Step 3: Align the model to the measurements
- Step 4: Repeat steps 1-3 with DC bias (8mA + IEEE802.3af DC bias)
- At this point we created a reference TF for a channel meeting 802.3af
- Step 5: Insert to the model the minimum requirements for the inductance per ANSI X3.263-1995 (TP-PMD) subclause 9.1.7 under the conditions of 802.3af and worst case channel parameters.
- Step 6: Define TF according to Step 5.
- Compliant Midspan gain/frequency shall not be less then the TF gain by more then TBD db.
  - TBD includes: w.c analysis gain, Test Equipment Errors, Test Setup errors and Design Margin.
  - Note: Midspn TF gain has different requirements for Frequency >=1MHz (Defined by current connecting hardware specifications and for frequencies below 1MHz (New requirements. Apply only for ALT A Midspan as part of System Channel Model). It is the implementer responsibility to meet both requirements.

Add hoc agree

Proposed Solution



Add hoc agree

Key data used in this work

(1) Inductance variations of data transformer vs. frequency is negligible up to ~300KHz.

- Hence Inductance Model is not sensitive to frequency up to 300KHz
- Supported by measurements and magnetic core datasheet
- LM=895uH @ f=8855Hz (measurements).

(2) At High frequency, $XL >> Rs = R_L$ hence negligible effects on Gain(f) at 180KHz<frequency<= 1MHz

- $XL_{100} = 6.28 \cdot f \cdot 875uH = 100\Omega$ ➔ f= 18.19KHz
- At f>>18KHz (i.e. >180KHz) XL>>RL ➔ Inductance change at f>300KHz and its effect on Gain changes are negligible.

(3) At frequencies below 1MHz, the leakage inductance, winding capacitance and cable capacitance are not affecting the model.

- XC(1MHz) =1/ 6.28*1MHz*25PF =6370 Ω ➔ XC(f<1MHz) > 6370 Ω >> 100 Ω

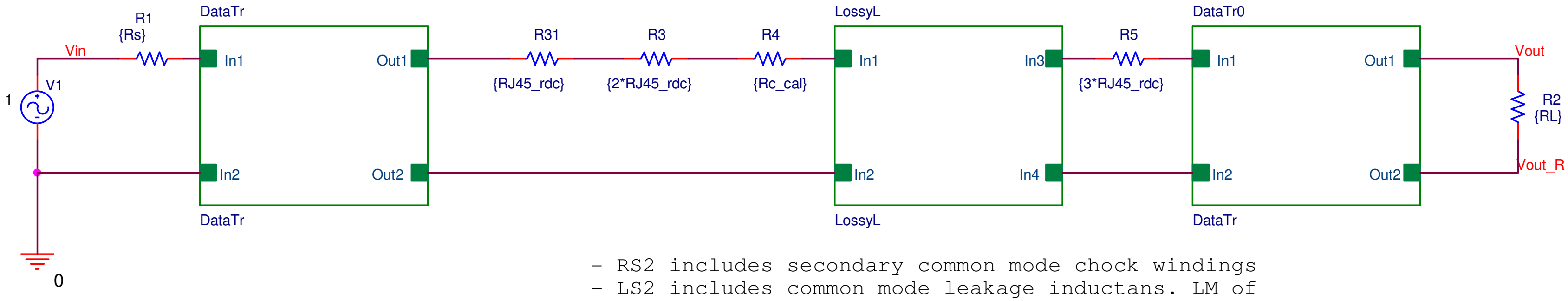
(4) Transfer function include signal source output impedance Rs and Channel load termination RL. Rs=RL=100Ω

(5) Transfer function is measured from signal source output at the Rs input side, to load termination.

- Rs and RL are part of the TF model for the System Channel Model w/o Midspan.
- Take in account droop effect of transformer at low frequency. Affects significantly affect TF poles and zeros at operating bandwidth.
- ***System Channel Model (SCM) is the expansion of the standard channel model including transformers, source and load impedances.***
- ***Reference of SCM will be based on meeting 802.3 and 802.3af requirements i.e. 350uH minimum at 8mA DC current, at 100KHz + Iunb/2 [mA] due to channel imbalance.***

Add hoc agree

Channel Model with and w/o DC bias effects



PARAMETERS:

Length = 100

R_Line = 0.1925
L_Line = 0.0405uH
C_Line = 0.0225nF
Nsec = 20

RJ45_rdc = 0.2

KRs1 and KRS2 need to be re-caliberated when using RJ45_rdc=0.2 ohms otherwise RJ45_rdc=0.05

PARAMETERS:

RS1 = {KRs1*0.27}
RS2 = {KRs2*0.47}
CPS = 5PF
CWN = 5PF

KRs1 = 2.511 Rs1 Cal Factor
KRs2 = 2.27 Rs2 Cal Factor
Rc_cal = 0.001

DCbias = 18.8

Ue70 = {100000/(24.211335+40.116496*H0^3+2.9841983*EXP(-H0))}
Le70 = {0.000001*(1.26*NT*NT*Ae*Ue70*0.01/Le)}
Le_wc = 350uH Le_wc can be 350uH or Le70
Rs = 105
RL = 95

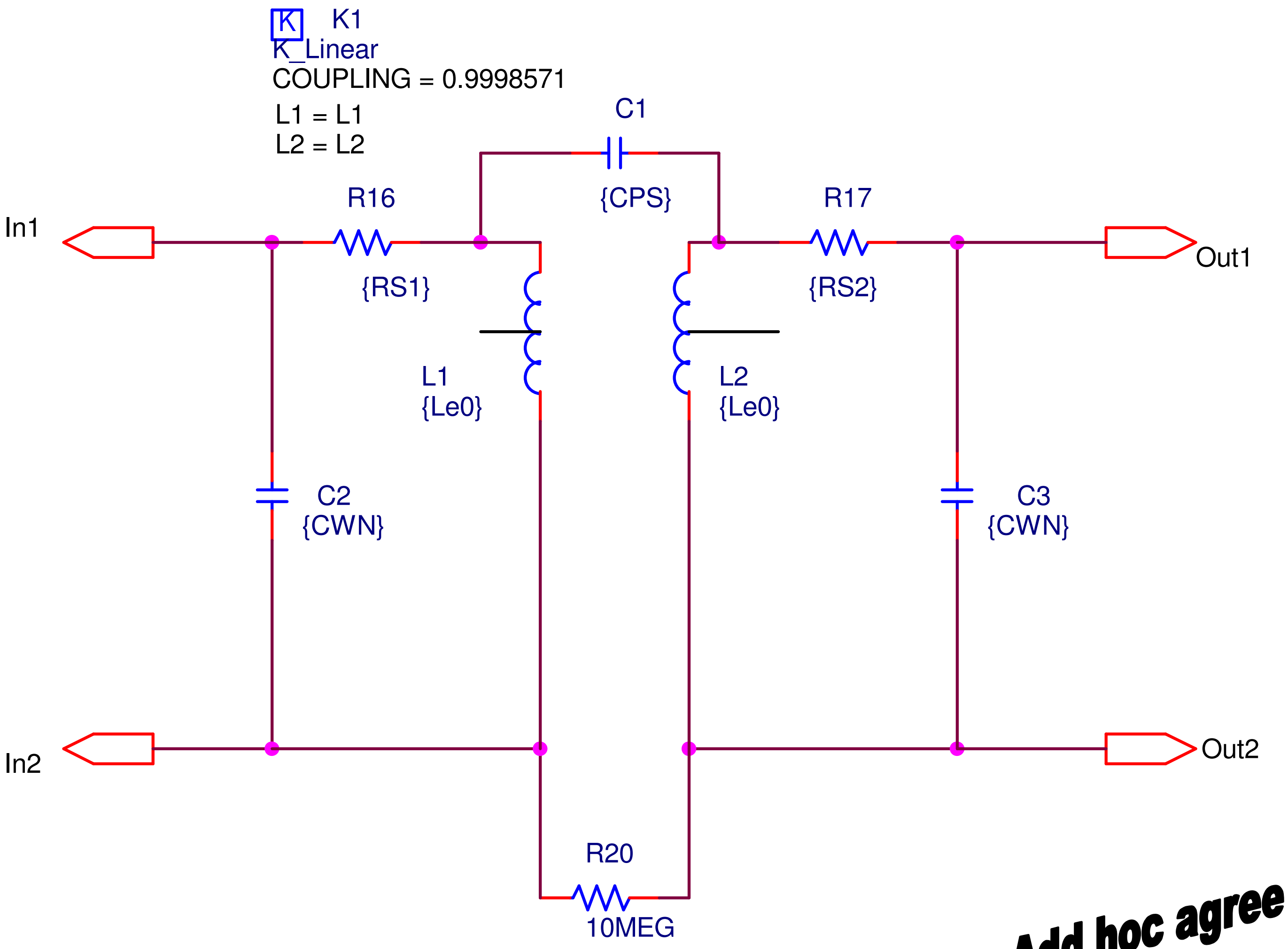
- RS2 includes secondary common mode chock windings
- LS2 includes common mode leakage inductans. LM of common mode is canceled.

Notes:
Specification: LM = 350uH minimum at 100KHz , 8mADC.
Actual results of tested channel w/o DC bias:

LM	Frequency
902uH	8855Hz

Add hoc agree

Data Transformer Model - Simplified



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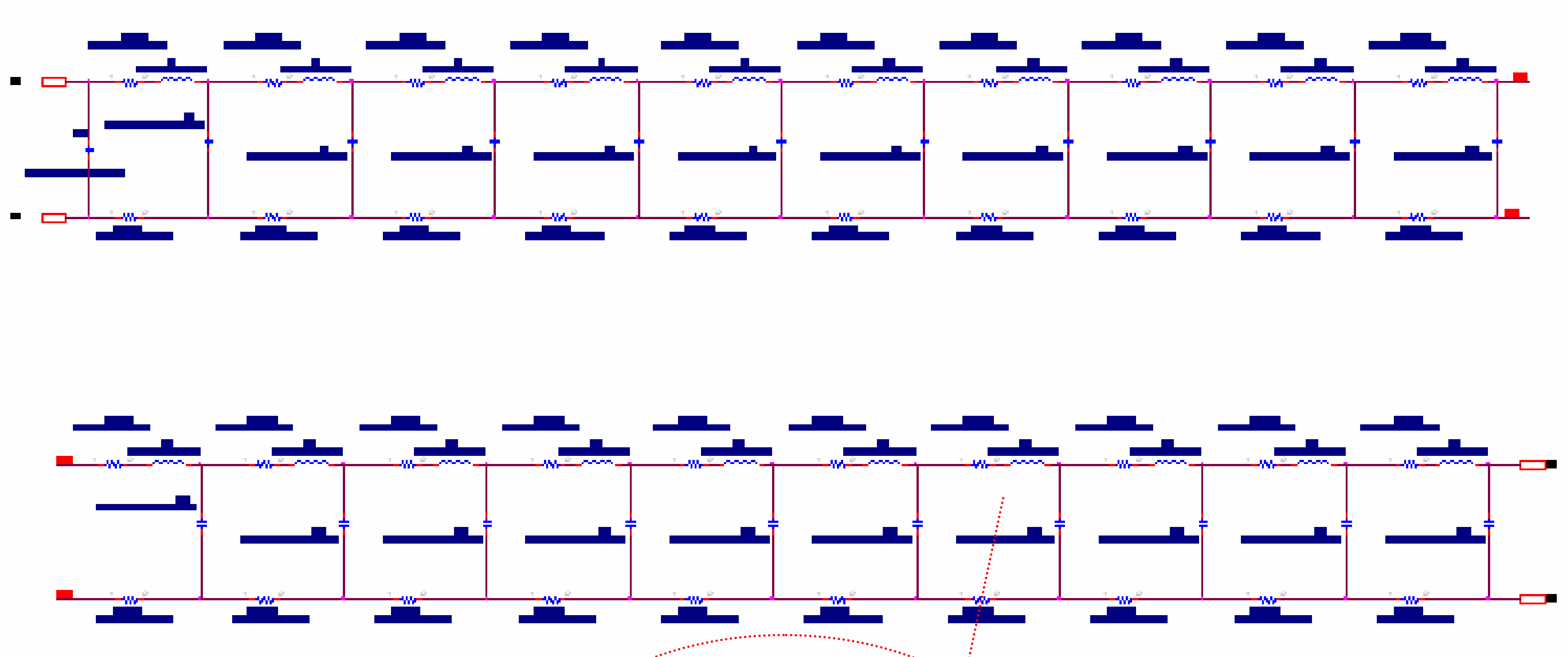
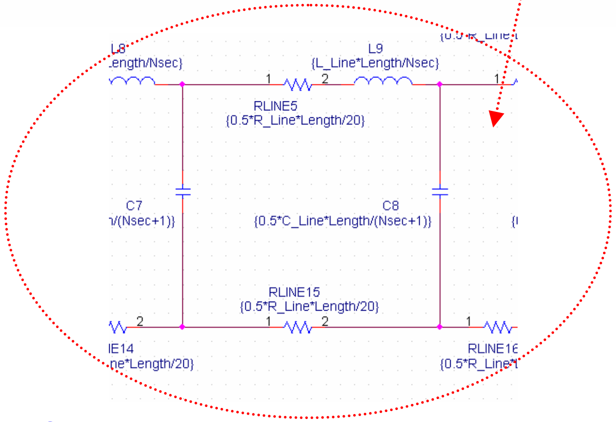
Channel Model at Low Frequency <=1MHz

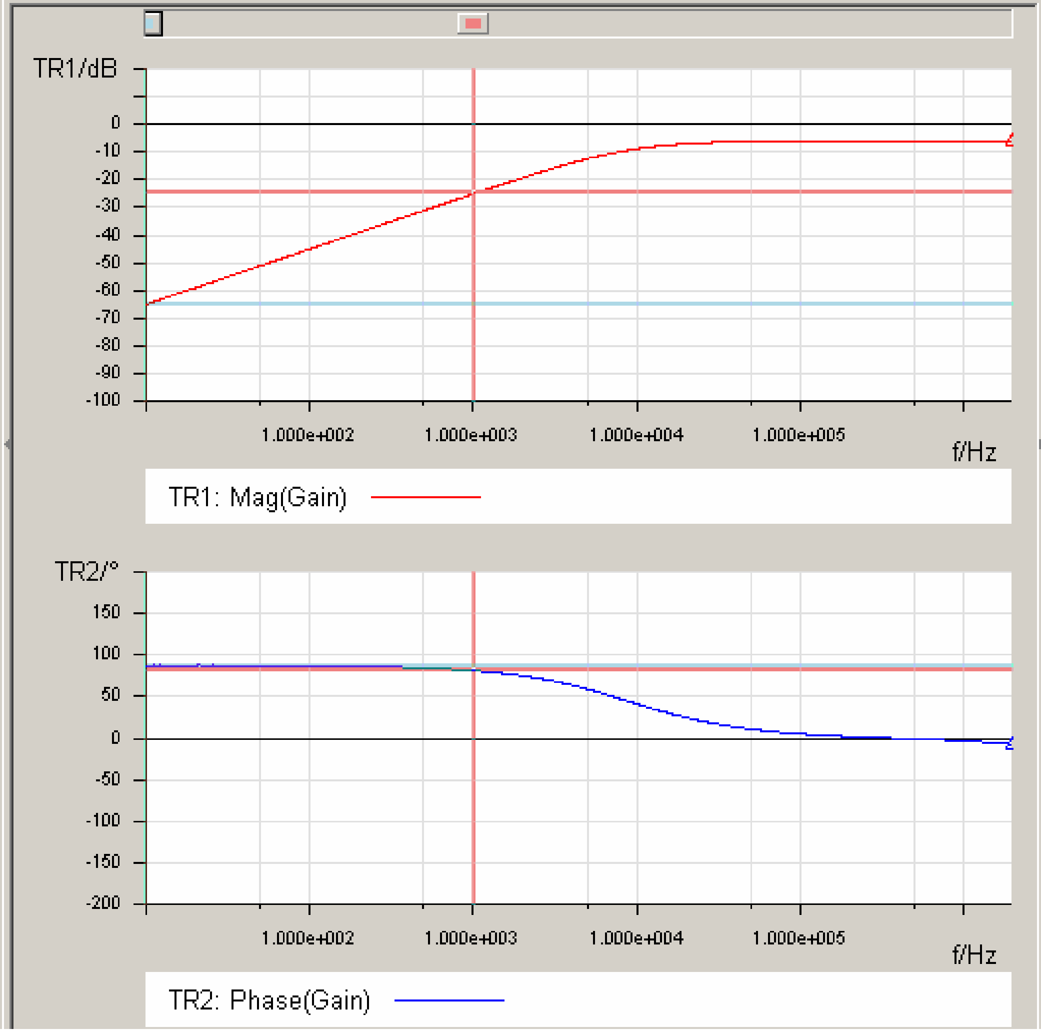




Add hoc agree

Measurements: Single Transformer TF, Idc=0, Length=0.5m

	Frequency	Trace 1	Trace 2
Cursor 1	1.017 kHz	-25.082 dB	81.100 °
Cursor 2	10.000 Hz	-65.204 dB	86.609 °
delta C2-C1	-1.007 kHz	-40.122 dB	5.509 °



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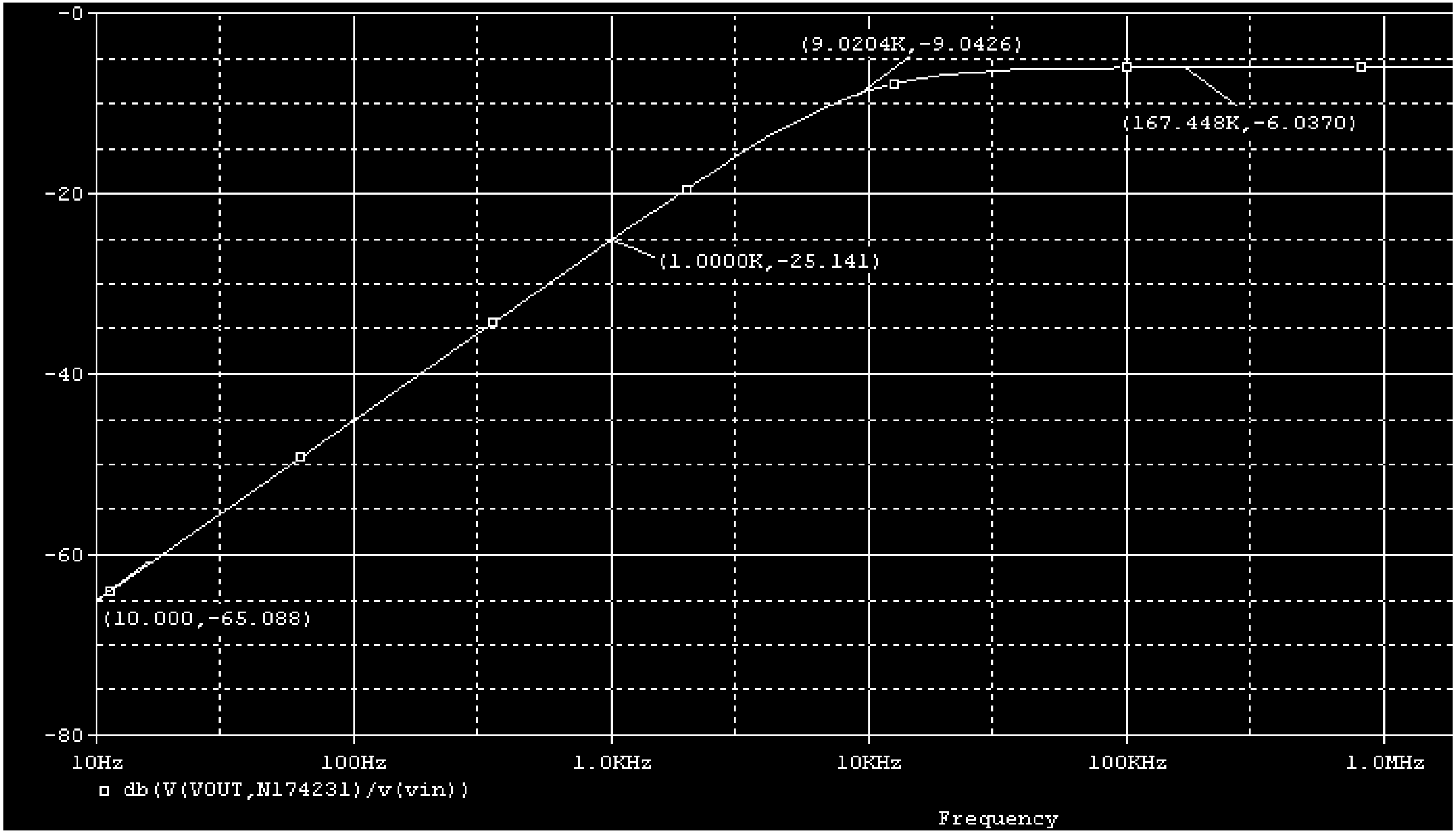
Simulation: Single Transformer TF, Idc=0, Length=0.5m



Add hoc agree

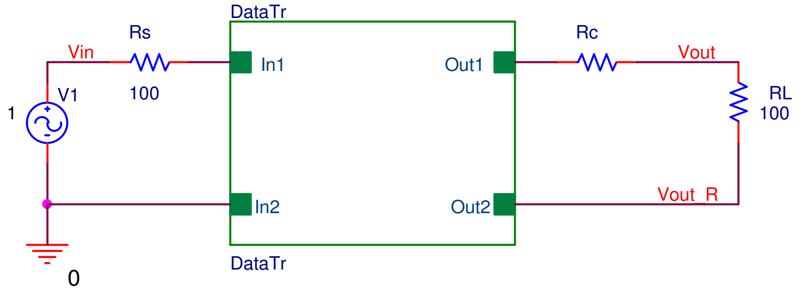
Equations derivation: Single Transformer, Idc=0, Length=0.5m

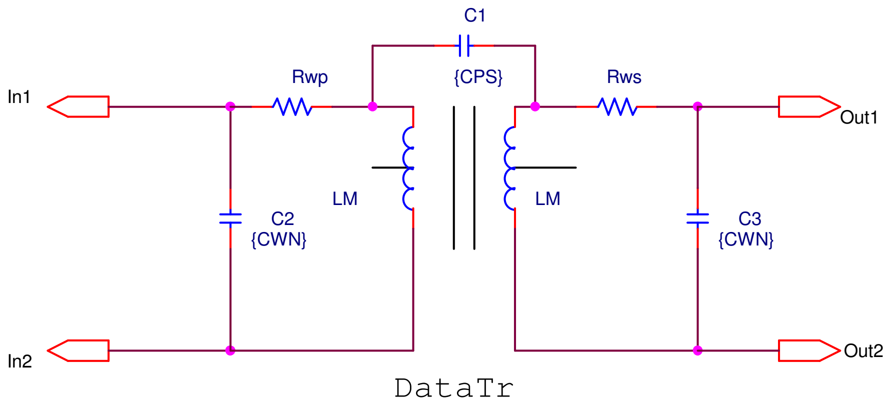
- Low Frequency model (<=1MHz)
  - Includes Rs and RL effects.
  - Lk<<Lm
  - Rs=RL=R=100Ω, Rs'=Rwp+Rs, RL'=Rws+Rc+RL
  - Xcw, Xcps >> XLm
  - Lm is constant up to 300KHz (Magnetic core data sheet)

$$H(s)=\frac{sL_M\cdot R_L}{Rs'\cdot R_L'}\left(\frac{1}{\left(1+\frac{sL_M\cdot(R_L'+Rs')}{Rs'\cdot R_L'}\right)}\right)$$

$$Fz = zero\ at\ origin\ at\ slope=\frac{sL_M\cdot R_L}{Rs'\cdot R_L'}$$

$$Fp = Pole\ at\ :\frac{Rs'\cdot R_L'}{2\cdot\pi L_M\cdot(R_L'+Rs')}$$





Add hoc agree

Single Transformer: Equation Derivation

$$Htr(s)=\frac{Vo(s)}{Vin(s)}=\frac{I(s)\cdot R_L}{Vin(s)}=\frac{\frac{Vin\_eqv}{Zeqv+Rws+R_L}\cdot R_L}{Vin(s)}$$

$$R_L{}'=Rws+R_L \quad R_s{}'=Rwp+R_s$$

$$Vin\_eqv=\frac{Vin(s)\cdot sL_M}{Rs'+sL_M}$$

$$Zeqv=\frac{(Rs+Rwp)\cdot sL_M}{Rs+Rwp+sL_M}=\frac{Rs'\cdot sL_M}{Rs'+sL_M}$$

$$Htr(s)=\frac{Vo(s)}{Vin(s)}=\frac{\left(\frac{Vin\_eqv}{Zeqv+Rws+R_L}\right)\cdot R_L}{Vin(s)}=\frac{\left(\frac{\frac{Vin(s)\cdot sL_M}{Rs'+sL_M}}{Zeqv+R_L{}'}\right)\cdot R_L}{Vin(s)}$$

$$=\left(\frac{sL_M}{(Rs'+sL_M)\cdot\left(\frac{Rs'\cdot sL_M}{Rs'+sL_M}+Rws+R_L{}'\right)}\right)\cdot R_L=\left(\frac{sL_M(Rs'+sL_M)}{(Rs'+sL_M)\cdot((Rs'+sL_M)\cdot R_L{}'+Rs'\cdot sL_M)}\right)\cdot R_L=$$

$$=\left(\frac{sL_M}{((Rs'+sL_M)\cdot R_L{}'+Rs'\cdot sL_M)}\right)\cdot R_L=\left(\frac{sL_M}{(Rs'\cdot R_L{}'+sL_M\cdot(R_L{}'+Rs'))}\right)\cdot R_L=$$

$$\frac{sL_M}{Rs'\cdot R_L{}'}\left(\frac{1}{\left(1+\frac{sL_M\cdot(R_L{}'+Rs')}{Rs'\cdot R_L{}'}\right)}\right)\cdot R_L=\frac{sL_M\cdot R_L}{Rs'\cdot R_L{}'}\left(\frac{1}{\left(1+\frac{sL_M\cdot(R_L{}'+Rs')}{Rs'\cdot R_L{}'}\right)}\right)$$

$$Fz=zero\ at\ origin\ at\ slope=\frac{sL_M\cdot R_L}{Rs'\cdot R_L{}'}$$

$$Fp=Pole\ at\ :\frac{Rs'\cdot R_L{}'}{2\cdot\pi L_M\cdot(R_L{}'+Rs')}$$

Add hoc agree

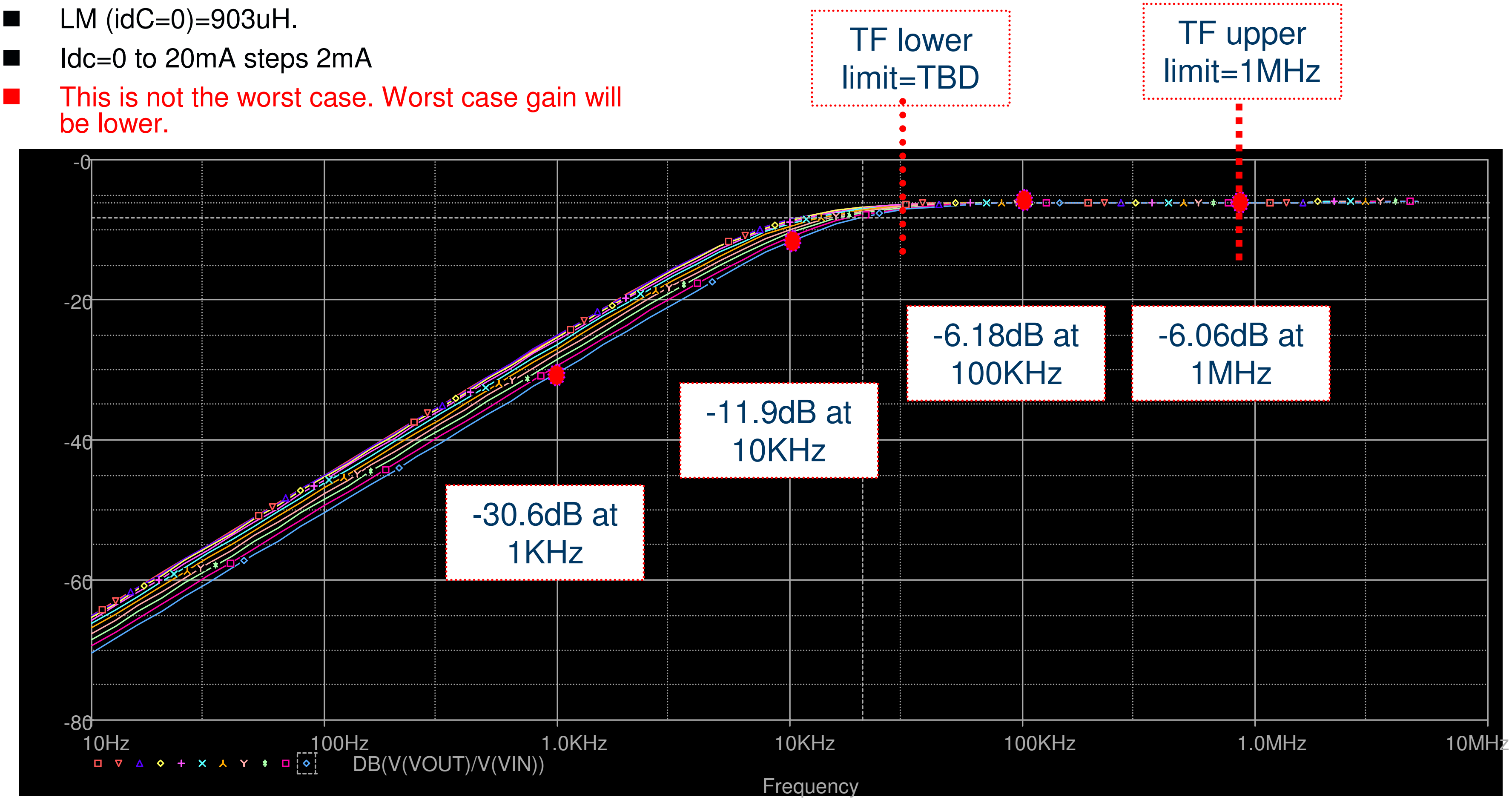
Single Transformer TF data comparison, Idc=0, Length=0.5m

Parameter	Units	Calc.	Sim.	Measured	Notes	Error
L_M (20degC)	uH	-	895	875 to 902	-	2.28%
DC Gain	dB	-6.02	-6.037	-6.135	-	-0.098dB
Gain (10Hz)	dB	-65	-65.152	-65.141	-	-0.011dB
Gain (1KHz)	dB	-25.054	-25.205	-25.082	-	0.123dB
Fp	Hz	8891.45	9020	9574	-	-5.7%
Gain(Fp)	Hz	-9.02	-9.037	-9.135	-	-0.098dB

Add hoc agree

Single Transformer TF simulation Idc=0 to 20mA, Length=0.5m

- LM (idC=0)=903uH.
- Idc=0 to 20mA steps 2mA
- This is not the worst case. Worst case gain will be lower.



-Total built in attenuation in a Channel with single transformer = 8.2d

- Channel insertion loss =2.2dB max. at 1MHz
- Additional transmitter transformer attenuates 6dB min. with Rs and RL
- Additional gain loss at lower frequencies due to transformer inductance

Tests with DC bias

- Preliminary results shows:
- For a given core material with given permeability curves, the difference between measurements to calculation was (TR #1) 6.8% and (TR #2) 8.3%at the worst case points.
- Transformer #1: Measurement was taken at 8.9KHz (to to the use of the measured TF to extract the inductance value.
- Transformer #2: Measurement was taken at 9.02KHz
- In reality, if we require 350uH at any dc bias from 0mA to TBD mA then the worst case Inductance for derivation of the TF is 350uH hence DC bias can be out of the equation.
  - The dependence of Inductance with DC bias is good to evaluate Core size and design as function of DC bias.
  - If we allow lower inductance then 350uH under DC bias then we need to use the model with DC bias to evaluate the TF under DC bias.
  - It is recommended to develop the TF as function of :

  (Actual Inductance/350uH)xActual Inductance so when actual inductance is 350uH we will get 1x350uH which is the reference TF. See example below for single Transformer:

$$Htr(s) = \frac{sL_M \cdot R_L}{Rs' \cdot R_L'} \left(\frac{1}{\left(1 + \frac{sL_M \cdot (R_L' + Rs')}{Rs' \cdot R_L'}\right)} \right)$$

$$L_M = \frac{L_{ACTUAL}}{350uH} \cdot 350uH$$

Add hoc agree

In this way we can define different requirements for Type1 and Type 2 systems if we want to?

Proposed TF for transmitter side data transformer

(This is not a Midspan TF, it is to help the 350uH ad hoc)

- Should include Rs, RL terminations effect (worst case scenario)
- Bandwidth: FL=1MHz, *FL=100KHz*. Rwp=0.3+0.1, Rws=0.5+0.1+0.2, RL=RS=100, Rs'=Rws+Rs, RL'=RL+Rws, LM=350uH at maximum total Ibias =8mA+Iimbalance/2.
- Inductance is set at Idc_max (to discuss our options)
  - Option 1: Idc_max=8mA (ANSI X3.263-1995 (TP-PMD))
  - Option 2: Idc_max=8mA+10.5mA/2=13.25mA (ANSI X3.263-1995 (TP-PMD) + Table 33-5 /802.3af)
  - Option 3: Idc_max=8mA+ TBD>10.5mA/2 (ANSI X3.263-1995 (TP-PMD) + Transformer) and channel ad hoc results=worst case)
- Do we want to differentiate between 802.3af and 802.3at?
  - 802.3af: requirements apply to either options 1,2 and 3
  - 802.3at: 8mA+ unbalanced current/2 (at worst case)?

$$H(s) = \frac{sL_M \cdot R_L}{Rs' \cdot R_L'} \left(\frac{1}{\left(1 + \frac{sL_M \cdot (R_L' + Rs')}{Rs' \cdot R_L'}\right)} \right)$$

$$Fz = zero\ at\ origin\ at\ slope = \frac{sL_M \cdot R_L}{Rs' \cdot R_L'}$$

$$Fp = Pole\ \ at\ :\frac{Rs' \cdot R_L'}{2 \cdot \pi L_M \cdot (R_L' + Rs')}$$

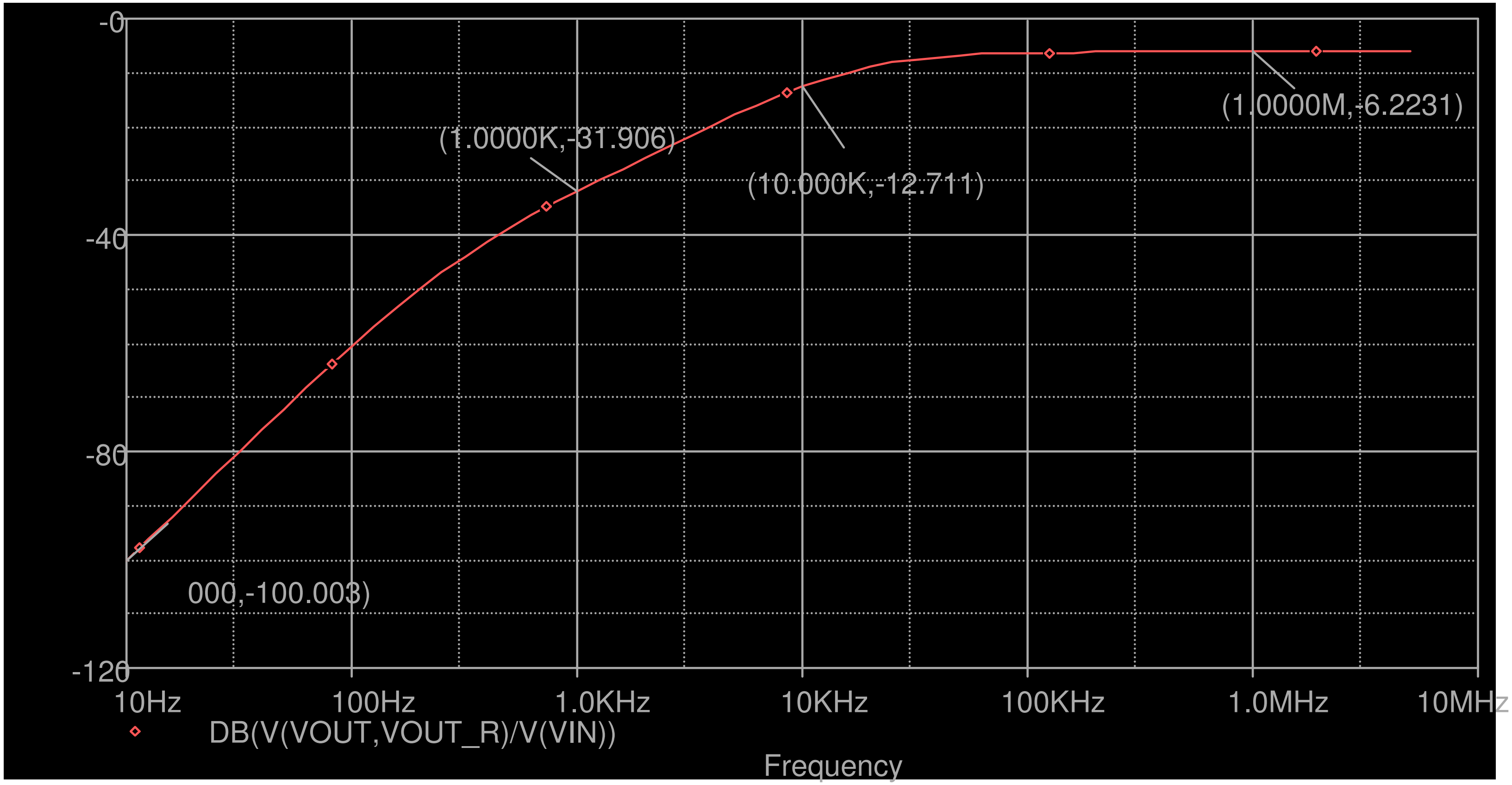
- Ad hoc to discuss options.
- Transformer and Channel ad hoc to supply value for 802.3at
- 350uH ad hoc may use this TF for generating transmitter template by convoluting Transmitter output with TF

Conclusions for single transformer model

- Comparison between Measurements, Simulations and Calculations shows good match for single data transformer model with and without DC current
- Next Step: to synchronize tests and simulations with two transformer.
- What is the bandwidth of the TF
  - FH=1MHz (closed issue)
  - FL=100KHz (Agreed at Marc 2008 plenary ad hoc meeting)

Add hoc agree

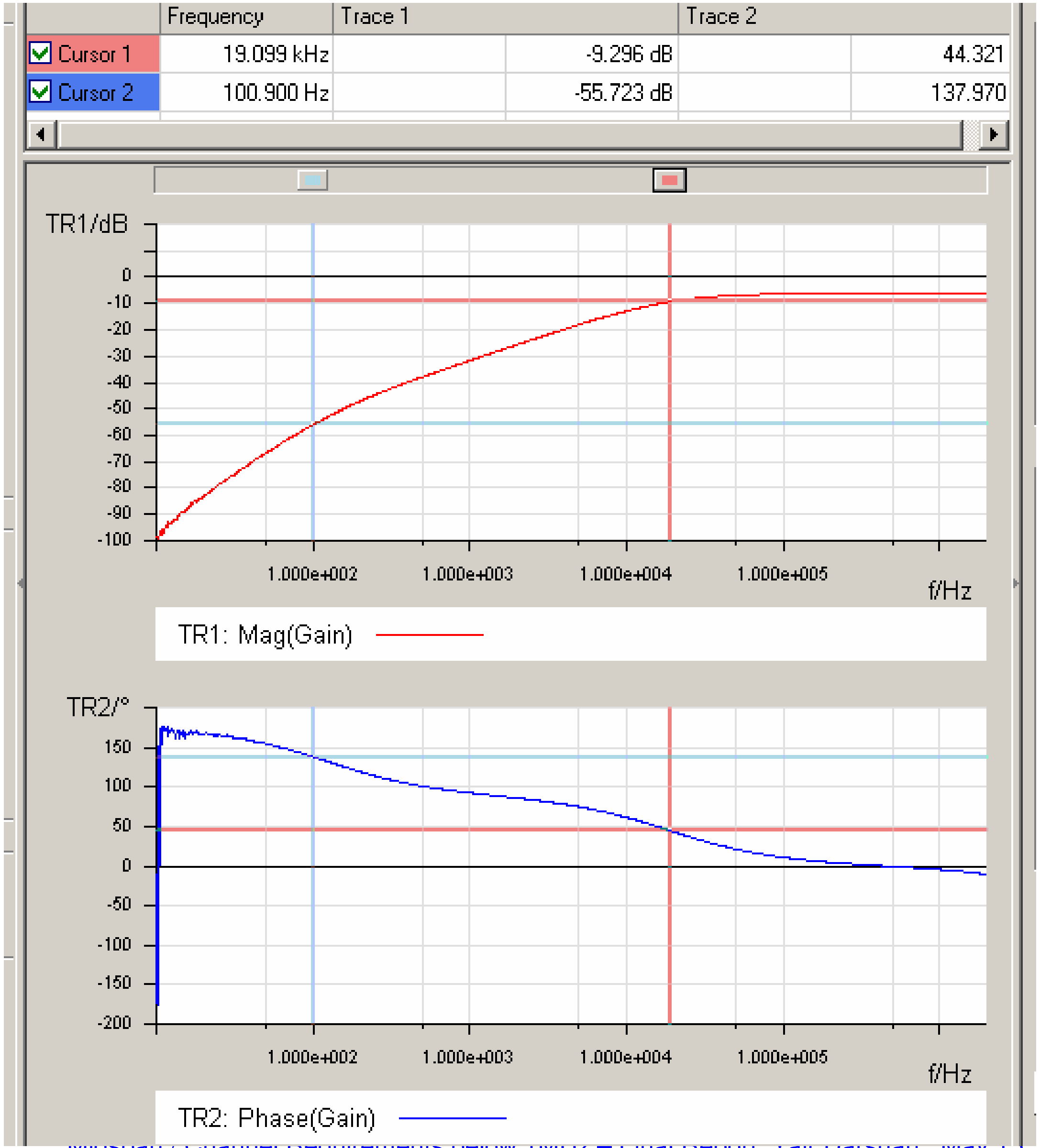
Simulation: Two Transformer TF, Idc=0, Length=0.5m



Two transformers measurements and simulations

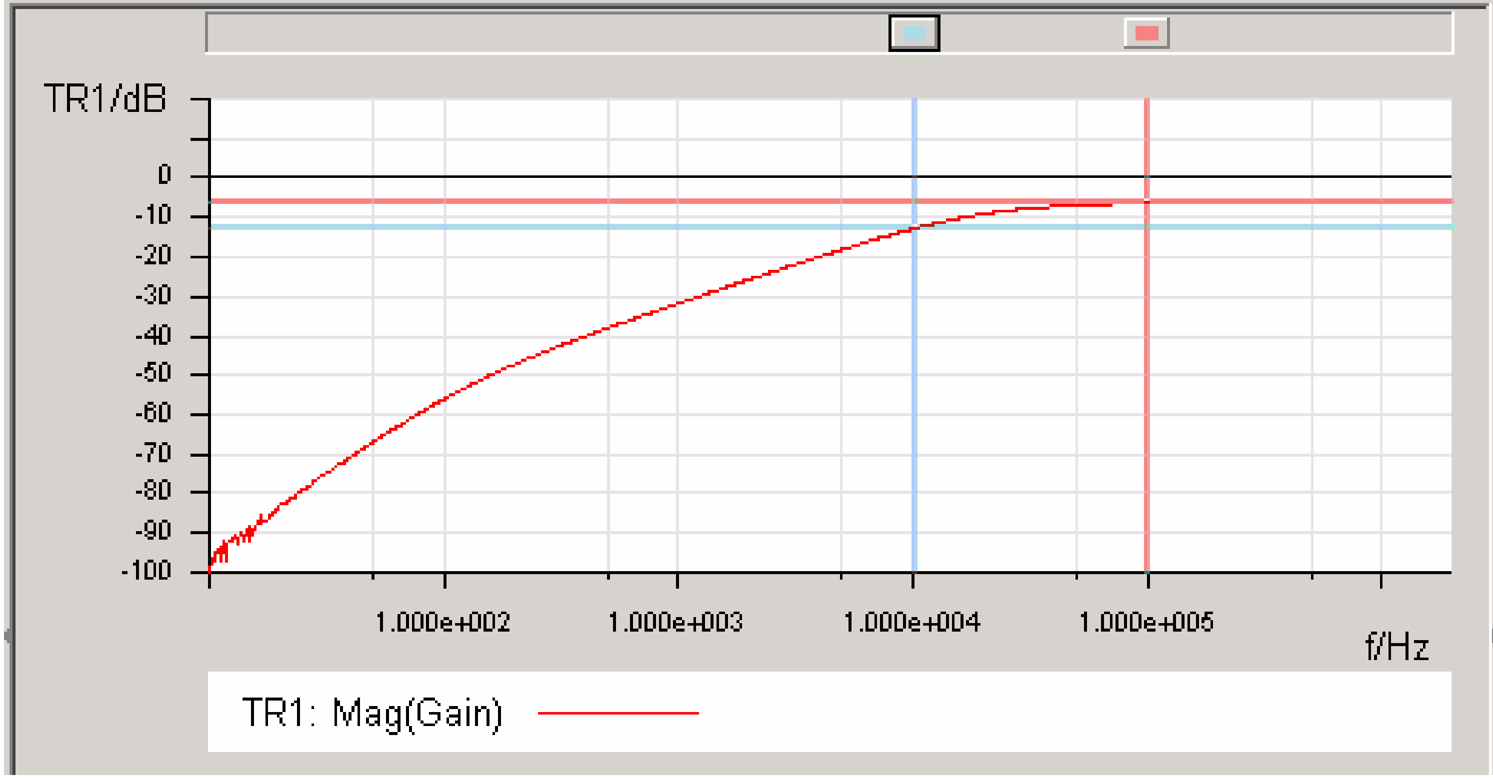
- We need to calibrate the model for two transformers as well due to the high sensitivity of the results at low frequency when Rwp and Rws are within the impedance range of the magnetizing inductance.
- The calibration is done for Rs=0 RL=>>100K and with short cable <=0.5m
- After calibration, Rs=RL=100 ohms inserted back to the circuit.

Measurements: Two Transformers TF, Idc=0, Length=0.5m



Measurements: Two Transformers TF, Idc=0, Length=0.5m (Different data points)

	Frequency	Trace 1		Trace 2	
Cursor 1	100.767 kHz		-6.374 dB		10.477
Cursor 2	10.272 kHz		-12.708 dB		60.941



Comparison: Measurements vs Simulations: Two Transformers TF, Idc=0, Length=0.5m.

Parameter	Units	Calc.	Sim.	Measured	Notes	Error
L_M (20degC)	uH	-	895	875 to 902	1	0.008%
DC Gain	dB	TBD	-6.223	-6.303	1	0.08dB
Gain (1KHz)	dB	TBD	-31.9	-31.74	1	0.16dB
Fp1	Hz	TBD	18700	19090	1	2%
Gain(Fp1)	Hz	TBD	-9.223	-9.303	1	0.08dB

1) Down to 1KHz, the model is accurate and verified.

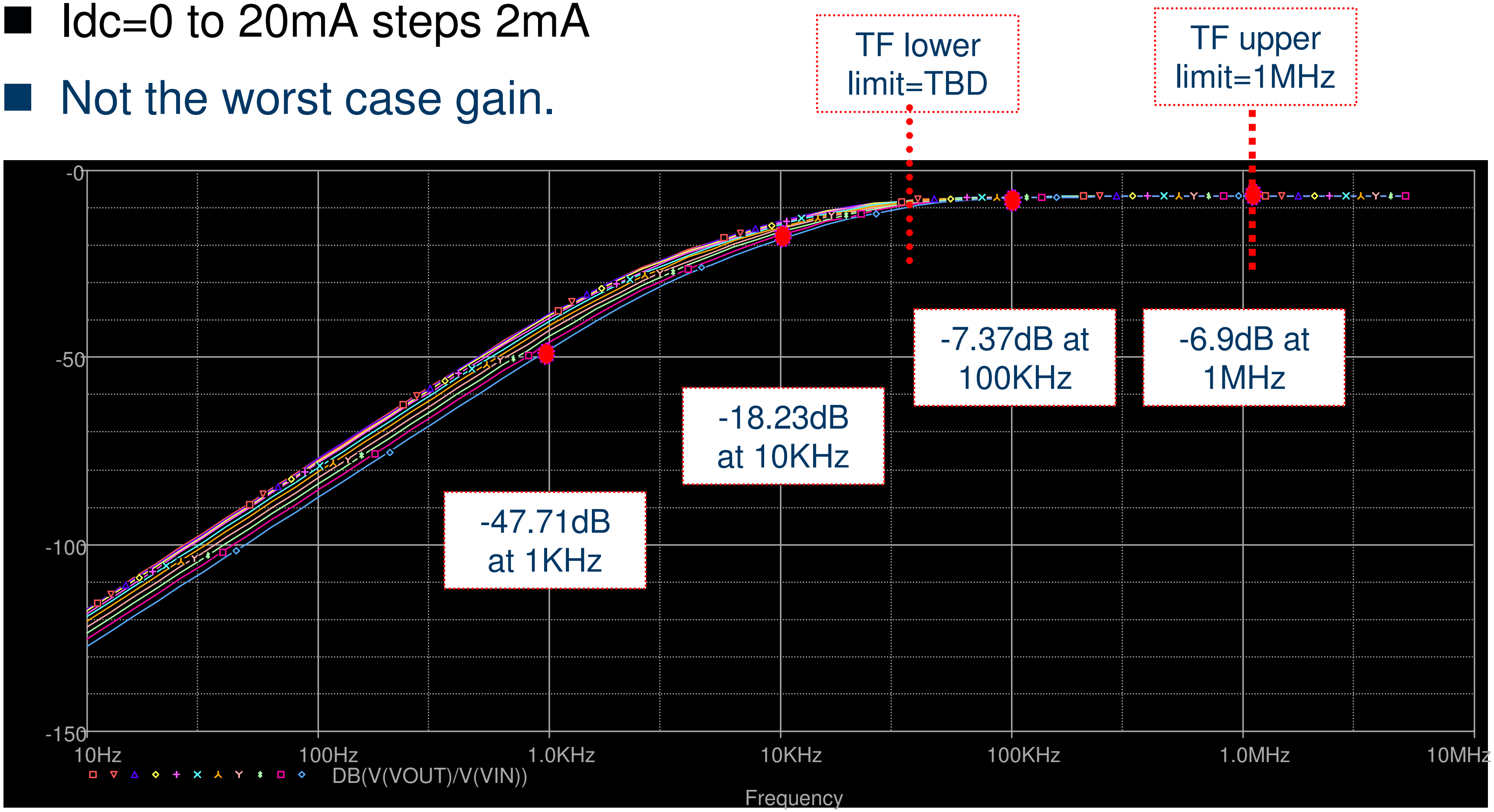
2) At 100Hz range there is some differences however they are not relevant for our task. Main reasons: Rws,Rwp, setup connections at low resistance affect most at very low frequency which then their value close to XL.

Equations derivation: Two Transformer, Idc=0, Length=0.5m

- Not required.
  - Simulations agrees with Lab Tests and Single transformer equations were proven.

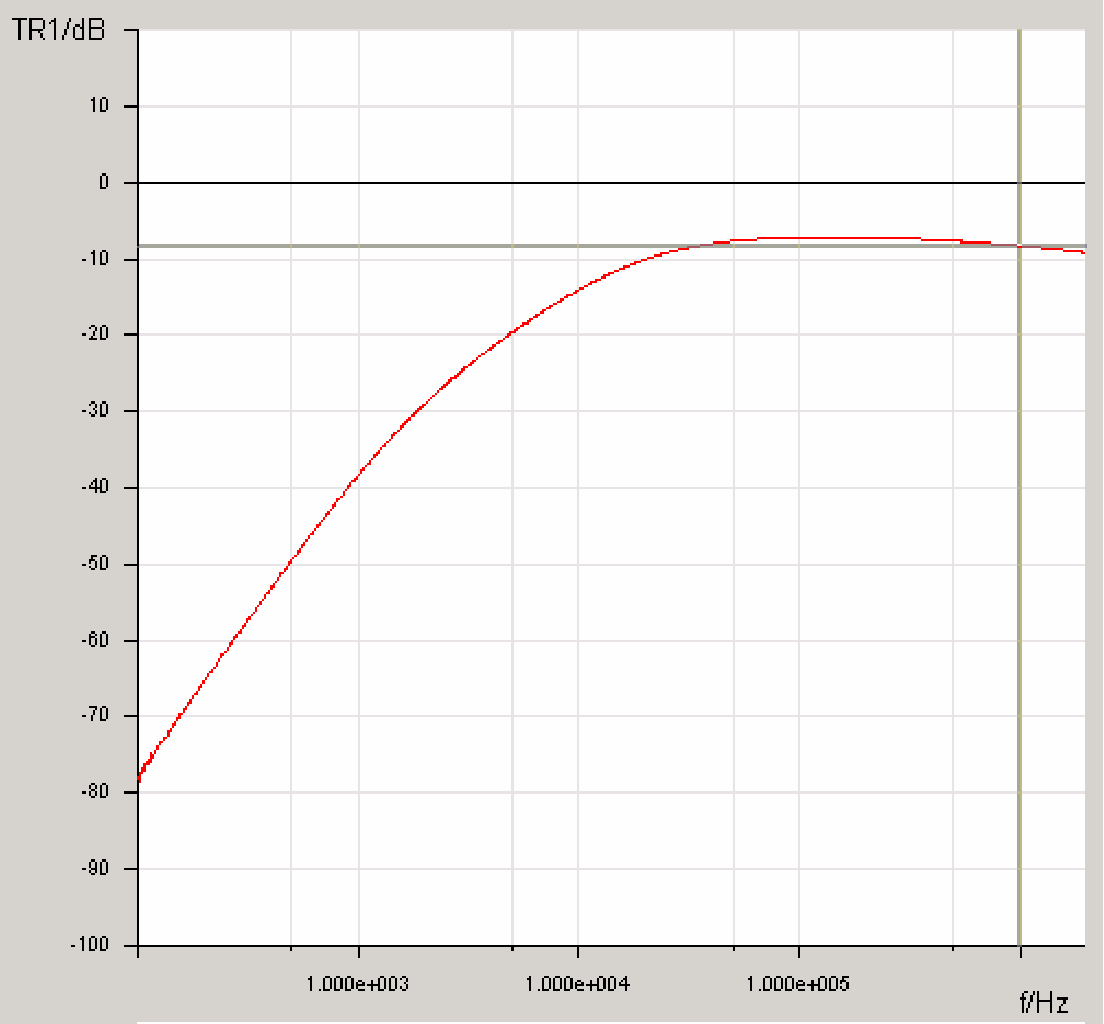
Simulation: System Channel Model TF, Length=100m

- Idc=0 to 20mA steps 2mA
- Not the worst case gain.



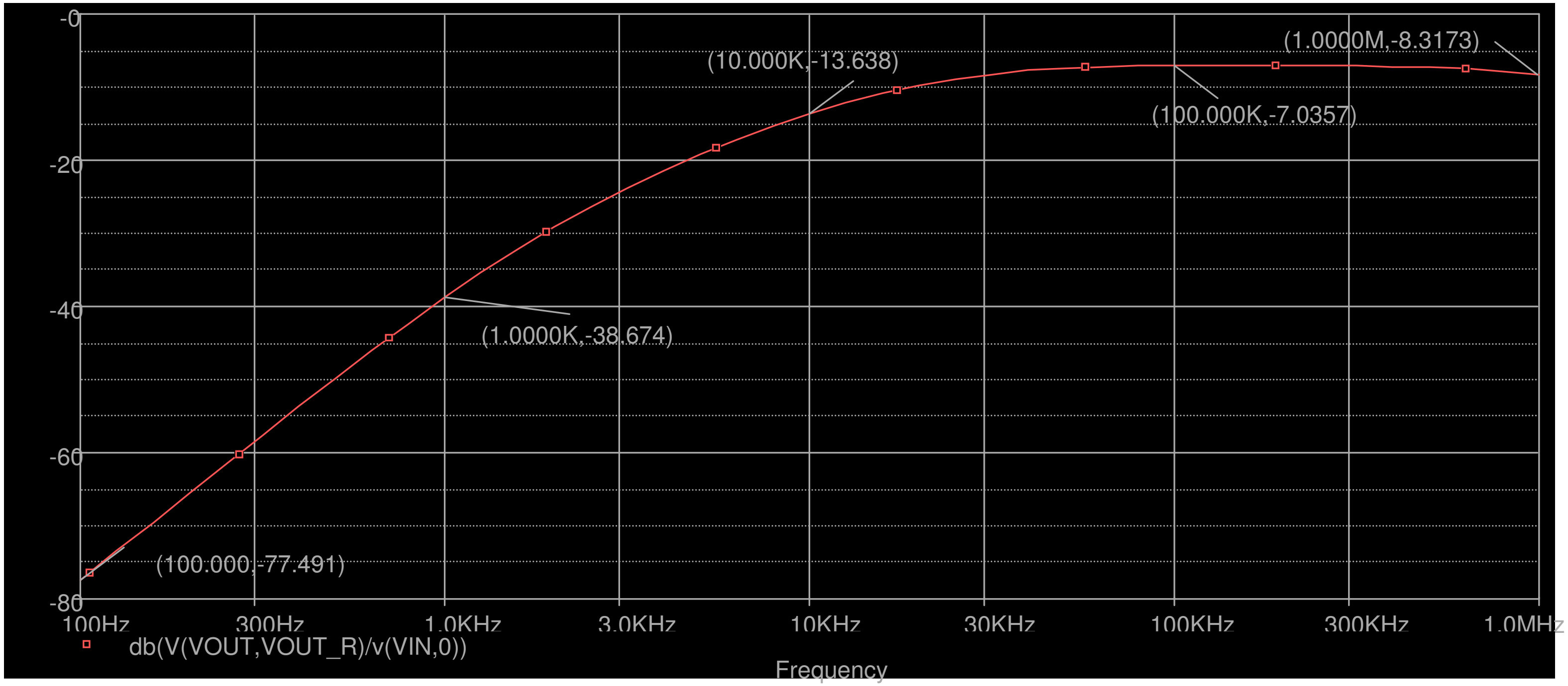
Measurements: System Channel Model TF. Length=100m, Idc=0. LM=903uH.

(This is not a w.c. conditions. Worst case conditions will result with lower gain)



F[KHz]	Gain[dB]
0.1	-78
1	-38.24
3	-24.44
10.15	-13.96
102.26	-7.171
150.86	-7.139
249.5	-7.251
1000	-8.318

Simulations: System Channel Model TF. Length=100m, Idc=0. LM=903uH.



Comparison: Measurements vs Simulations: Complete System Channel TF, Idc=0, Length=100m.

Parameter	Units	Calc.	Sim.	Measured	Notes	Error
L_M (20degC)	uH	-	895	902		0.008%
Gain (1KHz)	dB	TBD	-38.67	-38.24		0.43
Gain (10KHz)	dB	TBD	-13.64	-13.96		0.32
Gain (100KHz)	dB	TBD	-7.12	-7.17		0.05
Gain (1000KHz)	dB	TBD	-8.31	-8.318		0.08

Summary – Model Calibration

- Now that the Model match the simulation we can use the Model to derive worst case TF.
- Worst case TF is obtained at:
  - 350uH (or lower) at Ibias max.
    - Ibias max=8mA+Iimbalance/2
  - Worst case of all parasitic resistive elements
    - Rwp, Rws, Rrj45,Rpcb, Rs
    - Min of RL
    - Cable =100m
  - Add margin for measurements errors=TBD
  - Add margin for design=TBD

Determine the bandwidth of the TF

- We have few options

- Option 1: Due to the fact that 350uH is required only for 100BT and BLW is relevant for 100BT and Inductance is originally defined for 100KHz which is much less then 1MHz, then the lower frequency is 100KHz.
- Option 2: If the transmitter transmit 2Vpp and the receiver without any tricks or special algorithms can detect 45mV minimum then the relevant worst case attenuation is 45mV/2Vpp=0.0225=-32.96dB~=-33dB .This will determine the lower We need to verify if 45mV is the number (Typical data from Dan Dove)
- Option 3: To determine the lowest frequency based on energy content of the signal. First results shows the this is not realistic method in our case due to the fact that when BLW is present there is concentrated energy at very low frequencies (including DC level..) <10KHz which is detected by the spectrum analyzer due to its high sensitivity but it is not relevant because the Channel + Transformers attenuation at these frequencies is:

~-130dB at 10Hz, -90dB at 100Hz, -50dB at 1KHz (preliminary numbers) while requirements for attenuation is much lower i.e. -2.4dB at 1MHZ…

<u>It is recommended to focus on Option 1 and option 2.</u>

Option 1:

Pros: No need to change legacy specifications or to address it, Less burden on Transformer requirements at transmit side, Less cost and size at the transmit side, fits to actual ANSI X3.263-1995 (TP-PMD) specifications.

Cons: There is some BLW data below 100KHz although most of it is attenuated by the transformer anyway and doesn't get to the PHY at low frequencies

Option 2:

Pros: Take in account actual PHY limitations so It covers most of the useful BLW bandwidth.

Cons: It is a bit over design since the BLW phenomena is at low probability and in case of BER system will re-transmit. It will not allow future reduction in inductance due to modern PHYs ability to compensate BLW and works with lower higher droop. In any case 350uH specification limits the practical discussion to 100KHz.

Adhoc have decided for option 1

TF Bandwidth Options 1, 2 comparison.

- Discussion by the group
  - PHY experts and system users:
  - No need for lower frequency then 100KHz

BER Tests – Group # 1 summary

- Preliminary BER tests shows similar behavior for channel with and without Midspans in most tested equipment.
- In general, it seems that if a device passes a BLW test without a Midspan in-line, it will pass with the addition of the midspan.
- There are a few cases where the addition of the Midspan caused the device to go from passing to failing.
- If the device fails the test without the Midspan, the addition of a Midspan introduces minimal error.
- For the handful of devices tested it seems that if the device can handle BLW packets properly, the addition of a Midspan will not introduce enough error to cause significant packet loss.
- All tests done for 100BT for 100BT equipment in different OCLs for 10 random equipment samples and different length. No knowledge if the equipment under test had BLW compensation.

BER Tests – Group # 2 summary

- 2nd group results shows similar behavior to the 1st group results.
- 13 Switch devices were tested with two different devices
- In 10 devices no differences with or without Midspan
- In 2 devices Switch fails without Midspan. Addition of Midspan shows no change.
- In 1 device, the addition of Midspan add 6 lost packets and on an other test eliminate lost packets (the addition of Midspan improved from 2 to zero…)
- In 1 device, the addition of Midspan add some lost packets.
- In 2 devices out of 13, no changes in BER received also with OCL=224uH and 202uH
- No knowledge if the switch had BLW tracing.
- Conclusions: Similar to the 1st group results
  - BER tests shows similar behavior for channel with and without Midspans in most tested equipment.
  - In general, it seems that if a device passes a BLW test without a Midspan in-line, it will pass with the addition of the midspan.
  - If the device fails the test without the Midspan, the addition of a Midspan introduces minimal error.
  - For the handful of devices tested it seems that if the device can handle BLW packets properly, the addition of a Midspan will not introduce enough error to cause significant packet loss.

BER Tests – Group #3 summary

- Step 1 :Using compliant ALT A channel w/o BLW tracking function and reducing inductance by increasing Bias current until BER is increased.
- Step 2: Repeat the above for channel with Midspan connected on ALT A.
- Step 3: Repeat Steps 1 and 2 with BLW packets
- Step 4: analyze results

- Status: Not started yet

Status and Next Steps

- Single transformer: To synchronize between Test setup to simulation model – **Done**
- To add transformer non linearities to the model - **Done**
  - Transformer model with and without DC bias – **Done**
  - Inductance - Frequency dependence of non linearities - **Done**
- Two transformer model: To synchronize between Test setup to simulation model – **Done**
- Determine TF lower limit frequency – **Done**
- To compare tests results with DC bias to the simulations results and calibrate simulation model to test setup – **Done**
- Run tests for different cable length and inductances - **Next meetings**
- To present other work of BER results for a channel with and without Midspan and with DC bias effects - 2ND group **done**.
- BER vs DC bias - **Next meetings (No need for this Ad hoc work due too the other results from simulations, calculations and lab tests)**
  - Evaluate data
  - How it affects design margins
  - How it affects relaxation of 350uH under DC bias
- Sensitivity analysis - **Done**
- Finalize TF for single transformer – **Done**.
- **Other A.I. ?**

Annex 1 – Typical magnetic core data

Typical Data Transformer Magnetic Material

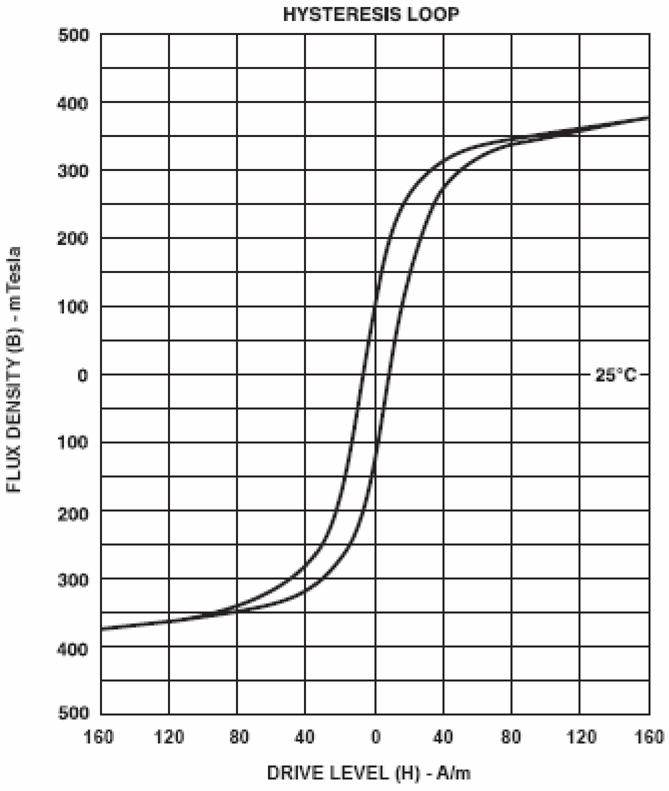
CHARACTERISTIC	V	T	B	G	J	K*	P*	UNITS
Initial Permeability (μi)	15,000	10,000	5000	1500	850	125	40	
Loss Factor (tan δ/μi)	≤ 7	≤ 7	≤ 15	60		150	85	X 10^{-6}
at frequency =	0.01	0.01	0.1	0.1	0.1	10	10	MHz
Hysteresis Factor (h/μ²)	-	-	< 2	10	6	-	-	X 10^{-6}
Saturation Flux Density (B_s)	370	380	450	320	280	320	215	*m*Tesla
	3700	3800	4500	3200	2800	3200	2150	Gauss
at H max=	1000	1000	1000	1000	1000	2000	2000	A/*m*
	12.6	12.6	12.6	12.6	12.6	25	25	Oersted
Remanence (B_r)	150	140	100	150	180	160	40	*m*Tesla
	1500	1400	1000	1500	1800	1600	400	Gauss
Coercivity (H_c)	2.4	3.2	5.6	19.9	31.8	119	278	A/*m*
	0.03	0.04	0.07	0.25	0.4	1.5	3.5	Oersted
Curie Temperature (T_c)**	≥ 120	≥ 120	≥ 165	≥ 130	≥ 140	≥ 350	≥ 350	°C
Temperature Coefficient of μi (α) -40°C to +80°C (T.C.)	0.8	0.8	0.9	1.0	1.0	0.1	0.1	%/°C
Volume Resistivity (p)	25	40	≥ 10^2	≥ 10^6	≥ 10^5	≥ 10^7	≥ 10^6	Ω-cm

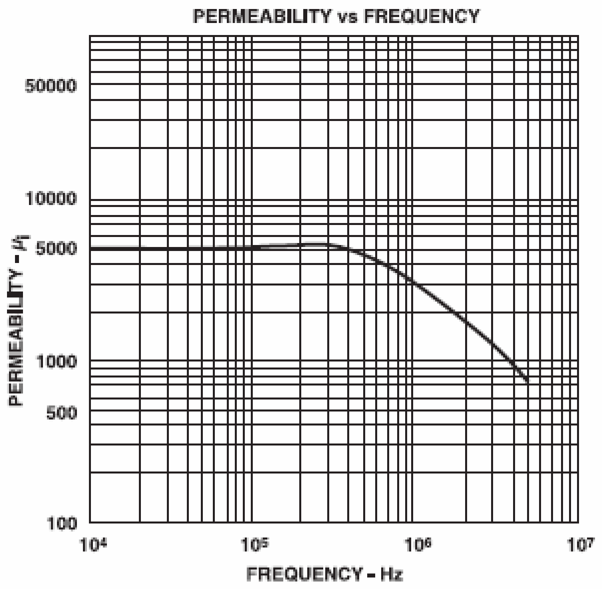
*In K and P materials, permeability and loss factor will irreversibly increase if excited with high magnetizing force. This should be considered when applying DC or high AC currents for test purposes.

- B material is the typical.

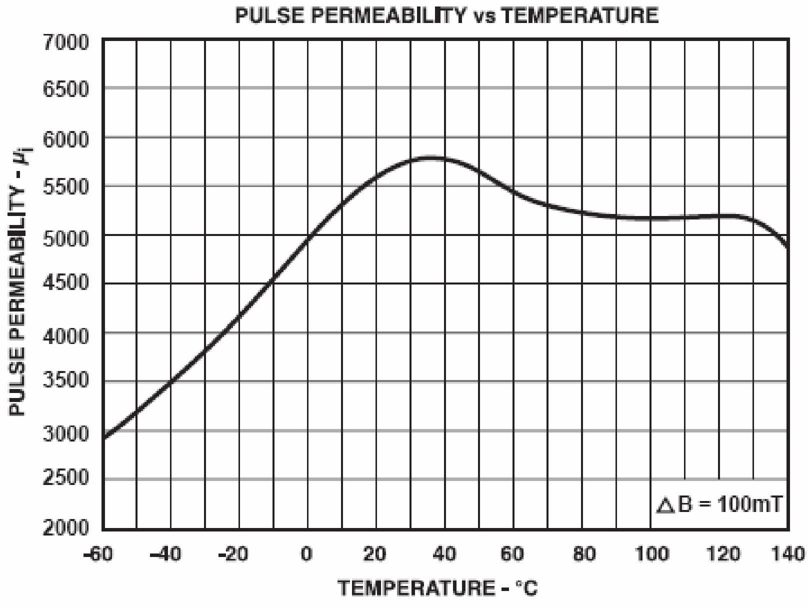
Typical Data Transformer Magnetic Material

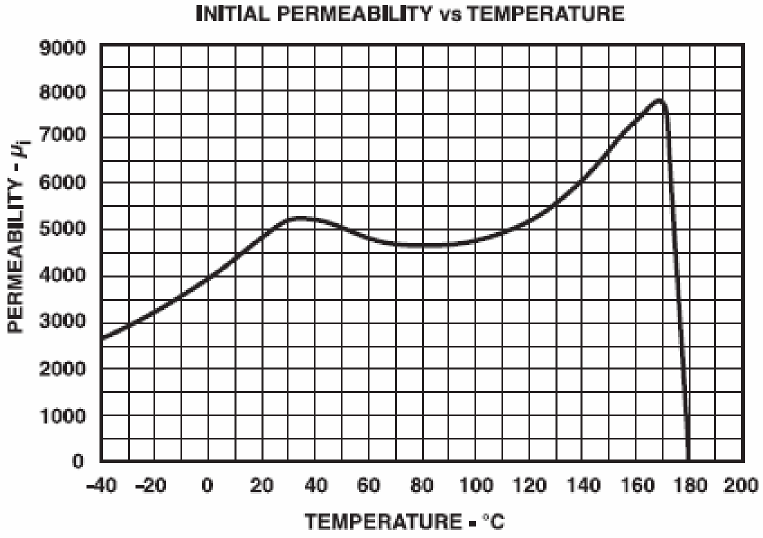
B MATERIAL (5,000μ_i) is a manganese-zinc ferrite suited for applications where high permeability and flux density and low power loss are required.



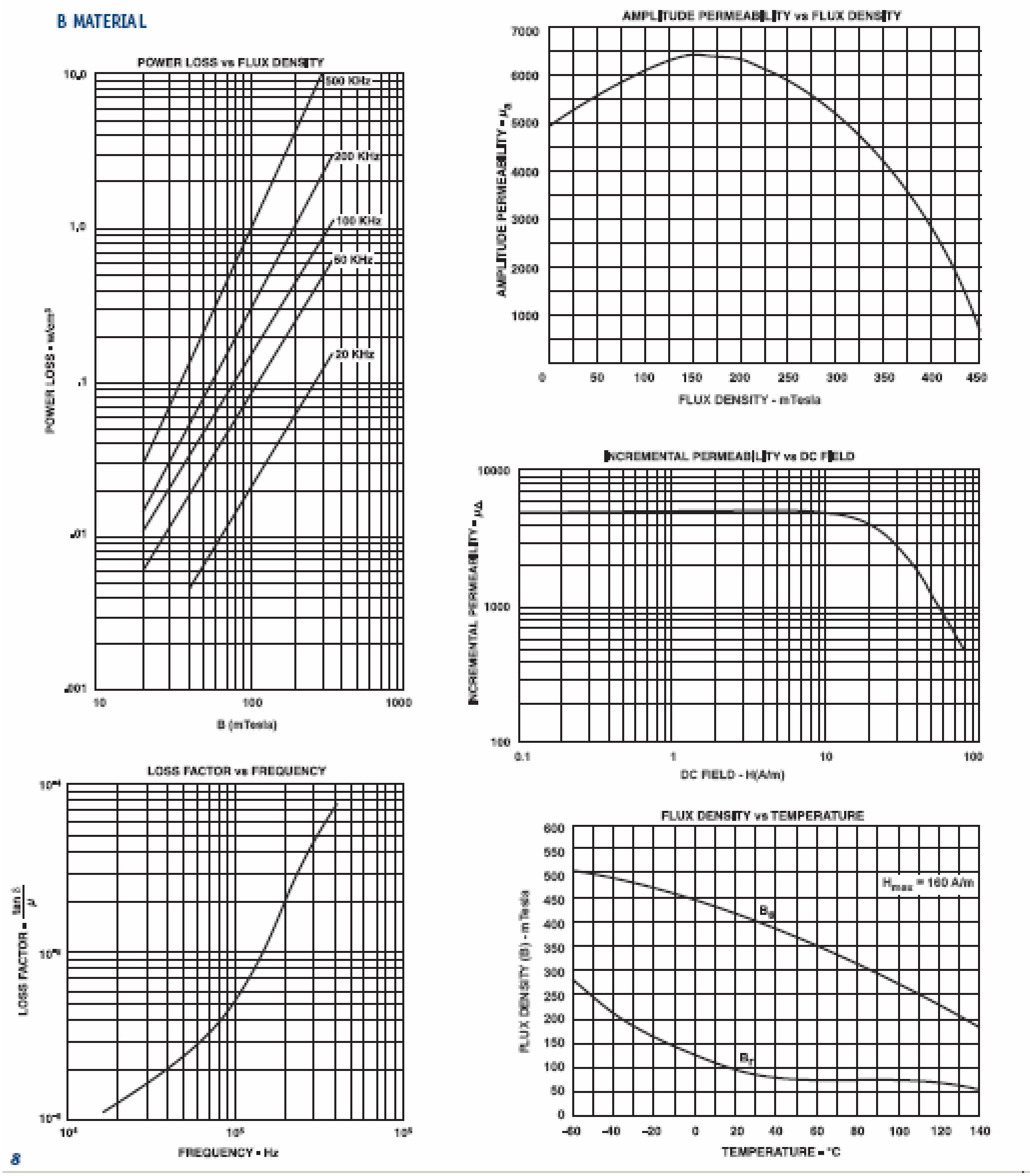


Typical Data Transformer Magnetic Material





Typical Data Transformer Magnetic Material



Annex 2 – Channel Requirements

Channel insertion loss per ANSI/TIA/EIA-568-B.1-2001

Table 11-1 Insertion loss @ 20 °C for channel test configuration
Length of horizontal cabling: 90 m (295 ft)
Length of equipment cords, patch cords and jumpers: 10 m (33 ft)

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)
1.0	4.2	2.2
4.0	7.3	4.5
8.0	10.2	6.3
10.0	11.5	7.1
16.0	14.9	9.1
20.0	--	10.2
25.0	--	11.4
31.25	--	12.9
62.5	--	18.6
100.0	--	24.0

NOTE – Category 3 channel insertion loss requirements are derived using a connecting hardware contribution of 0.4 dB per connection point over the frequency range of 1 – 16 MHz. The category 3 connecting hardware requirements of ANSI/TIA/EIA-568-B.2 provide additional margin to the channel requirements.

Maximum Channel Insertion loss

Table 7 - Maximum channel insertion loss

Frequency (MHz)	Category 3 (dB)	Category 5e (dB)	Category 6 (dB)
1.00	4.2	2.2	2.1
4.00	7.3	4.5	4.0
8.00	10.2	6.3	5.7
10.00	11.5	7.1	6.3
16.00	14.9	9.1	8.0
20.00	-	10.2	9.0
25.00	-	11.4	10.1
31.25	-	12.9	11.4
62.50	-	18.6	16.5
100.00	-	24.0	21.3
200.00	-	-	31.5
250.00	-	-	35.9
300.00	-	-	-
400.00	-	-	-
500.00	-	-	-

Normative insertion loss values for channel from ISO/IEC 11801:2002

Table 4 – Insertion loss for channel

Class	Frequency MHz	Maximum insertion loss [a] dB
A	$f = 0{,}1$	16,0
B	$f = 0{,}1$	5,5
	$f = 1$	5,8
C	$1 \le f \le 16$	$1{,}05 \times \left(3{,}23\sqrt{f}\right) + 4 \times 0{,}2$
D	$1 \le f \le 100$	$1{,}05 \times \left(1{,}910\,8\sqrt{f} + 0{,}022\,2 \times f + 0{,}2/\sqrt{f}\right) + 4 \times 0{,}04 \times \sqrt{f}$ =2.3986dB @1MHz
E	$1 \le f \le 250$	$1{,}05 \times \left(1{,}82\sqrt{f} + 0{,}016\,9 \times f + 0{,}25/\sqrt{f}\right) + 4 \times 0{,}02 \times \sqrt{f}$
F	$1 \le f \le 600$	$1{,}05 \times \left(1{,}8\sqrt{f} + 0{,}01 \times f + 0{,}2/\sqrt{f}\right) + 4 \times 0{,}02 \times \sqrt{f}$

[a] Insertion loss (IL) at frequencies that correspond to calculated values of less than 4,0 dB shall revert to a maximum requirement of 4,0 dB.

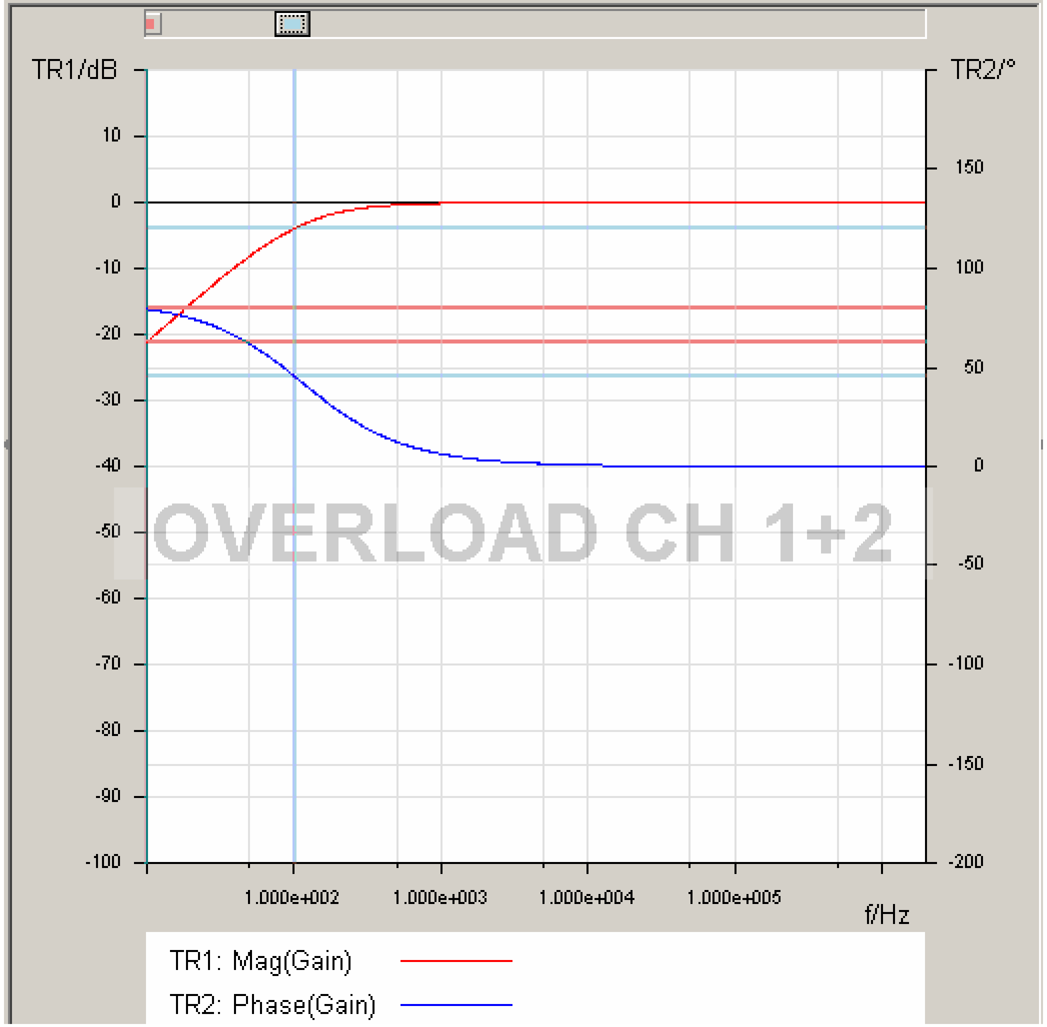
Informative Insertion Loss values for channel from ISO/IEC 11801:2002

Table 5 – Informative insertion loss values for channel at key frequencies

Frequency MHz	Maximum insertion loss dB					
	Class A	Class B	Class C	Class D	Class E	Class F
0,1	16,0	5,5	N/A	N/A	N/A	N/A
1	N/A	5,8	4,2	4,0	4,0	4,0
16	N/A	N/A	14,4	9,1	8,3	8,1
100	N/A	N/A	N/A	24,0	21,7	20,8
250	N/A	N/A	N/A	N/A	35,9	33,8
600	N/A	N/A	N/A	N/A	N/A	54,6

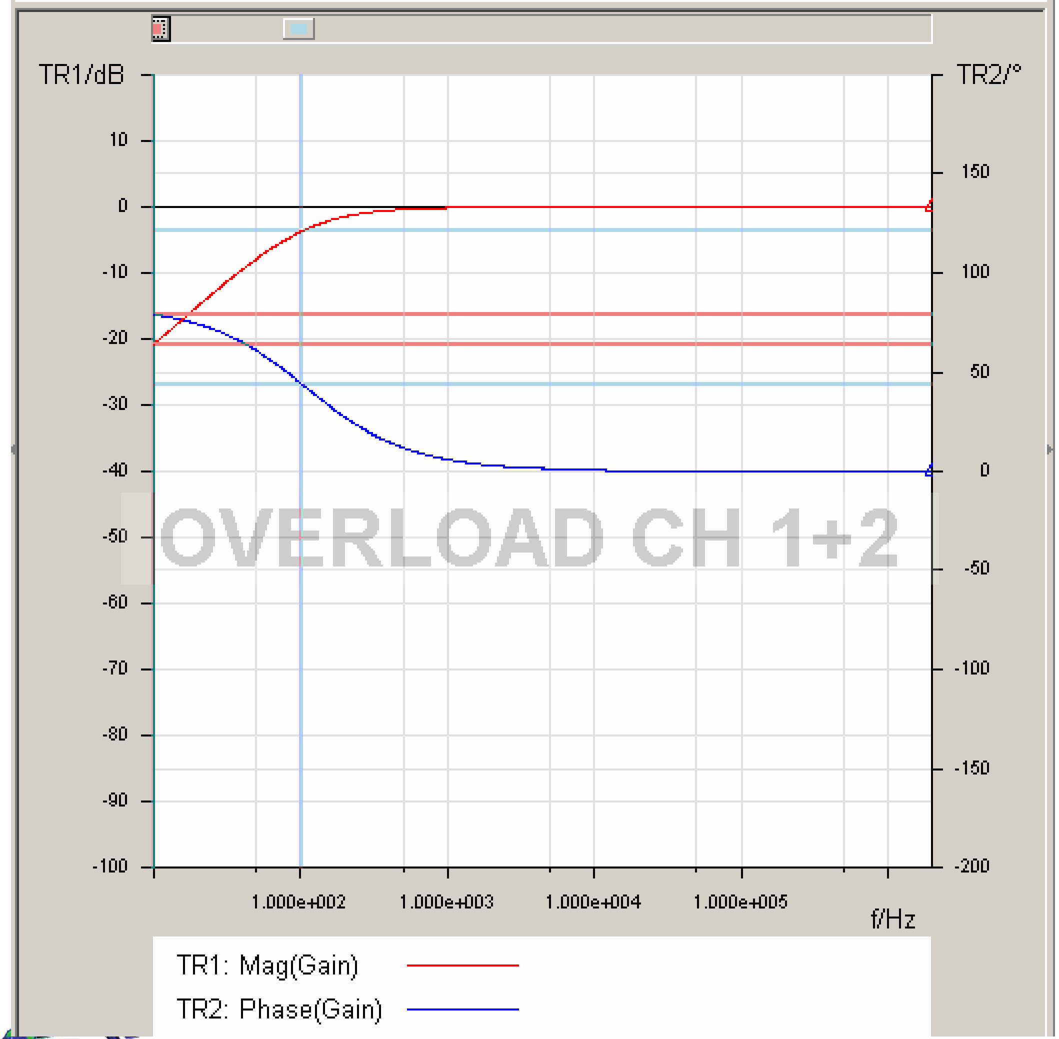
Setup Calibration – Single TR no Rs, RL, Trafo #2

	requency	Trace 1		Trace 2	
Cursor 1	10.000 Hz		-21.194 dB		79.431 °
Cursor 2	101.958 Hz		-3.859 dB		45.117 °



Setup Calibration – Single TR no Rs, RL, Trafo #1

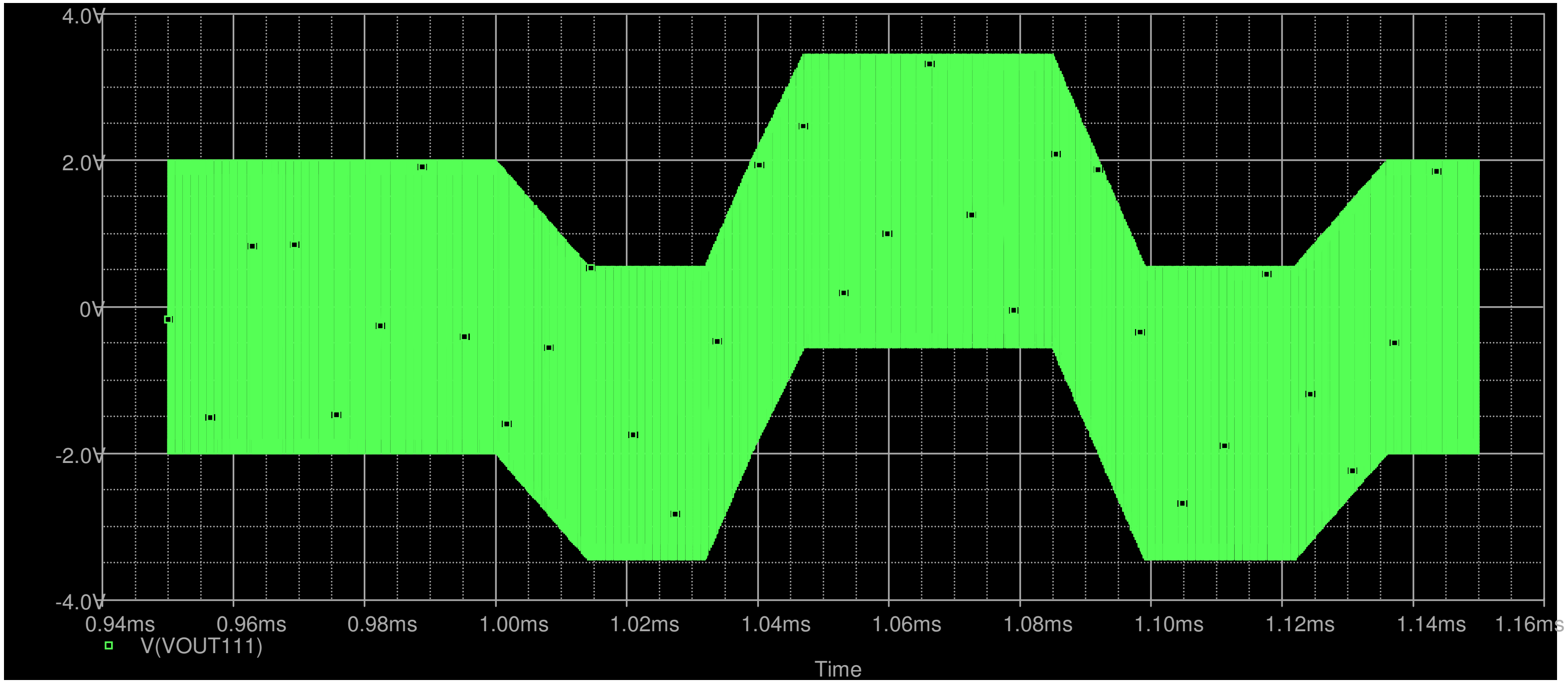
	requency	Trace 1		Trace 2	
Cursor 1	10.000 Hz		-20.860 dB		78.899 °
Cursor 2	101.958 Hz		-3.692 dB		43.864 °



Transformer data

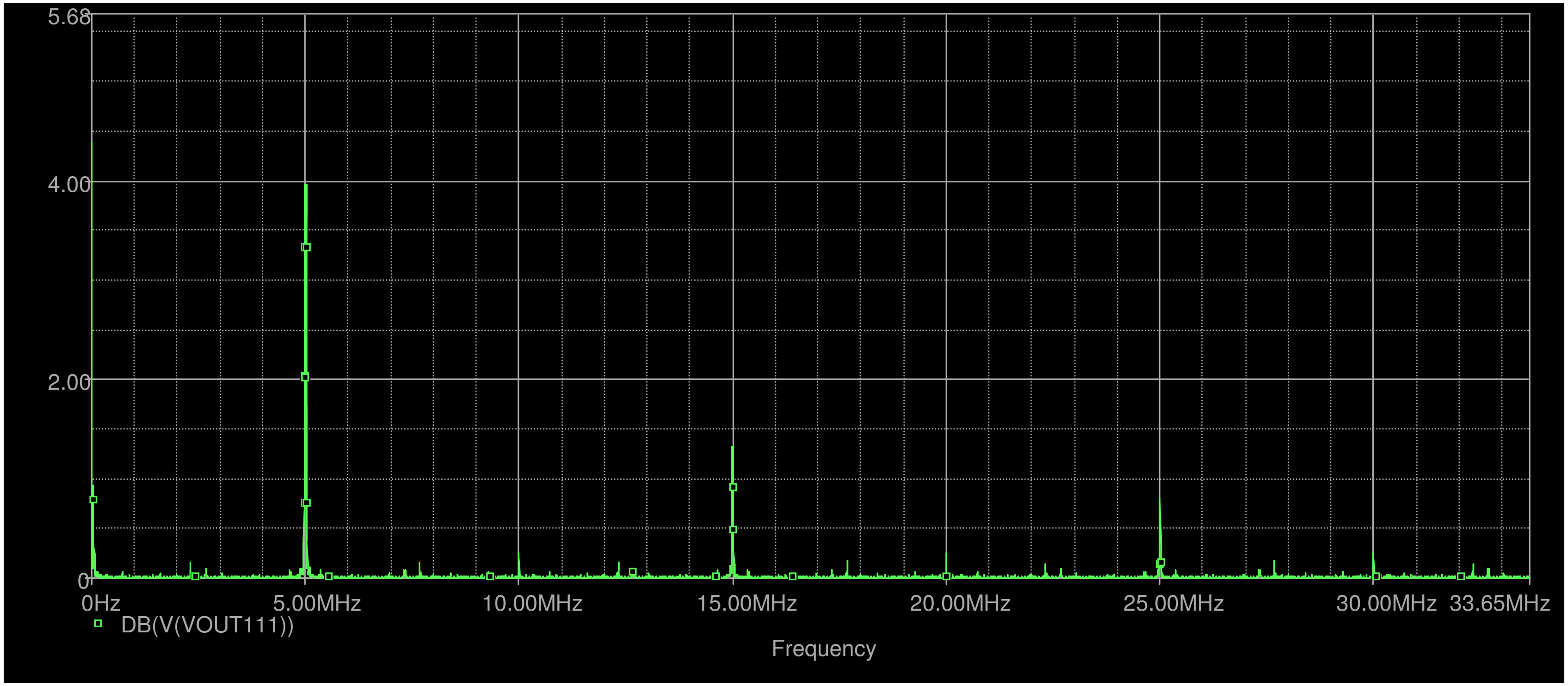
NT=~28		Idc=0	Idc=8	Idc=18.5
	0 degC	839	793	513
	20degC	875	831	546
	70degC	748	719	400
NT=20		Idc=0	Idc=8	Idc=18.5
	0 degC	453	448	352
	20degC	472	468	371
	70degC	404	403	306

BLW Time Domain Simulations - Preliminary



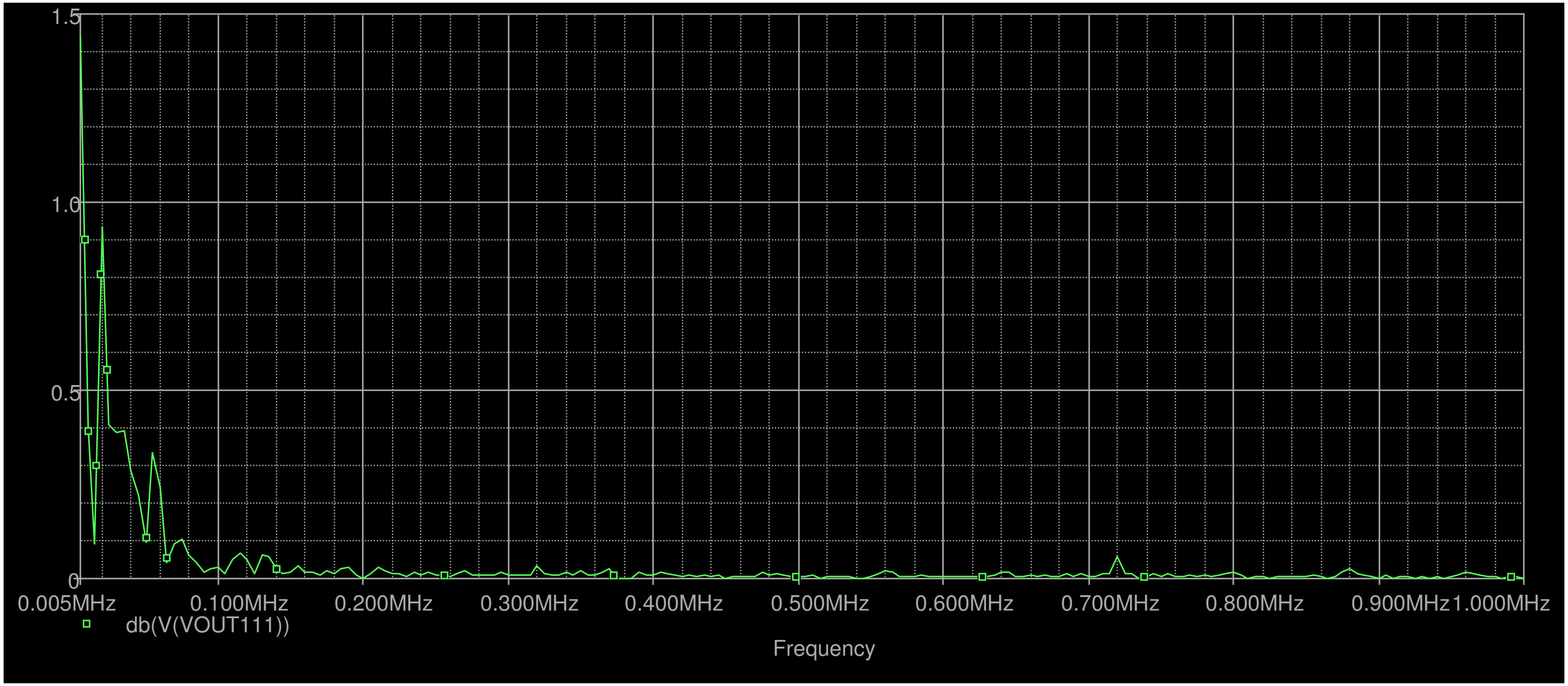
BLW Frequency Domain Simulations - Preliminary

Data Bandwidth



BLW Frequency Domain Simulations - Preliminary

<=1MHz Bandwidth



Frequency Domain, <100KHz Data Bandwidth – Simulations
Preliminary