Reflectivity Curves and DGS Sizing

Paul Grosser CEng
ISO9712 Level 3 MT, PT, ET, RT, UT, PAUT, ToFD

Introduction

- The use of Reflectivity Curves and the Distance Gain Size (DGS) method are useful techniques for the detection and sizing of discontinuities using Ultrasonics.

- The principal works on the theoretical relationship between the signal of a reflector at a specific distance and amplitude when compared to a known reflector.

These assessments are typically carried out in two ways:

- Reflectivity Curves
- DGS Software or Calculations

History

- Initially developed for Flat Bottom Holes (FBH) by the Krautkramer brothers in 1958.
- Ermolov (1972) proposed a variety of formulas for different reflector types including point reflectors (smaller than the beam spread), elongated targets (one axis greater than the beam spread) and infinite targets (larger than the beam spread e.g. Back Wall Echo).
- Formulas were defined for both the Near Zone and the Far Zone.
- These generated curves are often normalised, so that a variety of probe, frequency, material combinations can be employed by the same curve.
- The normalisation is typically done though using the Near Zone Length and Amplitude in Decibels as the common axis.

Ermolov Equations

Far Zone

- Infinite Plane (BWE)

$$\frac{V_\infty}{V_o} = \frac{S}{2\lambda T} e^{-2T\delta}$$

- Sphere with diameter d_s

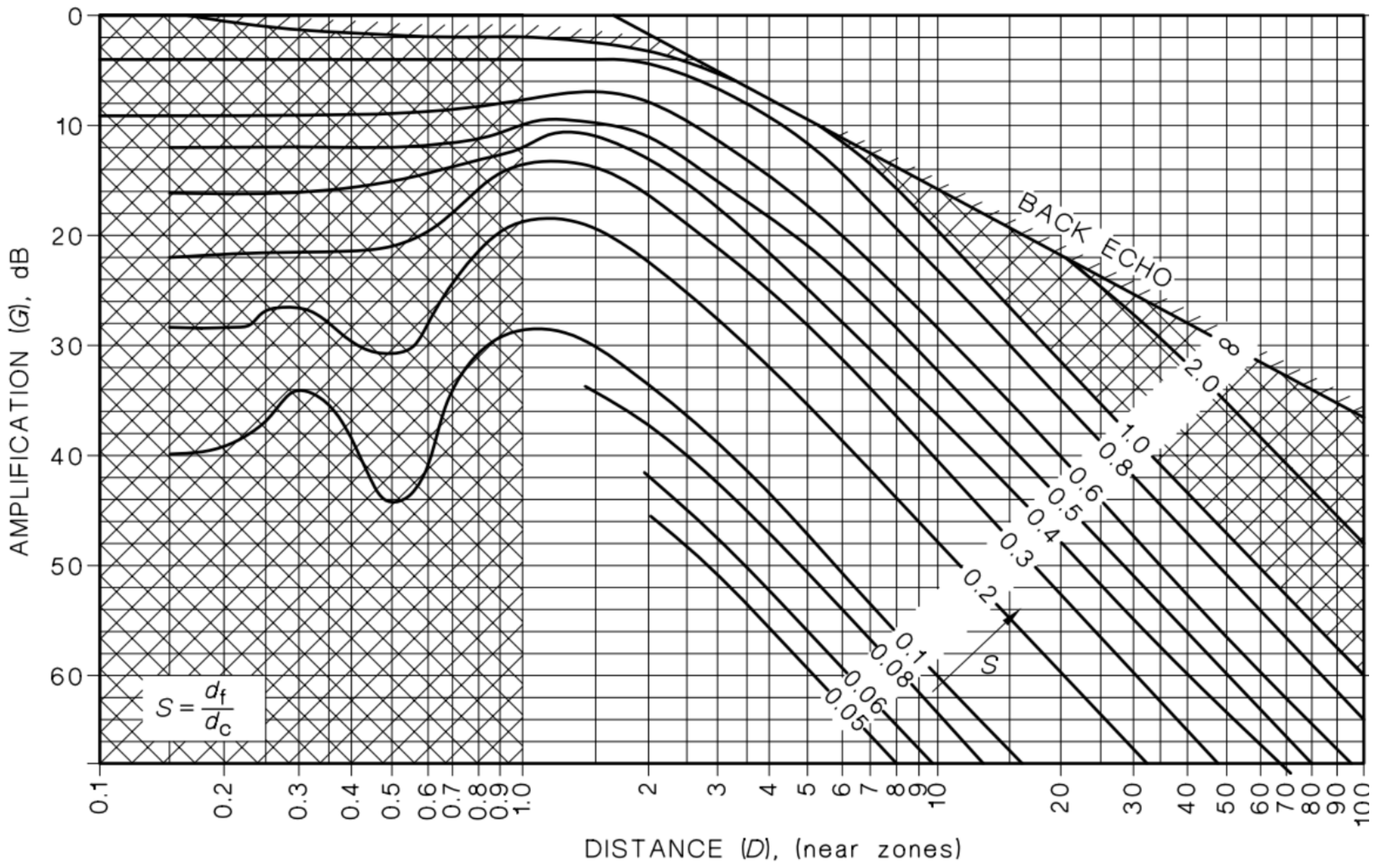
$$\frac{V_s}{V_o} = \frac{Sd_s}{4\lambda T^2} e^{-2T\delta}$$

- Cylinder with diameter d_c and length l_c

$$\frac{V_c}{V_o} = \frac{Sl_c}{T^2} \sqrt{\frac{d_c}{\lambda^3}} e^{-2T\delta}$$

V = maximum amplitude of the echo from the target
V_o = maximum possible signal amplitude if all energy is returned to the receiver
T = distance along the beam axis to the target
S = area of the probe
λ = wavelength
δ = attenuation coefficient

Example: Normalised Reflectivity Curve



LEGEND:

D = Distance, in near zones
G = Amplification, in decibels
S = Relative equivalent reflector diameter
d_f = FBH diameter, in millimetres
d_c = Probe crystal diameter, in millimetres

Normalised Reflectivity Curves

In the right normalised curve, the following relationships are evident.

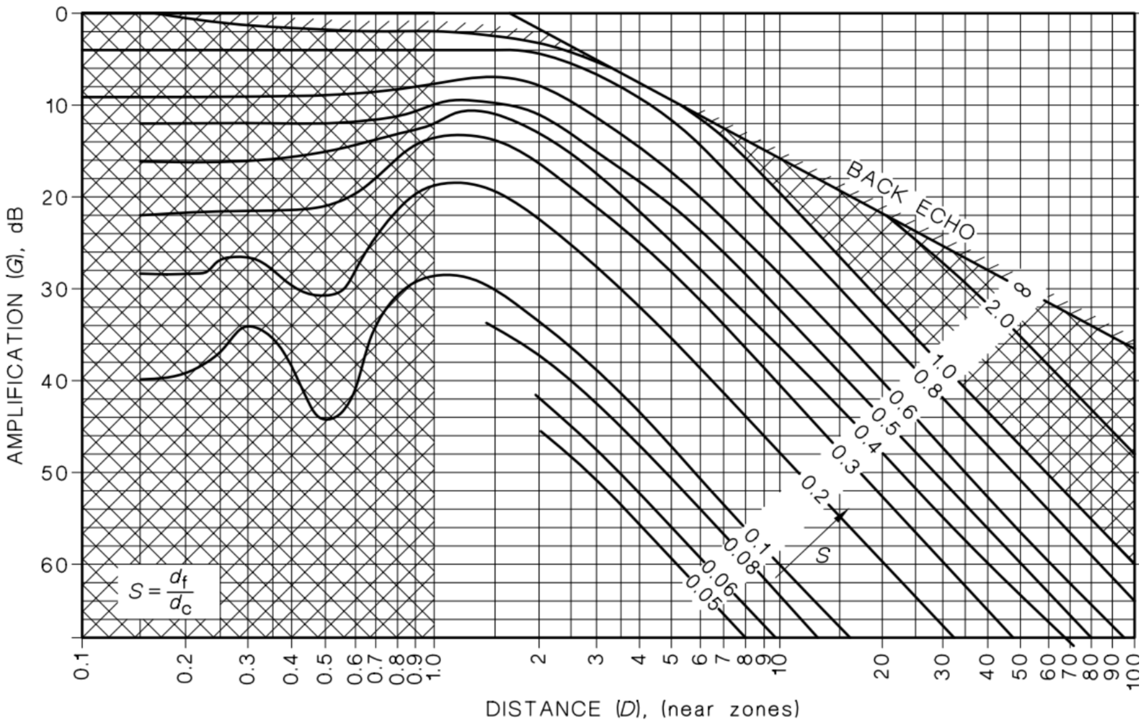
- Back Wall Echo (BWE)

  The BWE is larger than the beam spread, therefore the relationship between distance and amplitude is theoretically inversely proportional. Double the distance, receive half the reflected amplitude (-6dB).

- Flat Bottom Hole Reflector (FBH)

  The if FBH is smaller than the beam spread, the relationship between distance and amplitude is theoretically inversely squared.

  - Double the distance, receive one quarter of the reflected amplitude (-12dB).
  - Double the diameter, receive four times the reflected amplitude (+12dB).



LEGEND:

D = Distance, in near zones
G = Amplification, in decibels
S = Relative equivalent reflector diameter
d_f = FBH diameter, in millimetres
d_c = Probe crystal diameter, in millimetres

Normalised Reflectivity Curves

- Side Drilled Hole Reflector (Finite Length)
  - Double the distance, -12 dB
  - Double the diameter, +3 dB

- Side Drilled Hole Reflector (Infinite Length)
  - Double the distance, -9 dB
  - Double the diameter, +3 dB

Diameter can be simplified to

$$dB = 10\log\left(\frac{d_2}{d_1}\right)$$

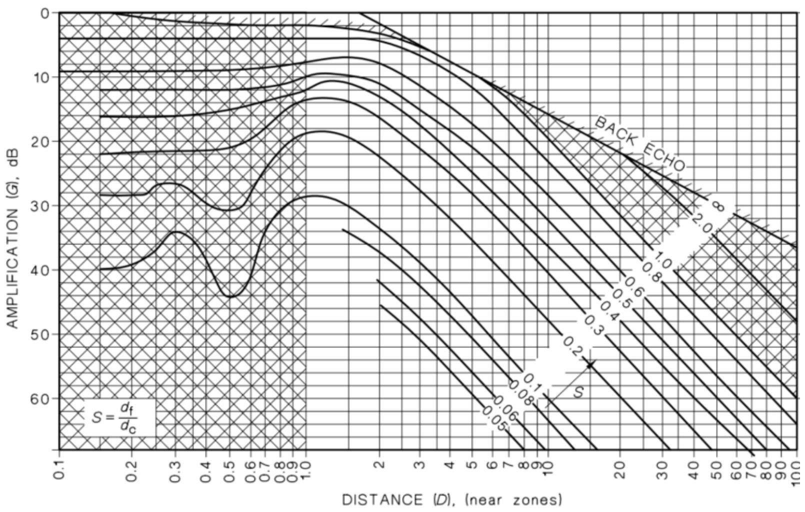
Normalised Reflectivity Curves (FBH)

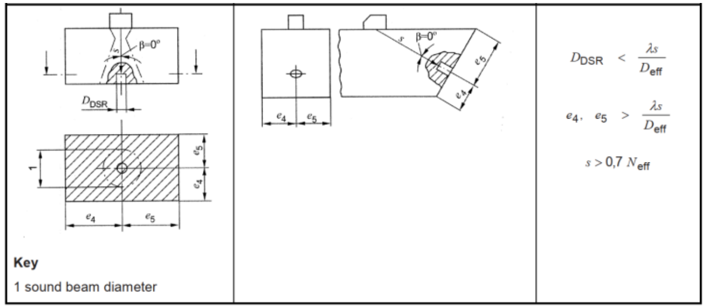
- It can also be seen that stabilisation of the curve gradients does not occur until approximately three (3) Near Zone lengths.

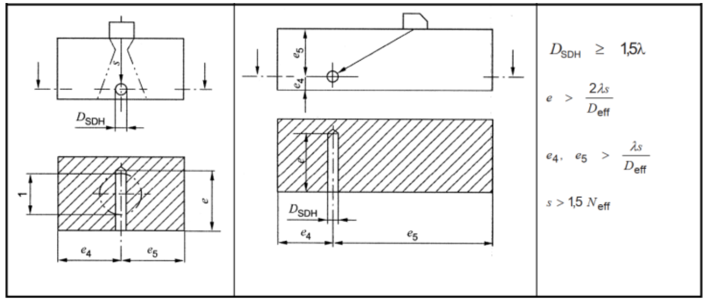
- For this reason, wherever practicable to minimise significant possible amplitude variations (predicted to be up to 12 dB), the curves should be utilised beyond a minimum of three (3) Near Zones.

- Different codes have varying requirements for minimum sound path to use.
    - ISO 16811-2012 > 0.7 NZ_{eff} FBH
    - ISO 16811-2021 > 1.5 NZ_{eff} SDH

- Note: The effect of the Near Zone amplitude variations is directly proportional to the bandwidth / pulse length, the shorter the pulse length, the less significant the effect of the Near Zone.







Example: Normalised Reflectivity Curve (FBH) Worked Example

Scenario 1:

Probe: 24mm Diameter, 2MHz normal probe, compression in steel.

Using the Back Wall Echo (BWE) at 500mm beam path as a reference, an indication at 300mm beam path is detected with an amplitude -18dB of the BWE reference. What is the approximate equivalent Flat Bottom Hole (FBH) size of the indication?

Probe Diameter (mm)	d_c	24
Probe Frequency (MHz)	f	2
Materials Velocity (m/s)	v	5920
Reference Echo Type	BWE / Known Reflector (FBH)	BWE
Reference Reflector Diameter (mm)*	s_{ref}	N/A
Reference Reflector Beam Path (mm)	d_{ref}	500
Indication Beam Path (mm)	d_{ind}	300
Indication dB difference to reference	G	-18

Calculations:		
Wavelength (mm)	$\lambda = \frac{V}{f}$	2.96
Near Zone (mm)	$N_c = \frac{{d_c}^2}{4\lambda}$	49
Reference Position Near Zones	$D_{ref} = \frac{d_{ref}}{N_c}$	10.3
Indication Position Near Zones	$D_{ind} = \frac{d_{ind}}{N_c}$	6.2
Reference Reflector Relative Size*	$S_{ind} = \frac{s_{ref}}{d_c}$	N/A

Example: Normalised Reflectivity Curve (FBH)

Scenario 1:

Probe: 24mm Diameter, 2MHz normal probe, compression in steel.

Using the Back Wall Echo (BWE) at 500mm beam path as a reference, an indication at 300mm beam path is detected with an amplitude -18dB of the BWE reference. What is the approximate equivalent Flat Bottom Hole (FBH) size of the indication?

- BWE 10.3 NZ
- Indication 6.2 NZ , - 18 dB

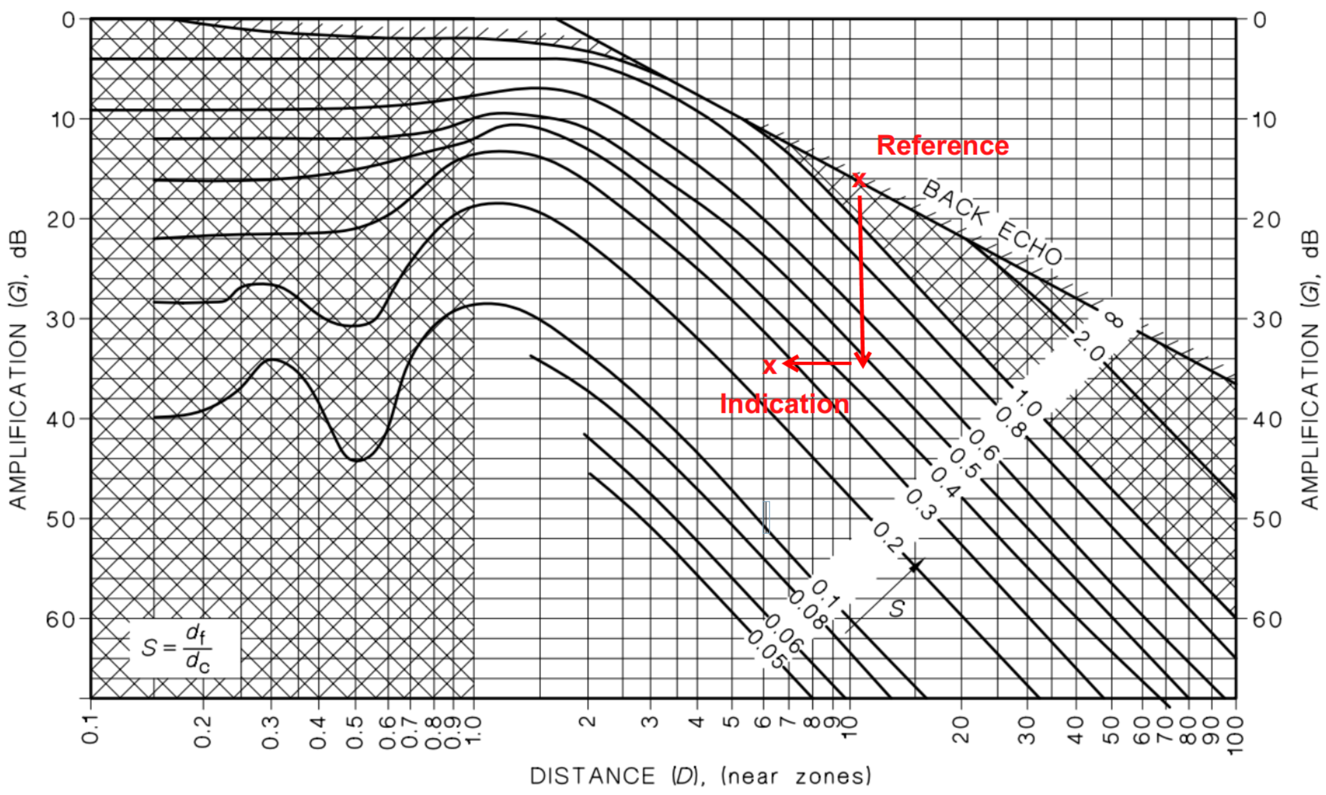
After Plotting: Indication position located at approximately

S = 0.275

$$d_f = S_{ind} \text{ x } d_c$$

$$d_f = 0.275 \text{ x } 24\text{mm}$$

$$d_f = 6.6mm\ approximatly$$



Example: Normalised Reflectivity Curve (FBH) Worked Example

Scenario 2:

Probe: 10mm Diameter, 4MHz normal probe, compression in steel.

Using a 4mm diameter Flat Bottom Hole (FBH) at 125mm beam path as a reference, an indication at 75mm beam path is detected with an amplitude +14dB of the reference. What is the approximate equivalent Flat Bottom Hole (FBH) size of the indication?

Probe Diameter (mm)	d_c	10
Probe Frequency (MHz)	f	4
Materials Velocity (m/s)	v	5920
Reference Echo Type	BWE / Known Reflector (FBH)	Known Reflector
Reference Reflector Diameter (mm)*	s_{ref}	4
Reference Reflector Beam Path (mm)	d_{ref}	125
Indication Beam Path (mm)	d_{ind}	75
Indication dB difference to reference	G	+ 14

Calculations:		
Wavelength (mm)	$\lambda = \frac{V}{f}$	1.48
Near Zone	$N_c = \frac{{d_c}^2}{4\lambda}$	16.9
Reference Position Near Zones	$D_{ref} = \frac{d_{ref}}{N_c}$	7.4
Indication Position Near Zones	$D_{ind} = \frac{d_{ind}}{N_c}$	4.4
Reference Reflector Relative Size*	$S_{ind} = \frac{s_{ref}}{d_c}$	0.4

Example: Normalised Reflectivity Curve (FBH)

Scenario 2:

Probe: 10mm Diameter, 4MHz normal probe, compression in steel.

Using a 4mm diameter Flat Bottom Hole (FBH) at 125mm beam path as a reference, an indication at 75mm beam path is detected with an amplitude +14dB of the reference. What is the approximate equivalent Flat Bottom Hole (FBH) size of the indication?

- Reference 4mm FBH (S = 0.4), 7.4 NZ
- Indication 4.4 NZ , + 14 dB

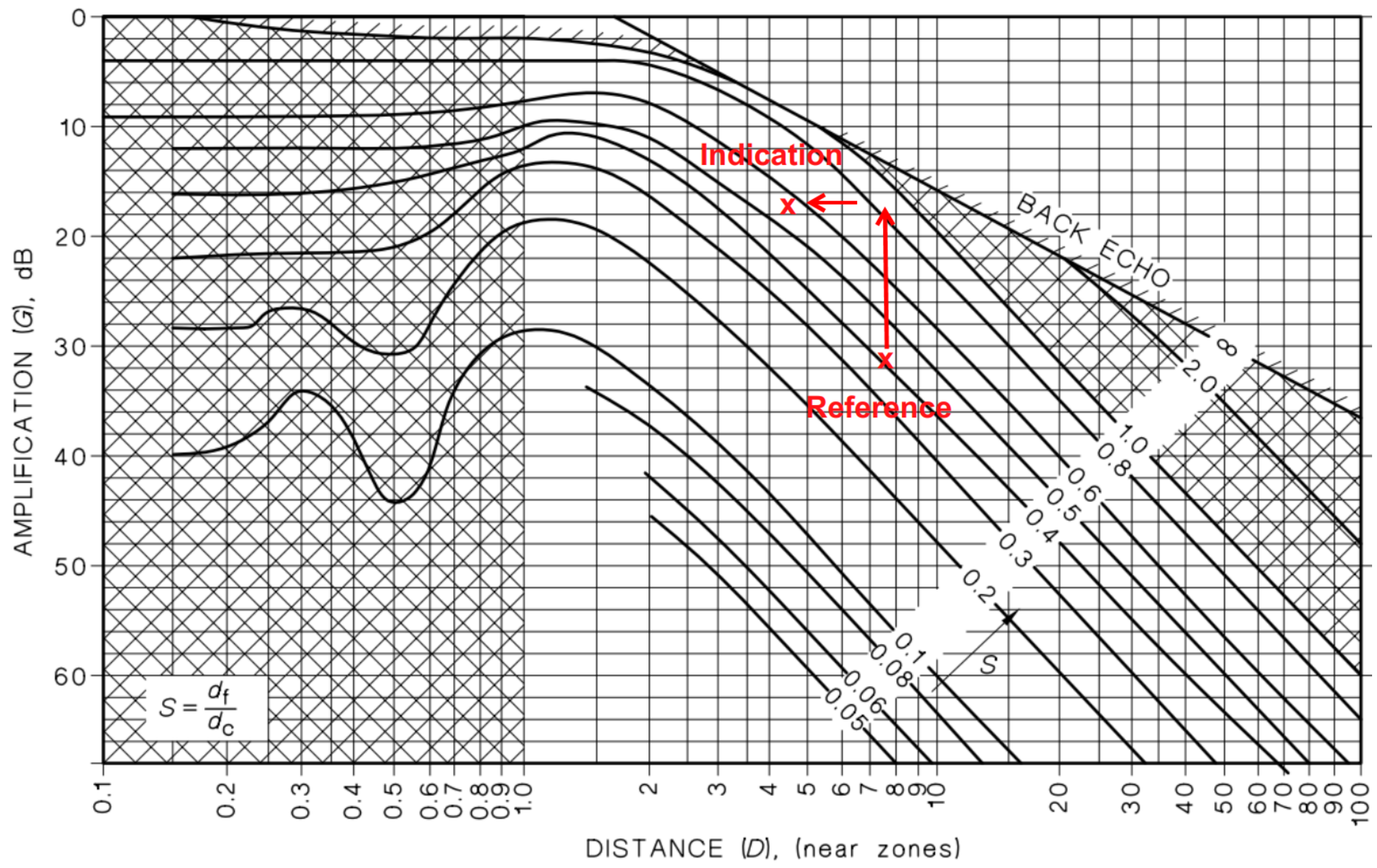
After Plotting: Indication position located at approximately

S = 0.55

$$d_f = S_{ind} \text{ x } d_c$$

$$d_f = 0.55 \text{ x } 10\text{mm}$$

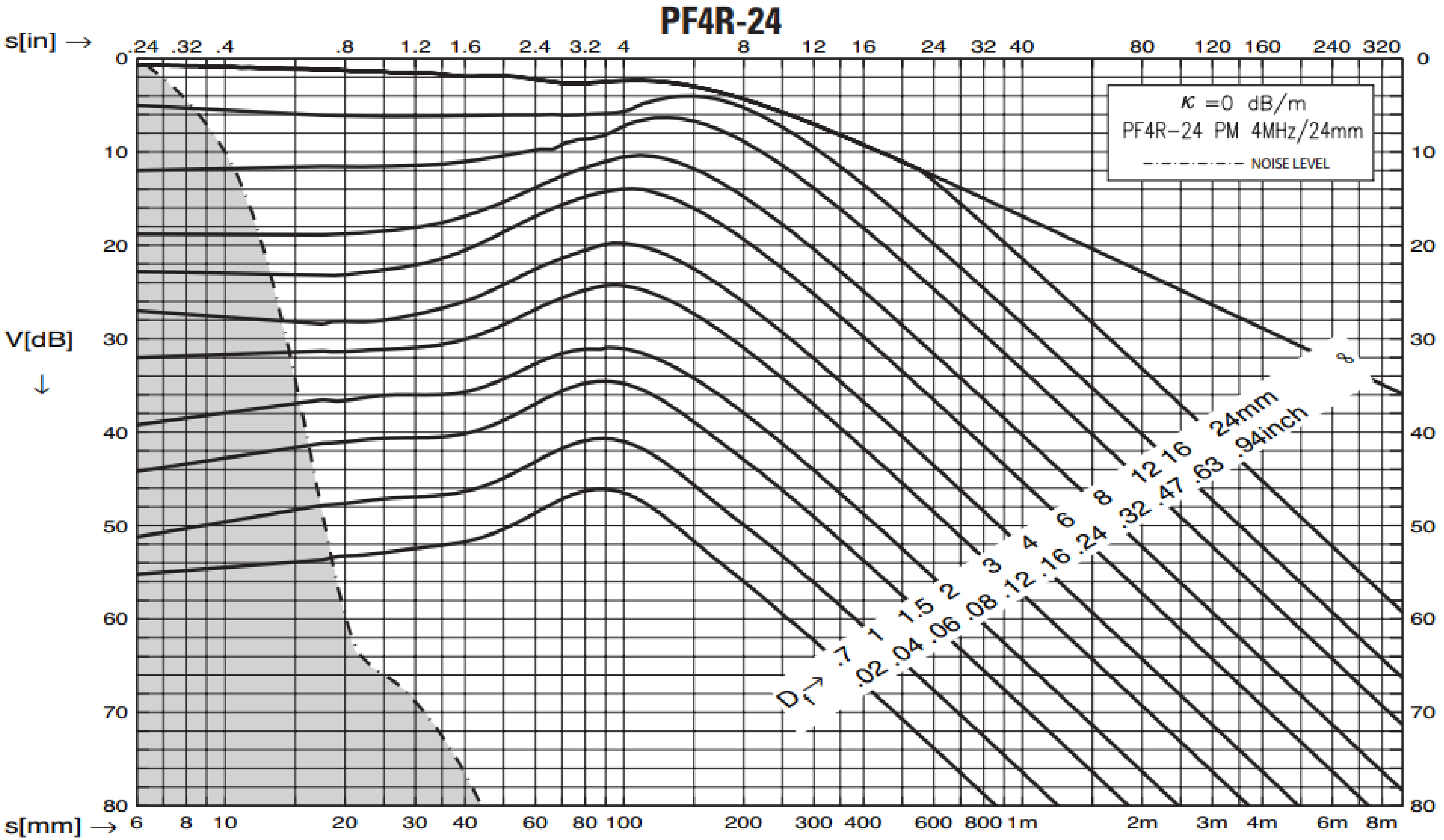
$$d_f = 5.5mm\ approximatly$$



DGS – Distance Gain Size

- When variables (velocity, diameter, frequency) are known, the normalised curve can be converted to a probe specific curve.
- These are now commonly built into flaw detectors to allow for rapid gain setting and sizing.
- Commonly referenced in standards for use.

DGS – Distance Gain Size



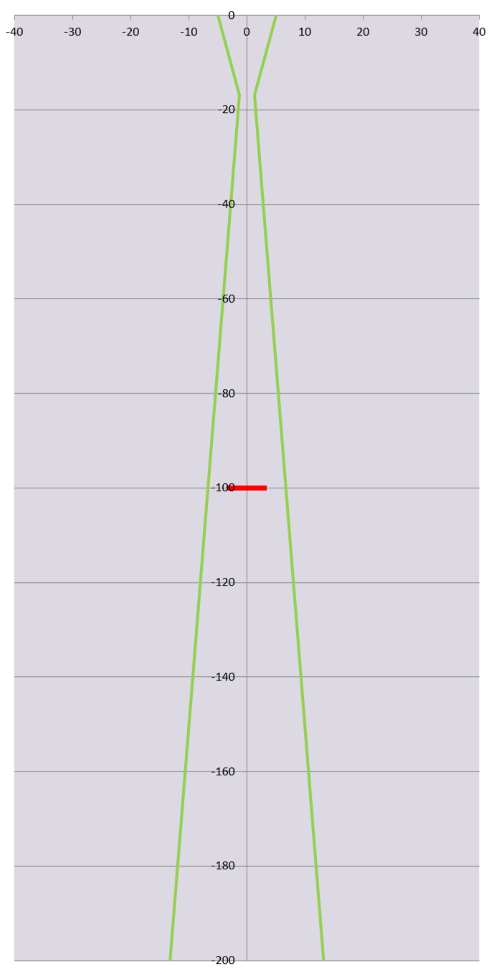
DGS – Distance Gain Size

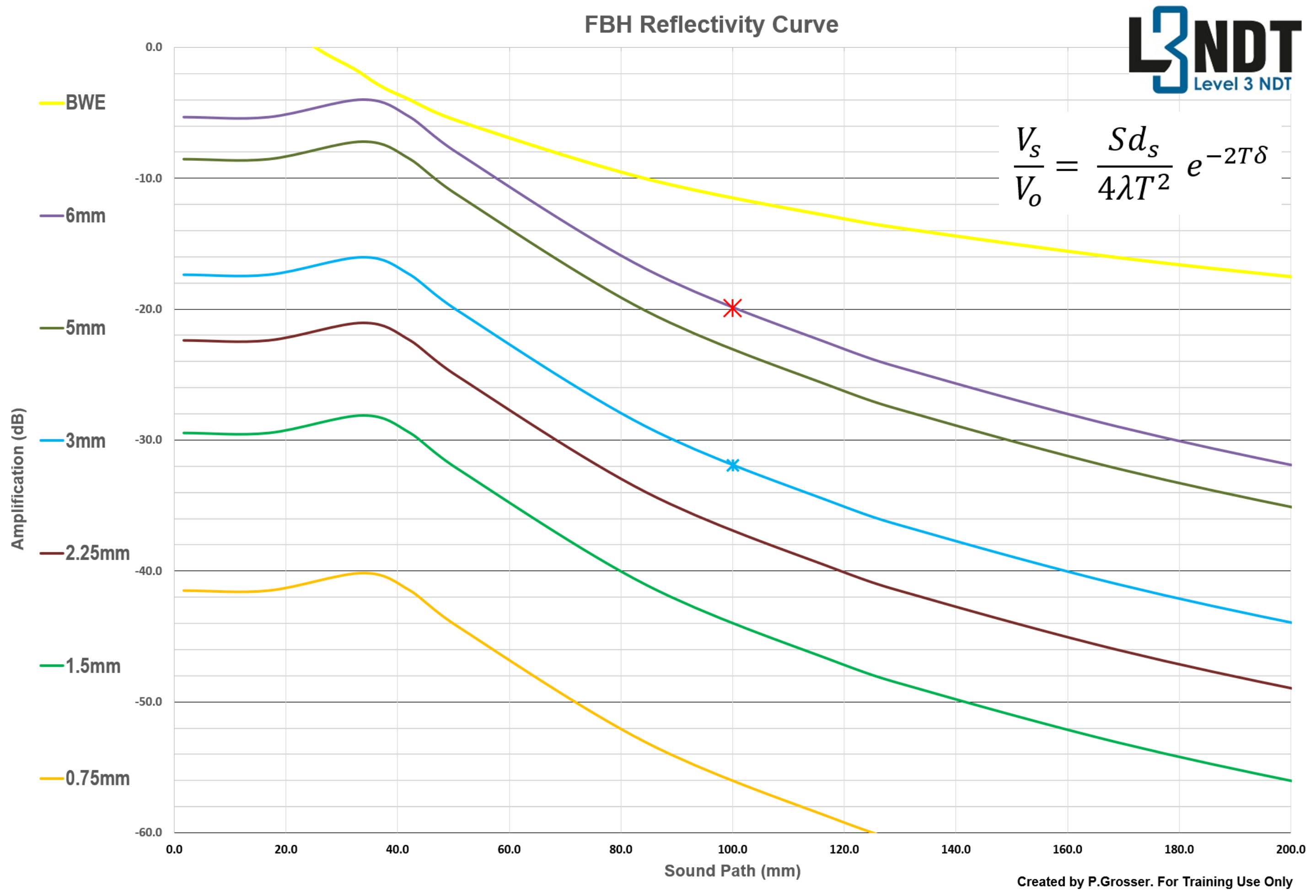
Probe	
Diameter (mm)	10
Frequency (MHz)	4
Velocity (m/s)	5920
Wavelength (mm)	1.48
Area (mm^2)	79
Near Zone (mm)	17

BWE	
Beam Path (mm)	500
Diameter @ Beam Path (mm)	65
Area (mm^2)	3360.9
# of Near Zones	29.6
Reference dB	-25.5

Known Reflector	
Beam Path (mm)	100
FBH Diameter (mm)	3
Diameter Ratio (S)	0.3
Area (mm^2)	7.1
# of Near Zones	5.9
dB Calculated	-31.9
dB diff to BWE	-6.4

Un-Known Reflector	
Reference	Known Reflector
Position (mm)	100
# of Nearzones	5.9
dB diff to Reference	12.0
Total dB	-19.9
Estimated Diameter (mm)	6.0





$$\frac{V_s}{V_o} = \frac{Sd_s}{4\lambda T^2} e^{-2T\delta}$$

DGS Simulation Software Showing Relationship Between 3mm and 6mm FBH (12 dB)

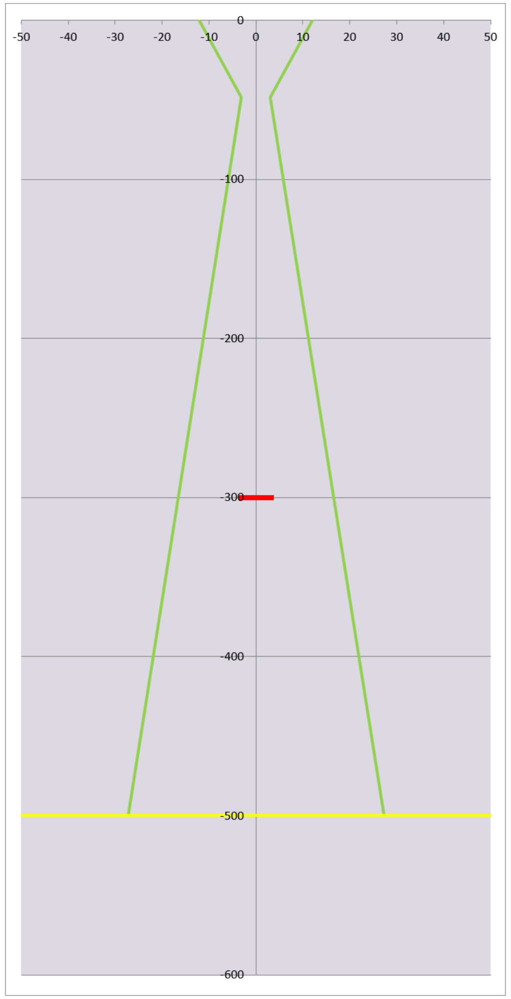
DGS – Distance Gain Size

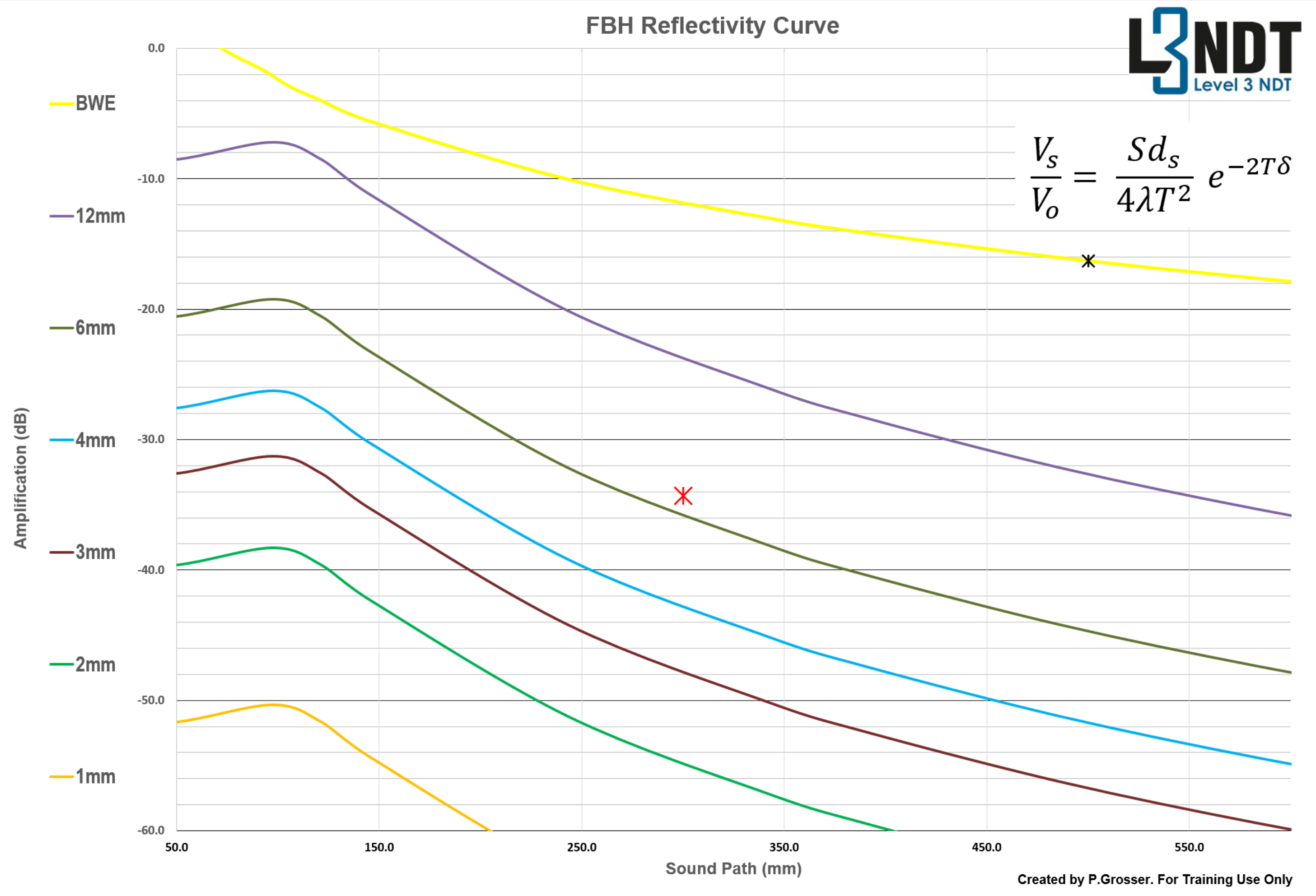
Probe	
Diameter (mm)	24
Frequency (MHz)	2
Velocity (m/s)	5920
Wavelength (mm)	2.96
Area (mm^2)	452
Near Zone (mm)	49

BWE	
Beam Path (mm)	500
Diameter @ Beam Path (mm)	55
Area (mm^2)	2334.0
# of Near Zones	10.3
Reference dB	-16.3

Known Reflector	
Beam Path (mm)	1000
FBH Diameter (mm)	4
Diameter Ratio (S)	0.2
Area (mm^2)	12.6
# of Near Zones	20.6
dB Calculated	-63.8
dB diff to BWE	-47.4

Un-Known Reflector	
Reference	BWE
Position (mm)	300
# of Nearzones	6.2
dB diff to Reference	-18.0
Total dB	-34.3
Estimated Diameter (mm)	6.5





DGS Simulation Software Showing Scenario 1 : 6.5mm vs 6.6mm

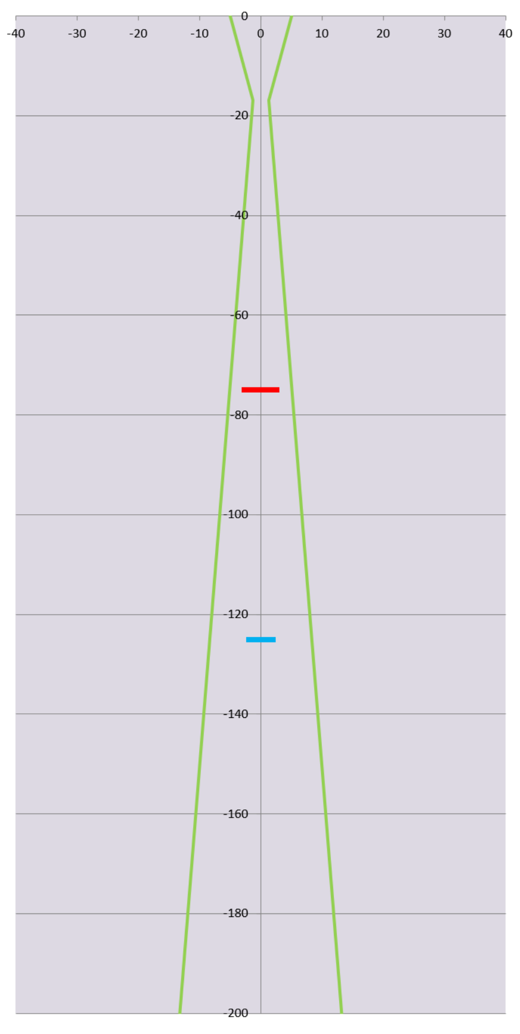
DGS – Distance Gain Size

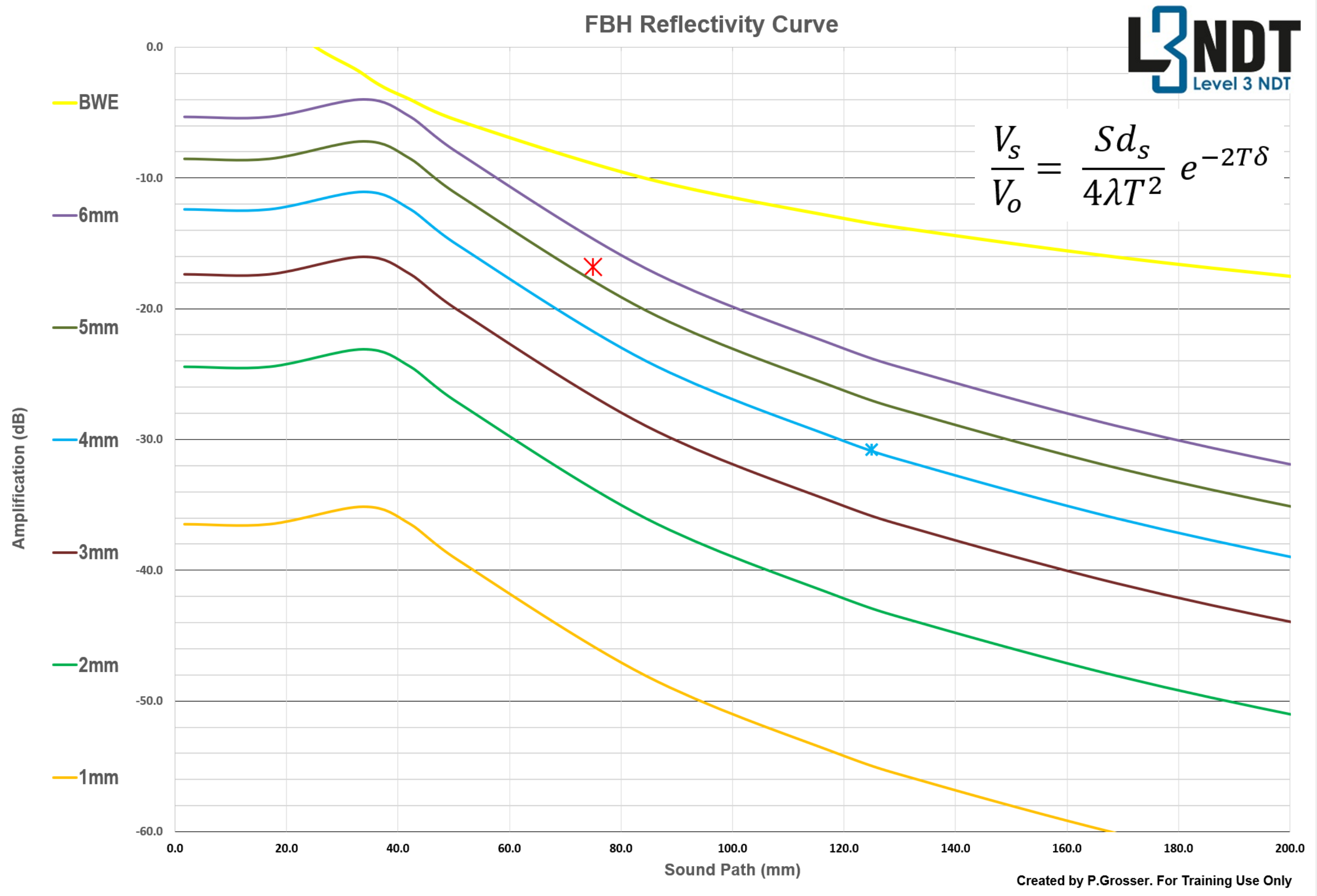
Probe	
Diameter (mm)	10
Frequency (MHz)	4
Velocity (m/s)	5920
Wavelength (mm)	1.48
Area (mm^2)	79
Near Zone (mm)	17

BWE	
Beam Path (mm)	500
Diameter @ Beam Path (mm)	65
Area (mm^2)	3360.9
# of Near Zones	29.6
Reference dB	-25.5

Known Reflector	
Beam Path (mm)	125
FBH Diameter (mm)	4
Diameter Ratio (S)	0.4
Area (mm^2)	12.6
# of Near Zones	7.4
dB Calculated	-30.8
dB diff to BWE	-5.3

Un-Known Reflector	
Reference	Known Reflector
Position (mm)	75
# of Nearzones	4.4
dB diff to Reference	14.0
Total dB	-16.8
Estimated Diameter (mm)	5.4





$$\frac{V_s}{V_o} = \frac{S d_s}{4\lambda T^2} e^{-2T\delta}$$

DGS Simulation Software Showing Scenario 2: 5.4mm vs 5.5mm

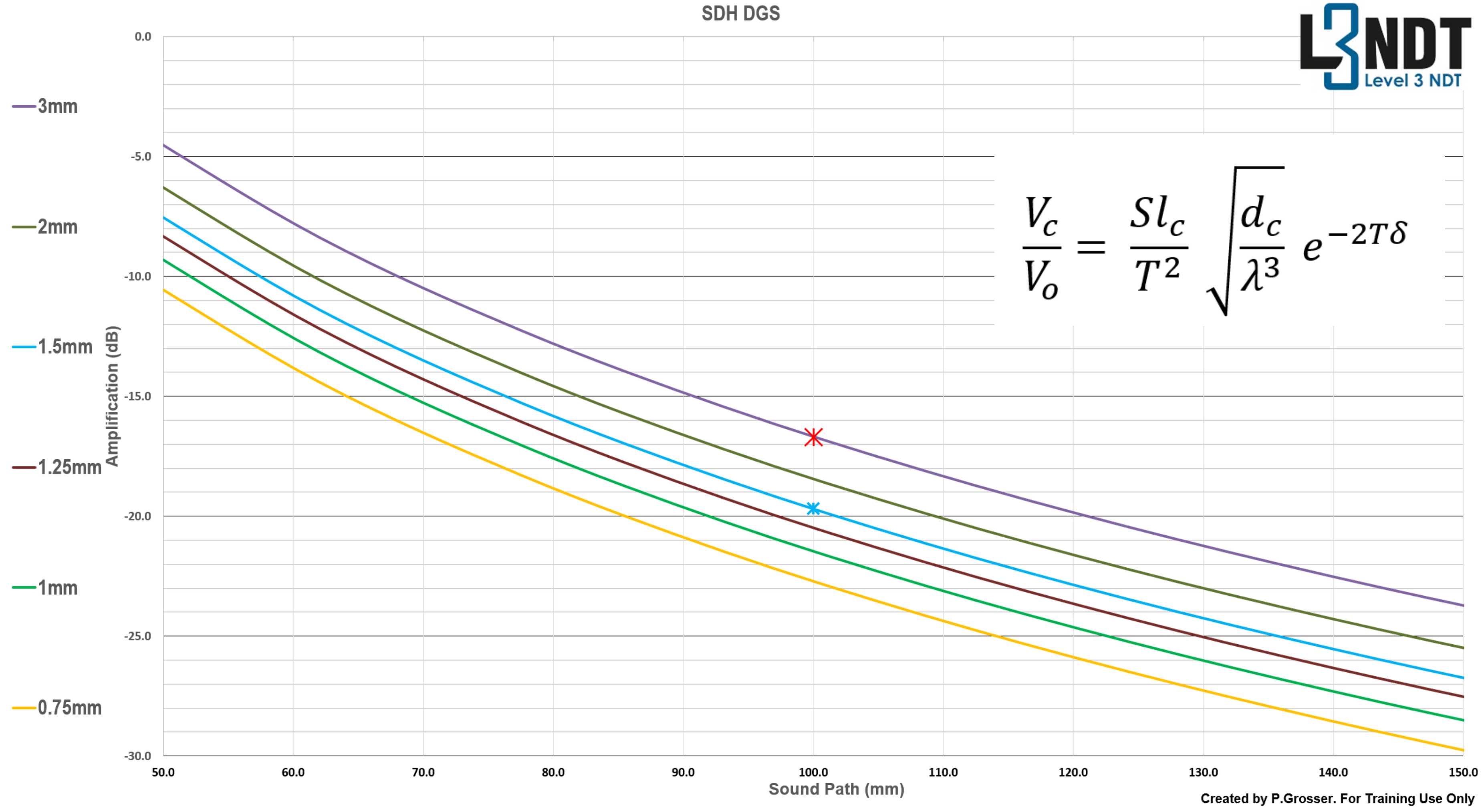
DGS – Distance Gain Size

Probe	
Diameter (mm)	10
Frequency (MHz)	2
Velocity (m/s)	3220
Wavelength (mm)	1.61
Area (mm^2)	79
Near Zone (mm)	16

BWE	
Beam Path (mm)	N/A
Diameter @ Beam Path (mm)	N/A
Area (mm^2)	N/A
# of Near Zones	N/A
Reference dB	N/A

Known Size Reflector	
Beam Path (mm)	100
Diameter @ Beam Path (mm)	1.5
Length (mm)	22.0
# of Near Zones	6.4
dB Calculated	-19.7

Un-Known Reflector Size	
Reference	Known Reflector
Position (mm)	100
# of Nearzones	6.4
dB diff to Reference	3.0
Total dB	-16.7
Estimated Diameter (mm)	3.0



$$\frac{V_c}{V_o} = \frac{Sl_c}{T^2}\sqrt{\frac{d_c}{\lambda^3}}\,e^{-2T\delta}$$

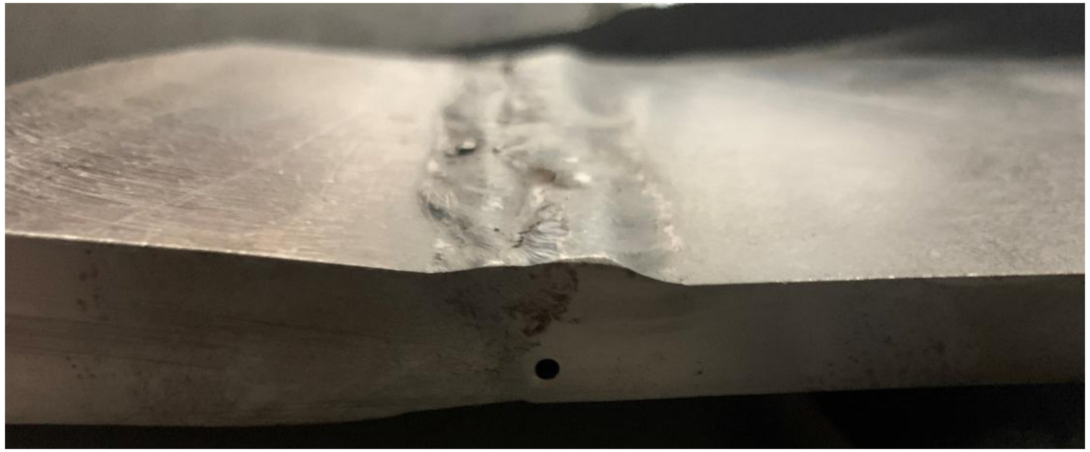
DGS Simulation Software Showing Relationship Between 1.5mm & 3mm SDH

Usage – Disadvantages

- Theoretical – but can be validated.
- Zero degree and FBH's, tends to undersize real flaws, whilst in linear sensitivity range.
- Angle probes typically oversize due to lack of rotational symmetry.
- Assumes amplitude is based on maximising on beam axis.
- Attenuation needs to be considered in attenuative materials.
- Not code compliant to all standards. EG ASME

Usage – Disadvantages

- Limitations adjacent to near zone (dependant on bandwidth / pulse length).
- Reflectivity curves typically based on circular transducers.
- Not suitable for notches. Does not account for corner reflector losses.



Usage - Advantages

- In most cases a single known reflector is used as reference.
- Code compliant in many cases: ASTM / ISO / AS
- For FBH inspections with a back wall available, nearly eliminates the need for Area Amplitude and Distance Amplitude Blocks.
- Saves money and weight.

Usage - Advantages

- Applies to a variety of reflector types.
- Less affected by transfer losses as sensitivity is set on part under test (BWE).
- Attenuation can be accounted for.
- May eliminate need for complex Time Corrected Gain (TCG) calibrations.
- Advanced software such as trueDGS, UltraVision and many others can account for variables such as bandwidth and rotational symmetry.

Summary:

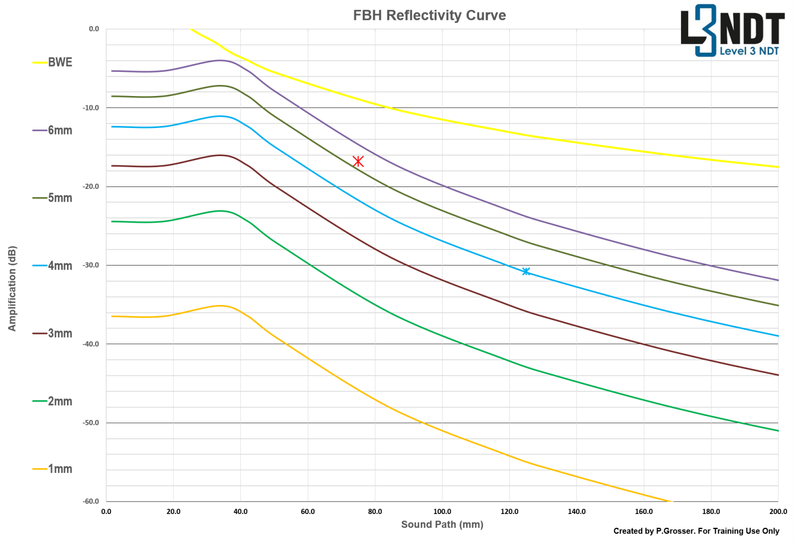
The use of reflectivity curves and DGS should be a technique and skillset that all advanced UT operators utilize where appropriate.

Probe	
Diameter (mm)	10
Frequency (MHz)	4
Velocity (m/s)	5920
Wavelength (mm)	1.48
Area (mm^2)	79
Near Zone (mm)	17

BWE	
Beam Path (mm)	500
Diameter @ Beam Path (mm)	65
Area (mm^2)	3360.9
# of Near Zones	29.6
Reference dB	-25.5

Known Reflector	
Beam Path (mm)	125
FBH Diameter (mm)	4
Diameter Ratio (S)	0.4
Area (mm^2)	12.6
# of Near Zones	7.4
dB Calculated	-30.8
dB diff to BWE	-5.3

Un-Known Reflector	
Reference	Known Reflector
Position (mm)	75
# of Nearzones	4.4
dB diff to Reference	14.0
Total dB	-16.8
Estimated Diameter (mm)	5.4



QUESTIONS?