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Sound Power and Intensity

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Pressure vs. Power

How can we quantify source strength?

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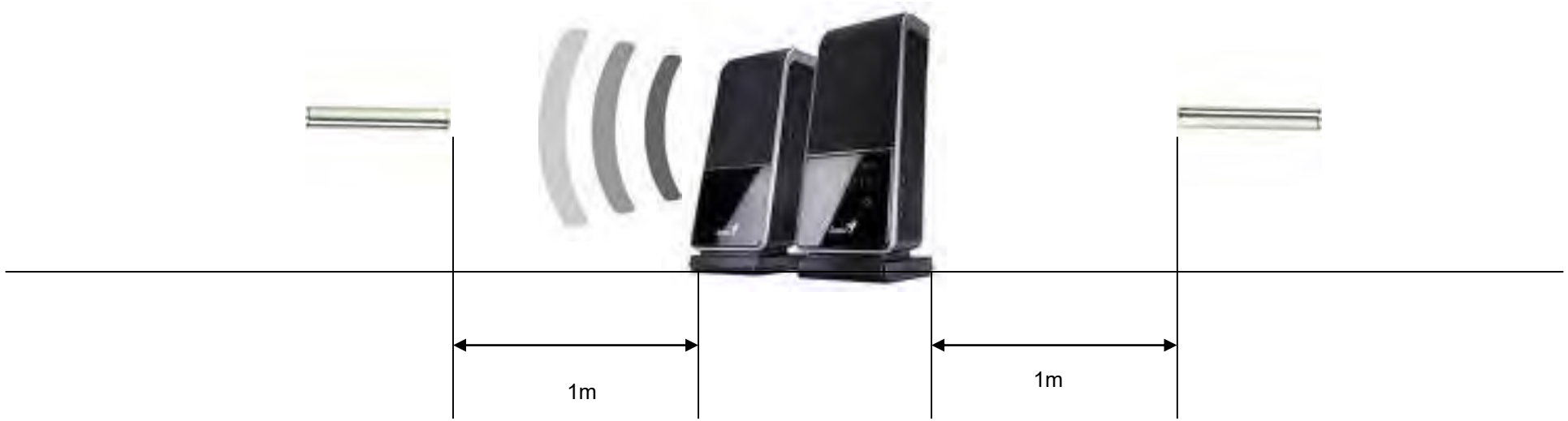
Sound Pressure Level = X?

How can we quantify source strength?

SPL has a distance dependency!

How can we quantify source strength?



SPL has a location dependency!

Sound Power as a source strength metric

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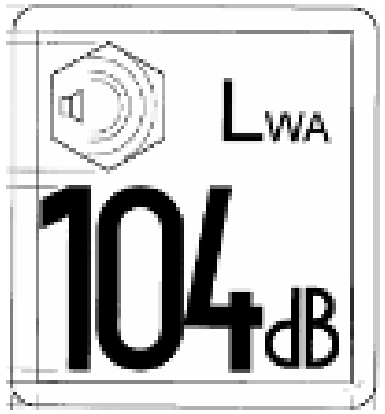

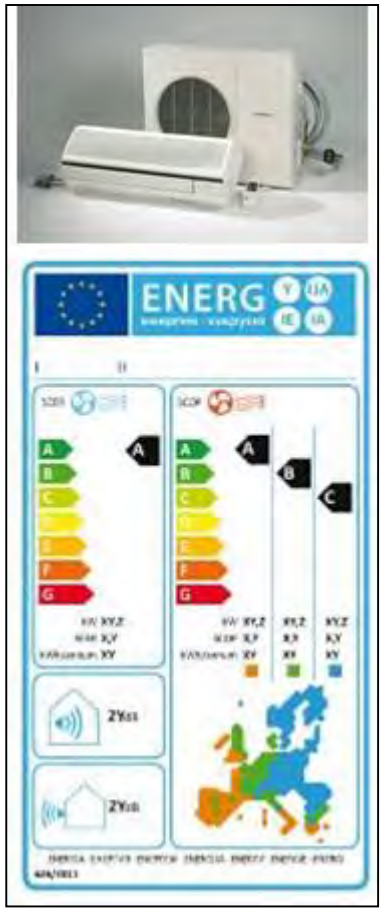

Sound Power as a source strength metric

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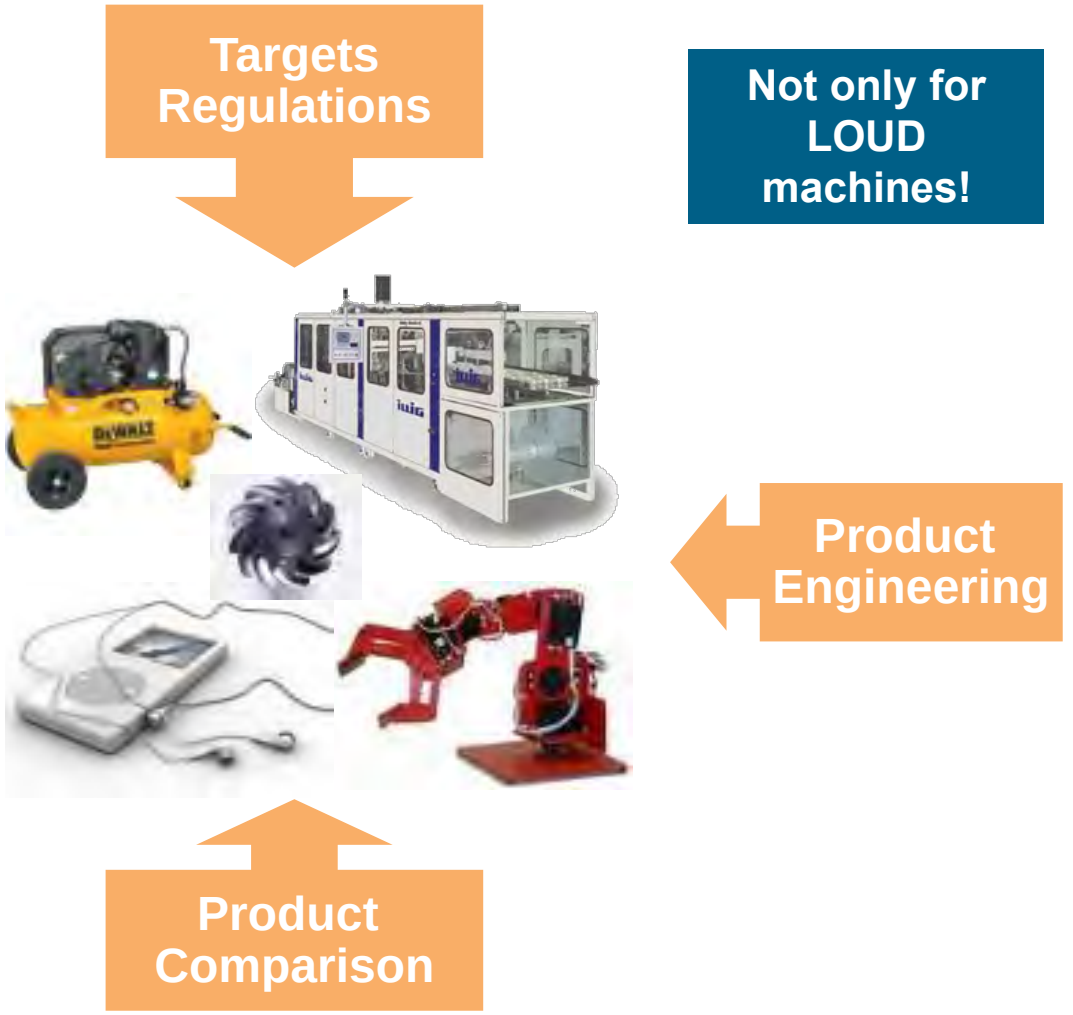
Targets & Regulations
- Comply with target specification
- Comply with Market Specifications
- Comply to legislation

Comparison
- Compare equipment (same / different types)
- Compare with competitive product
- Purchasing parameter in the selection process

Engineering
- Verification of the developed product
- Indicator for developing quitter product
- Quality control in production



Sound Power measurement techniques

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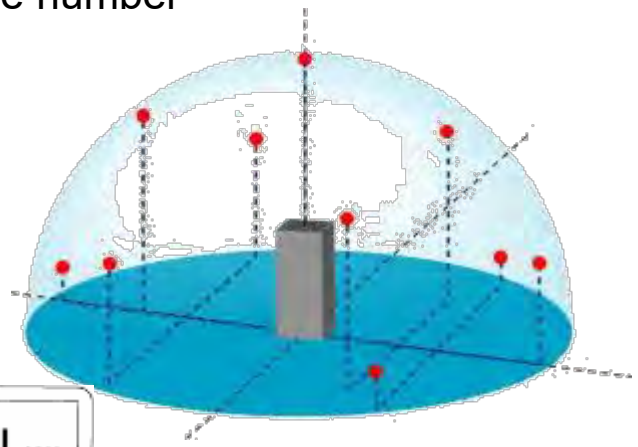
ISO3744 = Pressure based

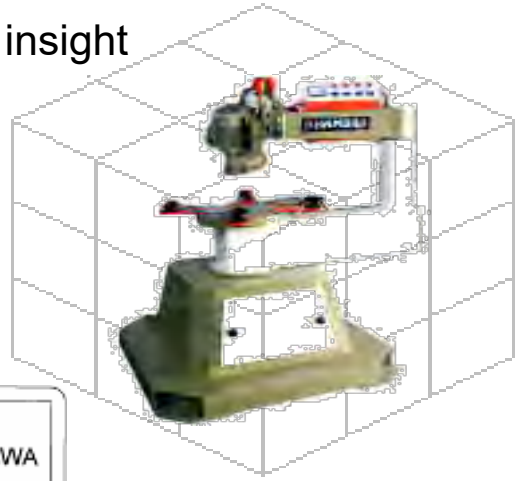
- Microphones around object
- ISO3741/42/43/44/45/46 till ISO3747
- Fast & easy method
- Only in controlled environment
- One number

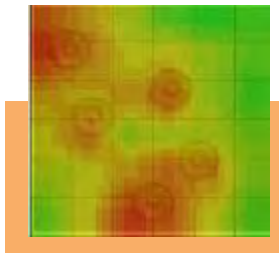


Quantification
Certification

ISO9614 = Intensity based

- Intensity Probe
- ISO9614-1 ISO9614-2
- more time consuming
- Can be used in-situ
- More engineering insight





In-situ use
Troubleshooting

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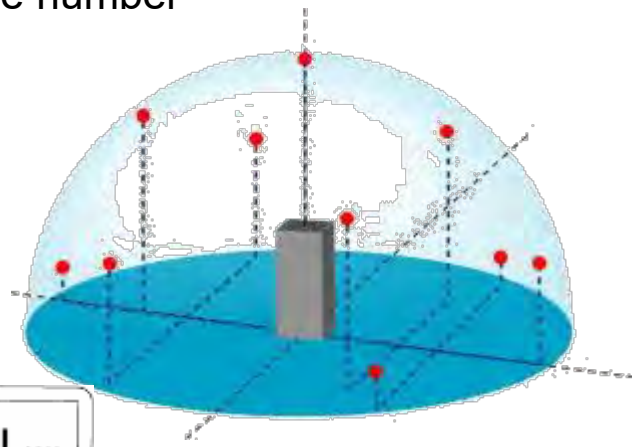

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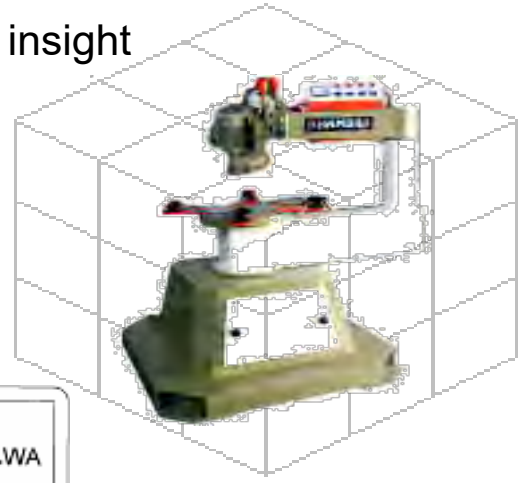

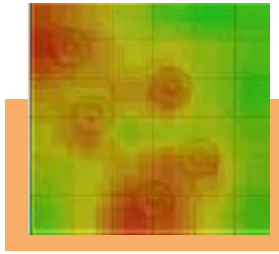

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Pressure-based Sound Power

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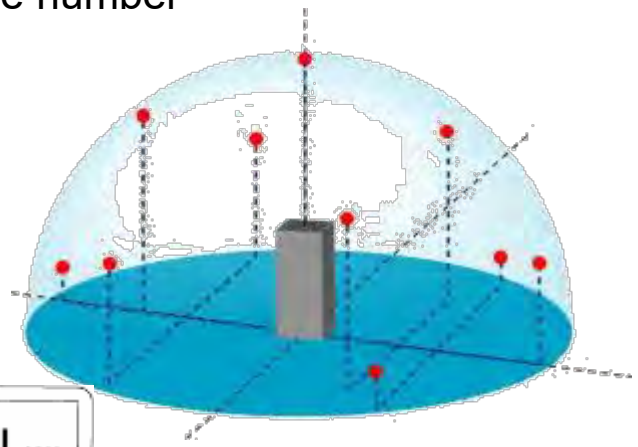
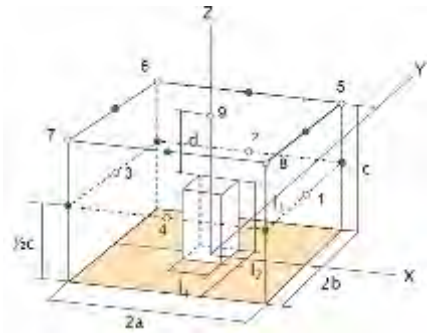
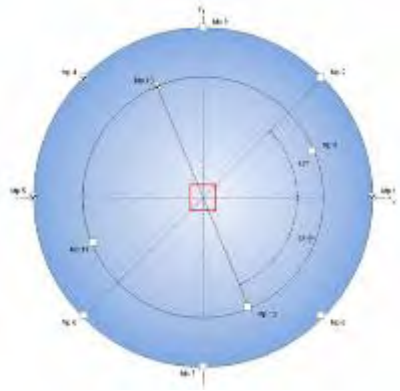


Quantification
Certification

- **Put # microphones on e.g. half sphere**





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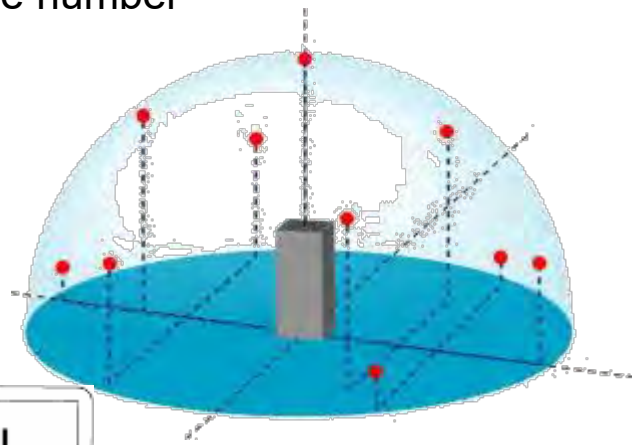


Quantification Certification

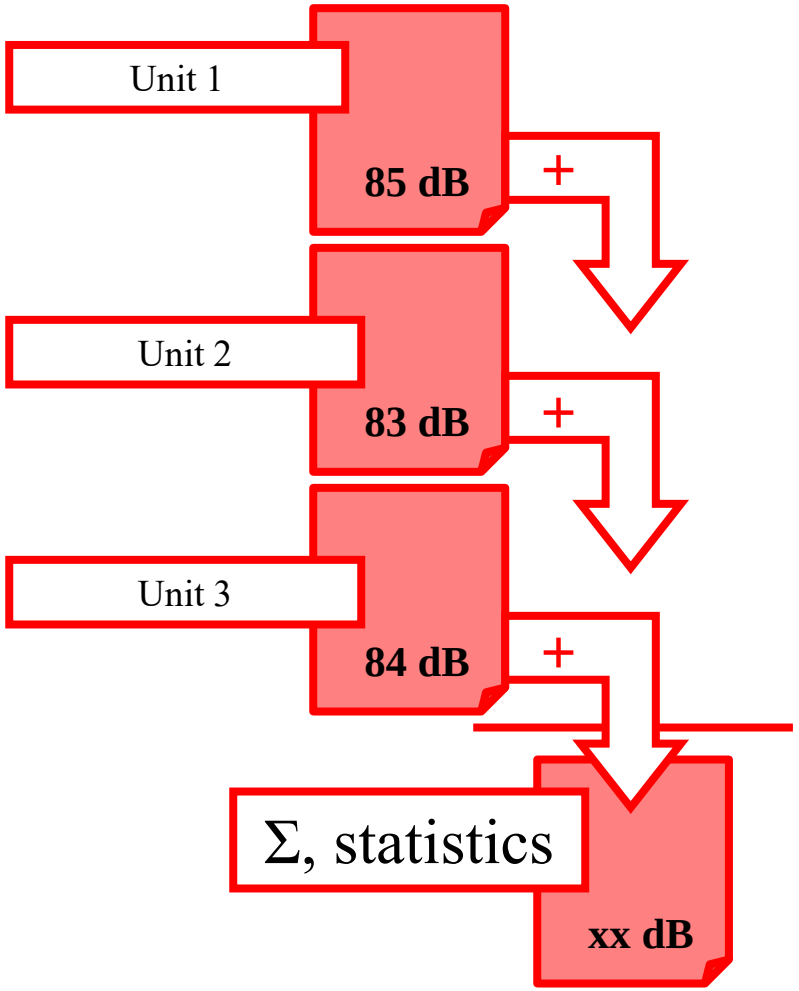
Includes corrections for room reverberation and background noise

Configuration | Calibration | Acquisition | **Report**

	Lwf	Lp'	Lp"	K1	K2	Mp 1	Mp 5	Bp 1	Op 1
Results									
Linear	70.10	77.07	28.35	0.00		78.97	73.63	11.28	14.86
A-weighted	71.05	78.03	25.55	0.00		79.93	74.58	11.00	14.80
Directivity									
Measurements									
20.00	17.92	21.31	16.47	1.30	2.09	22.98	18.57	-16.81	-14.25
25.00	19.01	22.34	13.45	0.60	2.73	24.04	19.49	-16.19	-12.56
31.50	17.17	21.80	17.21	1.30	3.33	23.42	19.18	-15.10	-11.47
40.00	22.43	26.33	11.12	0.00	3.90	28.01	23.57	-14.67	-11.63
50.00	27.37	31.75	15.81	0.00	4.38	33.41	29.02	-13.12	-10.17
63.00	27.44	32.25	9.85	0.00	4.81	33.95	29.41	-11.92	-9.50
80.00	21.95	27.15	3.81	0.00	5.20	28.85	24.31	-11.22	-8.06
100.00	31.24	36.76	3.92	0.00	5.52	38.47	33.91	-9.95	-6.88
125.00	29.20	34.99	8.67	0.00	5.79	36.69	32.16	-8.80	-6.11
160.00	32.30	38.33	18.30	0.00	6.04	40.00	35.59	-7.37	-4.86
200.00	36.14	42.37	6.01	0.00	6.22	44.08	39.51	-6.15	-3.66
250.00	36.87	43.25	15.76	0.00	6.38	44.96	40.40	-5.25	-2.53
315.00	44.22	50.74	12.06	0.00	6.51	52.44	47.88	-4.22	-1.34
400.00	46.91	53.53	13.66	0.00	6.62	55.24	50.67	-3.25	-0.36
500.00	51.30	58.01	14.48	0.00	6.71	59.73	55.14	-2.13	0.59
630.00	48.21	54.99	15.59	0.00	6.78	56.71	52.10	-1.55	1.34
800.00	45.76	52.60	14.31	0.00	6.84	54.33	49.69	-0.96	1.99
1000.00	49.67	56.55	15.34	0.00	6.88	58.29	53.60	-0.50	2.56
1250.00	60.51	67.43	14.44	0.00	6.92	69.19	64.45	0.28	3.65
1600.00	60.28	67.23	13.75	0.00	6.95	69.02	64.15	0.54	4.11
2000.00	61.44	68.42	14.02	0.00	6.98	70.24	65.22	0.63	4.56
2500.00	64.40	71.40	13.80	0.00	6.99	73.27	68.03	1.36	6.00
3150.00	60.36	67.37	13.98	0.00	7.01	69.32	63.73	0.12	4.15
4000.00	62.81	69.83	13.60	0.00	7.02	71.89	65.75	-0.07	4.63
5000.00	56.61	63.64	13.10	0.00	7.03	65.78	59.25	-2.17	1.58

- **Final step = ISO report in Word/Excel**

Pressure-based Sound Power
Declared Sound Power



- Statistical analysis is needed to obtain a 'Declared Sound Power Value'
- Relevant standards ISO9296/ECMA109

HAND HELD POWER TOOLS					
	OPERATOR1	OPERATOR2	OPERATOR3		MEAN
TEST1	71,2	71,8	71,3		71,4
TEST2	71,5	71,5	71,2		71,4
TEST3	71,1	71,3	71,3		71,2
TEST4	71,4	71,6	71,0		71,3
TEST5	71,4	71,3	71,2		71,3
MEAN	71,3	71,5	71,2		**71,3**

Average over units and operators

OFFICE EQUIPMENT			
	ECONO	NORMAL	BEST QUAL
PRINTER1	71,2	71,8	71,3
PRINTER2	71,5	71,5	71,2
PRINTER3	71,1	71,3	71,3
MEAN	71,3	71,5	71,3
DEV	0,2	0,3	0,1
DECL SPOW	**71,9**	**72,3**	**71,4**

Average over units and modes

OUTDOOR EQUIPMENT					
	LIFTING	DRIVING	TURNING		
TEST1	71,2	72,5	76,0		
WEIGHTING	0,5	0,2	0,3		
	65,2	58,5	65,5		**73,2**

Combine modes (weighting) to obtain single Sound Power value

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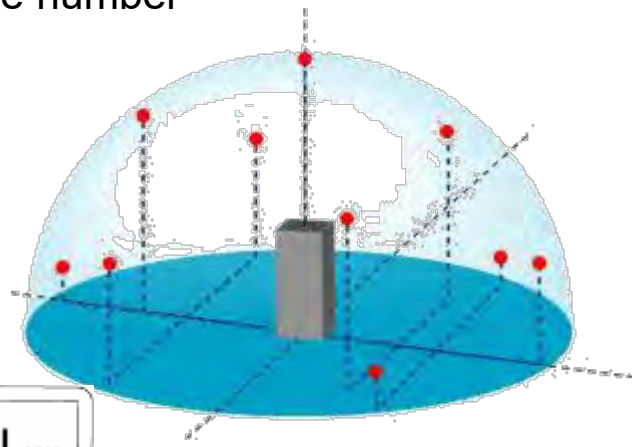

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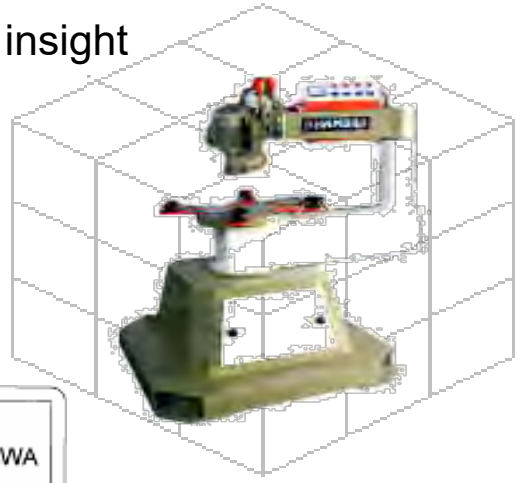

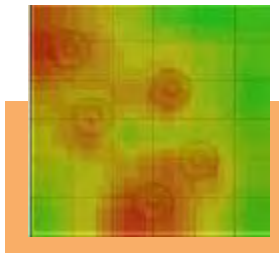

In-situ use
Troubleshooting

What is Sound Intensity?

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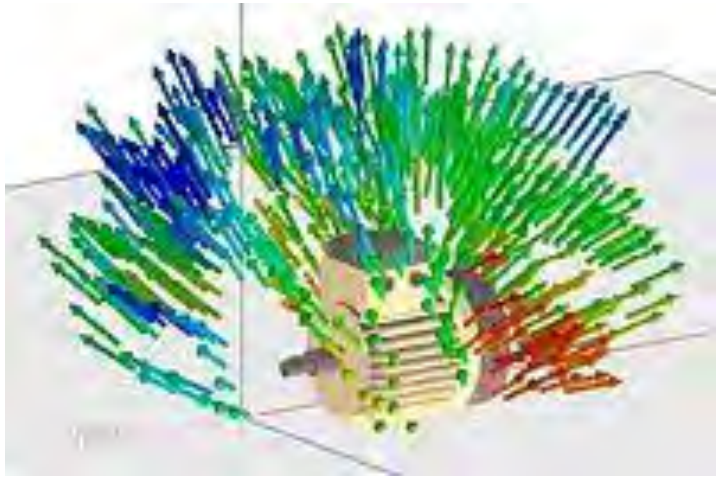
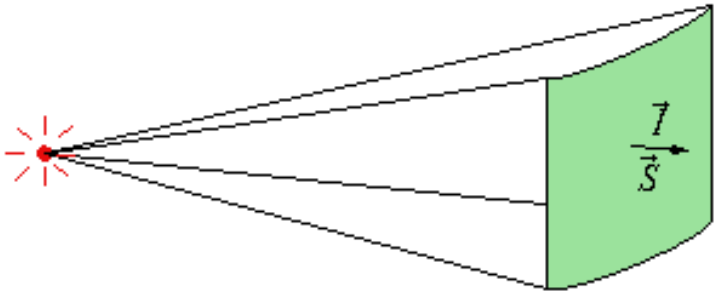
Sound Intensity = Power flow density vector!

Intensity = Pressure x Particle Velocity

$$\frac{\text{Force}}{\text{Area}} \times \frac{\text{Distance}}{\text{Time}} = \frac{\text{Energy}}{\text{Area} \times \text{Time}} = \frac{\text{Power}}{\text{Area}} \left[\frac{Watts}{m^2} \right]$$





How is Sound Intensity measured?

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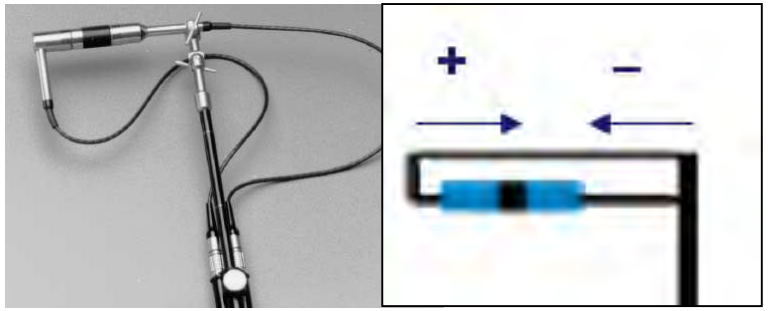
- Standard ICP microphone
- Measures sound pressure
- Has (almost) no directivity
- No idea where the sound comes from



- Acoustic Intensity probe
- Measures 2x sound pressure
- Directivity along microphone axis
- You perfectly know where the sound comes from

How is Sound Intensity measured?

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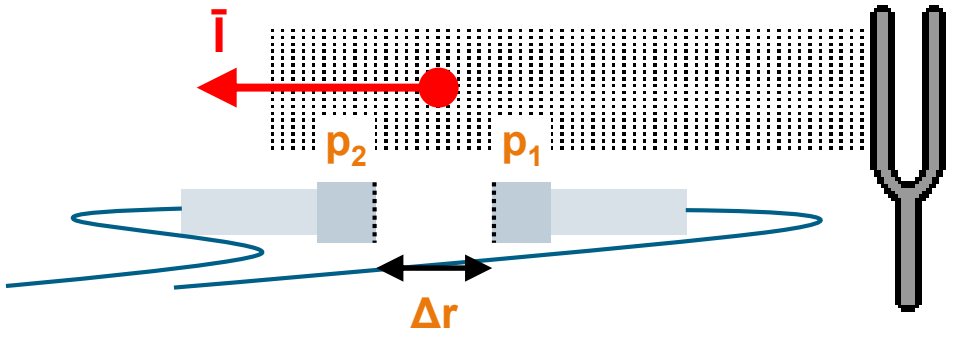
Sound Intensity = acoustic energy flow through unit area:

$$\vec{I} = p(t) \cdot \vec{v}(t) \approx p(t) \cdot \frac{\Delta p}{\Delta r}$$

Sound Intensity probe:

- p(t) = local pressure → average of p_1 and p_2
- v(t) = particle velocity → estimate from $p_1 - p_2$ over Δr



Spacer distance influence

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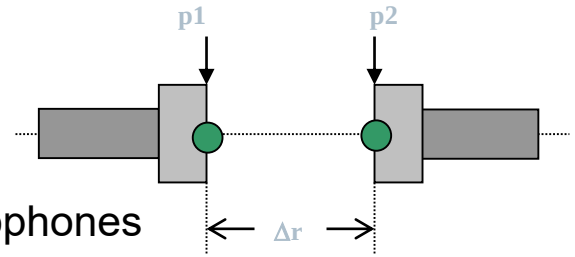
Lower Frequency Limit

Phase mismatch between microphones

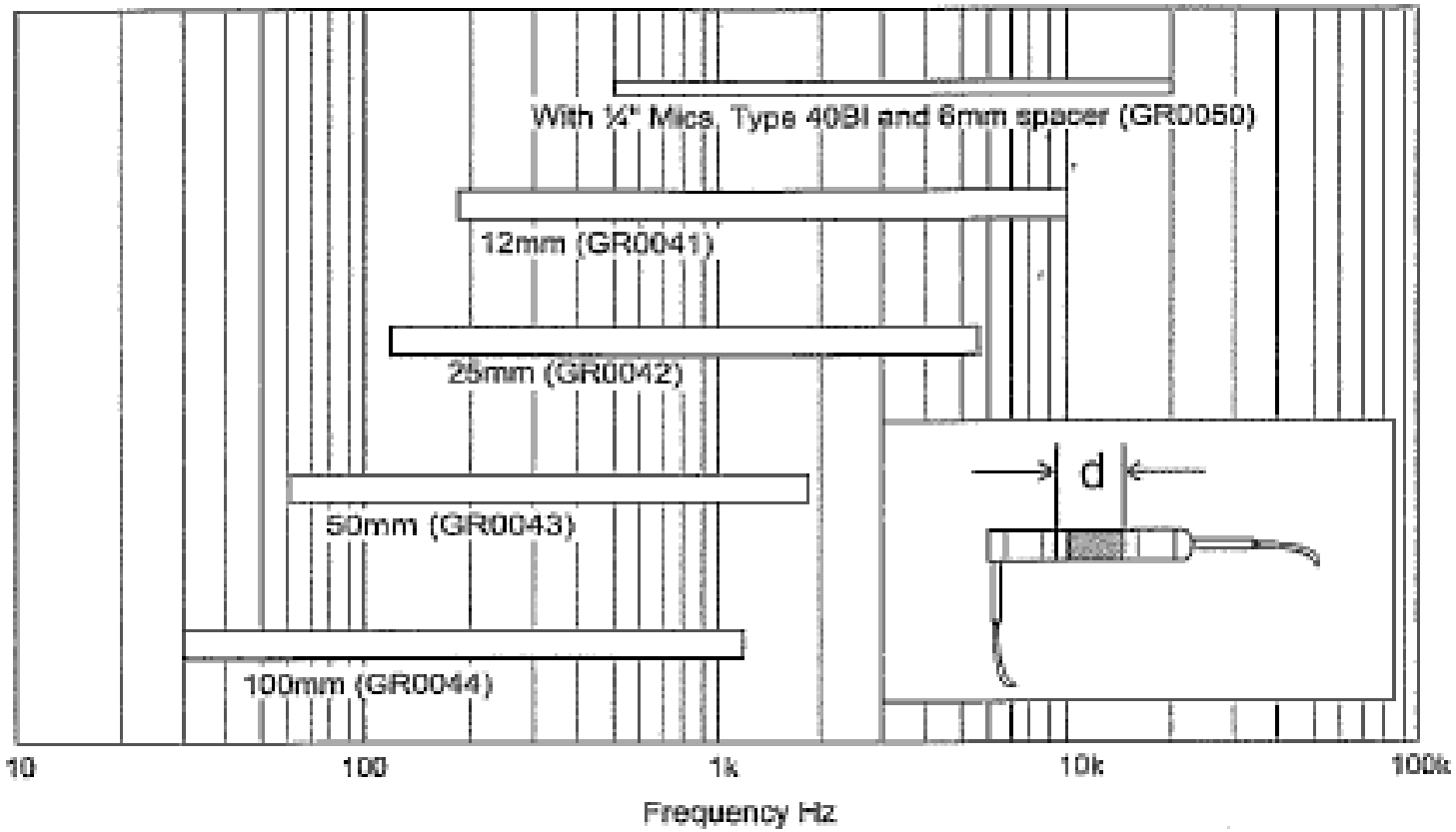
Typically < 0.3˚ degrees for matched probe microphones



Upper frequency Limit

Spacer distance :

< 1/6th of the wavelength



Intensity-based Sound Power

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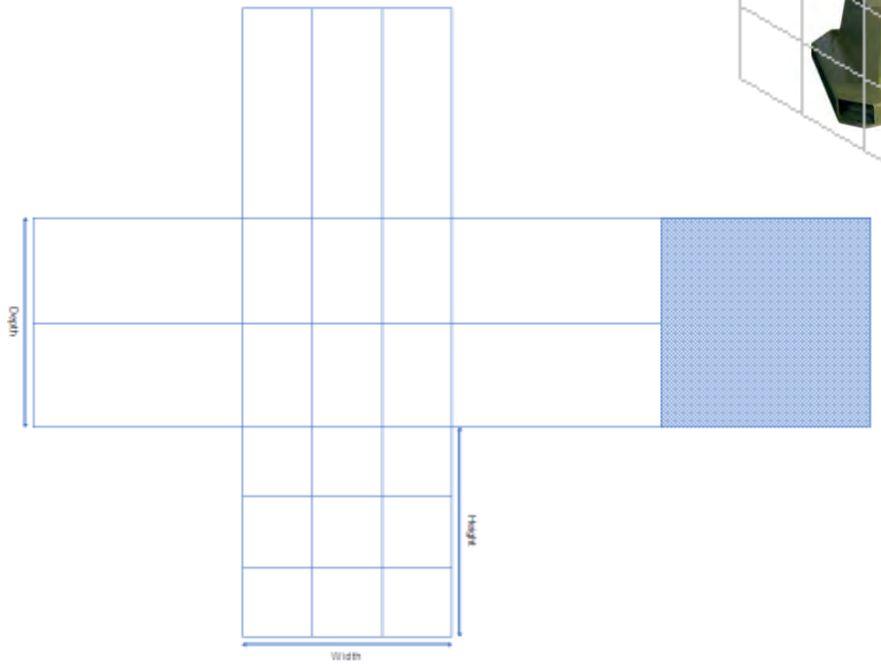
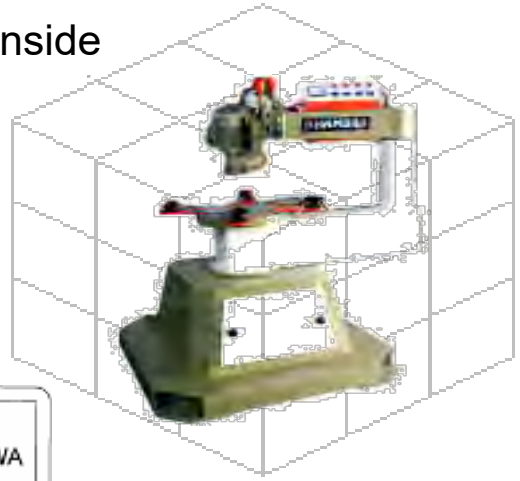
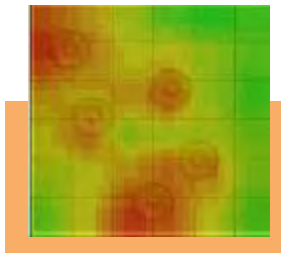
- *Use intensity probe (2 mic channels)*
- Rectangular “shoe-box” around the object
- Sub-divide each surface in sub-segments



ISO9614 = Intensity based

- Intensity Probe
- ISO9614-1 ISO9614-2
- more time consuming
- Can be used in-situ
- More engineering inside





In-situ use Troubleshooting

Intensity-based Sound Power

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- *Rectangular "shoe-box" around the object*
- *Sub-divide each surface in sub-segments*
- Calibration
  - Amplitude of both microphones
  - Phase calibration
- Measure Residual Intensity

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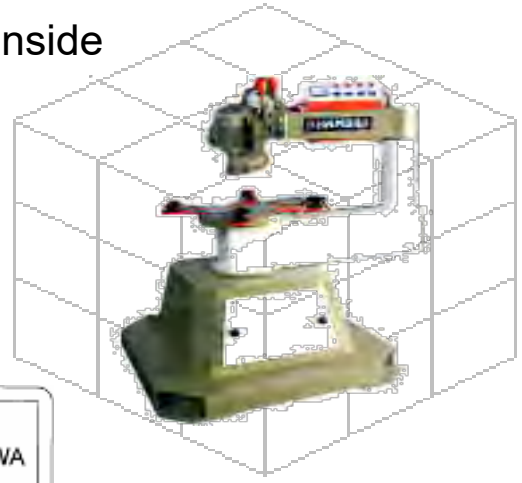

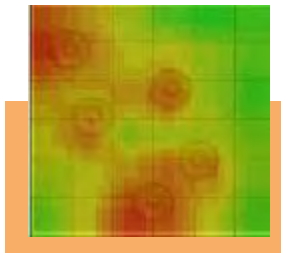

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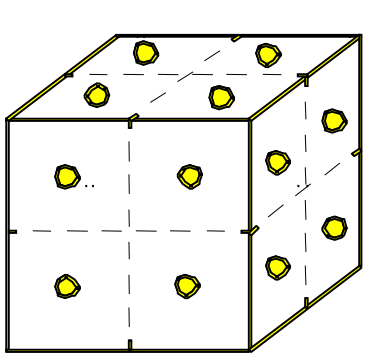
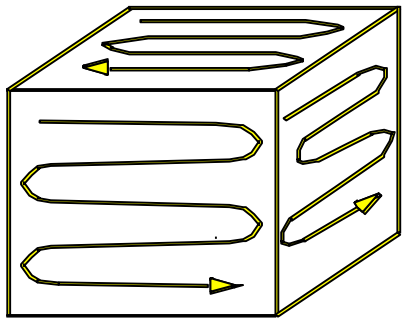
- *Sub-divide each surface in sub-segments*
- *Calibration*
  - *Amplitude of both microphones*
  - *Phase calibration*
- *Measure Residual Intensity*
- Measure each sub-segment sequentially
  - Point method – ISO9614-1
  - Scanning method – ISO9614-2





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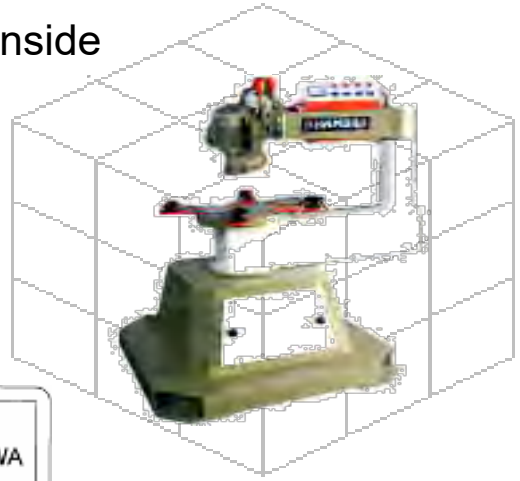

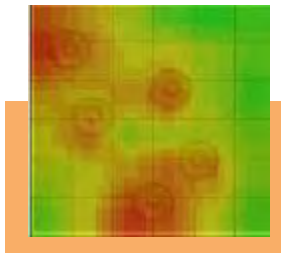

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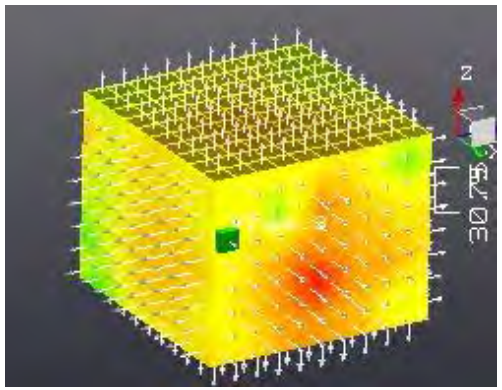
- *Sub-divide each surface in sub-segments*
- *Calibration*
  - *Amplitude of both microphones*
  - *Phase calibration*
- *Measure Residual Intensity*
- *Measure each sub-segment sequentially*
  - *Point method – ISO9614-1*
  - *Scanning method – ISO9614-2*
- ISO Sound power = sum of partial sound powers (Intensity x surface of sub-segment)

$$SPOW = \sum Int \times Surface$$



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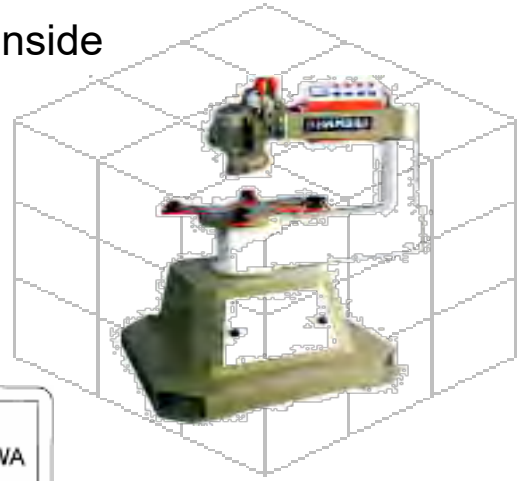
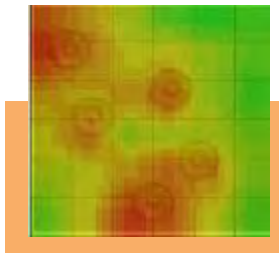
- More engineering inside





In-situ use Troubleshooting

Intensity-based Sound Power
ISO quality checks

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ISO 9614 Field Indicators ensure the quality of the measurements and meshes

F2: Surface pressure-intensity indicator
- Examines the difference between the pressure and the absolute values of intensity, which tells how diffuse or reactive a field is
  - Small value = good measurement conditions
  - Large value = probe not aligned well or measuring in a diffuse field

F3: Negative partial power indicator
- Examines the difference between measured intensity and pressure while taking the direction of the intensities into account, which gives amount of extraneous noise
  - Positive direction = intensity from source under investigation
  - Negative direction = intensity from extraneous sources

F4: Non-uniformity indicator
- Indicates the measure of spatial variability that exists in the field, which verifies the mesh adequacy

What about external sources?

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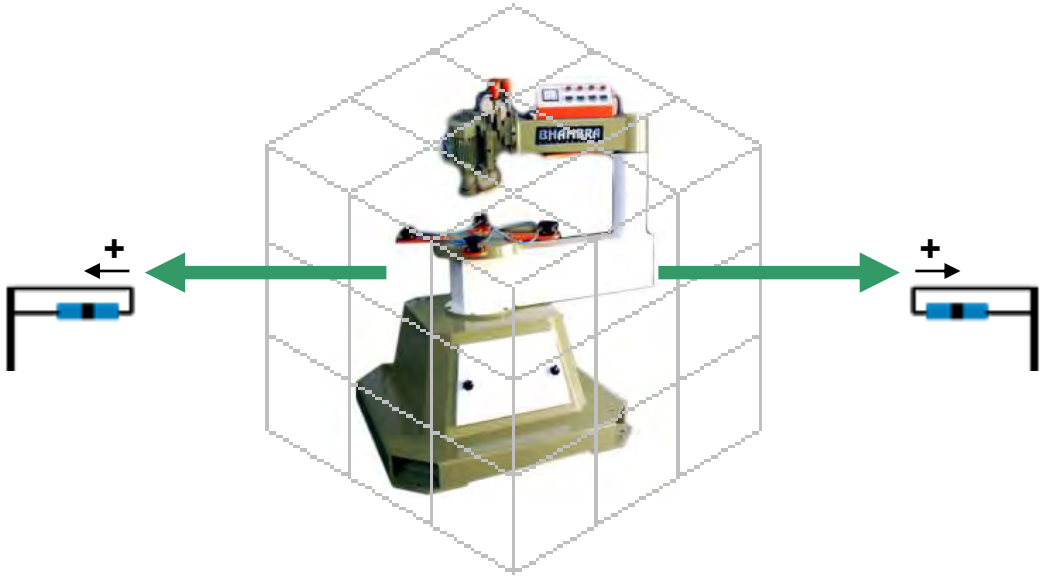

What about external sources?

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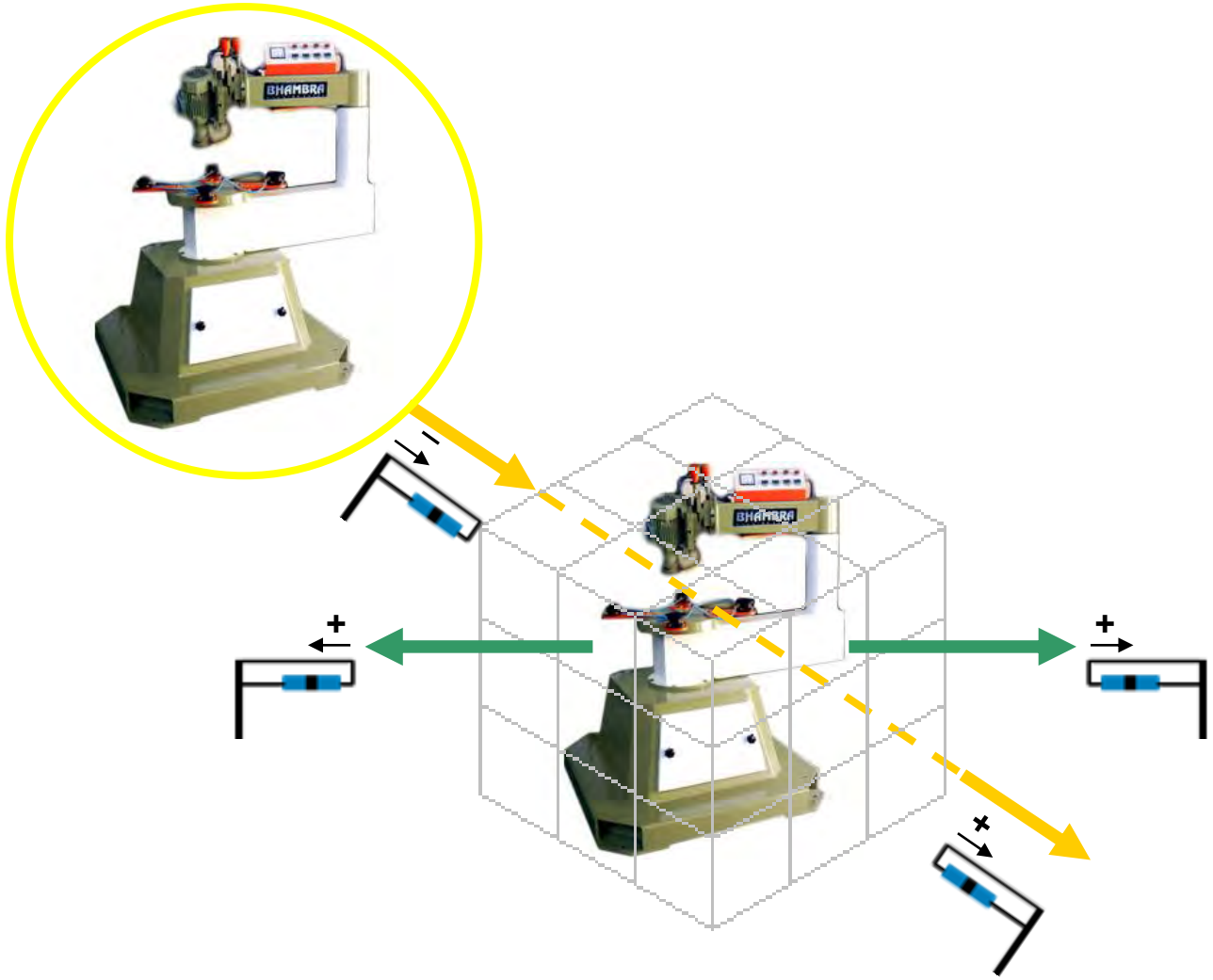

Sound Intensity as a source localization tool

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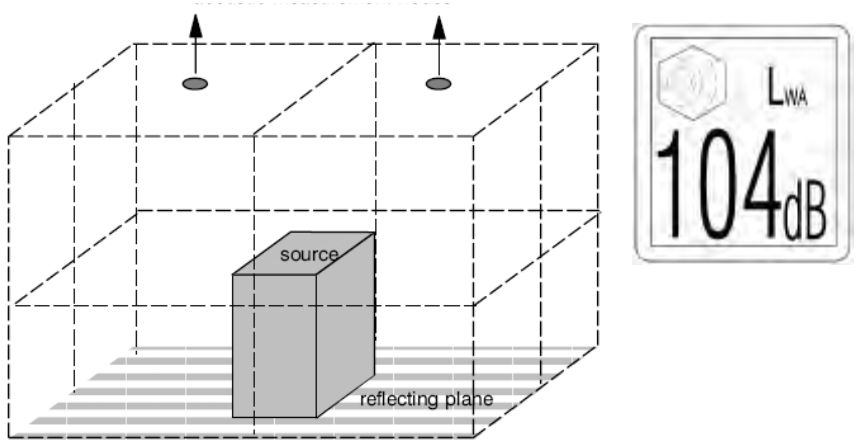
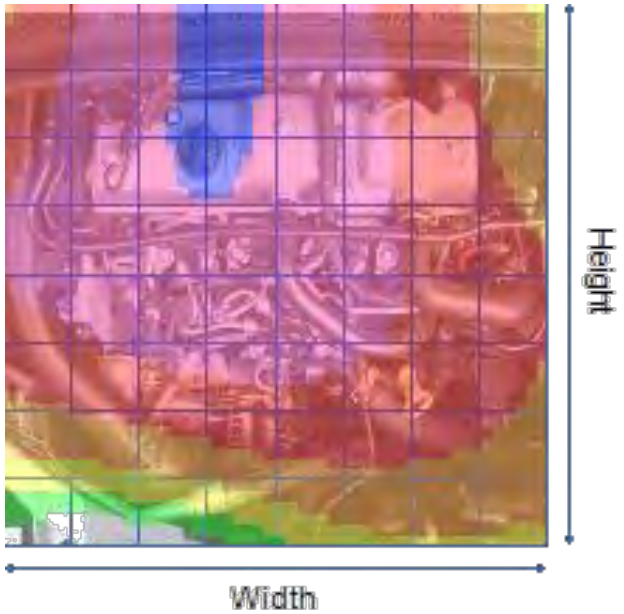
ISO sound power

- Scan all surfaces surrounding the object
- Intensity x surface = sound power
- Not influenced by “external” sources
- ISO9614 standard



Source localization

- Point-by-point method
- Keep individual partial sound power values
- “Easy” hotspot finding (1 source)
- Build full acoustical map (different sources, frequencies)
- Source ranking



Conclusions

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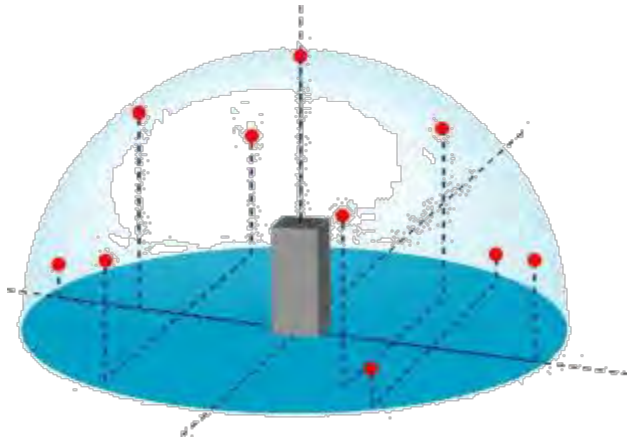
Pressure-based Sound Power

- ❑ Very fast results
- ❑ Easy to execute procedure

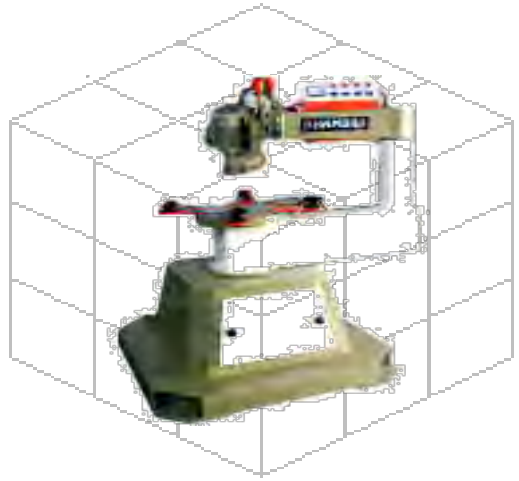
- ❑ Single value result only
- ❑ Sensitive to disturbances
- ❑ Requires specialized test environment



Intensity-based Sound Power

- ❑ Adds source localization capability
- ❑ Robust measurement method (environment, noise)

- ❑ Very time consuming
- ❑ More complicated test execution
- ❑ Limited frequency range (multiple test required)



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