The Use Of Ultrasonic Imaging To Determine Flaw Size In $BaTiO_3$ Ceramic Capacitors

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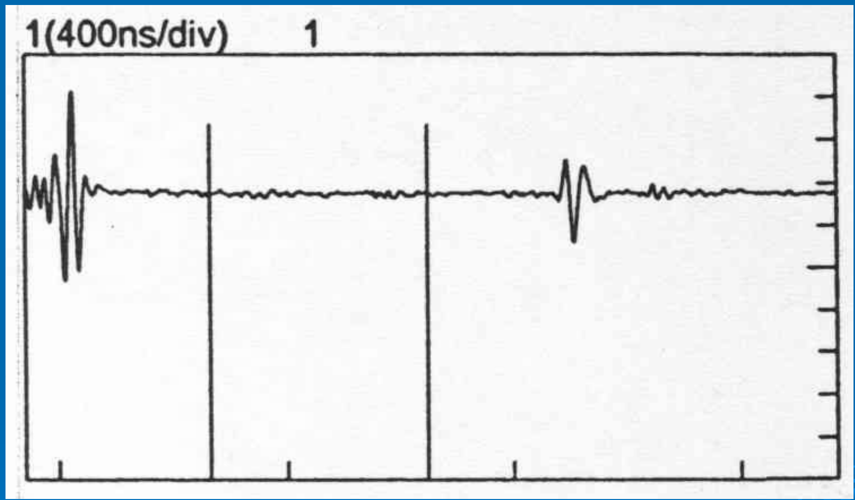
Ultrasonic Imaging

- Nondestructive Test – Mil-PRF-123
- Strong Echo From Air Gaps
- Should Detect Voids, Cracks & Delaminations
- Ability To Detect Microstructure Defects Is Key – 0.0008” Dielectric Thickness
- Newer Ultra High Frequency Transducers
  - To 300 MHz - Available
- Little Info Specific To $BaTiO_3$ Capacitors

Velocity Of Sound Calculation

- c = 2 X 2.51 mm/.9 μs
  = 5.57 X 10^3 m/s
- c = 2T/t
- c = $BaTiO_3$ Sound Velocity
- Material Thickness
- t = Time Of Flight



Fundamental Resolution

$\lambda = c/f$ Where λ = wavelength

c = material sound velocity

f = frequency

For $BaTiO_3$ c = 5.55 X 10^3 m/s

100 MHz Transducer λ = .00005 m or .00197"

$\lambda/2$ =.001"

Spot Size & Resolution

F# = Focal Length/ Diameter

Useful For Comparing Transducers

Spot Size $\Delta X = 1.22F\#\lambda$

Resolution $R = .707\Delta X$

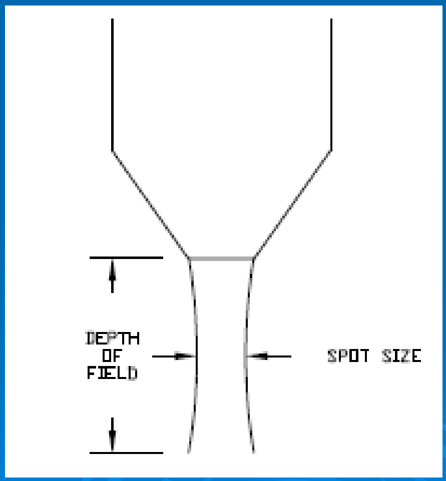
Depth Of Field $\Delta Z = 7.1(F\#)^2\lambda$

Table 2: Typical Transducer Resolution & Depth Of Focus For Barium Titanate Based Ceramic Capacitors

Transducer Frequency (MHz)	Fundamental Resolution		Focal Length (Inches)	Diameter (Inches)	F#	Spot Size (Inches)	Theoretical Resolution (Inches)	Optimal FOV (@ 512, in)	Optimal FOV (@ 1024,in)	Depth Of Focus (Inches)
	µm	Inches								
10	275	0.0100	2.000	0.500	4	0.0488	0.03450	24.9856	49.9712	2.2720
10	275	0.0100	0.750	0.375	2	0.0183	0.01294	9.3696	18.7392	0.5680
15	180	0.0070	0.750	0.500	1.5	0.0128	0.00906	6.5587	13.1174	0.2237
20	137	0.0050	1.250	0.250	5	0.0153	0.01078	7.8080	15.6160	1.7750
20	137	0.0050	0.500	0.250	2	0.0061	0.00431	3.1232	6.2464	0.2840
30	92	0.0036	1.250	0.250	5	0.0110	0.00776	5.6218	11.2435	1.2780
30	92	0.0036	0.750	0.250	3	0.0066	0.00466	3.3731	6.7461	0.4601
30	92	0.0036	0.500	0.250	2	0.0044	0.00311	2.2487	4.4974	0.2045
50	75	0.0030	1.000	0.250	4	0.0073	0.00518	3.7478	7.4957	0.6816
50	75	0.0030	0.500	0.250	2	0.0037	0.00259	1.8739	3.7478	0.1704
75	38	0.0015	0.500	0.250	2	0.0018	0.00129	0.9370	1.8739	0.0852
100	25	0.0010	0.500	0.250	2	0.0012	0.00086	0.6246	1.2493	0.0568
100	25	0.0010	0.200	0.250	0.8	0.0005	0.00035	0.2499	0.4997	0.0091
230	10	0.0004	0.375	0.187	2	0.0004	0.00026	0.1874	0.3748	0.0227
230	10	0.0004	0.250	0.125	2	0.0002	0.00017	0.1249	0.2499	0.0227
230	10	0.0004	0.150	0.187	0.8	0.0001	0.00010	0.0750	0.1499	0.0036

100 MHz Transducer

- F# = .500"/.250" = 2
- Spot Size = .0012"
- Resolution = .0009"
- Depth Of Focus = .0568"



100 MHz Transducer Comparison

Frequency	λ/2 Resolution (Inches)	Focal Length (Inches)	Diameter (Inches)	F#	Resolution (Inches)	Depth Of Focus (Inches)
100 MHz	.001	.500	.250	2.0	.00086	.057
100 MHz	.001	.200	.250	.8	.00035	.009

- Typical 0805 Cap Is .035 - .050”

50 MHz Transducer Comparison

Frequency	λ/2 Resolution (Inches)	Focal Length (Inches)	Diameter (Inches)	F#	Resolution (Inches)	Depth Of Focus (Inches)
50 MHz	.003	1.000	.250	4.0	.0052	.682
50 MHz	.003	.500	.250	2.0	.0026	.170

Scan Resolution

- Pixel Density X Spot Size
  = Optimal Field Of View (FOV)
- 100 MHZ Transducer @ 1024 Pixels
  = 1.24”
- Resolution of Monitor, Printer, Eyes….

All This Is Great, However…

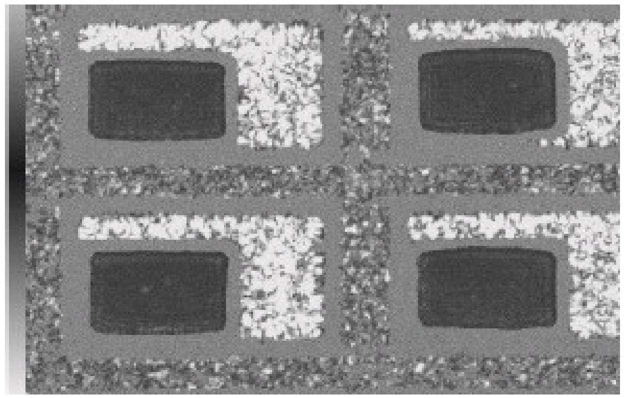


Figure 1 – 230 MHz Transducer

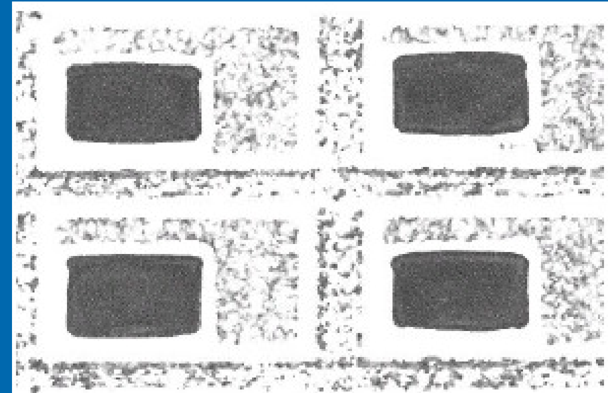


Figure 2 – 100 MHz Transducer

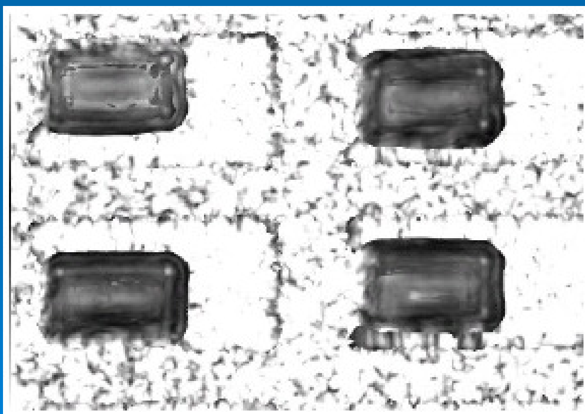


Figure 3 – 75 MHz Transducer

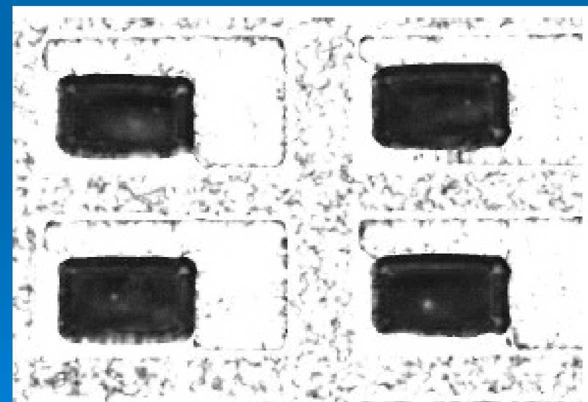


Figure 4 – 50 MHz Transducer

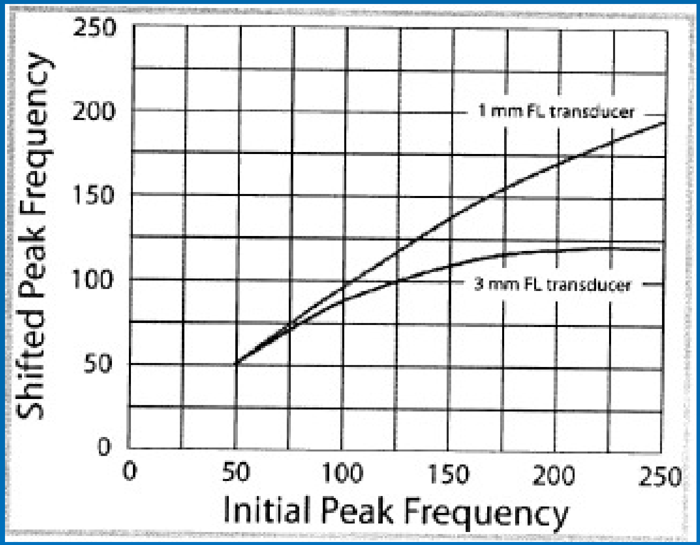
Frequency Downshift

- Frequency Attenuated In The Water Path
  - Diffraction
  - Scattering
  - Absorption

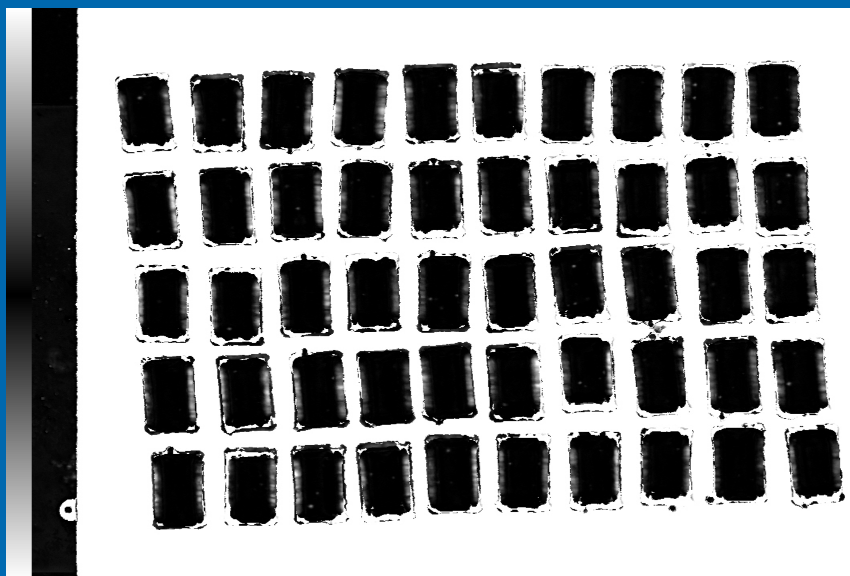
Table 3: Initial Transducer Frequency Vs. Reflected Frequency

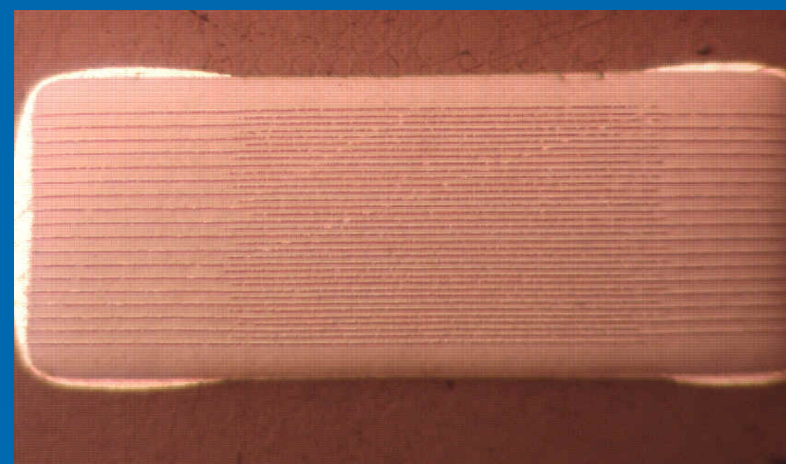
Initial Frequency	Theoretical Resolution (Inches)	Reflected Frequency	Revised Theoretical Resolution (Inches)
230 MHz	0.0001 - .00026	50 MHz	0.0026 - .0052
100 MHz	0.0003 - .00086	50 MHz	0.0026 - .0052
75 MHz	0.0013	28 MHz	0.0031 - .0078
50 MHz	0.0026 - .00052	40 MHz	0.0028 – 0.0065

Frequency Downshift 230 MHz Transducer



Delaminations Or Terminations





All parts with an acoustic reflection that indicate a possible defect, shall be removed from the lot.

Other Considerations

- Higher Frequencies Equate To Lower Energy & Therefore Less Penetration Of The Ceramic. Need Thin Samples.
- Non Flat Surfaces Scatter the Sound Waves & the Echo Is Lost. Need Flat Surfaces.

Conclusions

- Detecting Voids of <.0004" Is Possible With Ultra High Frequency Transducers But May Not Be Practical. Consider Lot Rejection.
- Detecting Rejectable Delaminations Is Possible But Take Care When Parts Are Terminated.
- Cracks In The X/Y Plane Can Be Detected With Ultrasonic Imaging But If Cracks Are In The Z Plane, They Are Not Detectable. Consider Lot Rejection.

Questions?

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