**Effect of quantization on lateral resolution**

BME 395 Mini-Project 1

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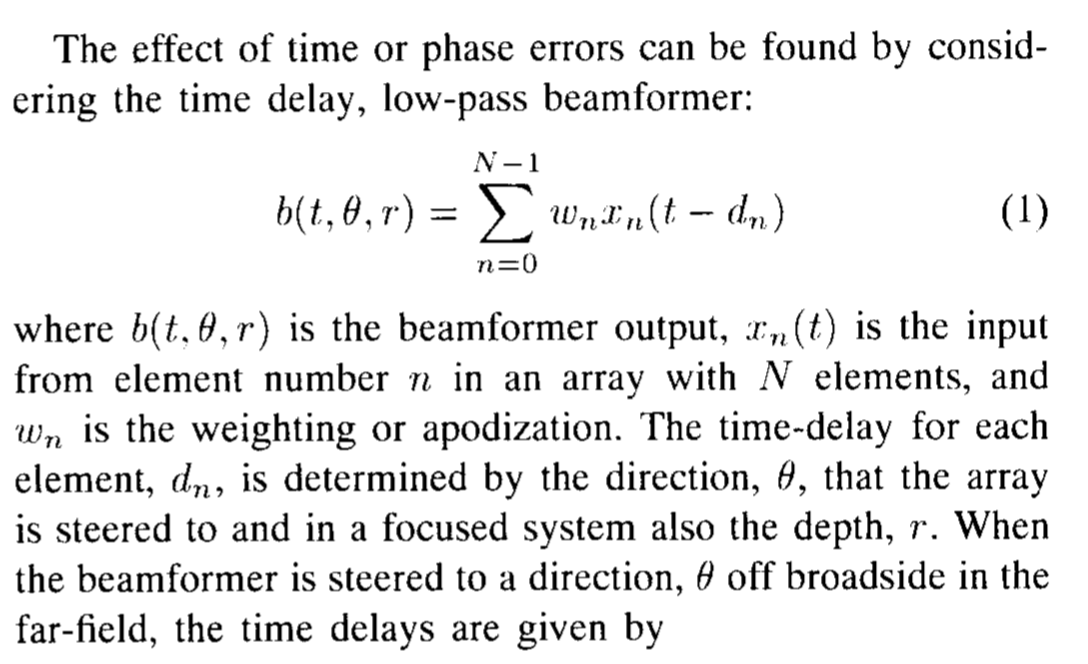
**Intro**: The purpose of this report is to investigate the effect of phase quantization error on lateral resolution.

Delaying channel data is a fundamental step in all ultrasound beamforming approaches as it enables steering and focusing. A linear phase delay profile with delay values increasing evenly from element to element will steer a non-focused or plane wave at an angle away from the array axis. A non-linear but parabolic phase delay profile focuses the beam towards a point. A combination of linear and a parabolic phase delay profiles permits both steering and focusing [1]. An ideal theoretical phase delay profile used in transmission or reception contains delays which can be precisely implemented. A quantized delay profile is an approximation of the ideal phase delay profile, with timing inaccuracy introduced as a result of hardware implementation. The deviation from the ideal phase delay profile is described as phase quantization error [2]. Modeling phase quantization error helps establish criterion for element geometries. Phase quantization error manifests as two types: random and periodic phase error [3].

***Random quantization lobes.*** Random quantization lobes result from phase quantization noise which is uniformly distributed over individual elements. The level of sidelobes from quantization is governed by the parameter *m,* where

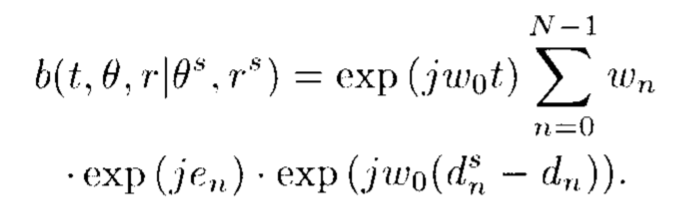
*m = fs / f0*

With *m*, phase error will fall in the range: *en =* [-π/m π/m]. The effect of phase errors can be found by considering the beamformer:

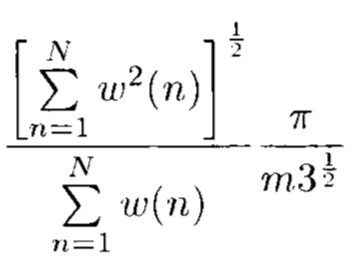


b is the beamformer output, xn the input from element n, and wn the apodization of element n. the time delay (dn) is determined by angle and depth.

With phase error *en =* [-π/m π/m], *b* can be expressed as:

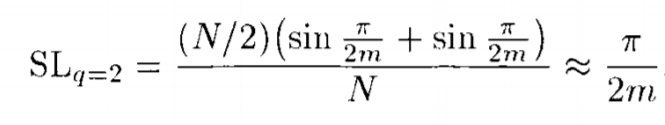


This expression demonstrates that the phase error occurs within the summing of signals across elements. From this expression, it can be shown through a power series expansion that the voltage noise from *en* to signal ratio is:



***Periodic phase error.*** The second effect of delay quantization is discrete quantization lobes that resemble grating lobes. This occurs when quantization error over the array becomes periodic. In particular, uniform arrays, continuous wave transmission, and far field operation enhance this effect.

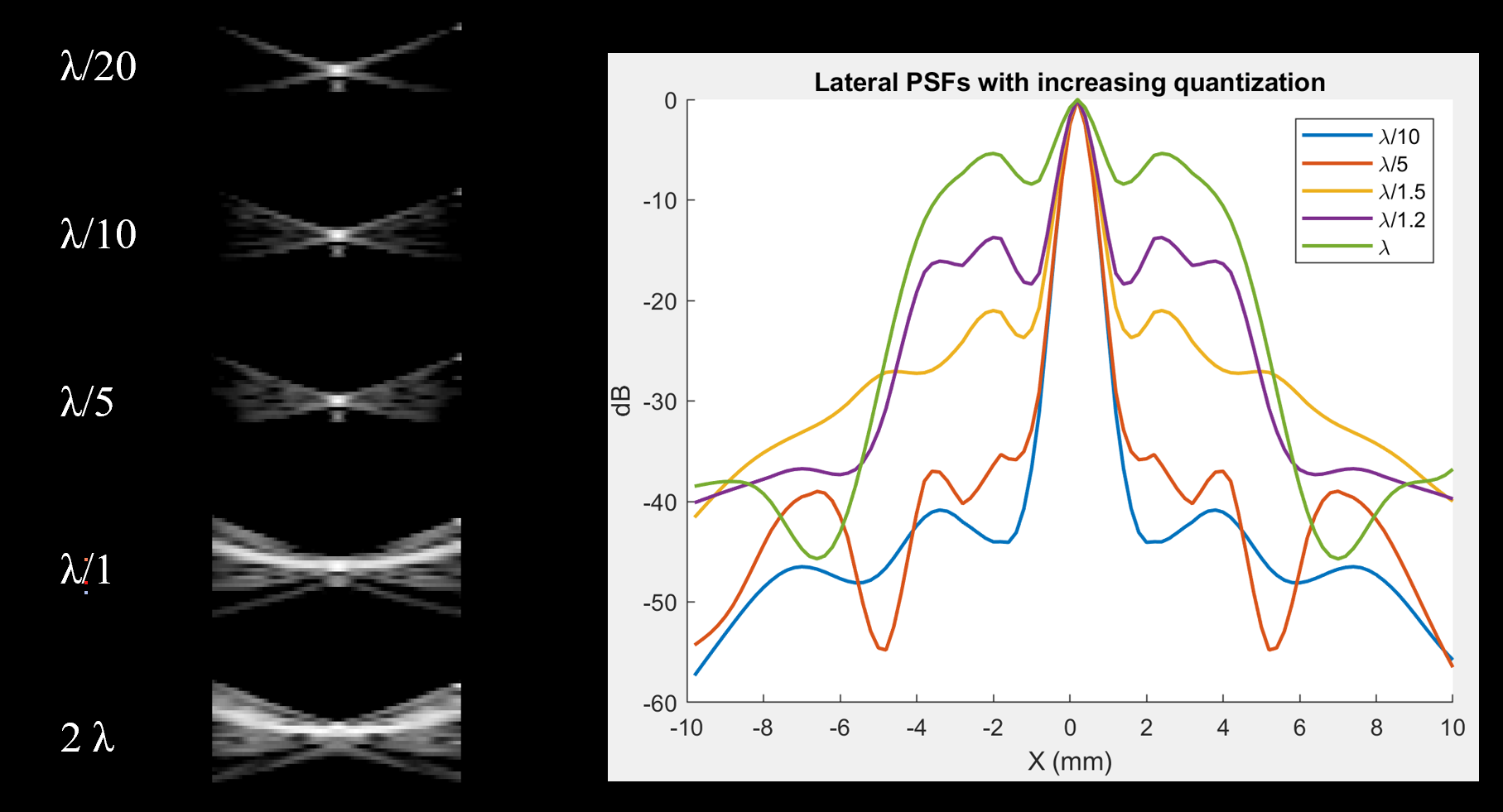
Rather than occurring with random distribution, periodic phase error occurs at certain steering angles. In particular it occurs when steering requires a time delay that is an integral number of quantization steps. The worse case is when the periodicity of this error is at a minimum (spans two elements). It can be shown that the ratio of side lobes from this error source to mainlobe is approximately:



Fortunately, focusing adds a quadratic time delay large enough for periodic error to become randomized at close targets. Only systems with a large number of elements that operate at high frequencies and low *m* will be affected by periodic phase error [3].

**Simulation Summary**: Simulations were run in field II which varied the minimum quantization value used in the delaying of channel data. The imaging scheme used fixed focus transmit and focused on the single point target in receive. The point target was placed at 50 mm in depth which was 20 mm above the natural focus of the transducer (70 mm). No apodization was used.

**Results:**



**Figure 1**. The effect of minimum quantization values on a point target phantom. **(Left)** The same point target was imaged with 5 different minimum quantization values. The effect on lateral resolution is apparent as higher quantization values impede delay focusing and result in lateral smearing. (**Right)** Plots of lateral point spread functions at 5 different quantization values.

[1] T. L. Szabo, Diagnostic Ultrasound Imaging: Inside Out, E. A. Press, Ed. Elsevier Academic Press, 2004.

[2] Smith, Peter R., et al. "Ultrasound array transmitter architecture with high timing resolution using embedded phase-locked loops." IEEE transactions on ultrasonics, ferroelectrics, and frequency control 59.1 (2012): 40-49.

[3] S. Holm and K. Kristoffersen, “Analysis of worst-case phase quantization sidelobes in focused beamforming,” Ultrasonics, Ferroelectrics and Frequency Control, IEEE Transactions on, vol. 39, no. 5, pp. 593 –599, Sep 1992.