Feed-Forward Compensation for All Digital Phase-Locked Loop based Synthesizers

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Abstract: Fast settling phase-locked loop based frequency synthesizers are necessary for fast frequency switching communication systems; for example in frequency hopping communication systems. Conventionally the loop filter's bandwidth is controlled to enable faster settling while maintaining low phase noise after settling. Feed-forward compensation is a perfect alternative candidate for all-digital phase-locked loop based frequency synthesizers. This technique is explored further here.

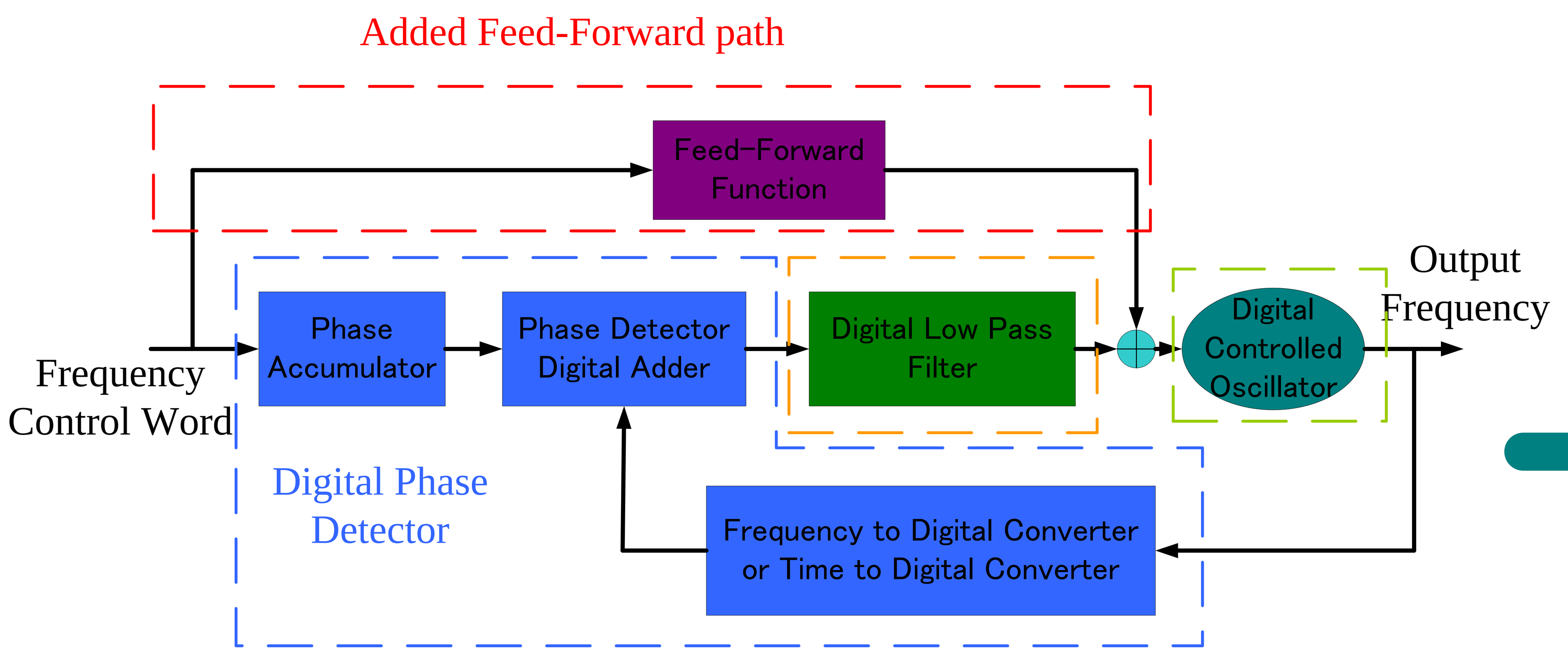

Fig. 1: All Digital Phase-Locked Loop with Feed-Forward Compensation

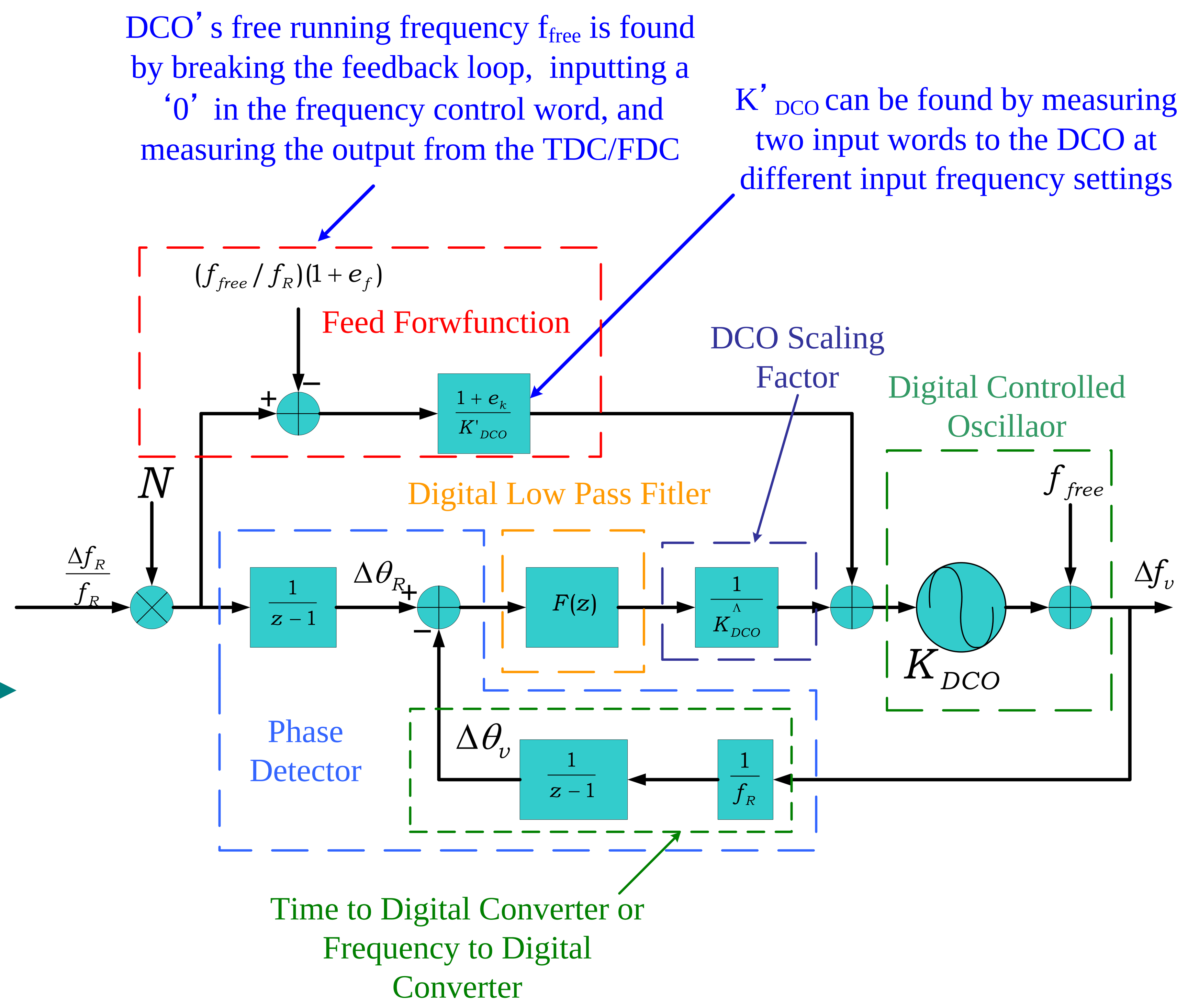

Fig. 2: All Digital Phase-Locked Loop Z-domain Model

The output of the ADPLL without the feed-forward path can be shown to be related to the input by the following equation

$$\Delta f_v = \frac{(N \cdot F(z) \cdot K'_{DCO})}{f_R \cdot (z-1) + F(z) \cdot K'_{DCO}} \cdot \frac{\Delta f_R}{f_R} + \frac{f_{free} \cdot (z-1) \cdot f_R}{f_R \cdot (z-1) + F(z) \cdot K'_{DCO}}$$

With the Feed-Forward Path and setting the DCO scaling factor to the reference frequency f_R and complete compensation by exact prediction of DCO gain and offset

$$\Delta f_v = N \cdot f_R \cdot \frac{\Delta f_R}{f_R}$$

In reality however, this is not possible due to the finite precision of the digital circuitry, and error in gain prediction. With prediction and precision error, the system's response then becomes

$$\Delta f_v = \frac{\Delta f_R}{f_R} \cdot N \cdot f_R + \frac{\Delta f_R}{f_R} \cdot N \cdot f_R \frac{e_k \cdot (z-1) \cdot f_R}{(z-1) \cdot f_R + F(z) \cdot K'_{DCO}} - \frac{(e_k + e_f + e_f \cdot e_k) \cdot (z-1) \cdot f_R}{(z-1) \cdot f_R + F(z) \cdot K'_{DCO}} f_{free}$$

- Δf_v Output Expected Frequency
- N Frequency Multiplication Factor
- $\frac{\Delta f_R}{f_R}$ Input Frequency time step
- $F(z)$ Low-Pass Filter Transfer Function
- f_{free} DCO Free Running Frequency
- e_K DCO gain prediction error
- $K'_{DCO} = \frac{K_{DCO}}{\hat{K}_{DCO}}$ Normalized DCO gain
- K_{DCO} DCO Gain
- $\hat{K}_{DCO}$ DCO Scaling Factor
- f_R Reference Frequency
- e_f DCO Offset frequency prediction error

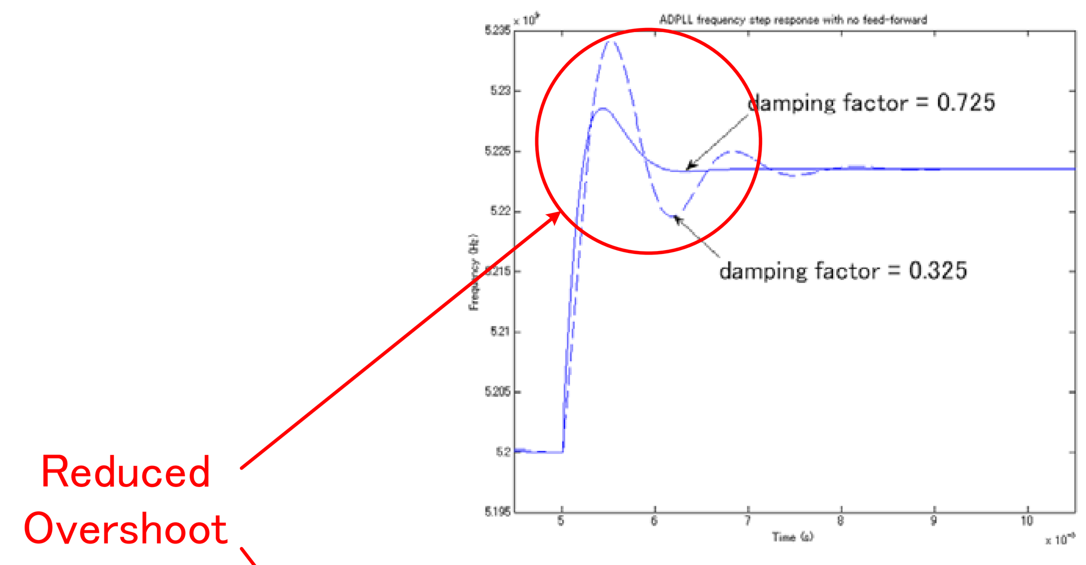

Fig. 3: All Digital Phase-Locked Loop Response without Feed-Forward Compensation

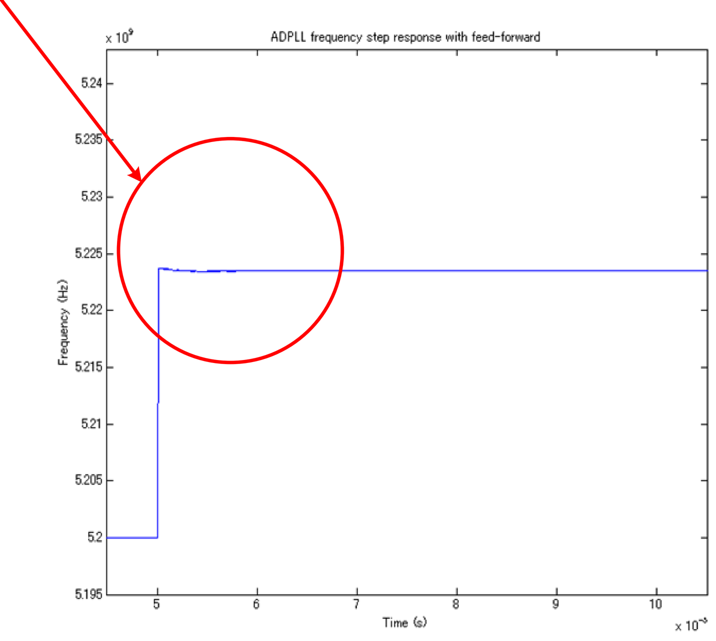

Fig. 4: All Digital Phase-Locked Loop Response with Feed-Forward Compensation

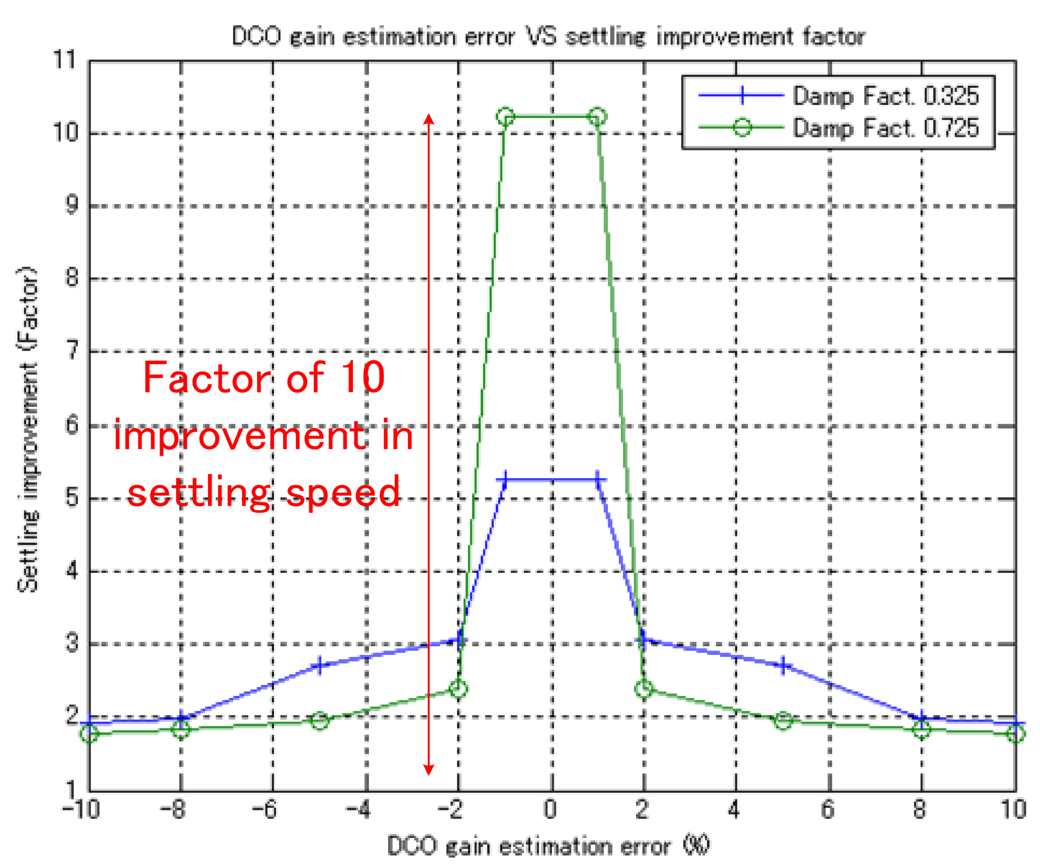

Fig. 5: All Digital Phase-Locked Loop Settling time improvement VS DCO gain estimation error

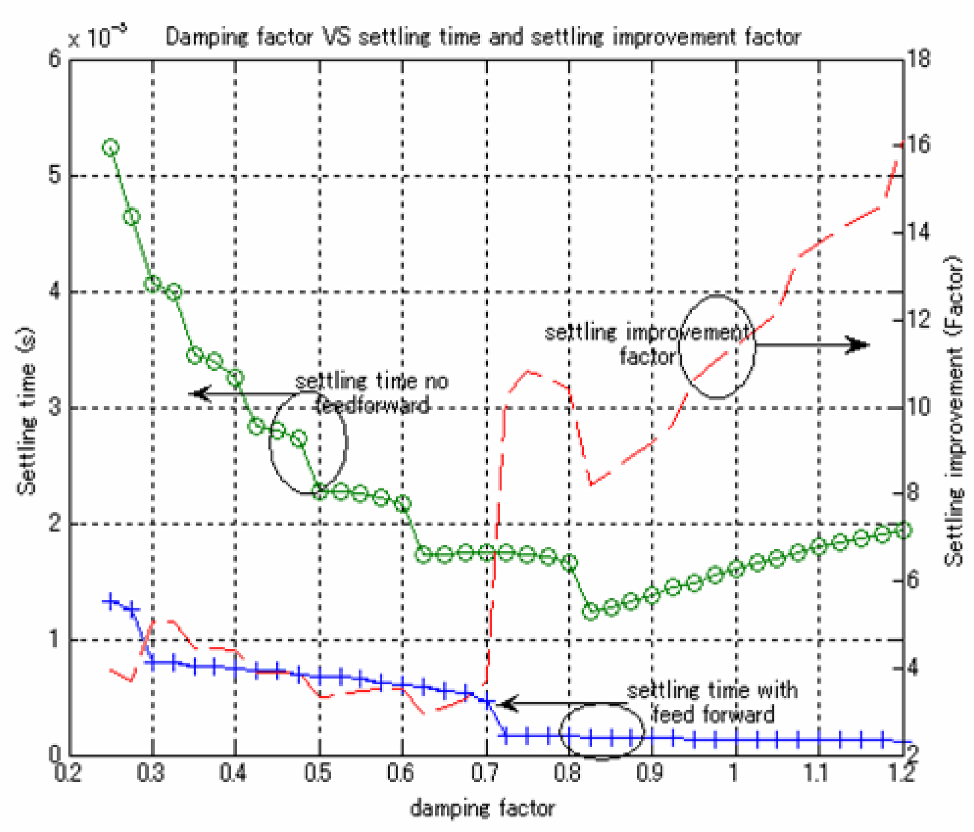

Fig. 6: All Digital Phase-Locked Loop Settling time and improvement factor VS damping factor at 1% DCO gain prediction error