Sec-I: Pull-in Range for Type-II charge-pump PLL [1] -

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The pull-in range for the PLLs using PFD as the phase detector is infinite. In practice, the pull-in range corresponds to the range frequency VCO can generate.

Why the pull-in range for this type PLL is infinite?

Because any loop filter cascaded with the PFD behaves as a real integrator when both flipflops of the PFD are in the 0 state, which means it has a pole at s=0. Hence, the DC gain of all loop filters is infinite and the pull-in range also becomes infinite.

Sec-II: Pull-in Time for Type-II charge-pump PLL [1]

For the pull-in process, we assume the frequency offset is so large that the lock-in process cannot take place. The pull-in process ends when the instantaneous frequency offset falls below the lock-in range.

Initially, the PLL is out of lock and the VCO operates at the center frequency ω_0. Its scaled-down output frequency is $\omega_0' = \omega_0/N$. The reference frequency or input frequency is ω_1 so the initial frequency offset is $\Delta\omega_0 = \omega_1 - \omega_0'$. The passive lead-lag filter used in the PLL is a RC series circuit.

Then the phase detector will toggle between the "UP" and "DOWN". The charge pump will charge or discharge the loop filter by current source I_{CP}. The average of the charge-pump output is a saw-tooth signal from $-I_{CP}$ to I_{CP}. Because the corner frequency of the loop filter is much smaller than the input reference frequency, the average output of the charge pump can be used by 50% duty cycle square wave with I_{CP} amplitude.

The time varying current source can be replaced by a equivalent current source.

$$I_{eq} = \frac{I_+ - I_-}{2} = I_{CP} = K_{PD} * 2\pi$$

The pull-in time T_P is the time required to charge the voltage on the capacitor of loop filter such that the scaled-down output frequency of VCO becomes equal to the reference frequency.

As we know $I = C\frac{dV}{dt}$, and $dV = \frac{N*\Delta\omega_0}{K_{VCO}}$. Hence, the pull-in time is

$$T_P = \frac{CdV}{I} = \frac{C\frac{N*\Delta\omega_0}{K_{VCO}}}{I} = \frac{C\frac{N*\Delta\omega_0}{K_{VCO}}}{K_{PD}*2\pi} = \frac{C*N*\Delta\omega_0}{K_{VCO}K_{PD}*2\pi}$$

Sec-III: Pull-in Time for Type-II tri-state PLL [1]

For the tri-state PLL, the output of the PFD is voltage. Initially, assume the input reference frequency is ω_1. And the output frequency of VCO is center frequency ω_0 so the input voltage is $\frac{VDD}{2}$ for the unipolar supply used in PFD. The frequency offset is $\Delta\omega_0 = \omega_1 - \omega_0$.

In order to get locked, the VCO must create an output frequency that is offset from the center frequency by the amount $N*\Delta\omega_0$. The input voltage is increased by $\frac{N*\Delta\omega_0}{\mathrm{K_{VCO}}}$.

The output of PFD is toggles between 0 and VDD which is a saw-tooth signal. Due to the reference frequency is higher than bandwidth of the loop filter (the RC series circuit is used as the loop filter), the 50% duty cycle of a square wave with VDD/2 amplitude can be used as average output of the PFD. Therefore, the pull-in time is the time for the square wave charging the capacitor of loop filter such that the input voltage of VCO is equal to $\frac{N*\Delta\omega_0}{\mathrm{K_{VCO}}}$.

Using the charging equation for the RC circuit, the pull-in time is written as

$$\frac{N*\Delta\omega_0}{\mathrm{K_{VCO}}} = \frac{\mathrm{VDD}}{2}(1 - e^{-\frac{T_P}{\tau}})$$

$$T_P = \tau * ln\frac{\frac{K_{VCO}VDD}{2N}}{\frac{K_{VCO}VDD}{2N} - \Delta\omega_0}$$

References:

1. Roland E. Best, “Phase-Locked Loops: Design, Simulation and Applications”, McGraw-Hill, 6th ed., 2007. ISBN 978-0071493758.