# Tutorial Overview Of Analog PLLs

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# Outline

- Introduction about PLLs, Types, and Applications
- PLL Components
- PD
- LF
- VCO
- Equations and Simulations

# What is a PLL?



Basic block diagram of PLL

A phase-locked loop (PLL) is a negative feedback system that synchronizes the voltage controlled oscillator (VCO) output signal to the phase of a reference input signal.

# Types of PLLs

PLL Types	Phase Detector	Loop Filter	Controlled Oscillator
Analog/Linear PLL (APLL)	Analog multiplier	Passive/active RC	Voltage controlled
Digital PLL (DPLL)	Digital detector	Passive/active RC	Voltage controlled
All digital PLL (ADPLL)	Digital detector	Digital filter	Digitally controlled
Software PLL (SPLL)	Software multiplier	Software filter	Software oscillator

# **Benefits of Analog PLL and Applications**

#### Benefits

- Low jitter
- Tunability
- Applications
  - RF systems
  - Modulation/Demodulation
  - Frequency synthesis
  - And much more ...

## Describing a PLL

- PLLs are described by type and order
- Туре
  - Number of poles of the open-loop transfer function located at origin
  - Number of integrators in the loop
- Order
  - Number of poles in closed-loop transfer function
  - Highest degree polynomial in the characteristic equation

Type 1 G(s)H(s) =  $\frac{10}{s(s+10)}$ Order 2  $s^2 + 10s + 10$ 

# **PLL Components**

- PD
  - Used to generate the phase difference between input signals
- LPF
  - Cancels high frequencies and keeps DC component of error signal
- VCO
  - Provides local frequency for the circuit
  - Controlled by the error signal from the PD

# Analog Multiplier/Mixer



Mixes RF and LO signal to produce their frequency sum and difference

- Produces an error signal proportional to phase deviation
  - Phase difference between input and output signal of PLL
- Signals in phase, output error is constant
- Signals not in phase, output error is varying
  - Negative feedback reduces error build up till phases match

Ref [5]

## **Basic Multiplier Mathematics**

$$\sin(x) * \sin(y) = \frac{1}{2}xy(\cos(x-y) - \cos(x+y))$$



# **Mixer Performance Parameters**

- Conversion gain/loss
  - ratio between IF and RF signals (voltage or power)
  - Impacts noise
- Noise figure
  - Measure of SNR degradation
  - Impacts receiver sensitivity
- Port isolation
  - Minimize feedthrough between ports
- Linearity
- Power
  - Low power dissipation desired

# Multiplier types

#### Discrete

- Single diode
  - Bad isolation
  - No conversion gain
- Diode-ring Mixer
  - Poor gain
  - Good isolation
  - Good linearity

#### ■ IC

- Mosfet passive mixer
  - Acts as a switch
  - Low power consumption
- Active mixer
  - Single balanced
    - Intermediate isolation
  - Double balanced
    - Good isolation
    - Good linearity

## **Double Balanced Multiplier**



Ref [7], [12]

# Mixer Simulation I

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# **Mixer Simulation I Continued**



# DC Characteristics of DBM I



Ref [8]

### **DC** Characteristics of DBM II

 $K \times V_y \times X_{int} = Y_{int}$ Ex- $K \times 0.1 \times 99.8m = 0.2$  $\rightarrow K = 20$ A K=20 B K=23.3 C K=22.7

D K=20.2



## **Different DBM phases**



 $0^{\circ}\, phase\, difference$ 



30° phase difference

Ref [9]

#### Phase Detector Gain







# Voltage Controlled Oscillator (VCO)

- The VCO generates a sinusoidal/pulse signal that is controlled by its input voltage
- The higher the control signal, the higher the frequency

#### VCO Specifications

- Phase noise
  - In frequency domain when phase and amplitude are time variant
- Tuning range
  - Output frequency is controlled by the input
- Power consumption
  - Low power consumption is desired

# VCO Types

- Ring VCO
  - Wide tuning range
  - High phase noise
- LC VCO
  - Large area
  - Narrow tuning range
  - Low phase noise
- Current-starved ring VCO
  - High phase noise
  - High frequency



Figure 19.25 Limiting the current in a current-starved VCO.

## **Current starved VCO Simulation**



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# Gain of VCO



$$K_{VCO} \cong 100 MHz/V$$

Ref [8]

# Loop Filter

- Low pass filter used to suppress noise and unwanted multiplier outputs.
- Passive
  - Uses R and C
- Active
  - Uses amplifier
- First order RC low pass filter was used

$$- K_F = \frac{1}{1+s}$$



# **PLL Equations**

$$H(s) = \frac{K_{PD}K_FK_{VCO}}{s + K_{PD}K_FK_{VCO}}$$

Second order, type II system TF

$$\omega_n = \sqrt{\frac{K_{PD}K_{VCO}}{RC}}$$

**Natural Frequency** 

$$H(s) = \frac{K_{PD}K_{VCO}\frac{1}{1+sRC}}{s + K_{PD}K_{VCO}\frac{1}{1+sRC}}$$

Second order, type II system TF  $\zeta = \frac{1}{2RC\omega_n}$ 

**Damping Ratio** 

# Analog PLL

	DBM \$	
	VDD VTL Vout p Vout p Vout m Vout	
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SINE(320m 100m 100MEG 0 0 0) SINE(320m 100m 100MEG 0 0 180)		
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## APLL Waveform I Zoomed in



LO and RF waves line up at the same point for every cycle so the loop is locked

#### **FFT Check**



The frequency of LO signal is exactly equal to RF signal so the loop is locked







#### References

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# THANK YOU