无线通信实验在线开放课程

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广东省教学质量工程建设项目

$$s_m(t) = A_c\big(k_a m(t)\big)\mathbf{cos}(2\pi f_c t)$$

$$s_m(t) = A_c\mathbf{cos}[2\pi f_c t + 2\pi k_f \int m(t)dt]$$

Lab 4: Frequency Modulation

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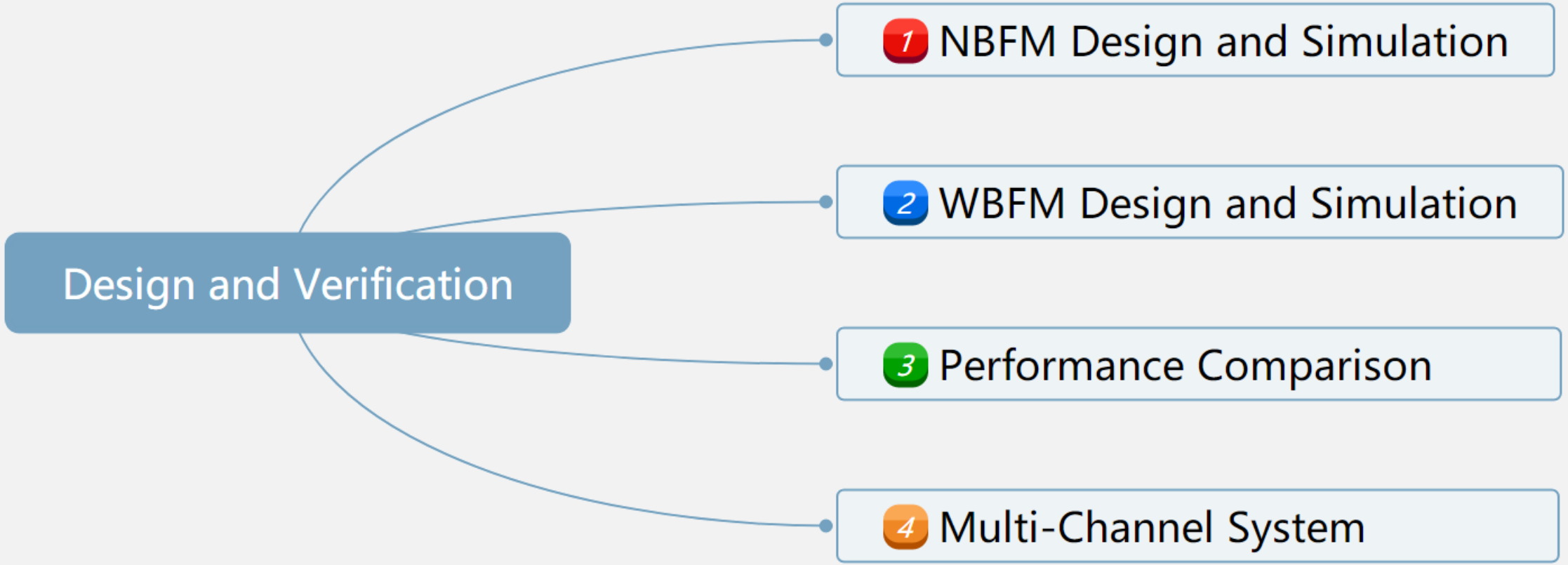
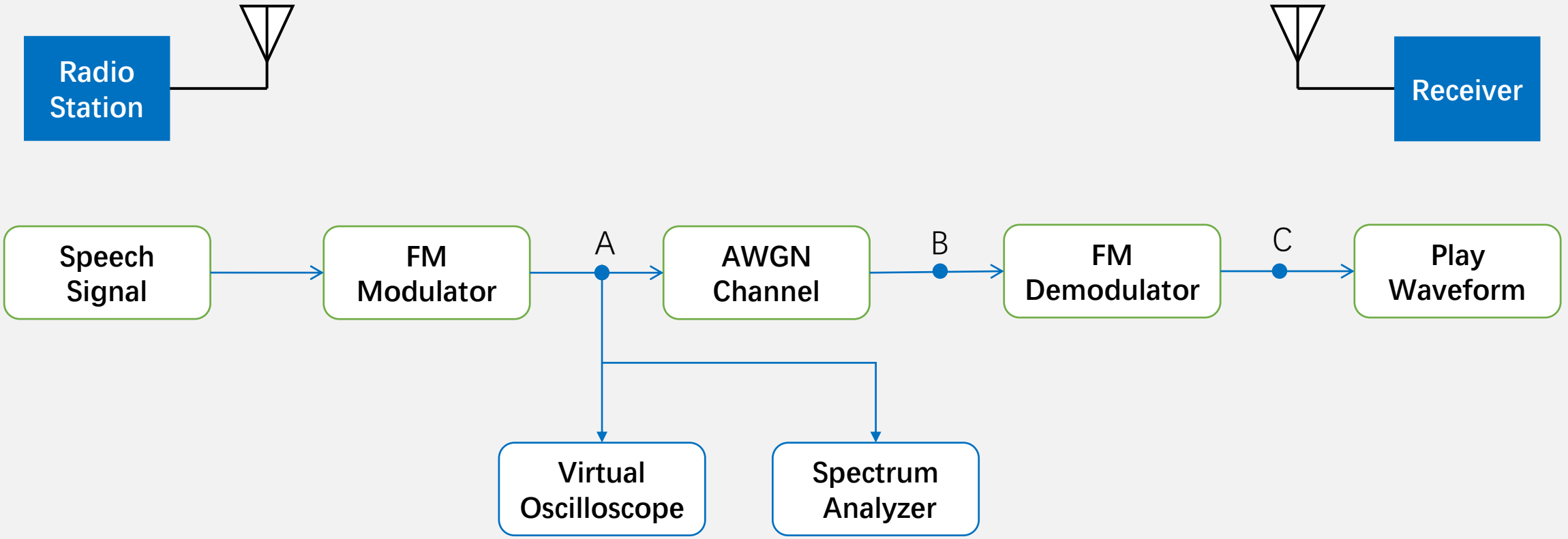

Design and Verification
1 NBFM Design and Simulation
2 WBFM Design and Simulation
3 Performance Comparison
4 Multi-Channel System

Demo: NBFM Simulation (Single Tone)

Simulation Model of FM System



$$\cos(\alpha + \beta) = \cos\alpha\cos\beta - \sin\alpha\sin\beta$$

$$s_{FM}(t) = A_c \mathbf{cos}[2\pi f_c t + 2\pi k_f \int m(t)dt]$$

$$\cos(\alpha + \beta) = \cos\alpha \cos\beta - \sin\alpha \sin\beta$$

$$s_{FM}(t) = A_c \cos\left[2\pi k_f \int m(\tau)d\tau\right] \cos(2\pi f_c t) - A_c \sin\left[2\pi k_f \int m(\tau)d\tau\right] \sin(2\pi f_c t)$$

$$f_i = 2\pi f_c + 2\pi k_f m(t)$$

$$\cos\left[2\pi k_f \int \mathrm{m}(\tau)\mathrm{d}\tau\right] \approx 1$$

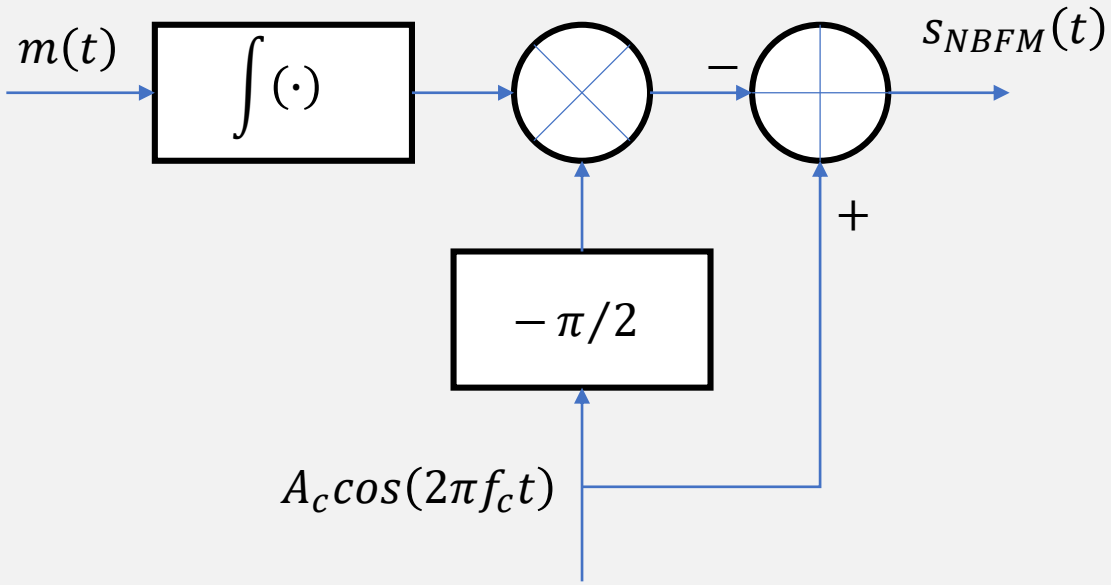
$$\sin\left[2\pi k_f \int m(\tau)\mathrm{d}\tau\right] \approx \left[2\pi k_f \int m(\tau)\mathrm{d}\tau\right]$$

$$s_{FM}(t) = A_c \cos\left[2\pi k_f \int m(\tau)d\tau\right]\cos(2\pi f_c t) - A_c \sin\left[2\pi k_f \int m(\tau)d\tau\right]\sin(2\pi f_c t)$$

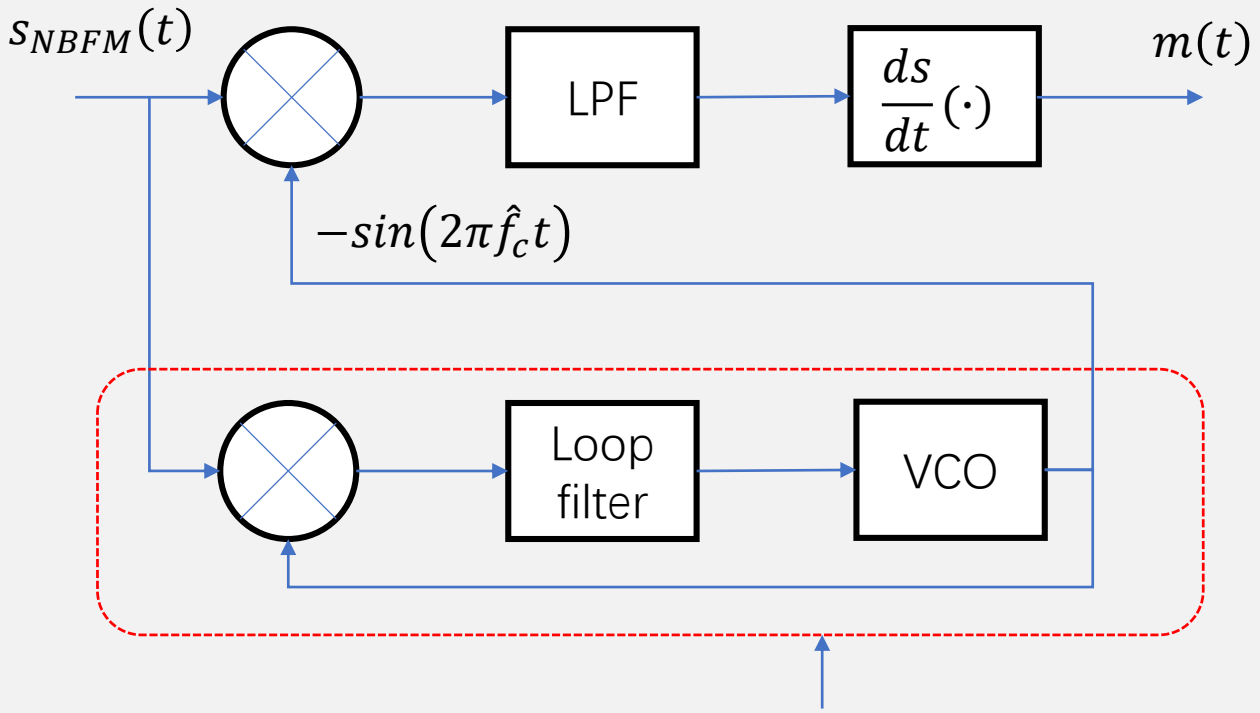
$$s_{NBFM}(t) = A_c \cos(2\pi f_c t) - A_c\left[2\pi k_f \int m(\tau)d\tau\right]\sin(2\pi f_c t)$$

Pre-Lab: NBFM Mathematical Model

Modulator



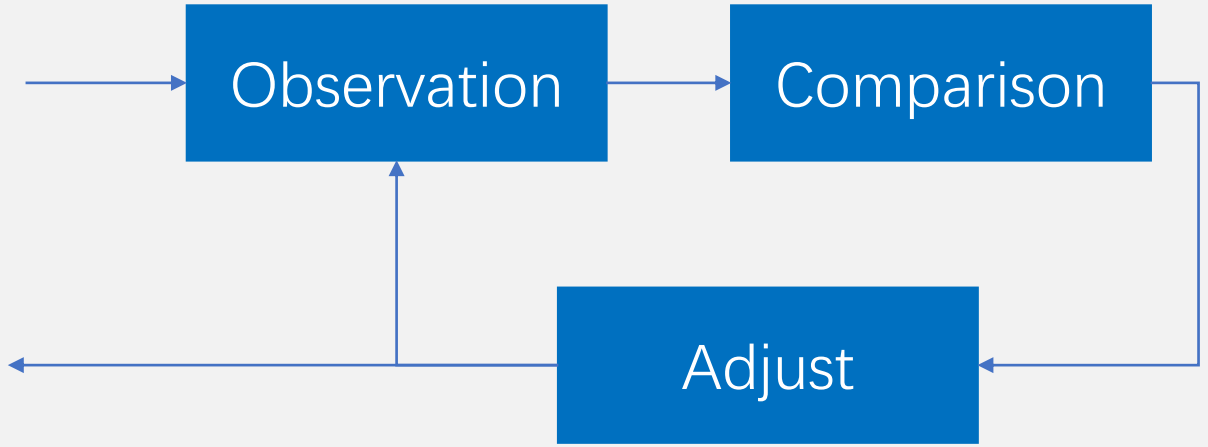
Demodulator



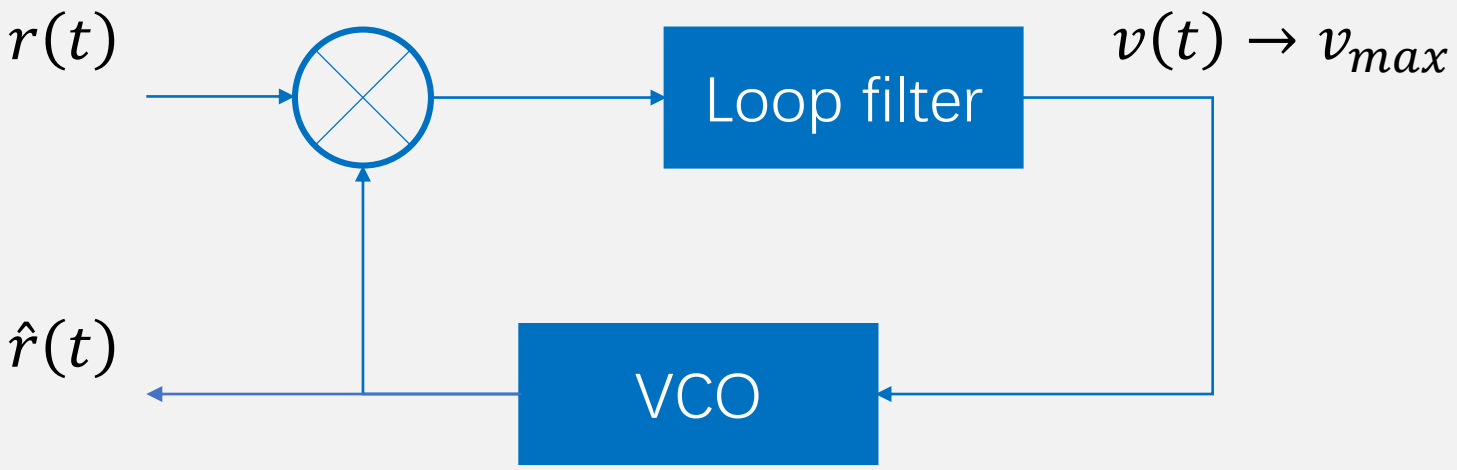
Phase Locked Loop (PLL)

$$s_{NBFM}(t) = A_c \cos(2\pi f_c t) - A_c \left[2\pi k_f \int m(\tau)d\tau\right] \sin(2\pi f_c t)$$

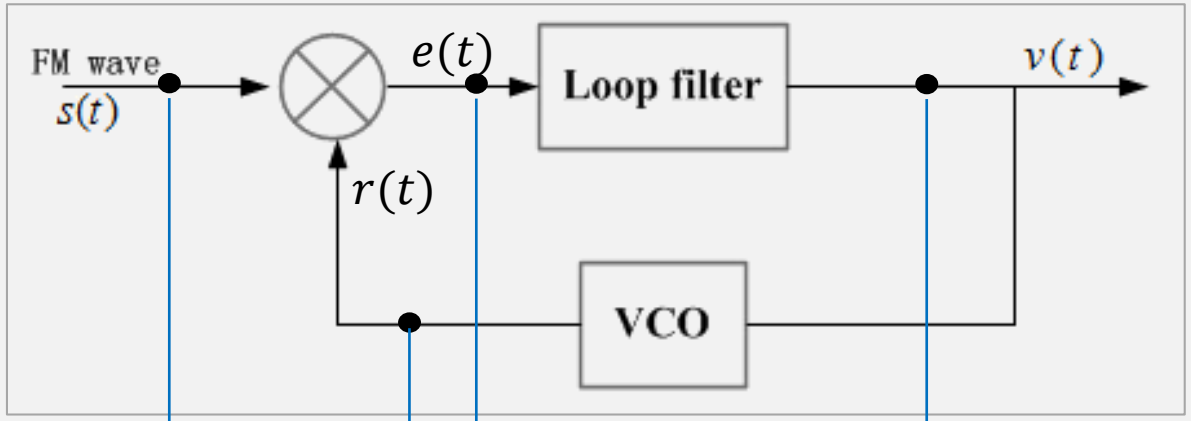
Feedback Control System

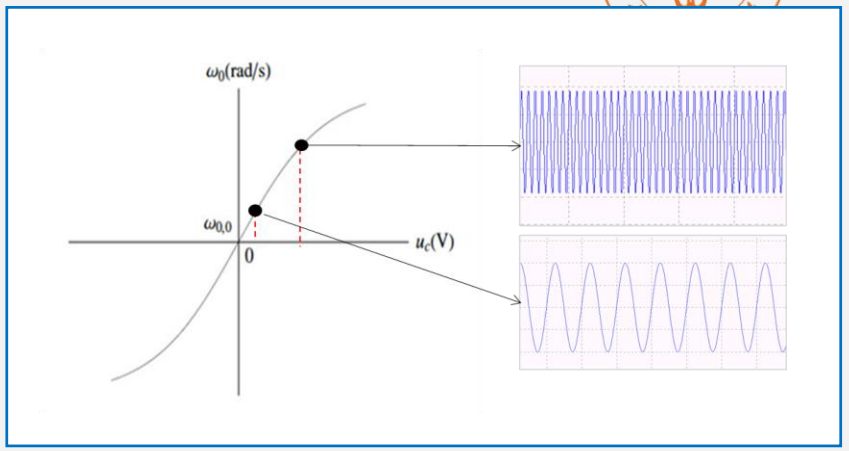


Analysis: Phase-Locked Loop



Analysis: Phase-Locked Loop





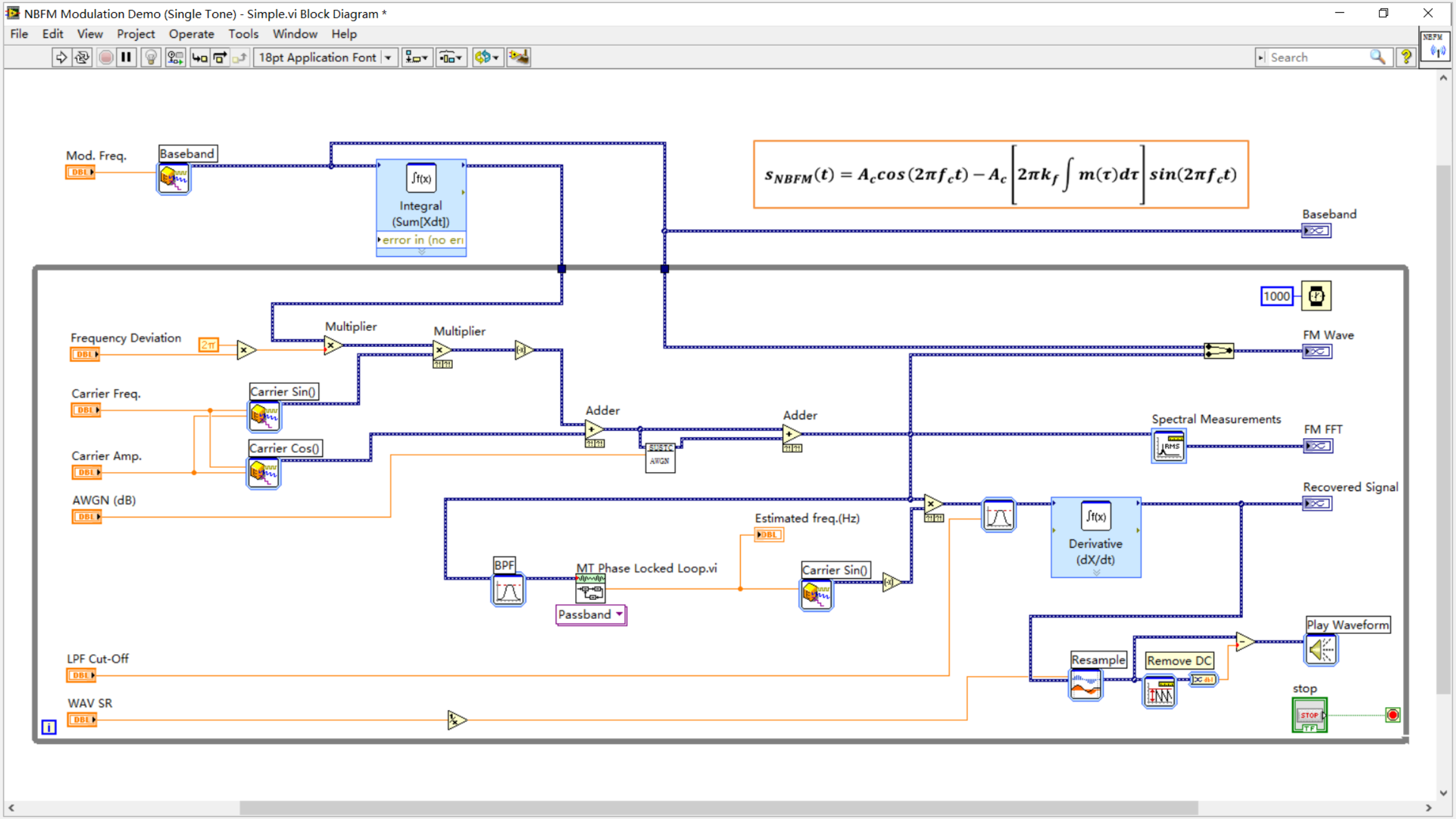
VCO
Voltage Controlled Oscillator

$$s(t) = \cos(2\pi f_c t + \varphi)$$

$$v(t) = \frac{1}{2}cos[2\pi(f_c - \hat{f}_c)t + (\varphi - \hat{\varphi})]$$

$$r(t) = \cos(2\pi \hat{f}_c t + \hat{\varphi})$$

$$e(t) = \frac{1}{2}\{\cos[2\pi(f_c - \hat{f}_c)t + (\varphi - \hat{\varphi})] + \cos[2\pi(f_c + \hat{f}_c)t + (\varphi + \hat{\varphi})]\}$$


NBFM Modulation Demo (Single Tone) - Simple.vi Block Diagram *
File Edit View Project Operate Tools Window Help
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$s_{NBFM}(t) = A_c cos(2\pi f_c t) - A_c \left[2\pi k_f \int m(\tau) d\tau \right] sin(2\pi f_c t)$
Mod. Freq.
Baseband
Integral (Sum[Xdt])
error in (no err
Baseband
1000
Frequency Deviation
2π
Multiplier
Multiplier
FM Wave
Carrier Freq.
Carrier Sin()
Adder
Adder
Spectral Measurements
FM FFT
Carrier Amp.
Carrier Cos()
AWGN (dB)
Recovered Signal
Estimated freq.(Hz)
BPF
MT Phase Locked Loop.vi
Passband
Carrier Sin()
Derivative (dX/dt)
Play Waveform
Resample
Remove DC
stop
LPF Cut-Off
WAV SR

Frequency Modulation

Carrier Amp. 1 | Carrier Freq. 100000 | WAV SR 44100 | Mod. Freq. 2000 | LPF Cut-Off 10000 | Estimated freq. 100000

AWGN (dB) 30

-20 -15 -10 -5 0 5 10 15 20 25 30 35 40 45 50

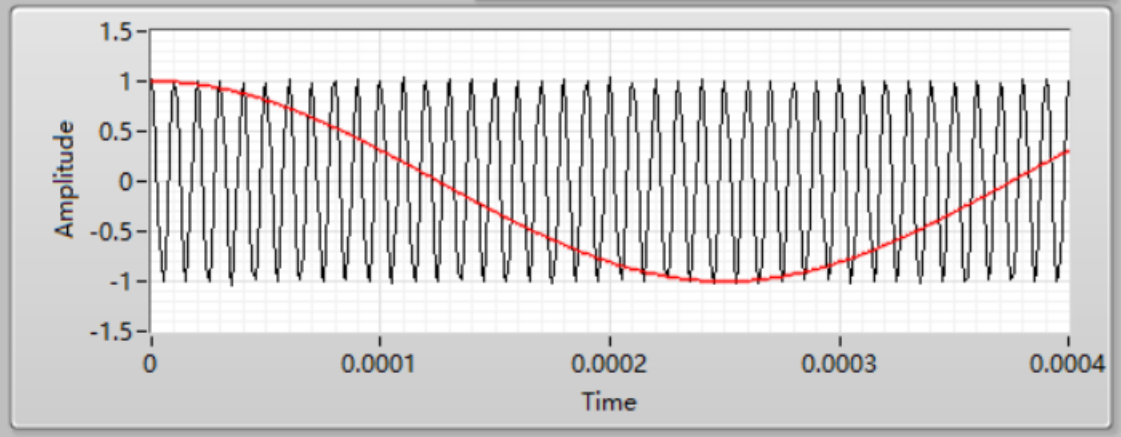
Frequency Deviation 400

0 50 100 150 200 250 300 350 400

stop STOP

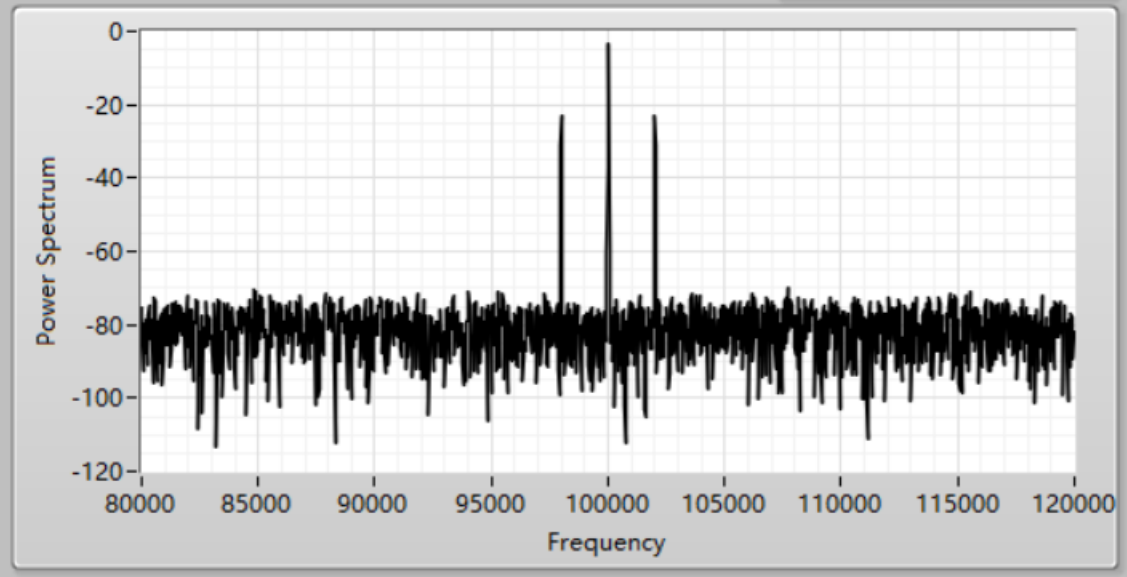
FM Wave

Baseband Signal | Modulated Signal

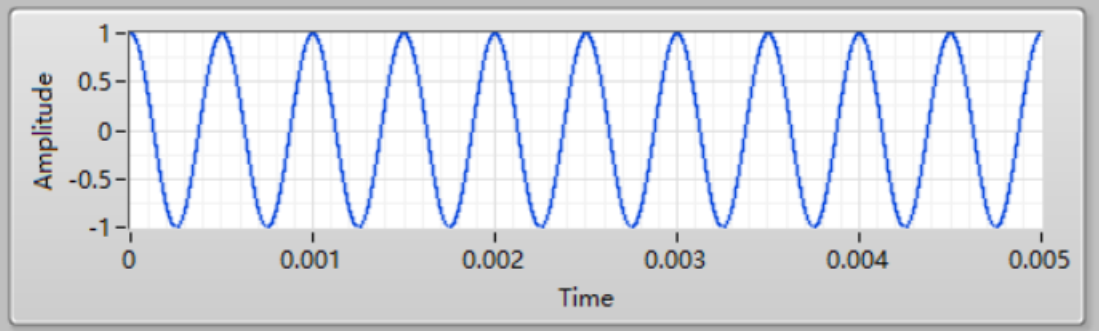


FM FFT

Sine (FFT - (RMS))

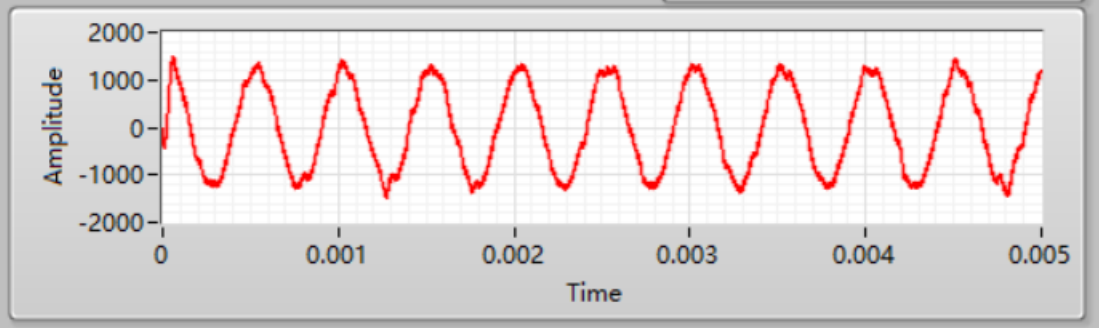


Baseband



Recovered Signal

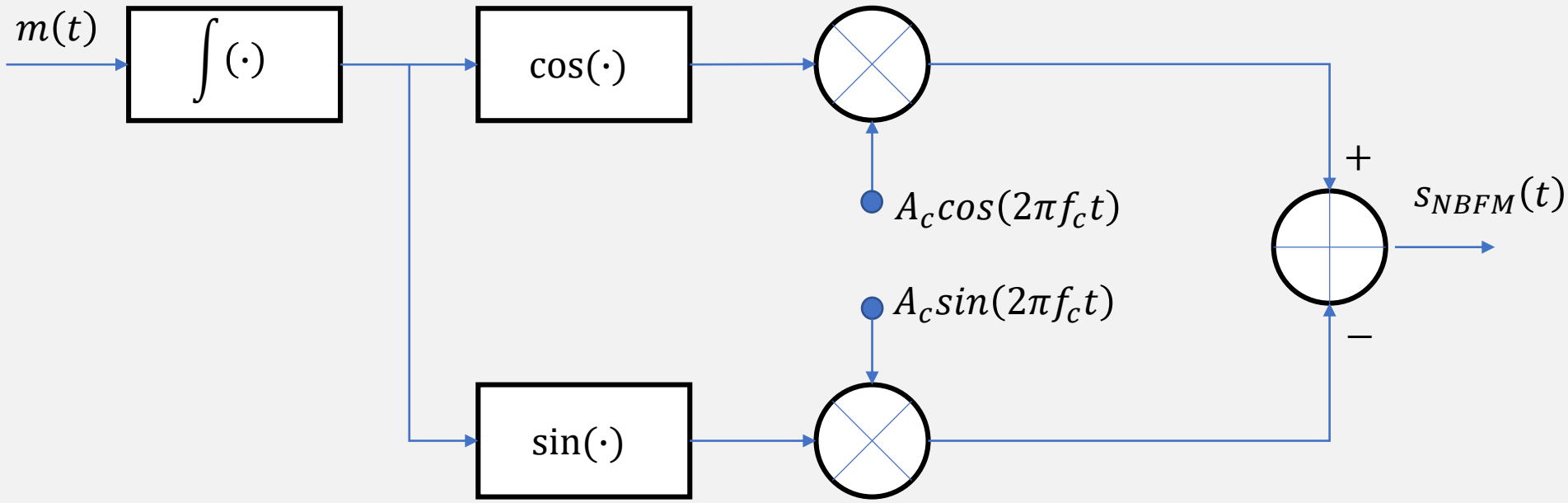
Sine (Derivative (dX/dt))



Demo: NBFM Simulation (Music)

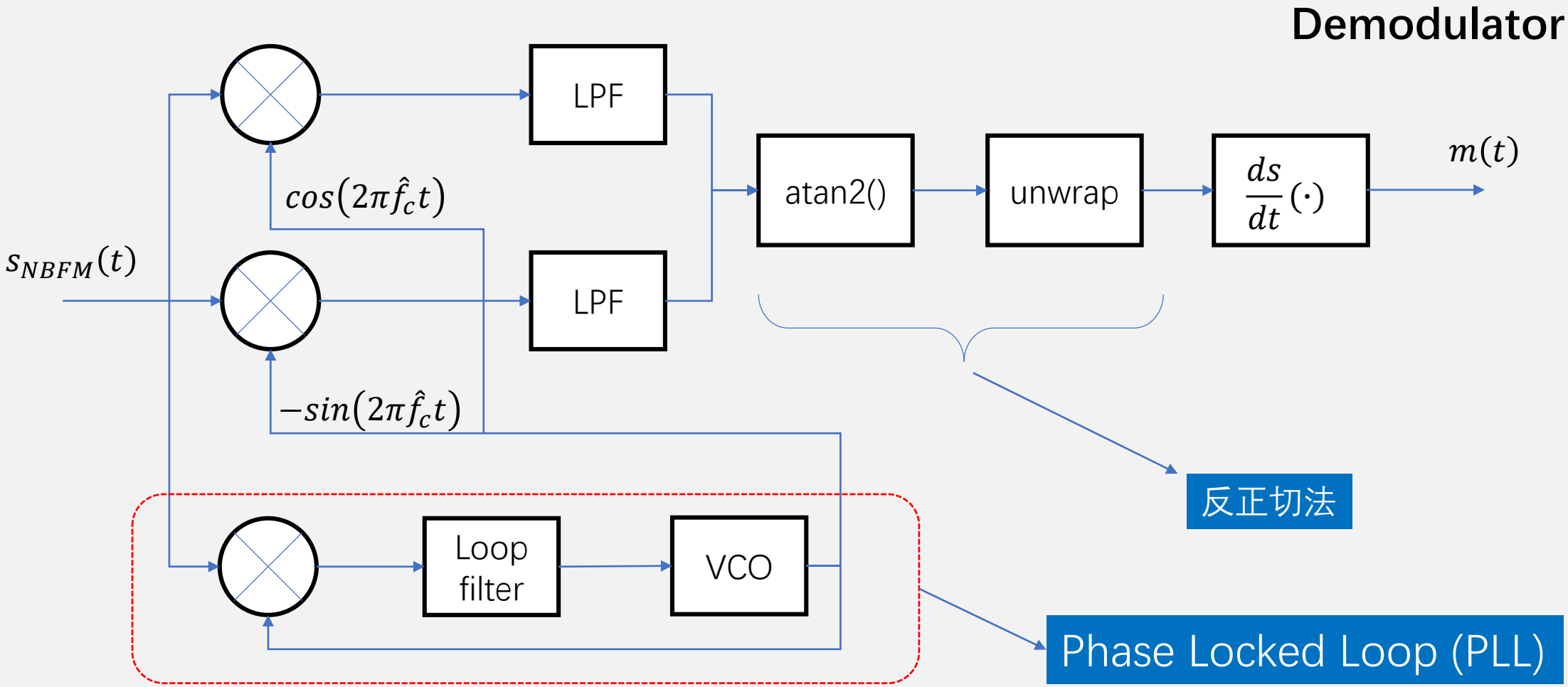
Pre-Lab: General Mathematical Model

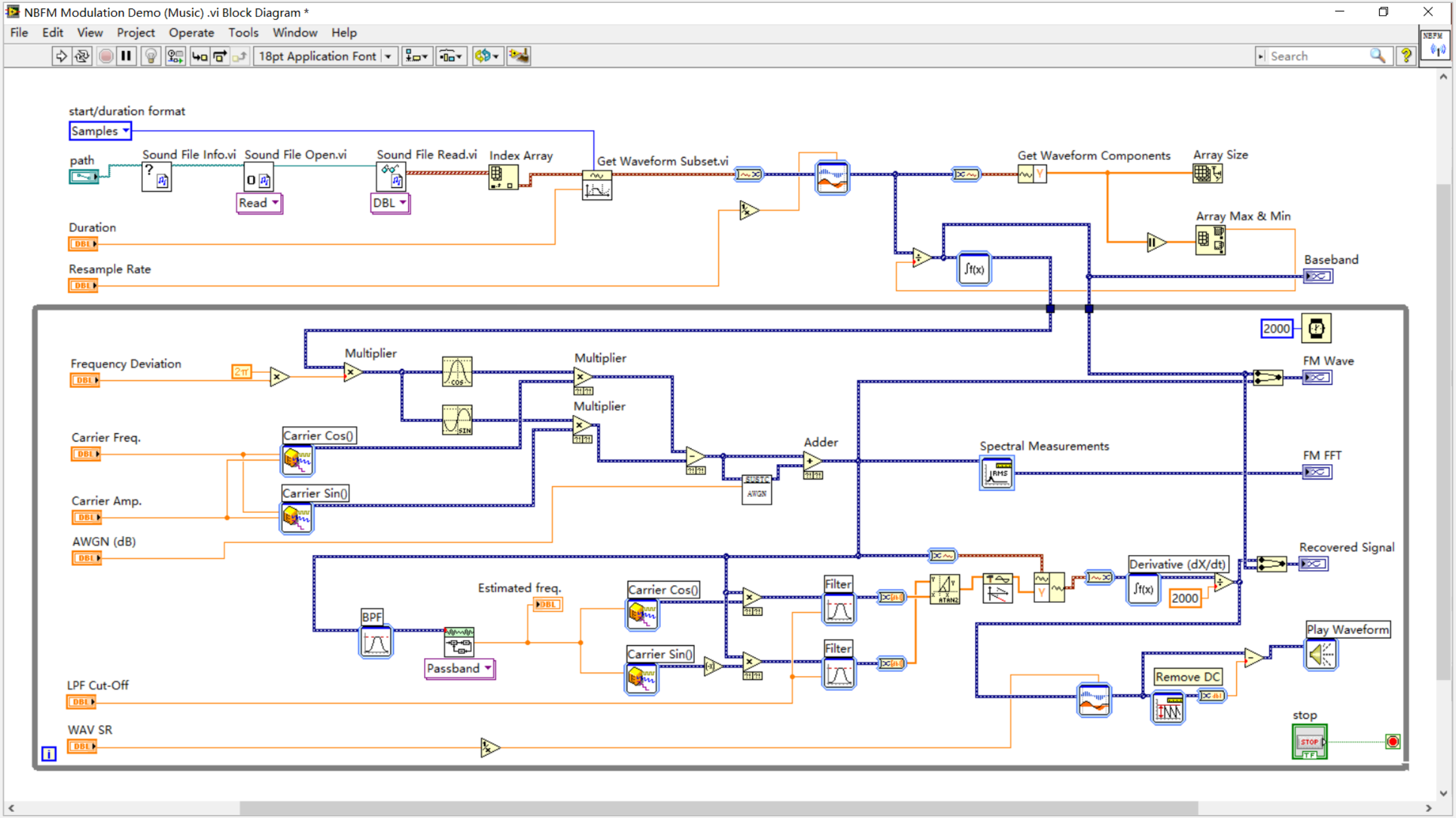
Modulator



$$s_{NBFM}(t) = A_c \cos\left[2\pi k_f \int m(\tau)d\tau\right] \cos(2\pi f_c t) - A_c \sin\left[2\pi k_f \int m(\tau)d\tau\right] \sin(2\pi f_c t)$$

Pre-Lab: General Mathematical Model




NBFM Modulation Demo (Music) .vi Block Diagram *
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start/duration format
Samples
path
Sound File Info.vi
Sound File Open.vi
Read
Sound File Read.vi
DBL
Index Array
Get Waveform Subset.vi
Get Waveform Components
Array Size
Array Max & Min
Duration
Resample Rate
Baseband
Frequency Deviation
2π
Multiplier
Multiplier
Multiplier
Carrier Freq.
Carrier Cos()
Carrier Amp.
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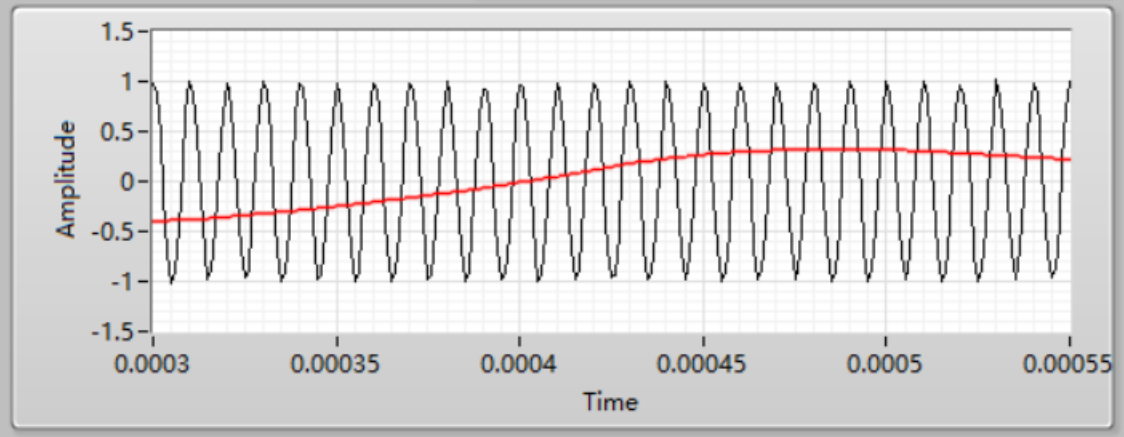
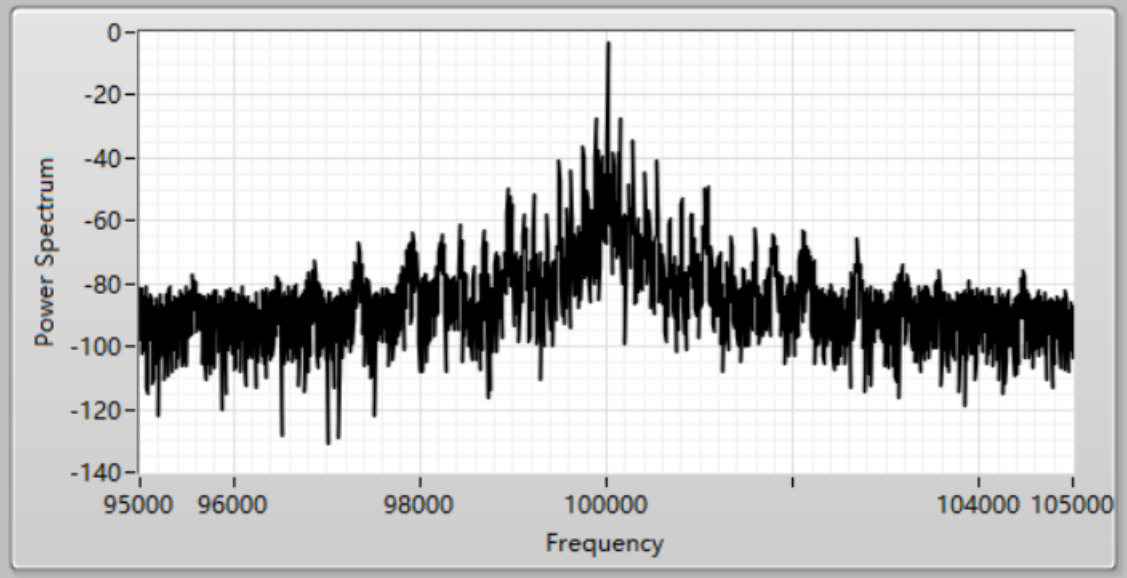
AWGN (dB)
Adder
SUSTC
AWGN
Spectral Measurements
RMS
2000
FM Wave
FM FFT
Recovered Signal
Derivative (dX/dt)
Estimated freq.
BPF
Passband
Carrier Cos()
Carrier Sin()
Filter
Filter
ATAN2
Play Waveform
Remove DC
LPF Cut-Off
WAV SR
stop
STOP
TF

Frequency Modulation

FM Wave



FM FFT



path

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Duration

44101

LPF Cut-Off

5000

Carrier Amp.

1

Carrier Freq.

100000

WAV SR

44100

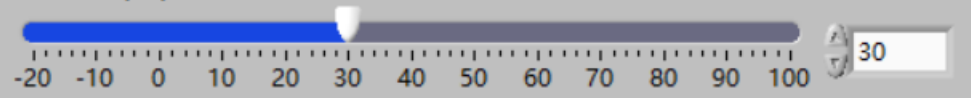
Resample Rate

1000000

Estimated freq.

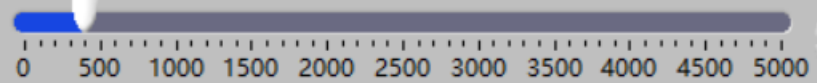
100016

AWGN (dB)



30

Frequency Deviation

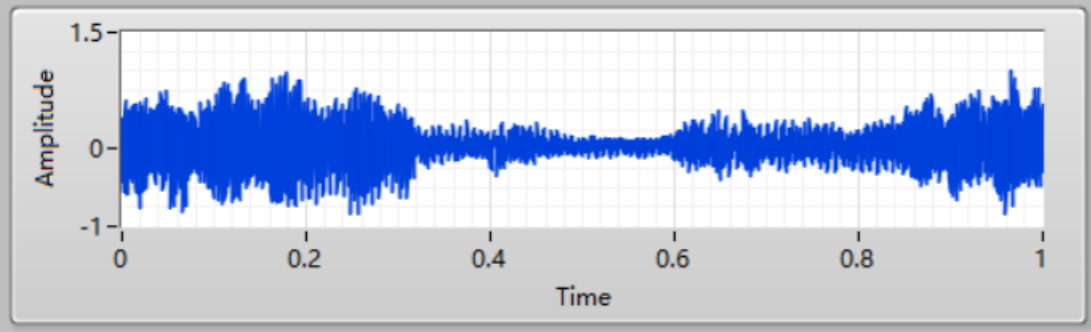


400

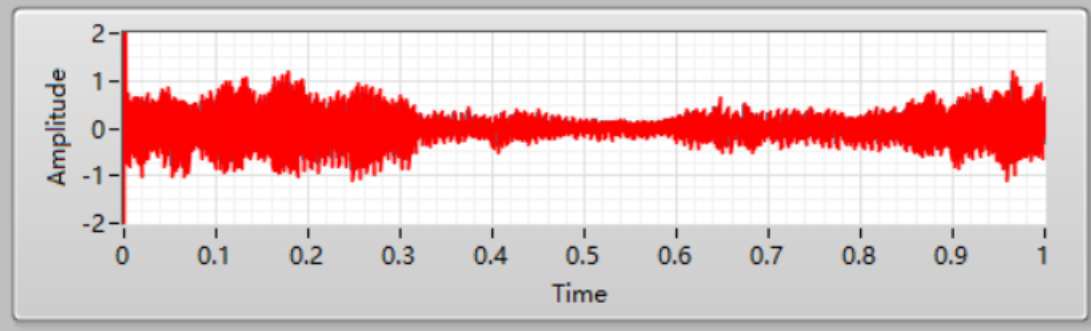
stop

STOP

Baseband



Recovered Signal



- Question ?

【通信新说】