SUSTech Southern University of Science and Technology

# Communication Principles

## Software Defined Radio
## Voice Transmission
## (Part 1)

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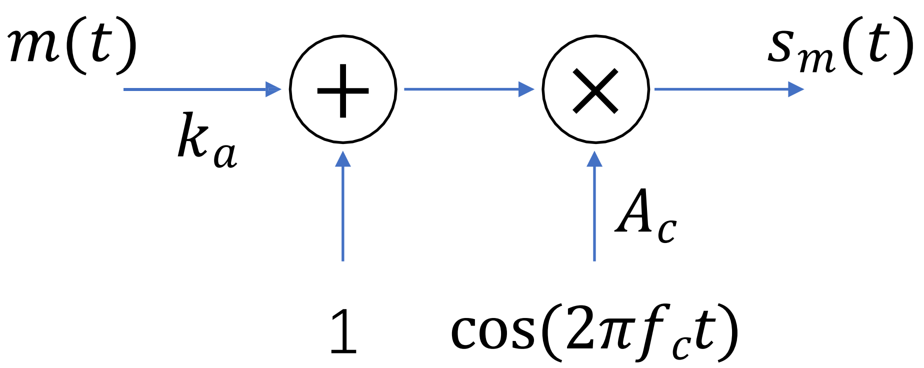
Tencent Meeting: 874-068-9694

# Review - AM

## Modulator



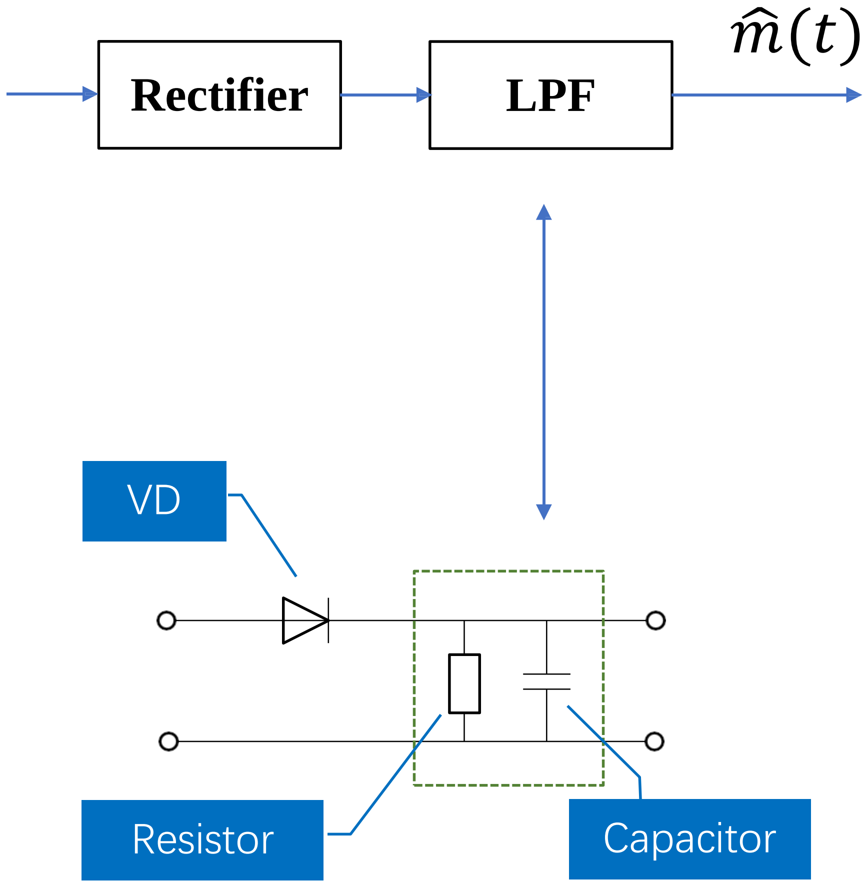

Sensitivity

Carrier

$$s_m(t) = A_c\big(1 + k_a m(t)\big)\cos(2\pi f_c t)$$

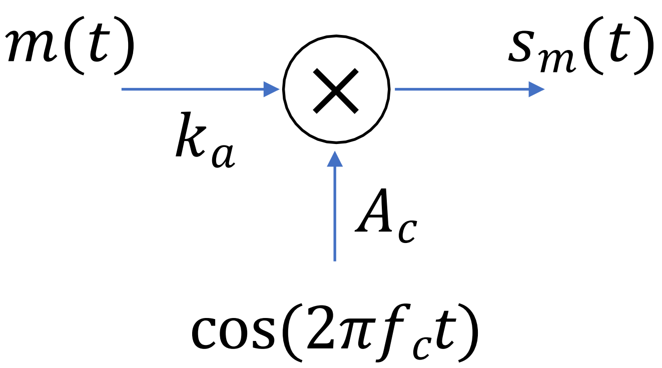
Baseband

## Demodulator



# Review - DSB

## Modulator



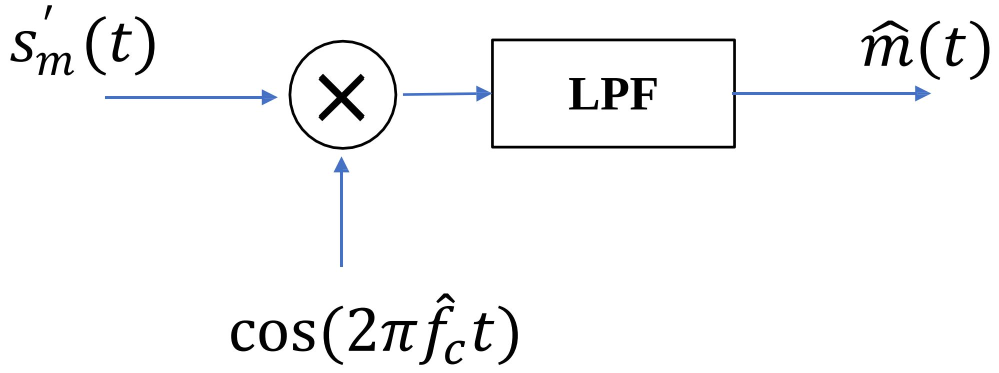

Sensitivity

Carrier

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

Baseband

## Demodulator



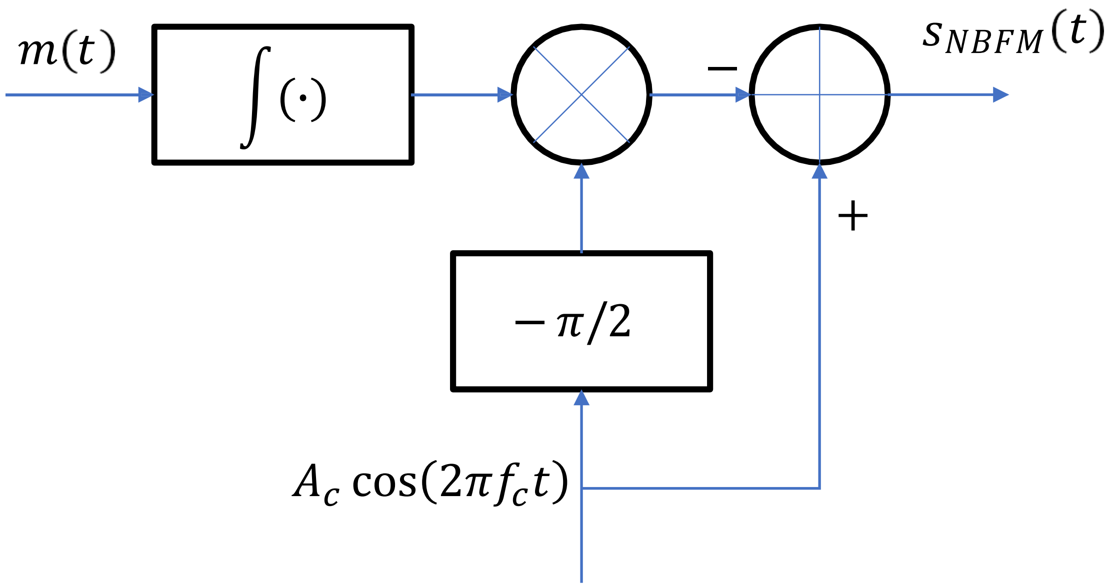

$$s'_m(t)\cos(2\pi \hat{f}_c t)$$

$\hat{f}_c = f_c$

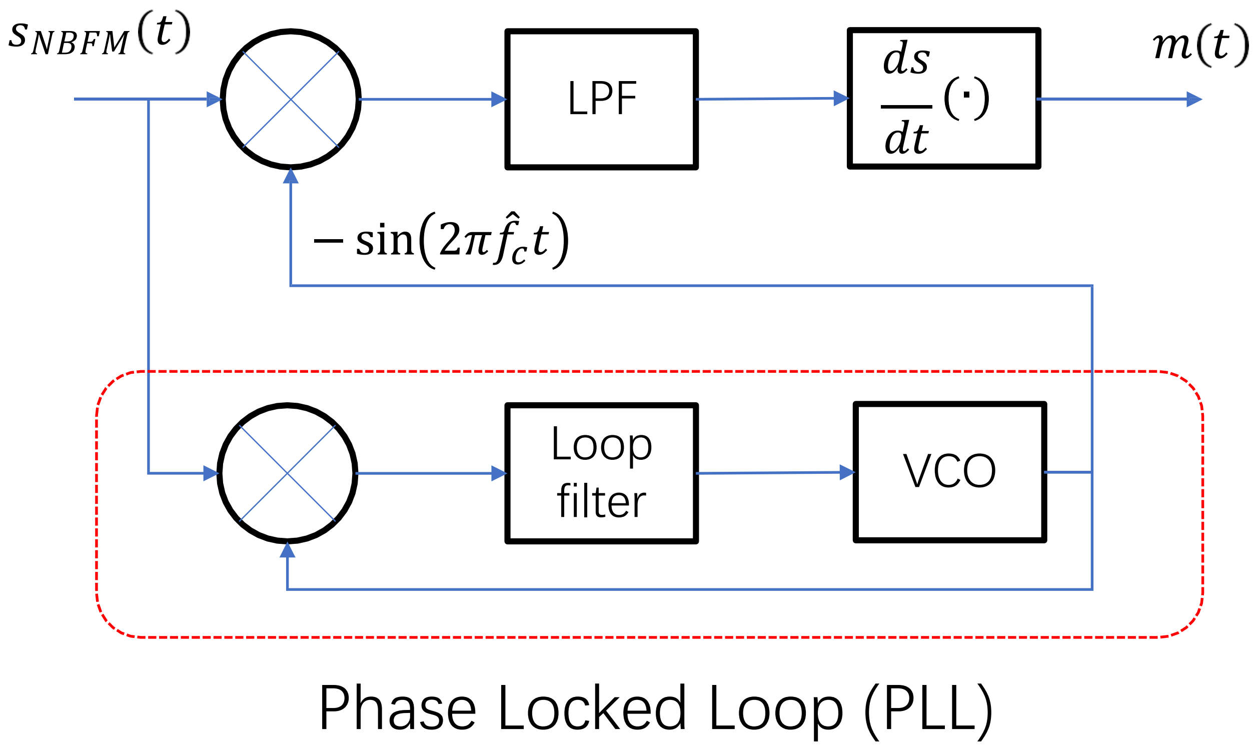
$$\frac{1}{2}A_c k_a m(t) + \frac{1}{2}A_c k_a m(t)\cos(4\pi f_c t)$$

# Review - NBFM

## Modulator

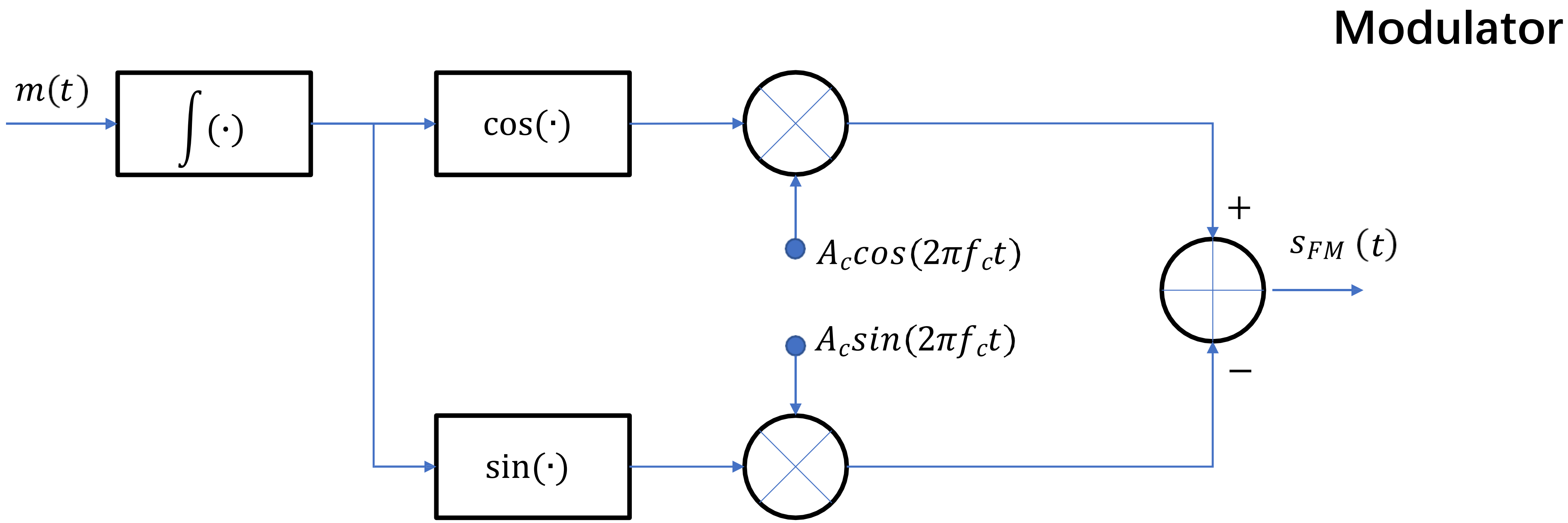



## Demodulator



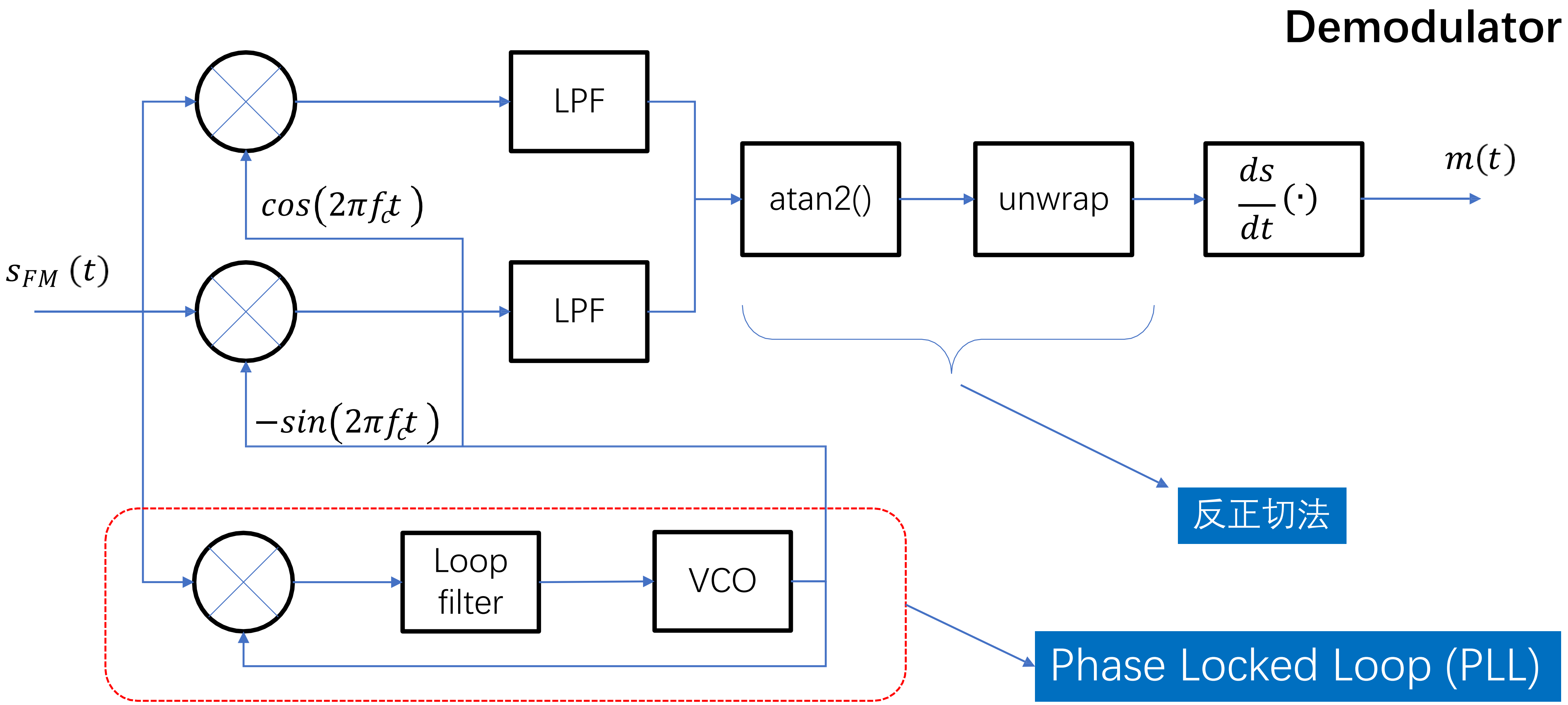

$$s_{NBFM}(t) = A_c \cos(2\pi f_c t) - A_c \left[2\pi k_f \int m(\tau)d\tau\right] \sin(2\pi f_c t)$$

# Review - General FM Model



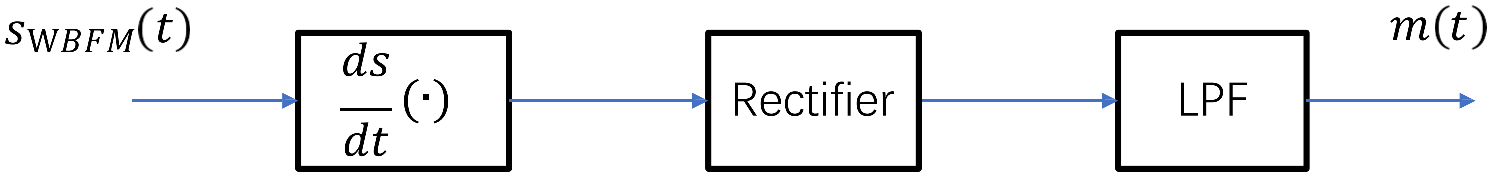

$$s_{FM}(t) = A_c \cos\left[2\pi k_f \int m(\tau)d\tau\right]\cos(2\pi f_c t) - A_c \sin\left[2\pi k_f \int m(\tau)d\tau\right]\sin(2\pi f_c t)$$

# Review - General FM Model



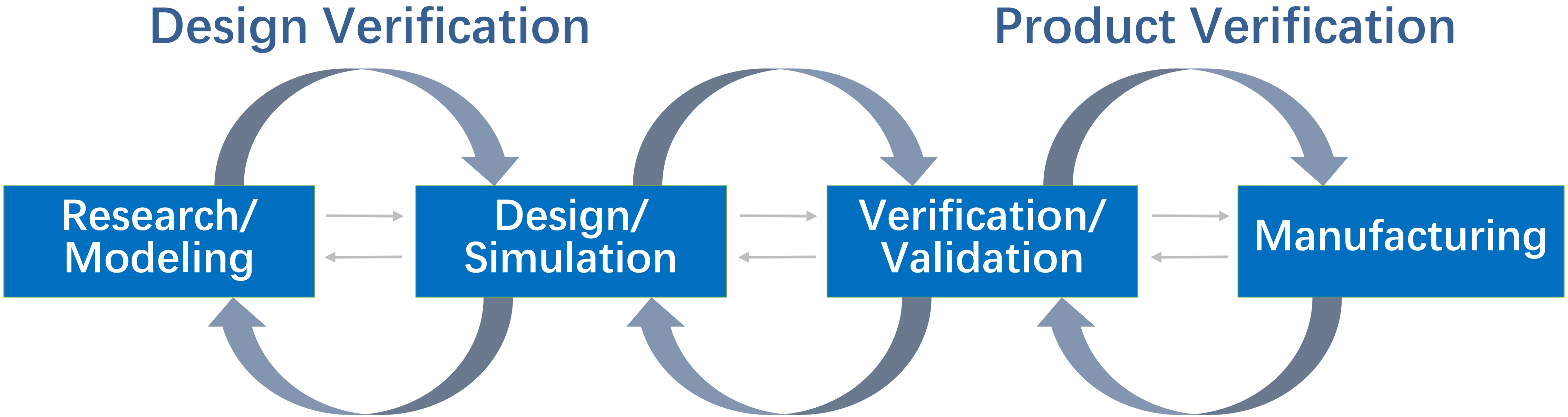
# Review - WBFM Mathematical Model

**Demodulator**

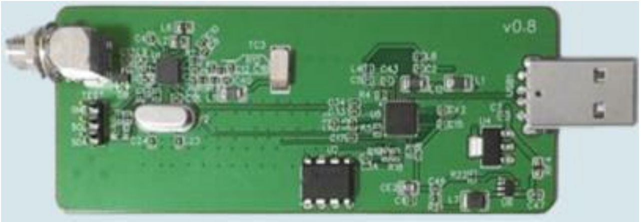



$$\frac{ds_{FM}(t)}{dt} = \frac{d}{dt} A_c \cos\left[2\pi f_c t + 2\pi k_f \int m(\tau) d\tau\right] = -2\pi A_c\left[f_c + k_f m(t)\right] \sin[\theta_m(t)]$$

# From Theory to Practice



# SDR Device




RTL-SDR


LimeSDR mini


HackRF


USRP

# USRP: Universal Software Radio Peripheral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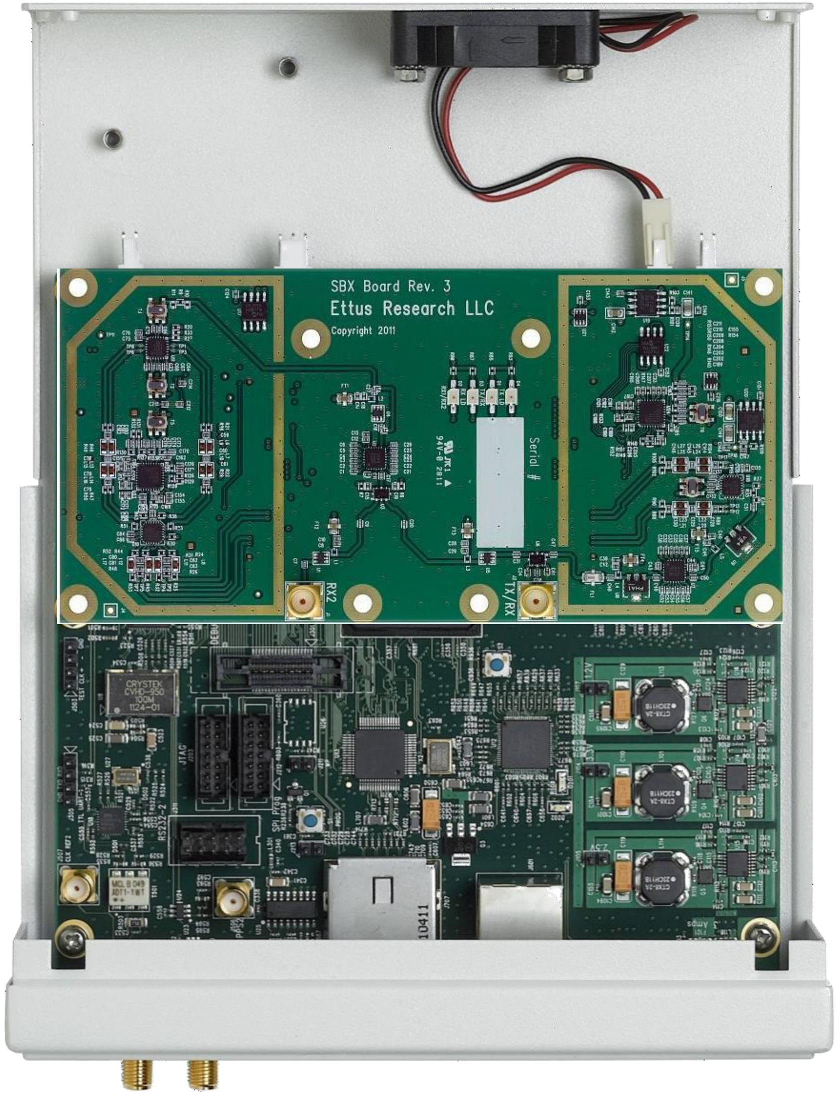
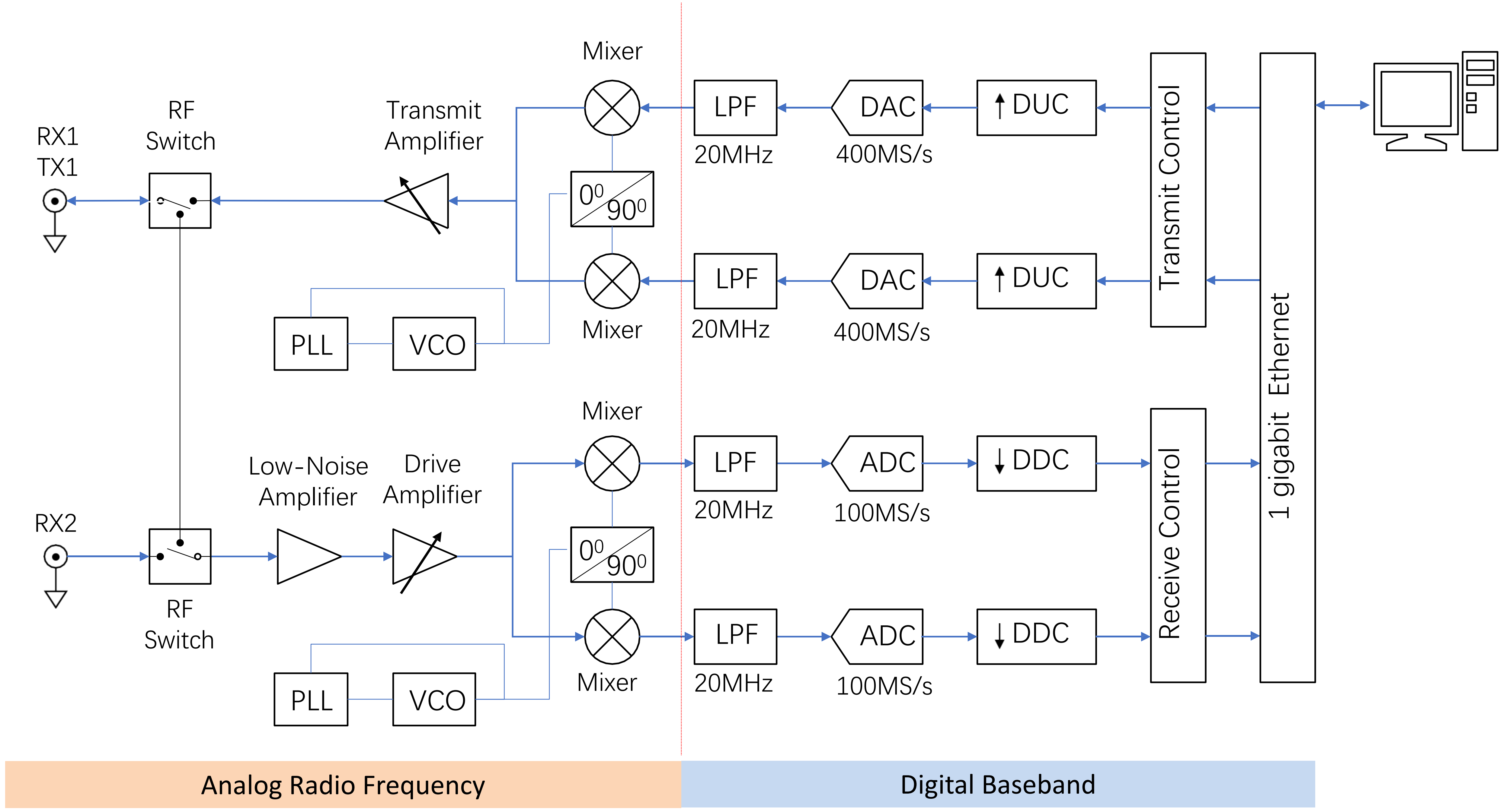
Ettus Research
A National Instruments Brand



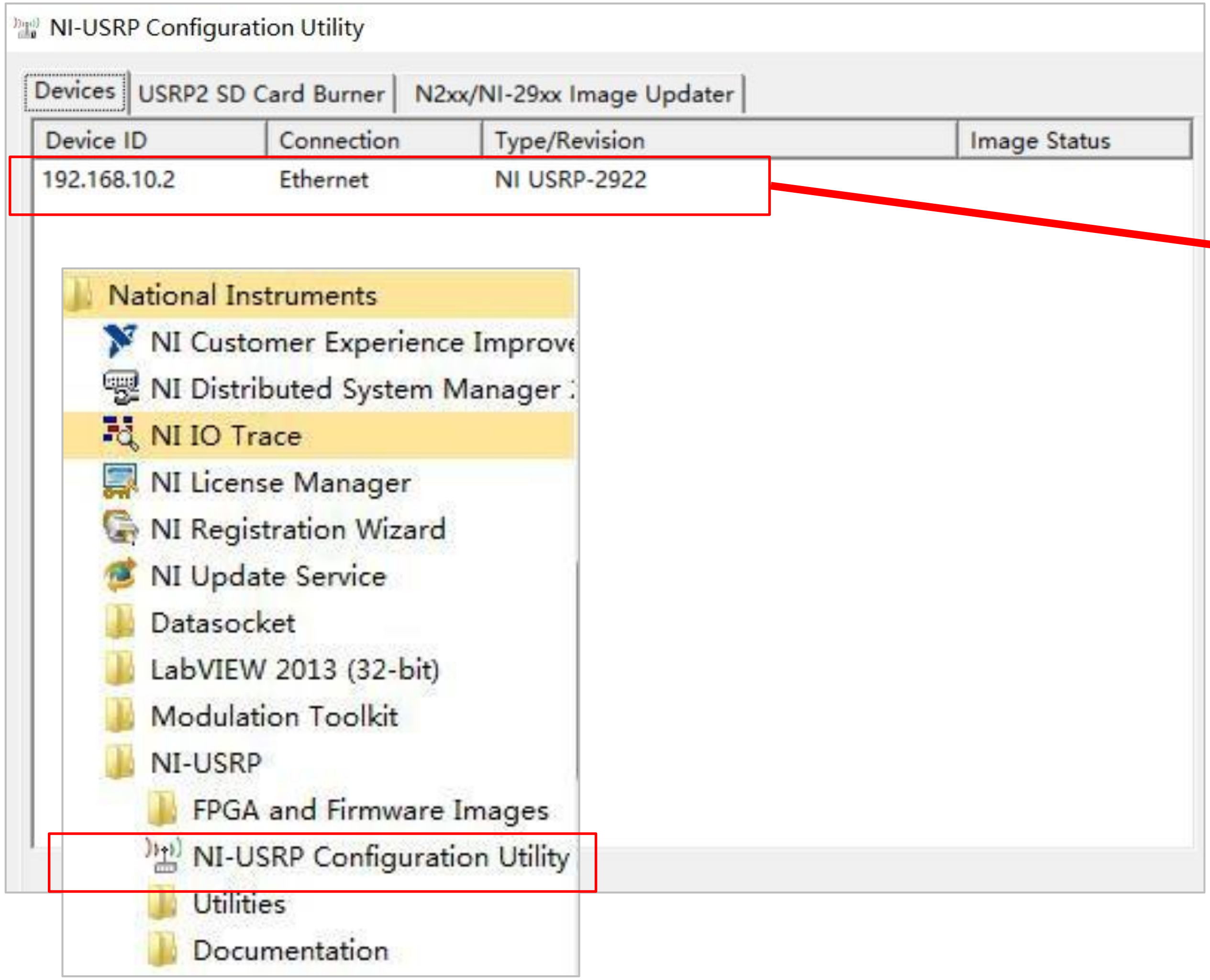

| Daughter board | Frequency range |
|---|---|
| SBX | 400 - 4400MHz |
| WBX | 50 - 2200MHz |
| XCVR2450 | 2400 - 2500MHz |
| Basic | 1 - 250MHz |

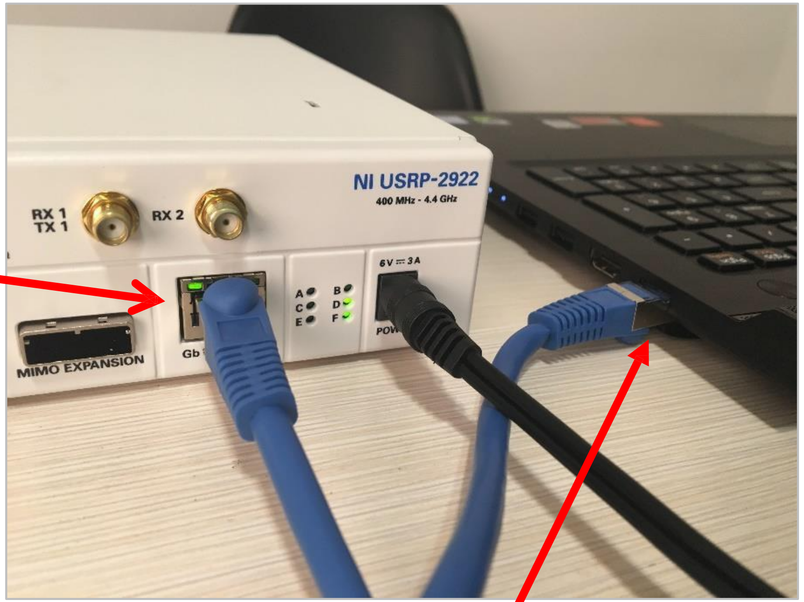


RX1
TX1
RF
Switch
Transmit
Amplifier
Mixer
0⁰
90⁰
Mixer
PLL
VCO
LPF
20MHz
DAC
400MS/s
↑DUC
LPF
20MHz
DAC
400MS/s
↑DUC
Transmit Control
1 gigabit Ethernet
RX2
RF
Switch
Low-Noise
Amplifier
Drive
Amplifier
Mixer
0⁰
90⁰
Mixer
PLL
VCO
LPF
20MHz
ADC
100MS/s
↓DDC
LPF
20MHz
ADC
100MS/s
↓DDC
Receive Control
Analog Radio Frequency
Digital Baseband

# Demo: Transmit a signal

# Find USRP

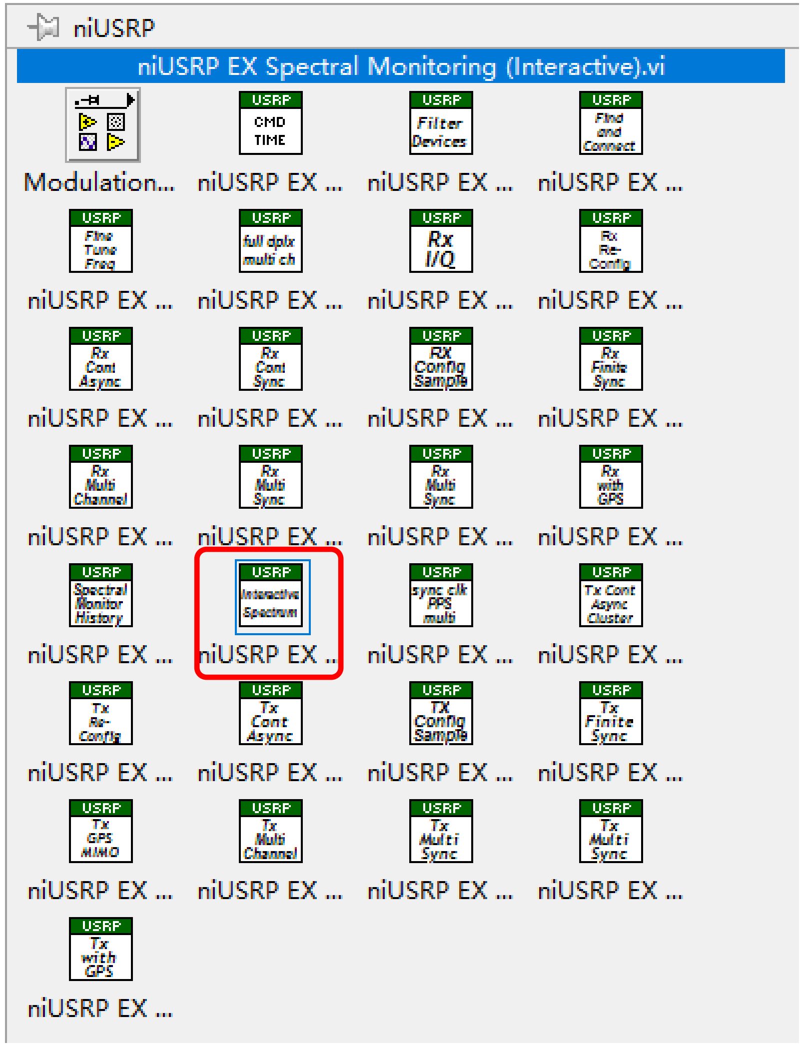


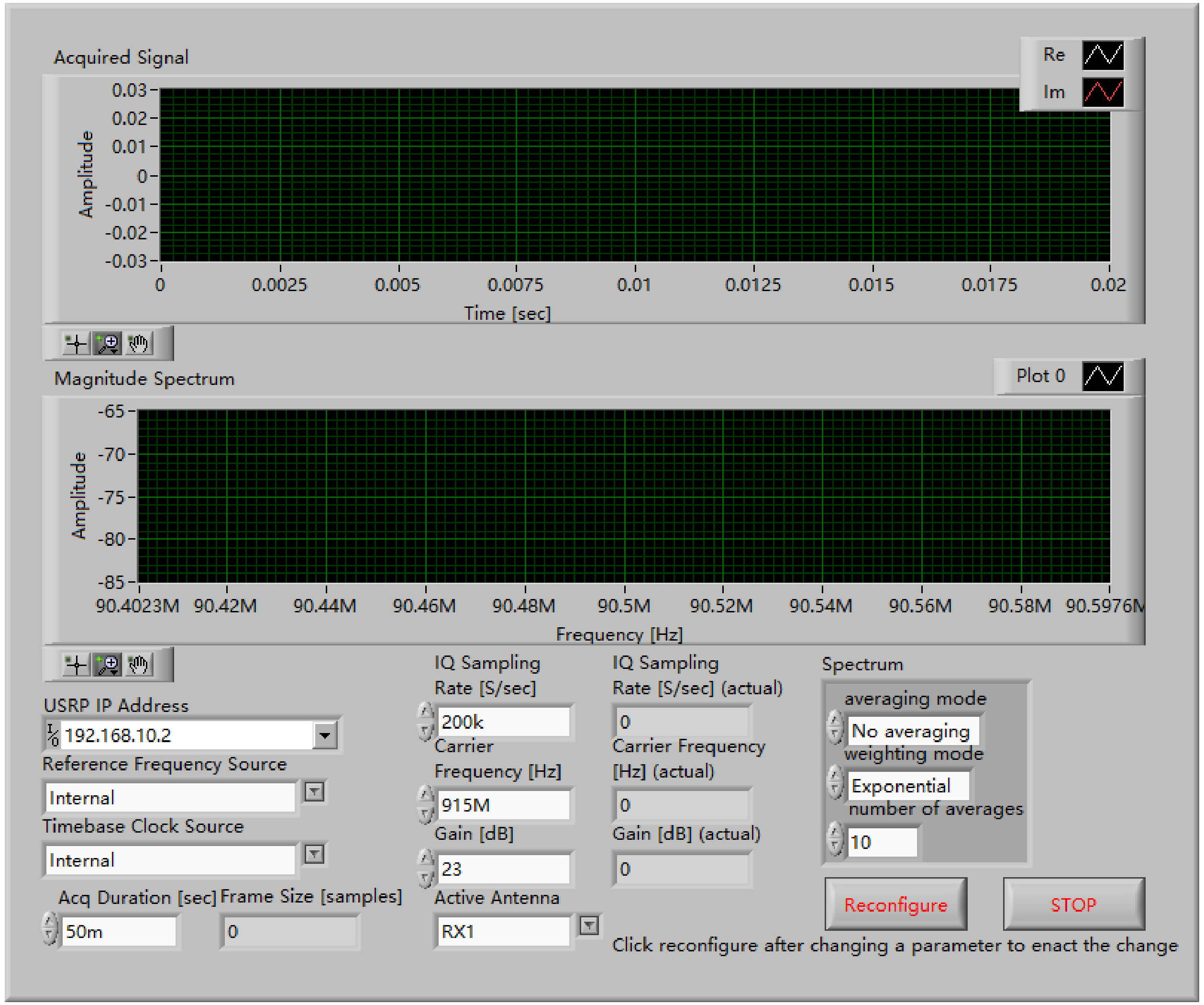




Host computer's IP:
**192.168.10.1**

# USRP Spectral Monitor Example

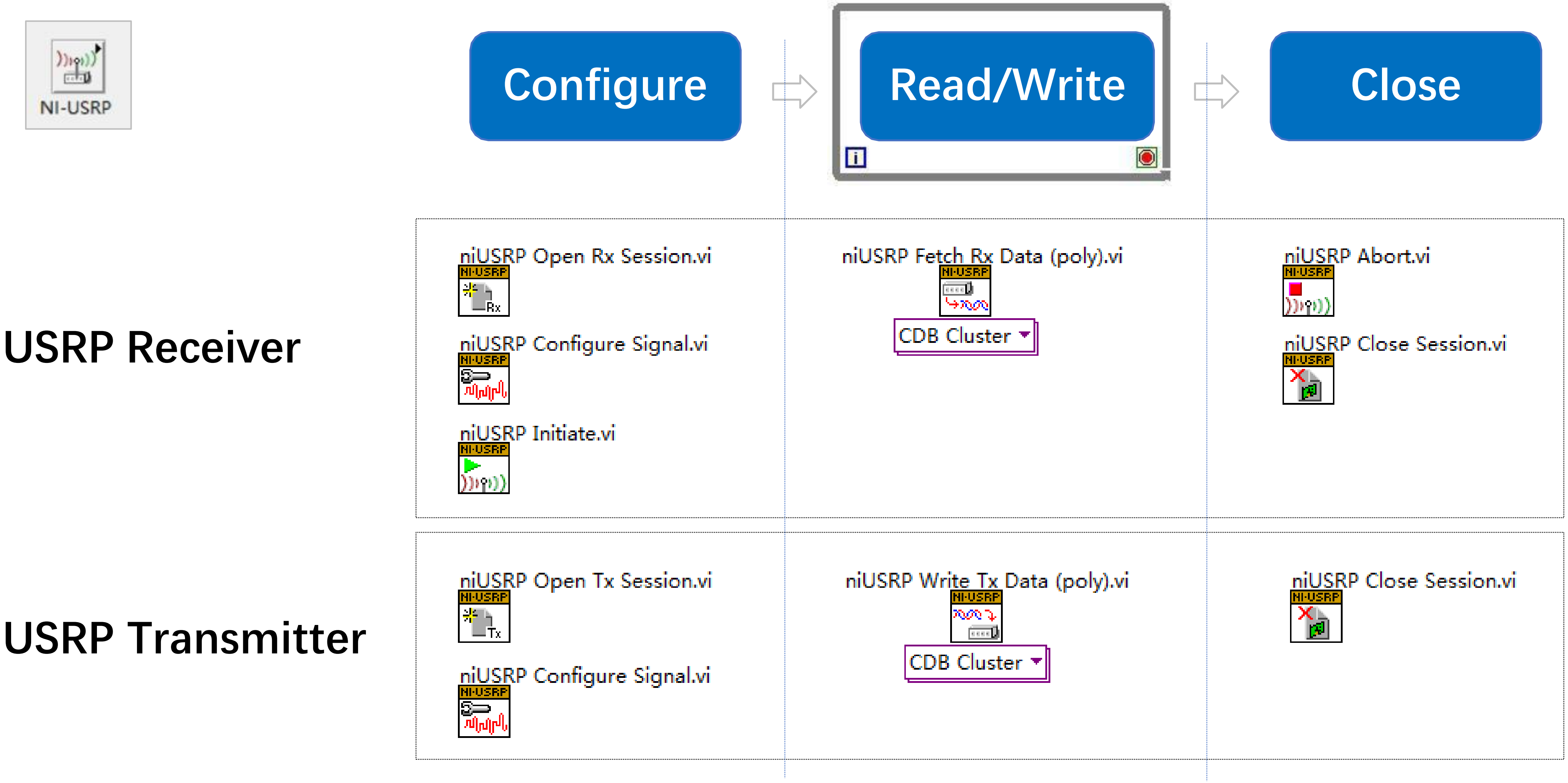
Right Click->Instrument I/O->Instrument Drivers->NI-USRP->Examples



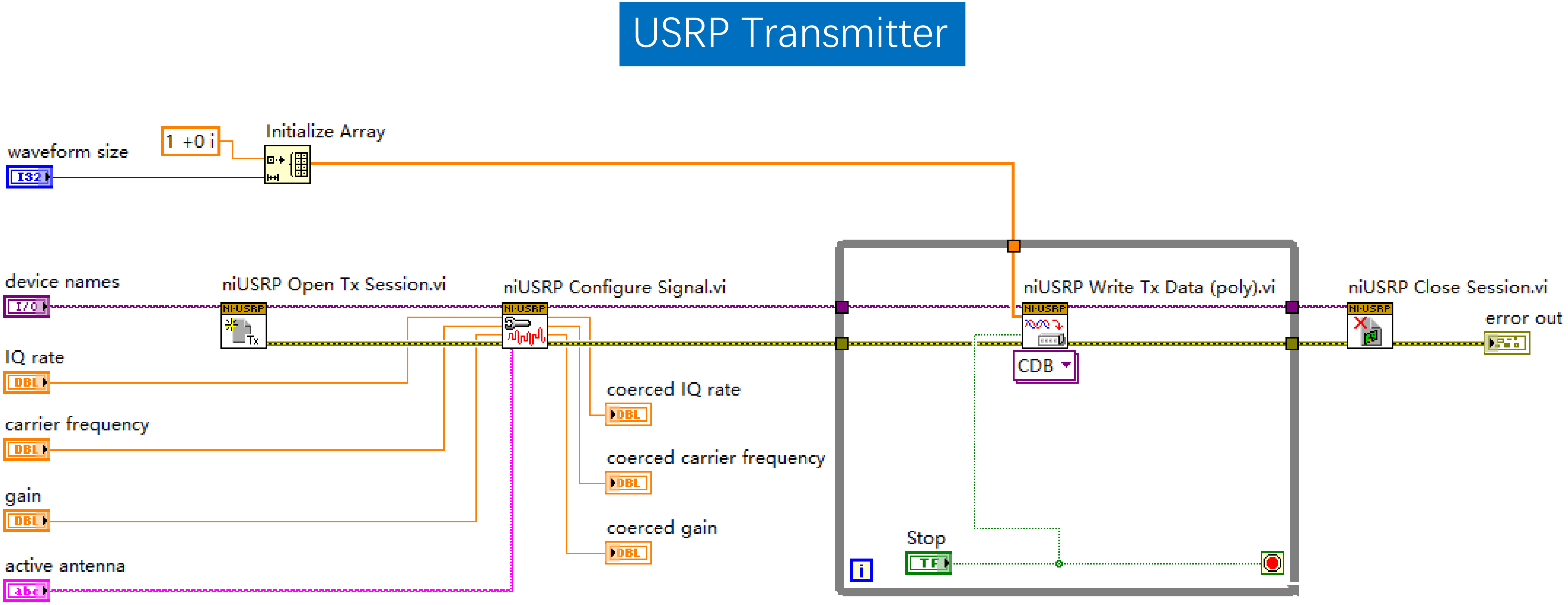



# Exercise: USRP Transceiver

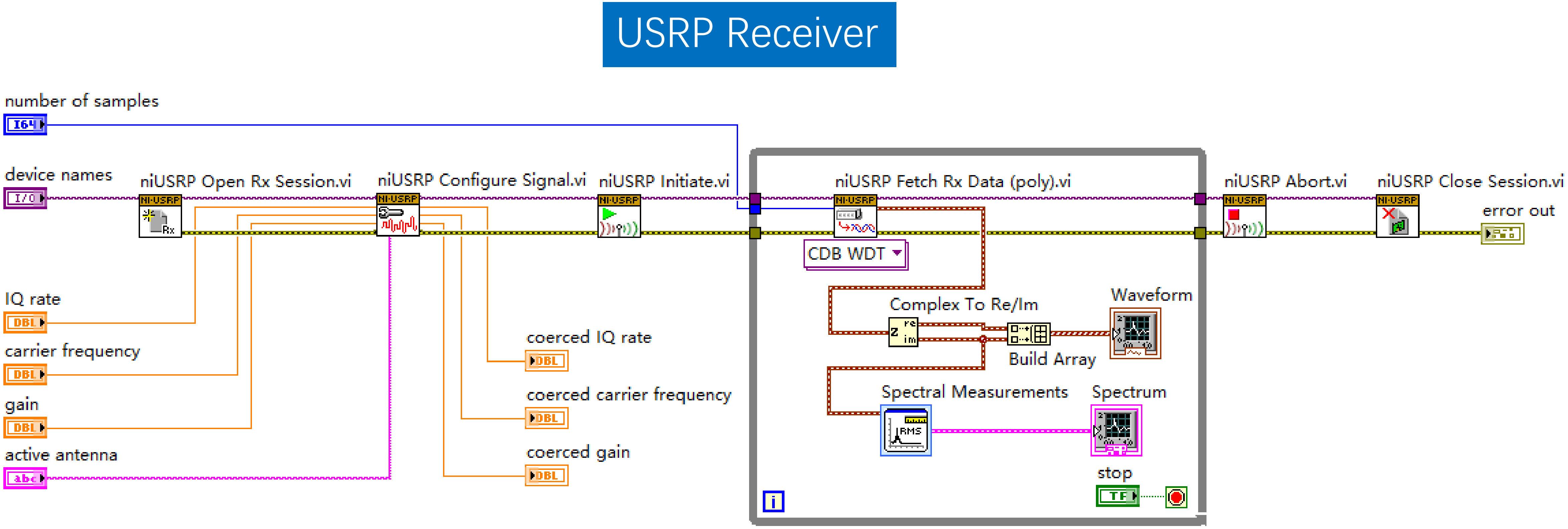
# Most-used USRP functions



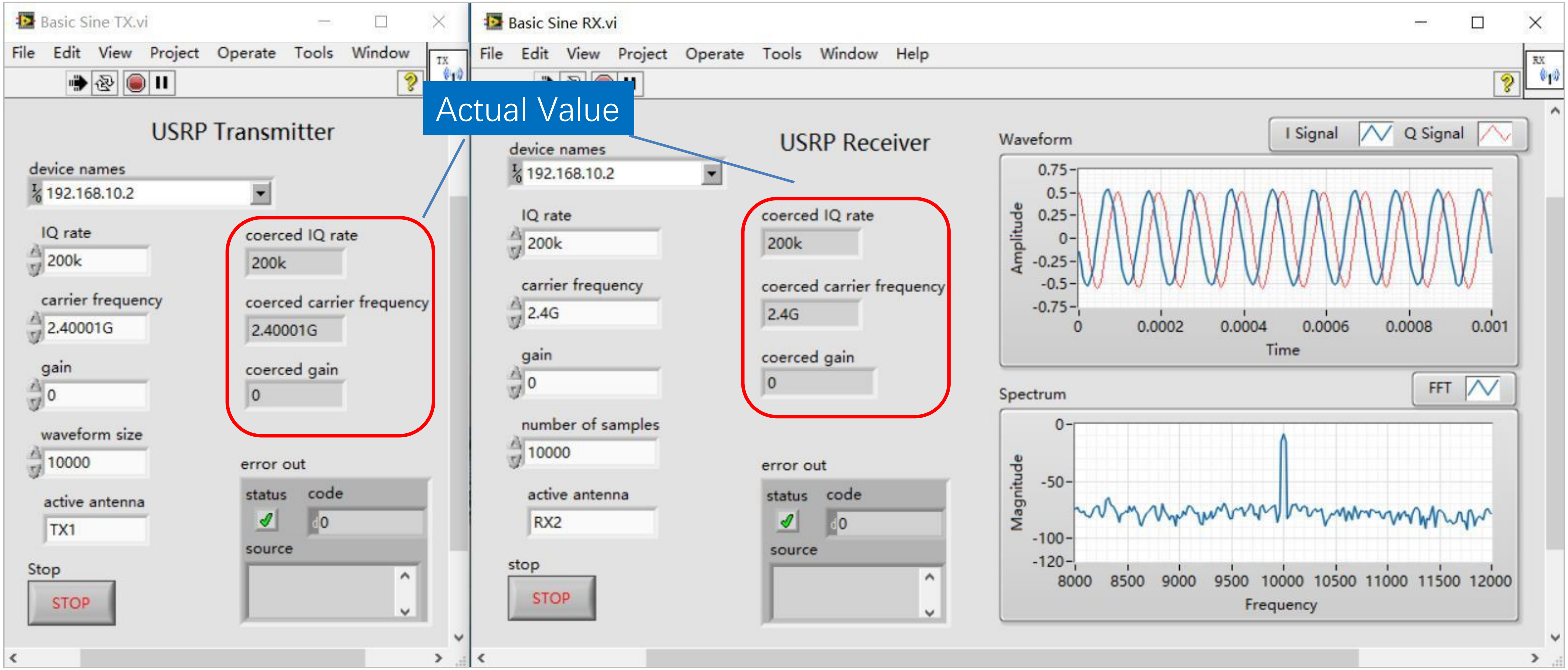
# Block Diagram of the Transmitter



# Block Diagram of the Receiver



# Configuration Parameters in Front Panel



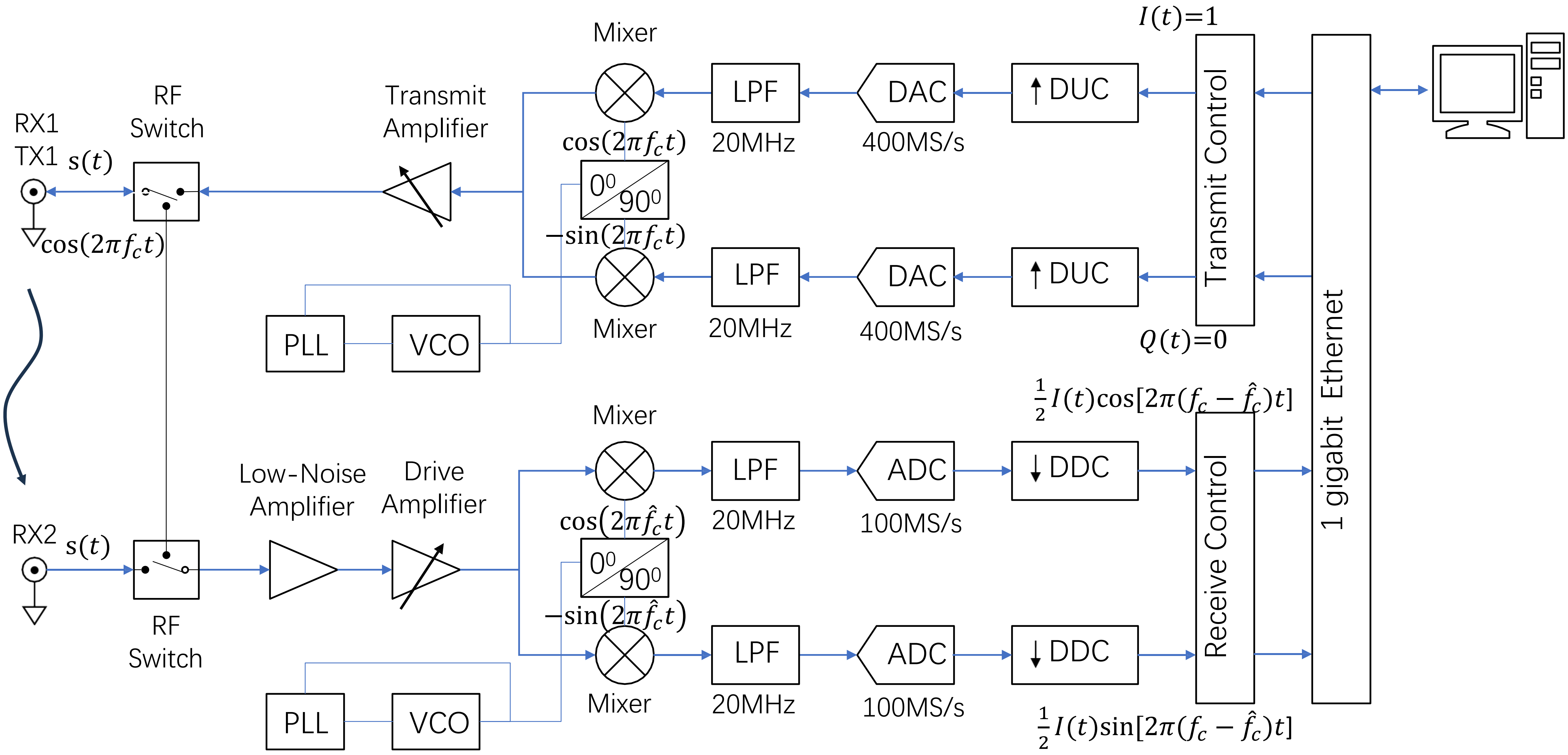
# Complex Baseband

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

$$s_l(t) = s_I(t) + js_Q(t)$$

$$s_I(t) = a(t)cos(\varphi)$$

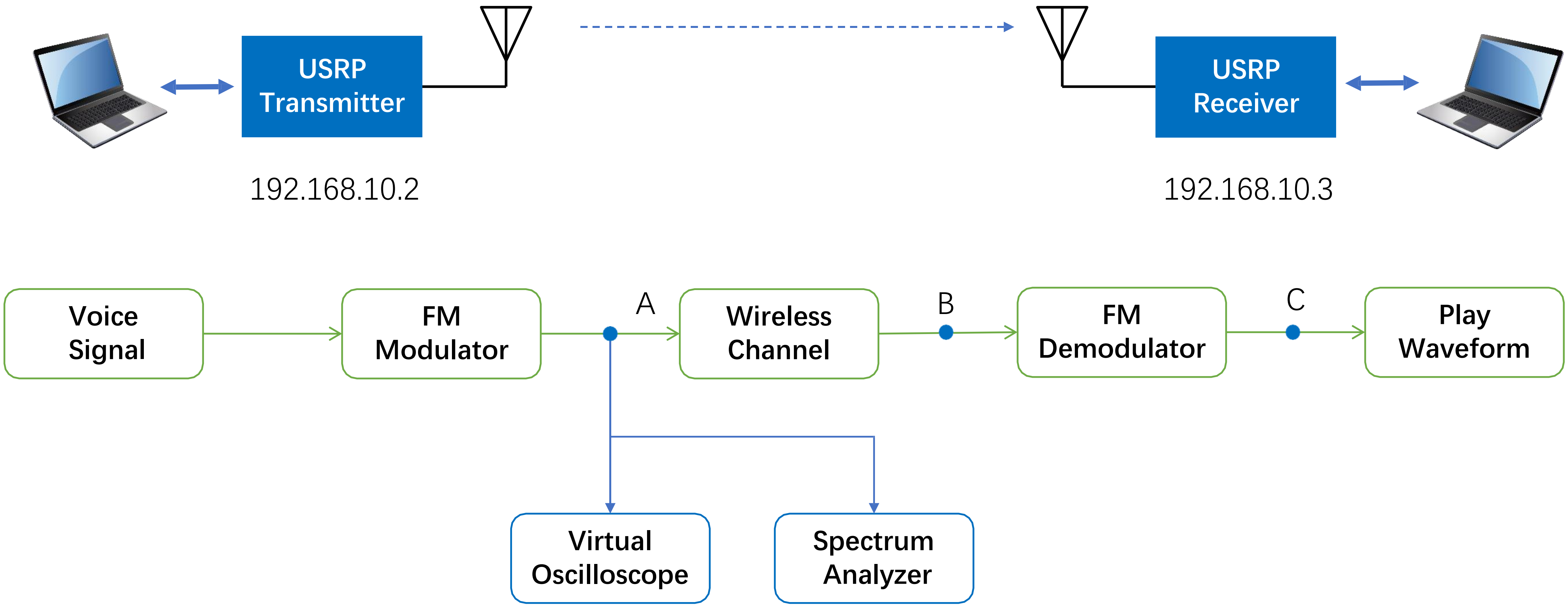
$$s_Q(t) = a(t)sin(\varphi)$$

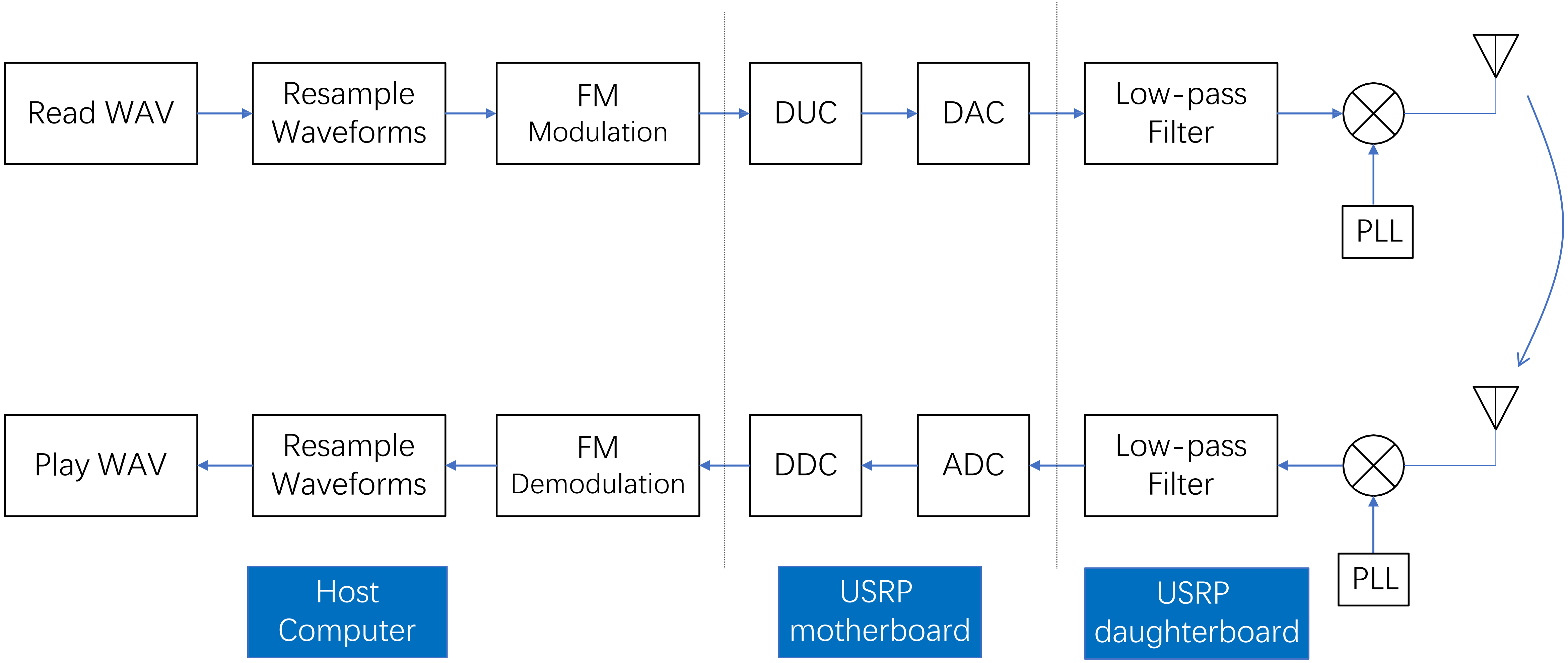


Mixer
LPF
DAC
DUC
$I(t)$=1
Transmit Control
1 gigabit Ethernet
RF Switch
Transmit Amplifier
RX1
TX1
$s(t)$
$\cos(2\pi f_c t)$
20MHz
400MS/s
$0^0$
$90^0$
$-\sin(2\pi f_c t)$
$\cos(2\pi f_c t)$
PLL
VCO
Mixer
20MHz
400MS/s
$Q(t)$=0
$\frac{1}{2}I(t)\cos[2\pi(f_c-\hat{f}_c)t]$
Mixer
Low-Noise Amplifier
Drive Amplifier
LPF
ADC
DDC
Receive Control
$\cos(2\pi \hat{f}_c t)$
20MHz
100MS/s
RX2
$s(t)$
$0^0$
$90^0$
$-\sin(2\pi \hat{f}_c t)$
RF Switch
PLL
VCO
Mixer
20MHz
100MS/s
$\frac{1}{2}I(t)\sin[2\pi(f_c-\hat{f}_c)t]$

# Voice Transmission using USRP

# System Model




Read WAV
Resample Waveforms
FM Modulation
DUC
DAC
Low-pass Filter
PLL
Play WAV
Resample Waveforms
FM Demodulation
DDC
ADC
Low-pass Filter
PLL
Host Computer
USRP motherboard
USRP daughterboard

# Modulation - Complex Baseband

Baseband

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

$$s_I(t) = a(t)cos(\varphi)$$

$$s_Q(t) = a(t)sin(\varphi)$$

$$s_l(t) = s_I(t) + js_Q(t)$$

Complex Baseband

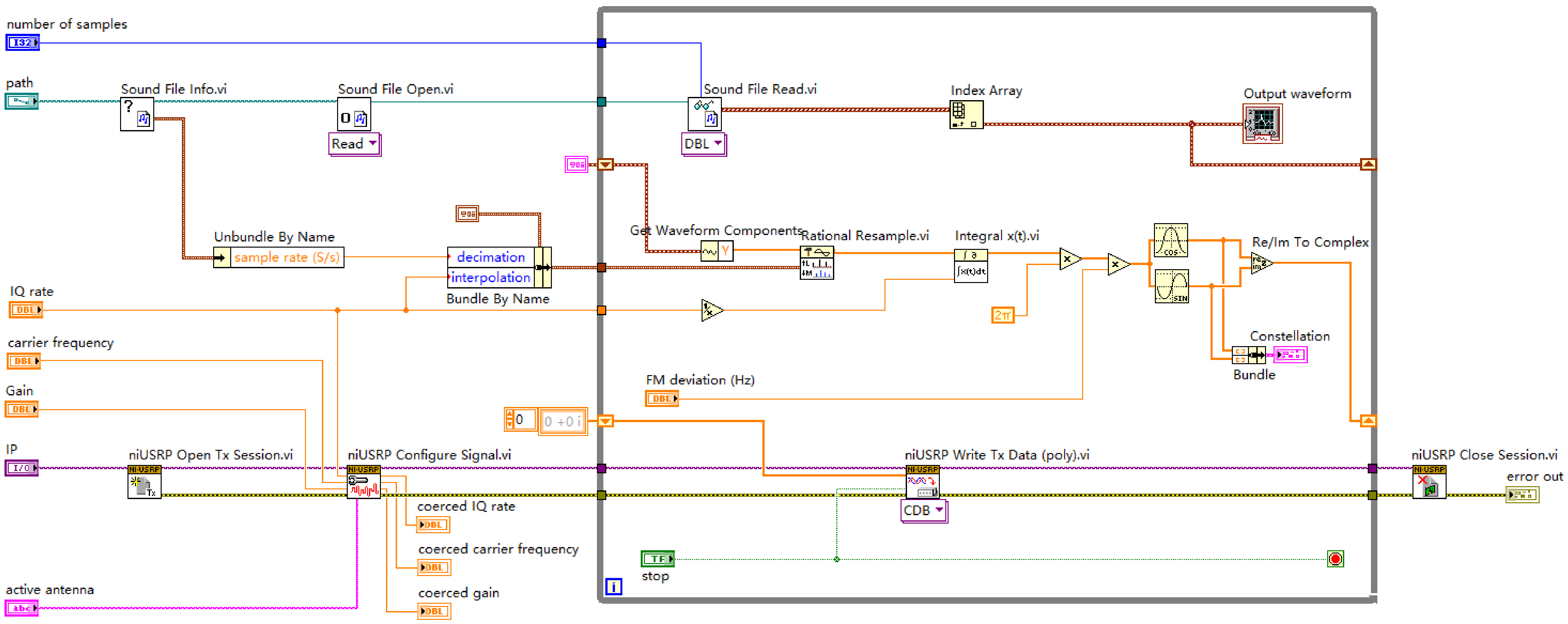
$$s(nT_s) = cos[2\pi f_c t + 2\pi \int k_f m(nT_s)dt]$$

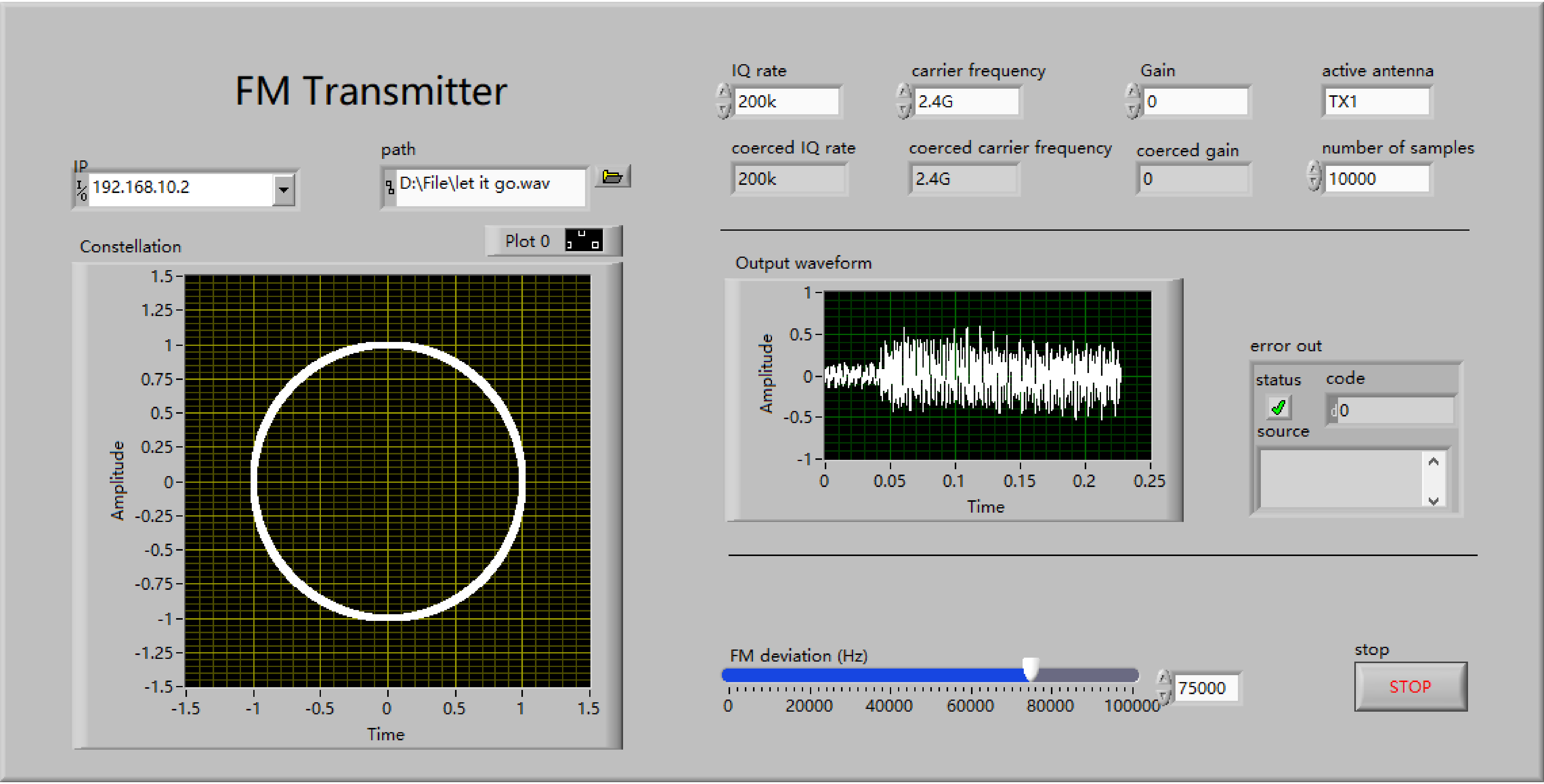
$$s_I(nT_s) = A_c cos(2\pi \int k_f m(nT_s)dt)$$

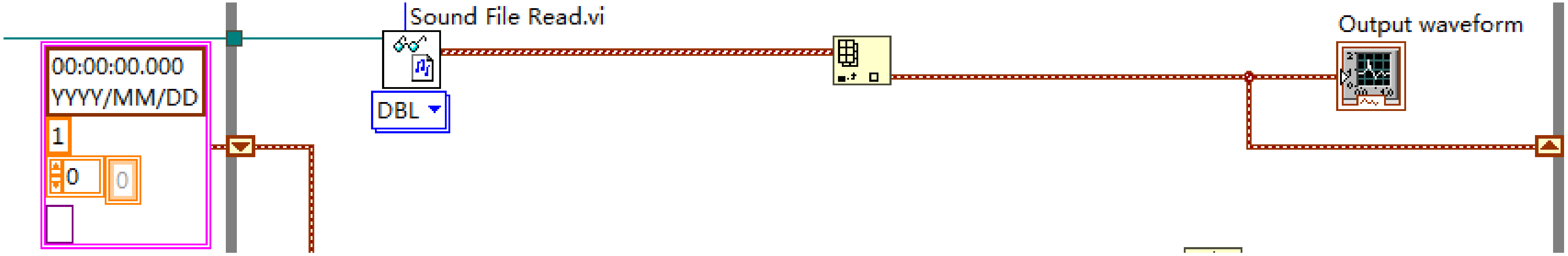
$$s_Q(nT_s) = A_c sin(2\pi \int k_f m(nT_s)dt)$$

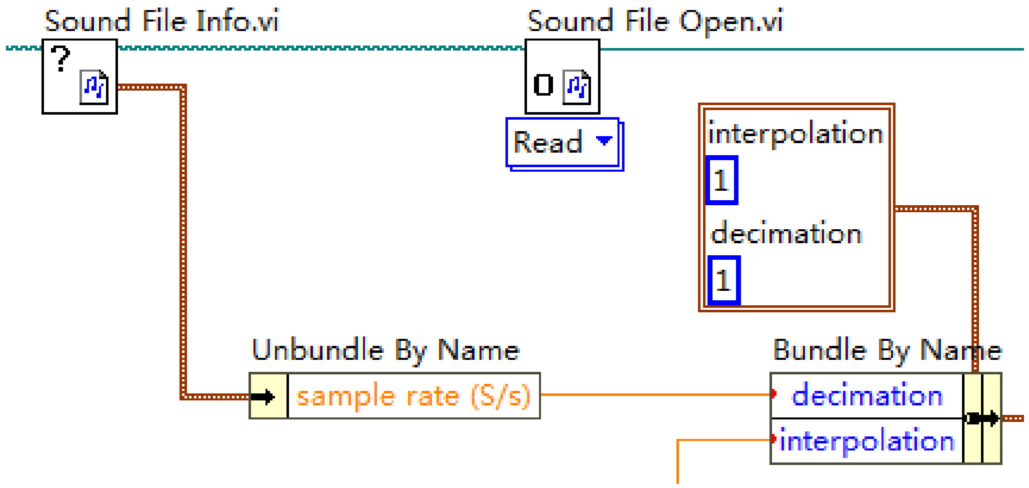
$$s_l(nT_s) = s_I(nT_s) + js_Q(nT_s)$$

**FM** Complex Baseband


number of samples
path
Sound File Info.vi
Sound File Open.vi
Read
Sound File Read.vi
DBL
Index Array
Output waveform
Unbundle By Name
sample rate (S/s)
decimation
interpolation
Bundle By Name
Get Waveform Components
Rational Resample.vi
Integral x(t).vi
Re/Im To Complex
IQ rate
2π
Constellation
Bundle
carrier frequency
FM deviation (Hz)
Gain
IP
niUSRP Open Tx Session.vi
niUSRP Configure Signal.vi
niUSRP Write Tx Data (poly).vi
CDB
niUSRP Close Session.vi
error out
coerced IQ rate
coerced carrier frequency
coerced gain
stop
active antenna


FM Transmitter
IQ rate
200k
carrier frequency
2.4G
Gain
0
active antenna
TX1
coerced IQ rate
200k
coerced carrier frequency
2.4G
coerced gain
0
number of samples
10000
IP
192.168.10.2
path
D:\File\let it go.wav
Constellation
Plot 0
1.5
1.25
1
0.75
0.5
0.25
0
-0.25
-0.5
-0.75
-1
-1.25
-1.5
Amplitude
-1.5
-1
-0.5
0
0.5
1
1.5
Time
Output waveform
1
0.5
0
-0.5
-1
Amplitude
0
0.05
0.1
0.15
0.2
0.25
Time
error out
status
code
0
source
FM deviation (Hz)
0
20000
40000
60000
80000
100000
75000
stop
STOP


Sound File Read.vi
Output waveform
00:00:00.000
YYYY/MM/DD
1
0
0
DBL


Sound File Info.vi
Sound File Open.vi
Read
interpolation
1
decimation
1
Unbundle By Name
sample rate (S/s)
Bundle By Name
decimation
interpolation

# Demodulation - Complex Baseband

Baseband

$$s(nT_s) = cos[2\pi f_c t + 2\pi \int k_f m(nT_s)dt]$$

$$s_I(nT_s) = A_c cos(2\pi \int k_f m(nT_s)dt)$$

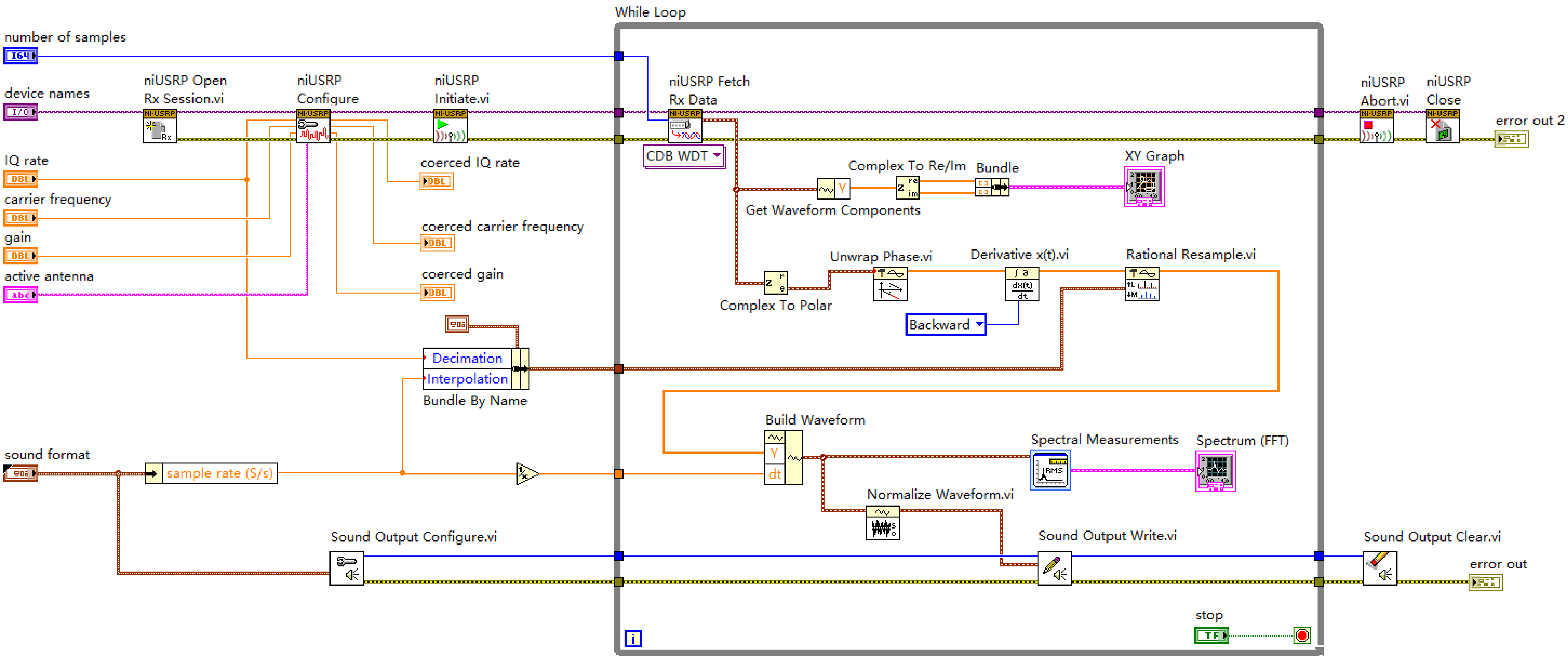
$$s_Q(nT_s) = A_c sin(2\pi \int k_f m(nT_s)dt)$$

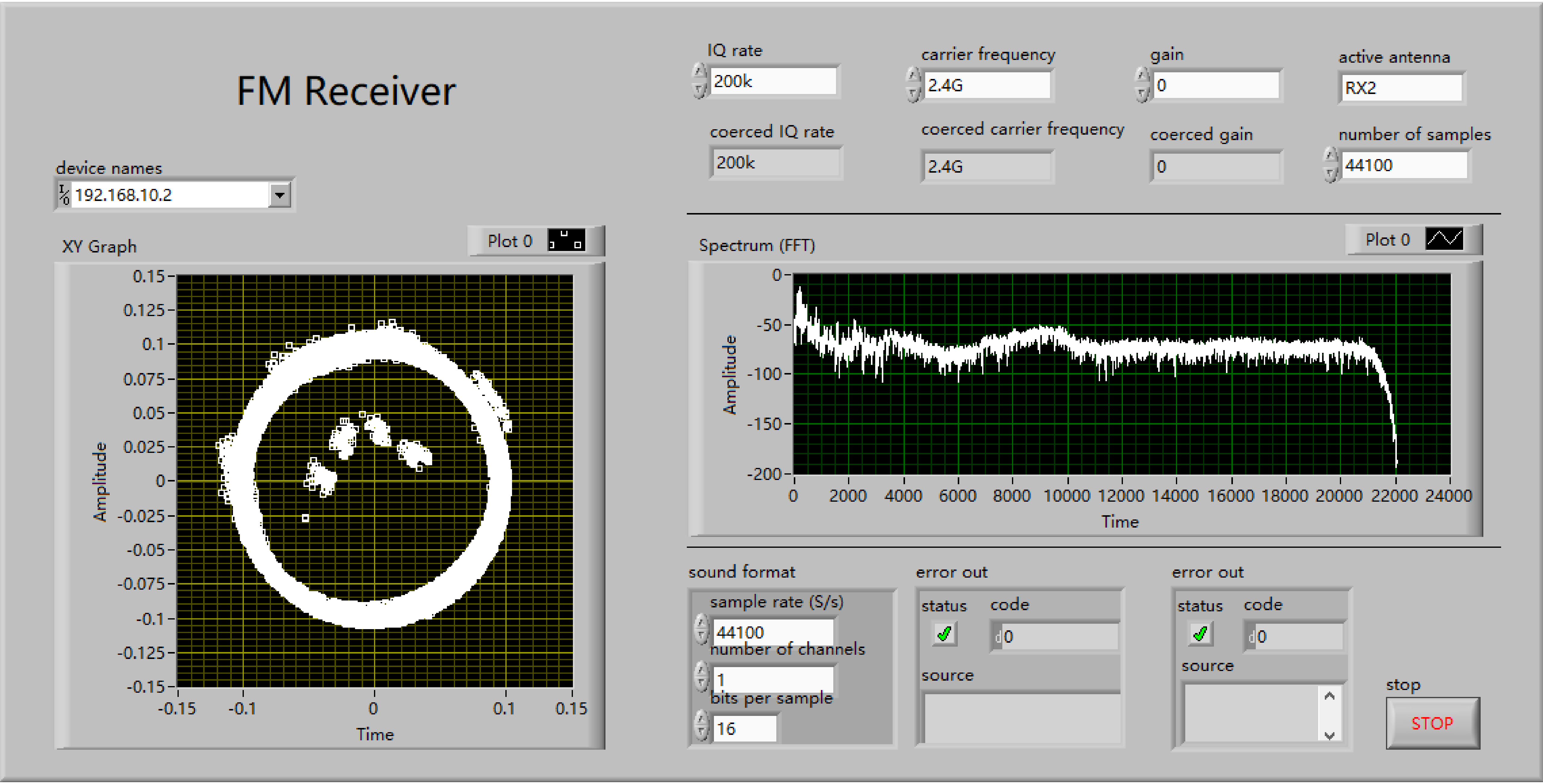
$$s_l(nT_s) = s_I(nT_s) + js_Q(nT_s)$$

$$2\pi \int k_f m(nT_s)dt = atan\left(\frac{s_Q(nT_s)}{s_I(nT_s)}\right)$$

$$m(nT_s) = \frac{1}{2\pi k_f}\frac{d}{dt}\left[atan\left(\frac{s_Q(nT_s)}{s_I(nT_s)}\right)\right]$$

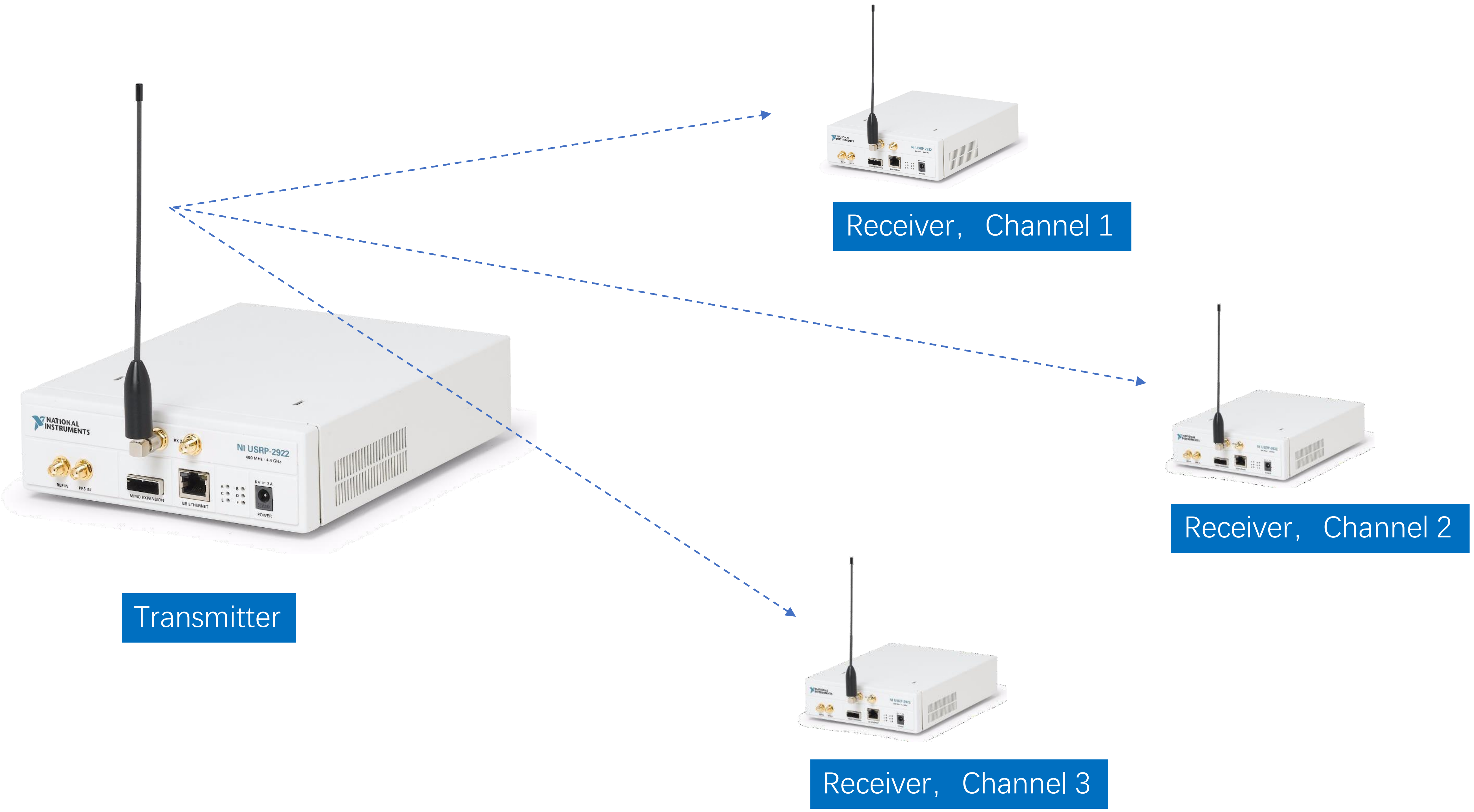
**FM** Complex Baseband


While Loop
number of samples
device names
niUSRP Open
Rx Session.vi
niUSRP
Configure
niUSRP
Initiate.vi
niUSRP Fetch
Rx Data
CDB WDT
niUSRP
Abort.vi
niUSRP
Close
error out 2
IQ rate
carrier frequency
gain
active antenna
coerced IQ rate
coerced carrier frequency
coerced gain
Complex To Re/Im
Bundle
XY Graph
Get Waveform Components
Unwrap Phase.vi
Derivative x(t).vi
Rational Resample.vi
Complex To Polar
Backward
Decimation
Interpolation
Bundle By Name
Build Waveform
Spectral Measurements
Spectrum (FFT)
sound format
sample rate (S/s)
Normalize Waveform.vi
Sound Output Configure.vi
Sound Output Write.vi
Sound Output Clear.vi
error out
stop

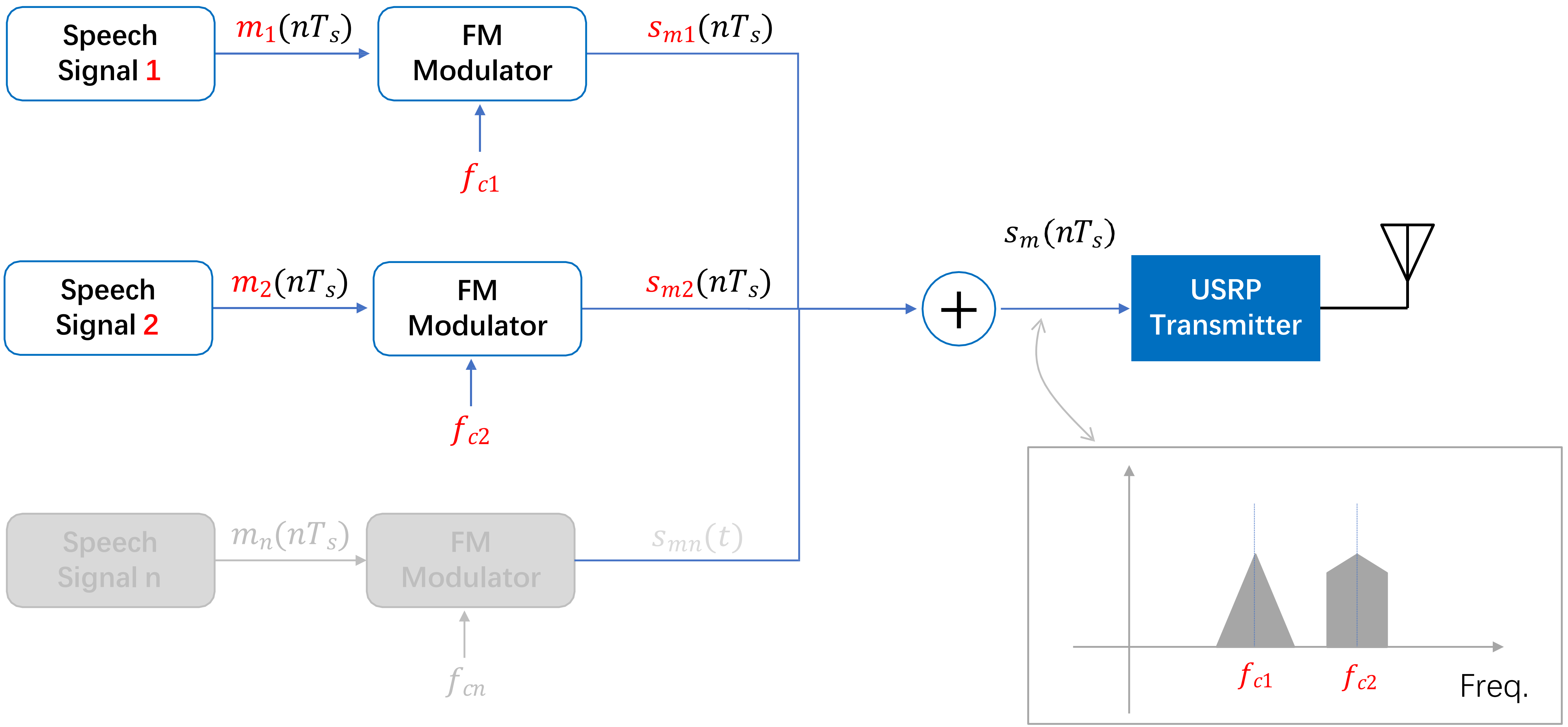


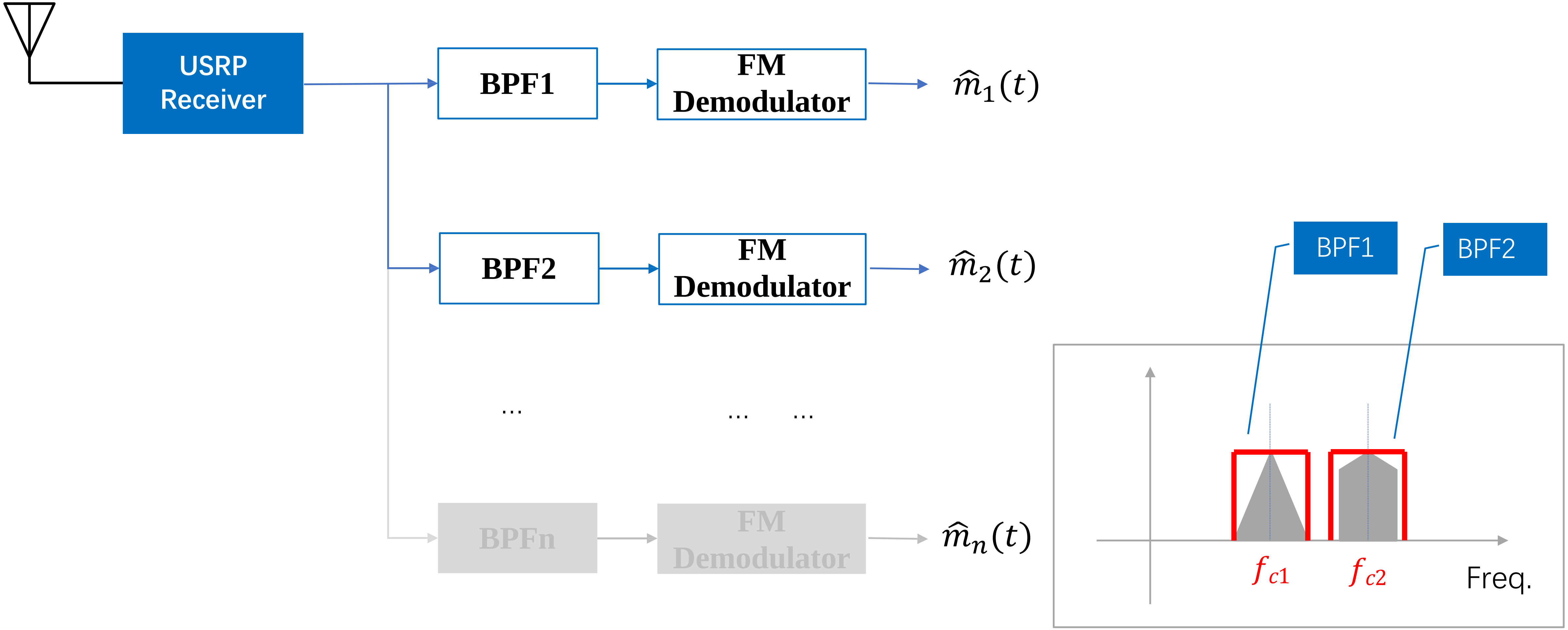
FM Receiver
IQ rate
200k
coerced IQ rate
200k
carrier frequency
2.4G
coerced carrier frequency
2.4G
gain
0
coerced gain
0
active antenna
RX2
number of samples
44100
device names
192.168.10.2
XY Graph
Plot 0
Amplitude
Time
Spectrum (FFT)
Plot 0
Amplitude
Time
sound format
sample rate (S/s)
44100
number of channels
1
bits per sample
16
error out
status
code
0
source
error out
status
code
0
source
stop
STOP

# Demo: Multi-channel System



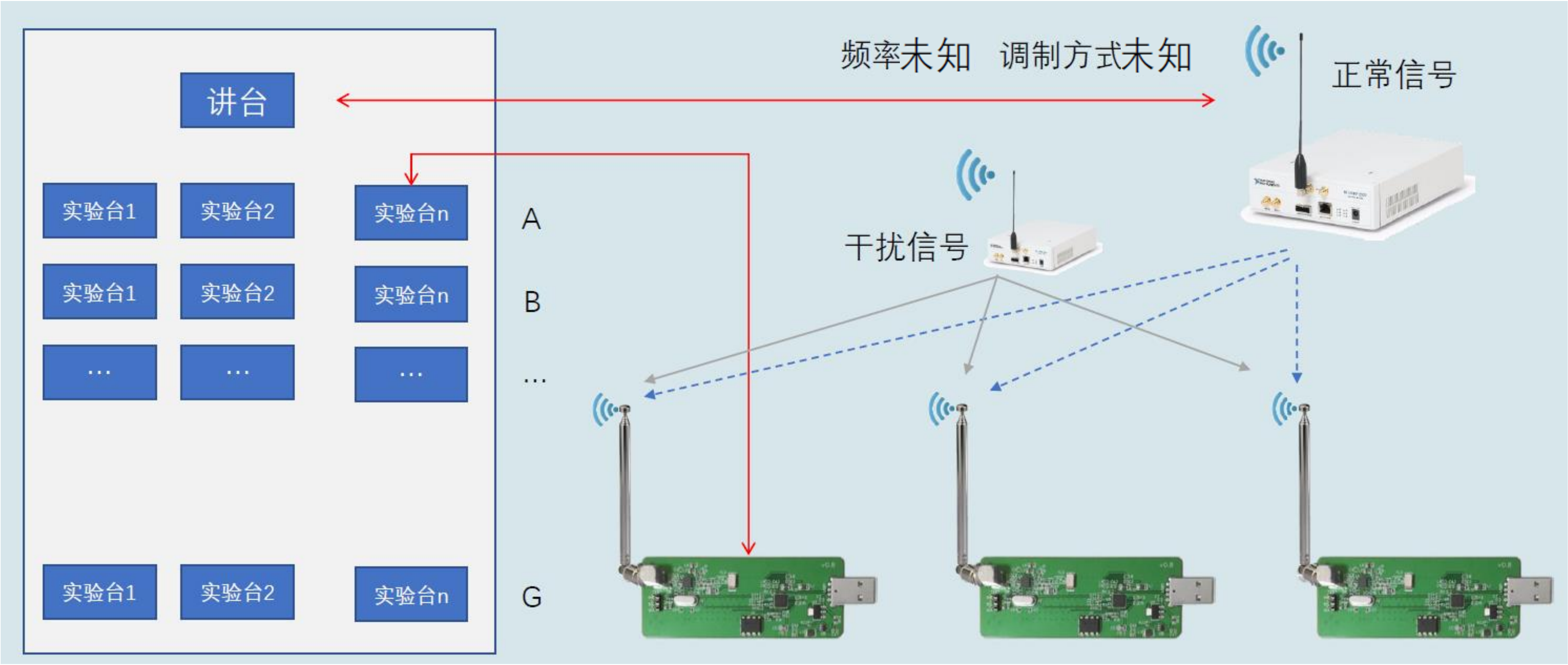
Receiver， Channel 1
Receiver， Channel 2
Transmitter
Receiver， Channel 3
NI USRP-2922
NATIONAL INSTRUMENTS


Speech Signal 1
$m_1(nT_s)$
FM Modulator
$s_{m1}(nT_s)$
$f_{c1}$
Speech Signal 2
$m_2(nT_s)$
FM Modulator
$s_{m2}(nT_s)$
$f_{c2}$
Speech Signal n
$m_n(nT_s)$
FM Modulator
$s_{mn}(t)$
$f_{cn}$
$s_m(nT_s)$
USRP Transmitter
$f_{c1}$
$f_{c2}$
Freq.


USRP Receiver
BPF1
FM Demodulator
$\hat{m}_1(t)$
BPF2
FM Demodulator
$\hat{m}_2(t)$
...
... ...
BPFn
FM Demodulator
$\hat{m}_n(t)$
BPF1
BPF2
$f_{c1}$
$f_{c2}$
Freq.

# Homework

Please consider how to demodulate AM and DSB signals.



讲台
实验台1
实验台2
实验台n
A
B
…
G
频率未知 调制方式未知
正常信号
干扰信号