Digital Communications Laboratory

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Chapter Two

Analog Modulations and Demodulations

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Section A

Amplitude Modulations and Demodulations

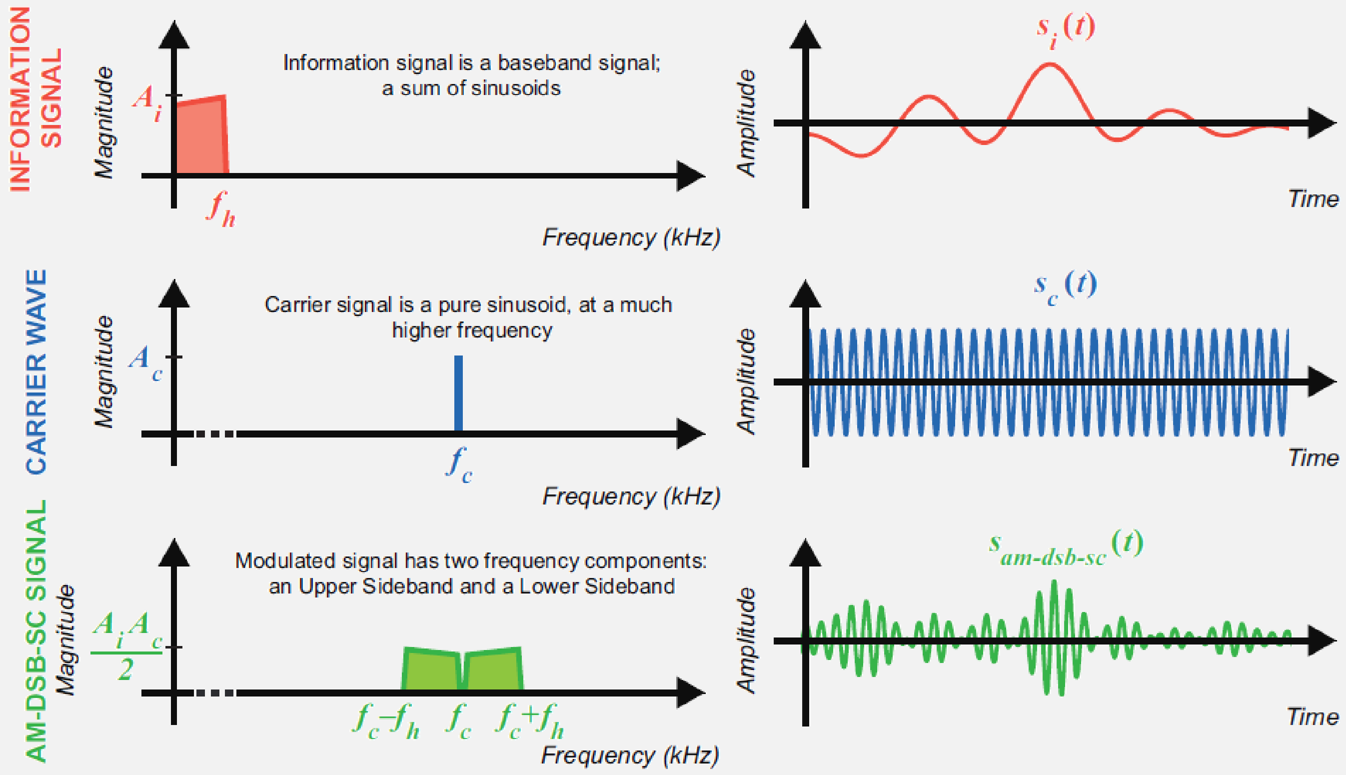
AM-DSB-SC Modulation

Expressions:

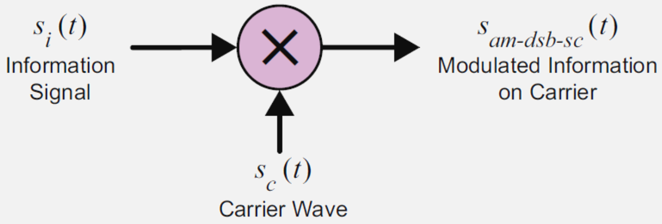
$$\left\{\begin{array}{l} s_i(t) = A_i\cos(2\pi f_i t) = A_i\cos(\omega_i t) \\ s_c(t) = A_c\cos(2\pi f_c t) = A_c\cos(\omega_c t) \end{array}\right.$$

$$s_{am-dsb-sc}(t) = A_i\cos(\omega_i t)\,A_c\cos(\omega_c t)$$

$$s_{am-dsb-sc}(t) = \frac{A_i A_c}{2}\left(\cos(\omega_c - \omega_i)t + \cos(\omega_c + \omega_i)t\right)$$

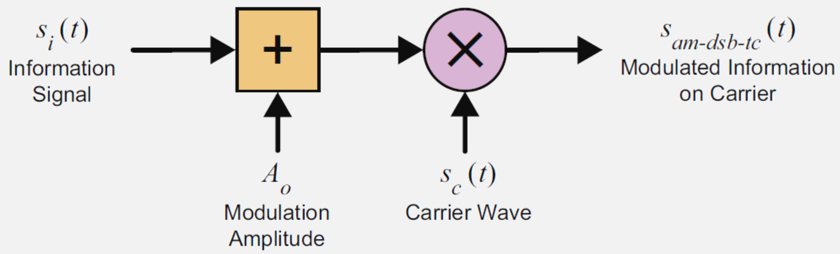


Modulator:



AM-DSB-TC Modulation

Modulator:



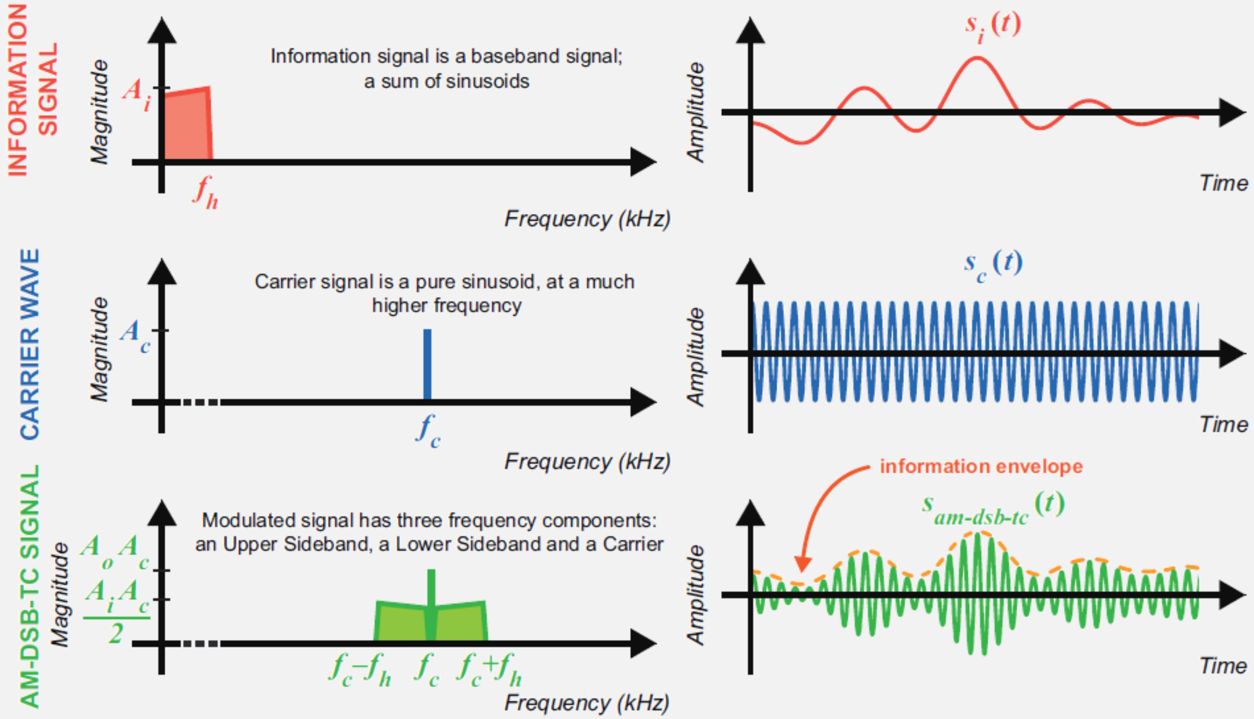
Expressions:

$$\begin{cases} s_i(t) = A_i\cos(2\pi f_i t) = A_i\cos(\omega_i t) \\ s_c(t) = A_c\cos(2\pi f_c t) = A_c\cos(\omega_c t) \end{cases}$$

$$s_{am-dsb-tc}(t) = \left[A_o + A_i\cos(\omega_i t) \right] A_c\cos(\omega_c t)$$

$$s_{am-dsb-tc}(t) = A_o\left[1 + m\cos(\omega_i t) \right] A_c\cos(\omega_c t)$$

$$= A_o A_c \cos(\omega_c t) + \frac{A_o A_c m}{2}\left(\cos(\omega_c - \omega_i)t + \cos(\omega_c + \omega_i)t \right)$$



AM Modulation Index: $m = \dfrac{A_i}{A_o}$

AM-SSB Modulation

Expressions:

$$s_{am-ssb}(t) = s_i(t)\,\Re e\big[s_c(t)\big] \mp \overline{s_i(t)}\,\Im m\big[s_c(t)\big]$$

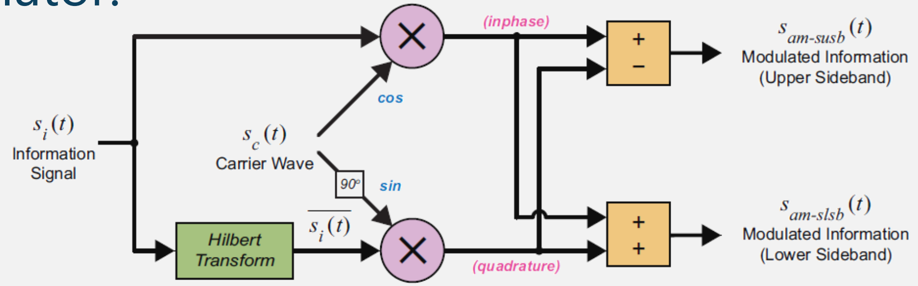
$$\begin{cases} s_i(t) = A_i\cos(2\pi f_i t) = A_i\cos(\omega_i t) \\ s_c(t) = A_c\cos(2\pi f_c t) + A_c\sin(2\pi f_c t) = A_c\cos(\omega_c t) + A_c\sin(\omega_c t) \end{cases}$$

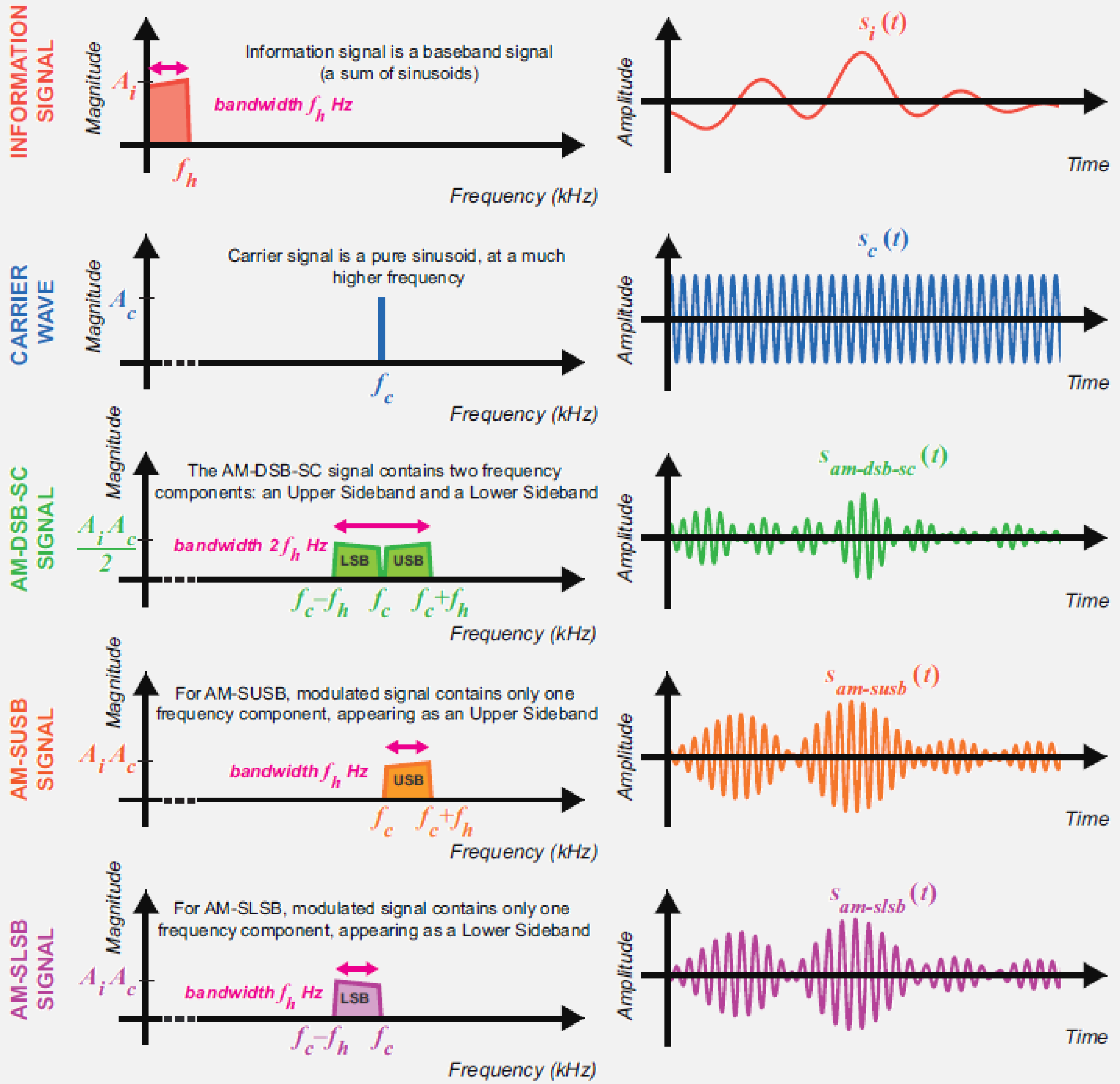
$$s_{am-ssb}(t) = A_i\cos(\omega_i t)\,A_c\cos(\omega_c t) \mp A_i\sin(\omega_i t)\,A_c\sin(\omega_c t)$$

$$s_{am-ssb}(t) = \frac{A_i A_c}{2}\Big(\cos(\omega_c - \omega_i)t + \cos(\omega_c + \omega_i)t\Big)$$

$$\mp \frac{A_i A_c}{2}\Big(\cos(\omega_c - \omega_i)t - \cos(\omega_c + \omega_i)t\Big)$$

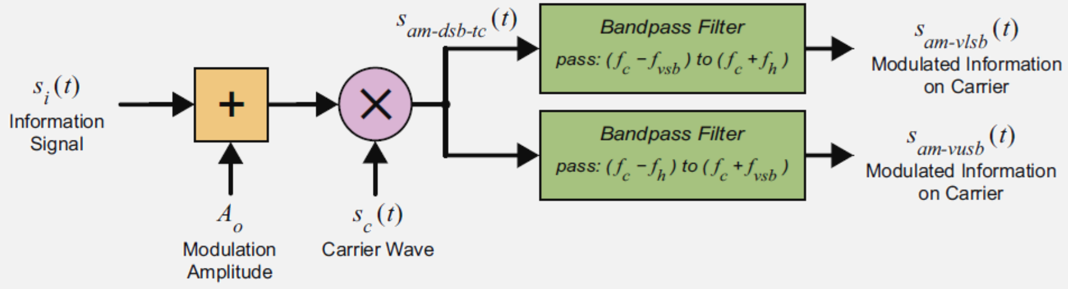
Modulator:

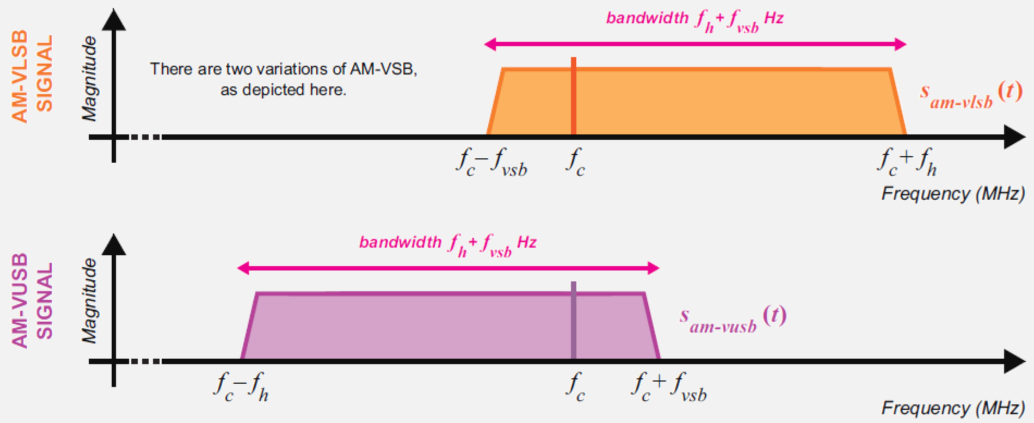




AM-VSB Modulation

Modulator:





Expression:

$$s_{am-vsb}(t) = BPF\left\{\left[A_o + s_i(t)\right] \times s_c(t)\right\}$$

Comparison of DSB, SSB, and VSB Modulations

Evaluation Table:

Parameter	AM-DSB	AM-SSB	AM-VSB
Power	Medium	Less	High
Bandwidth	2B	B	B<BW<2B
Usage	Radio broadcast	Radio broadcast	TV broadcast
Sideband Suppression	No	One side completely	One side partially
TX Efficiency	Moderate	Maximum	Moderate

Note: Each technique has some advantages and disadvantages, so based on deployment factor, a modulation should be selected.

Section B

Angle Modulations and Demodulations

Conventional PM and FM

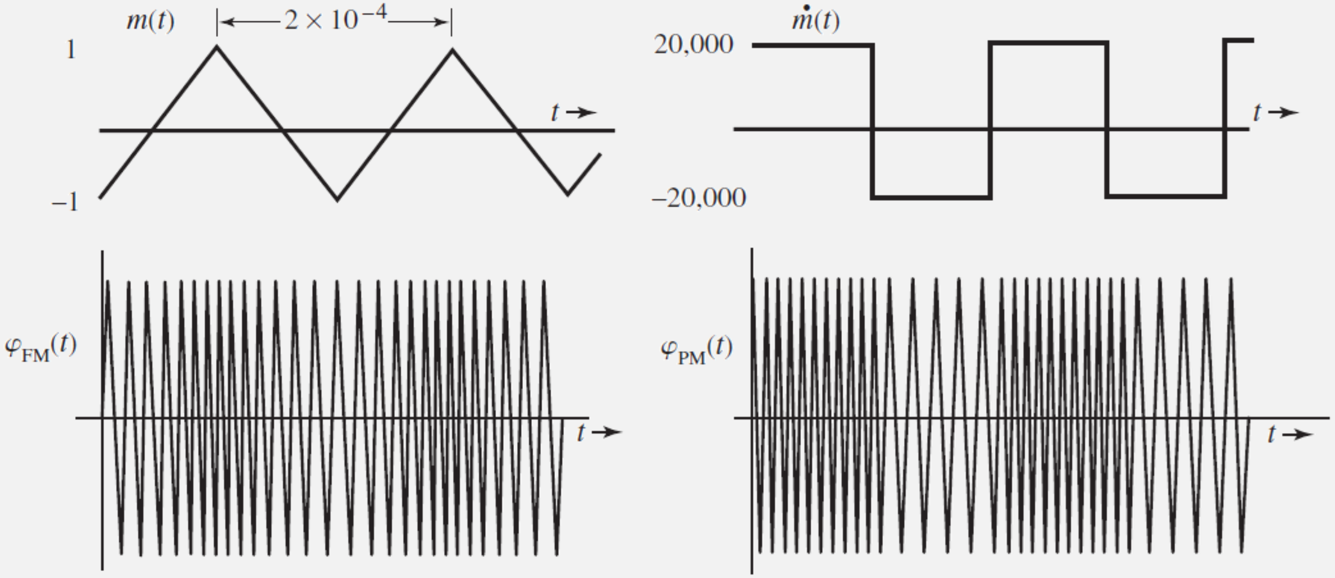
Expressions:

PM: $$\varphi_{\text{PM}}(t) = A\cos[\omega_c t + k_p m(t)]$$

Instantaneous angular frequency for PM: $$\omega_i(t) = \frac{d\theta}{dt} = \omega_c + k_p \dot{m}(t)$$

Instantaneous angular frequency for FM: $$\omega_i(t) = \omega_c + k_f m(t)$$

FM: $$\varphi_{\text{FM}}(t) = A\cos\left[\omega_c t + k_f \int_{-\infty}^{t} m(\alpha)\, d\alpha\right]$$



Conventional FM

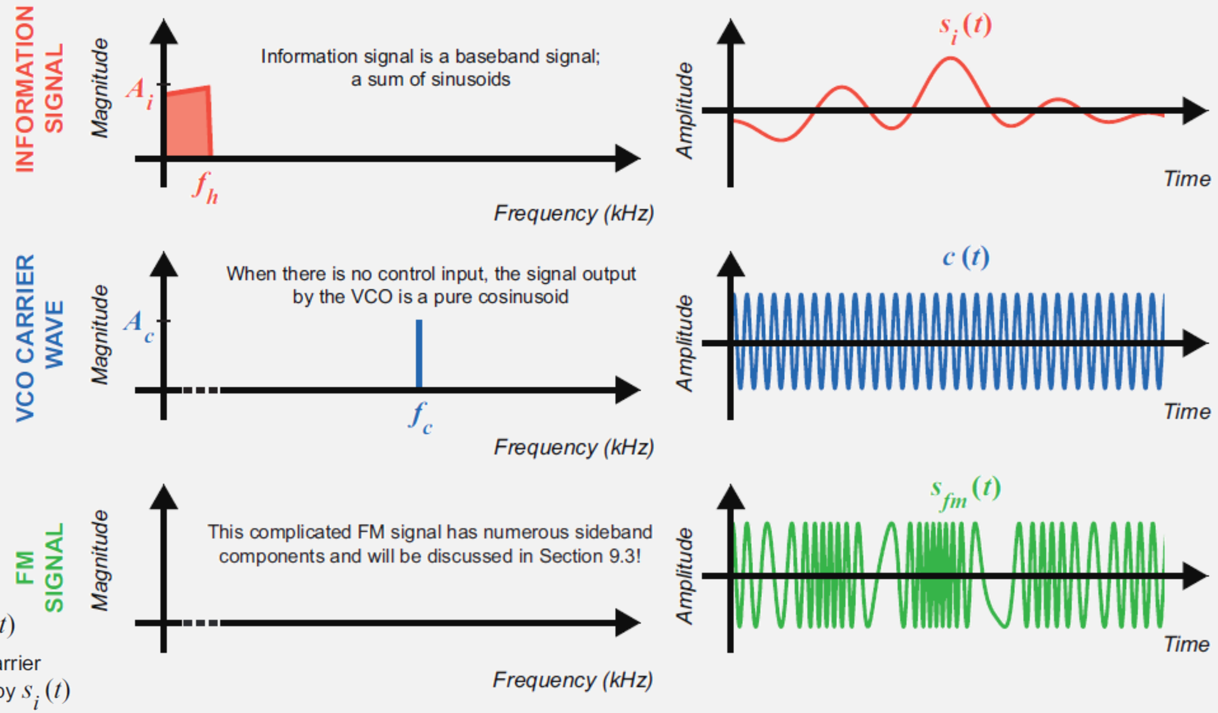
Expressions:

$$s_{fm}(t) = A_c \cos\left(\omega_c t + \theta_{fm}(t)\right) = A_c \cos\left(\omega_c t + 2\pi K_{fm} \times \int_{-\infty}^{t} s_i(t)\, dt\right)$$

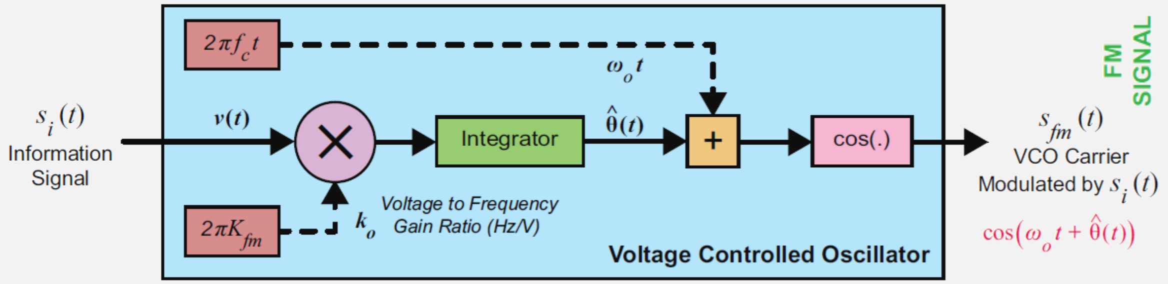
$$s_i(t) = A_i \cos(2\pi f_i t) = A_i \cos(\omega_i t)$$

$$s_{fm}(t) = A_c \cos\left(\omega_c t + \beta_{fm} \sin(\omega_i t)\right)$$

$$\omega_i = 2\pi f_i \qquad \omega_c = 2\pi f_c$$



Modulator:



Section C

Analog Phased-Lock Loop (APLL)

Analog PLL

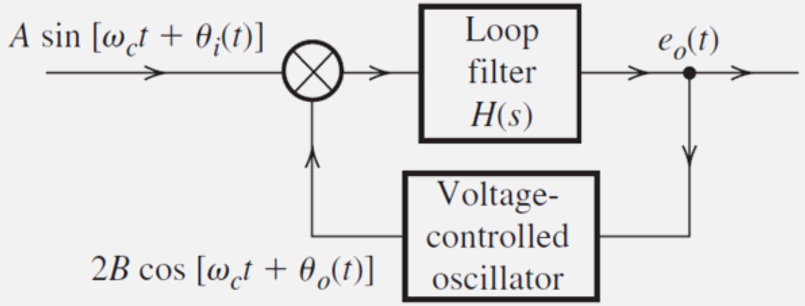
VCO:

Free-running angular frequency

Instantaneous angular frequency: $\omega(t) = \omega_c + ce_o(t)$

Output signal: $B\cos[\omega_c t + \theta_o(t)]$

$$\dot{\theta}_o(t) = ce_o(t) \quad \text{(A)}$$



Loop Filter:

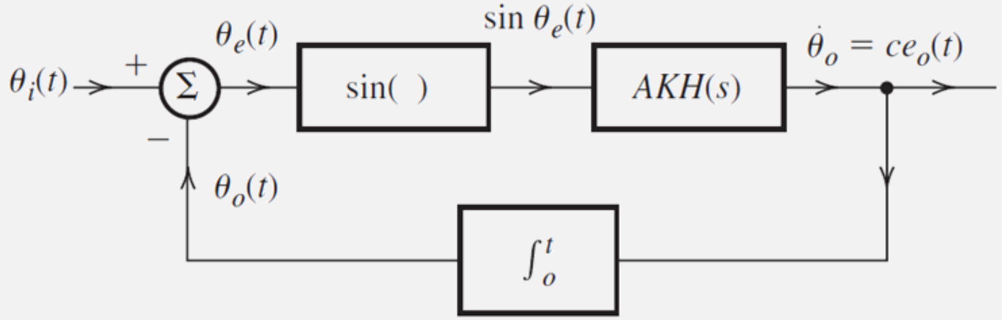
Input multiplied signal:

$$AB\sin(\omega_c t + \theta_i)\cos(\omega_c t + \theta_o) = \frac{AB}{2}[\sin(\theta_i - \theta_o) + \sin(2\omega_c t + \theta_i + \theta_o)]$$

Output signal:

$$e_o(t) = h(t) * \frac{1}{2}AB\sin[\theta_i(t) - \theta_o(t)]$$

$$= \frac{1}{2}AB\int_0^t h(t-x)\sin[\theta_i(x) - \theta_o(x)]\,dx \quad \text{(B)}$$



(A) → (B)

$$\dot{\theta}_o(t) = AK\int_0^t h(t-x)\sin\theta_e(x)\,dx$$

Phase error: $\theta_e(t) = \theta_i(t) - \theta_o(t)$

Section D

GNU Radio and SDR

GRC Example for AM-DSB-TC

Preferred GRC Blocks:

Transmitter	Wireless Channel	Receiver
Wav. file source	Channel model (AWGN)	Multiply
Signal source	-	Multiply constant
Low pass filter	-	Add
Multiply	-	Throttle
Multiply constant	-	Low pass filter
Add	-	Time sink
Throttle	-	Frequency sink
Time sink	-	Waterfall link
Frequency sink	-	Audio sink
Waterfall link	-	-

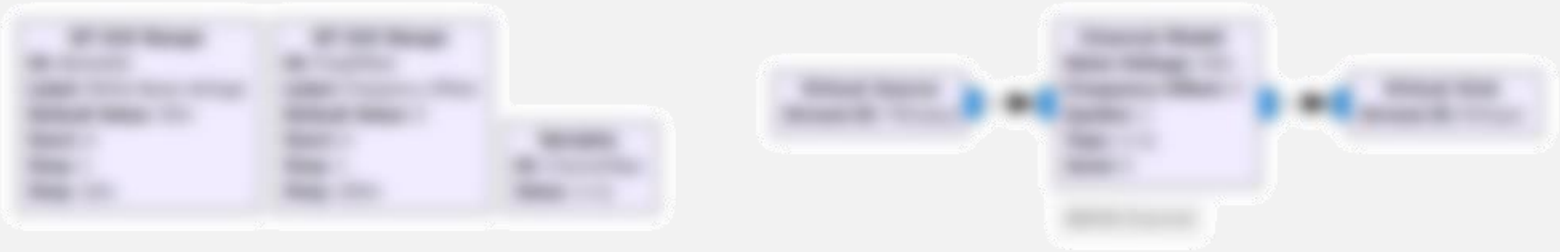
Note: You may need other essential blocks.

GRC Example for AM-DSB-TC

Transmitter’s Flow-Graph:

GRC Example for AM-DSB-TC

Channel's Flow-Graph:

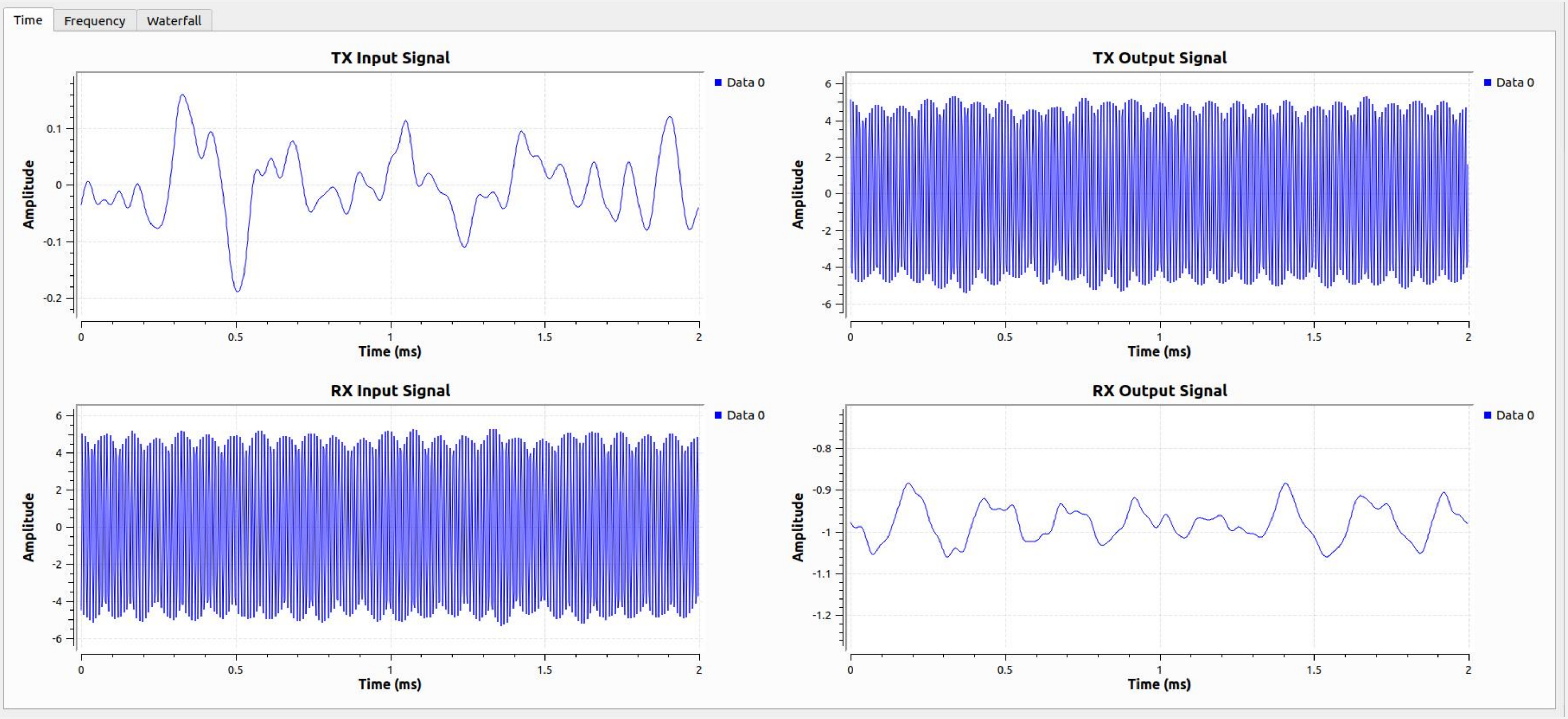


GRC Example for AM-DSB-TC

Receiver's Flow-Graph:

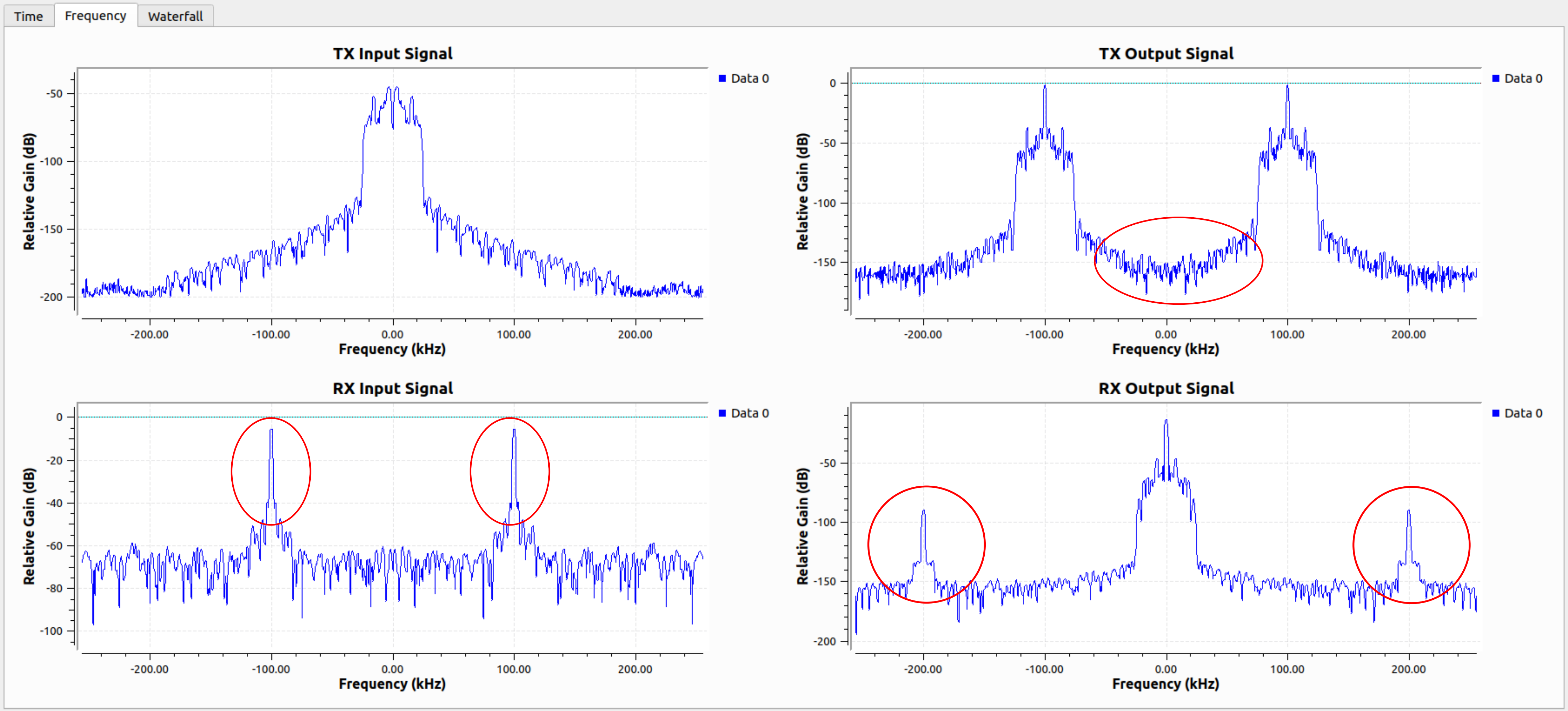
GRC Example for AM-DSB-TC

Signals' Figures in Time Series:



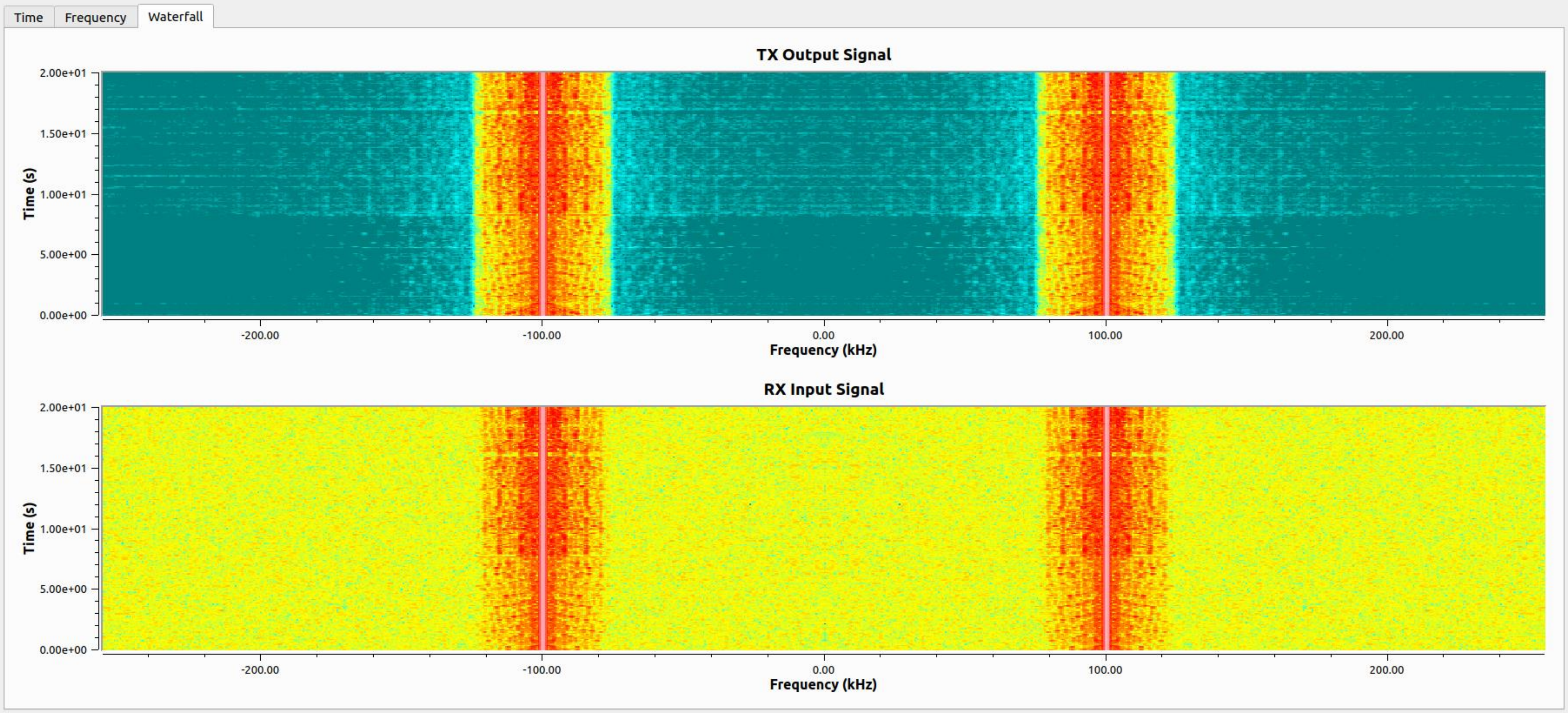
GRC Example for AM-DSB-TC

Signals' Figures in Frequency Series:



GRC Example for AM-DSB-TC

Signals' Waterfall Figures:



GRC Example for Conventional FM

Preferred GRC Blocks:

Transmitter	Wireless Channel	Receiver
Wav. file source	Channel model (AWGN)	Throttle
Signal source	-	Low pass filter
Low pass filter	-	WBFM Receiver
WBFM Transmitter	-	NBFM Receiver
NBFM Transmitter	-	Rational Resampler
Throttle	-	Time sink
Time sink	-	Frequency sink
Frequency sink	-	Waterfall link
Waterfall link	-	Audio sink

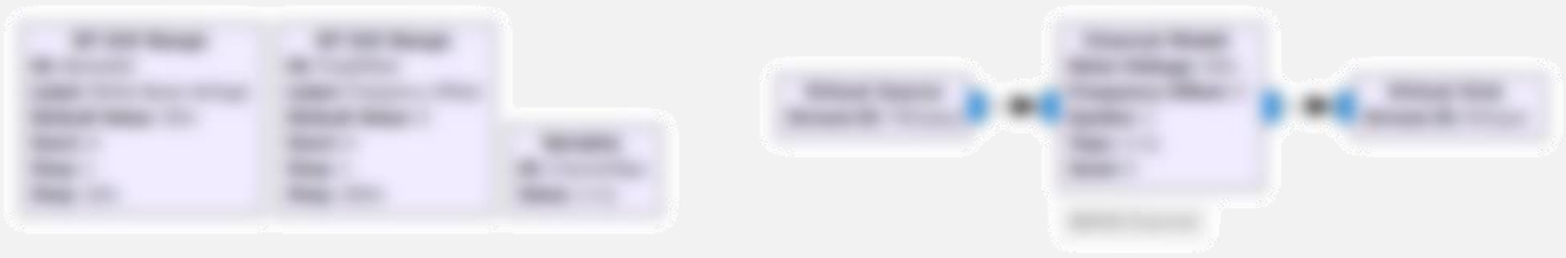
Note: You may need other essential blocks.

GRC Example for Conventional FM

Transmitter's Flow-Graph:

GRC Example for Conventional FM

Channel's Flow-Graph:

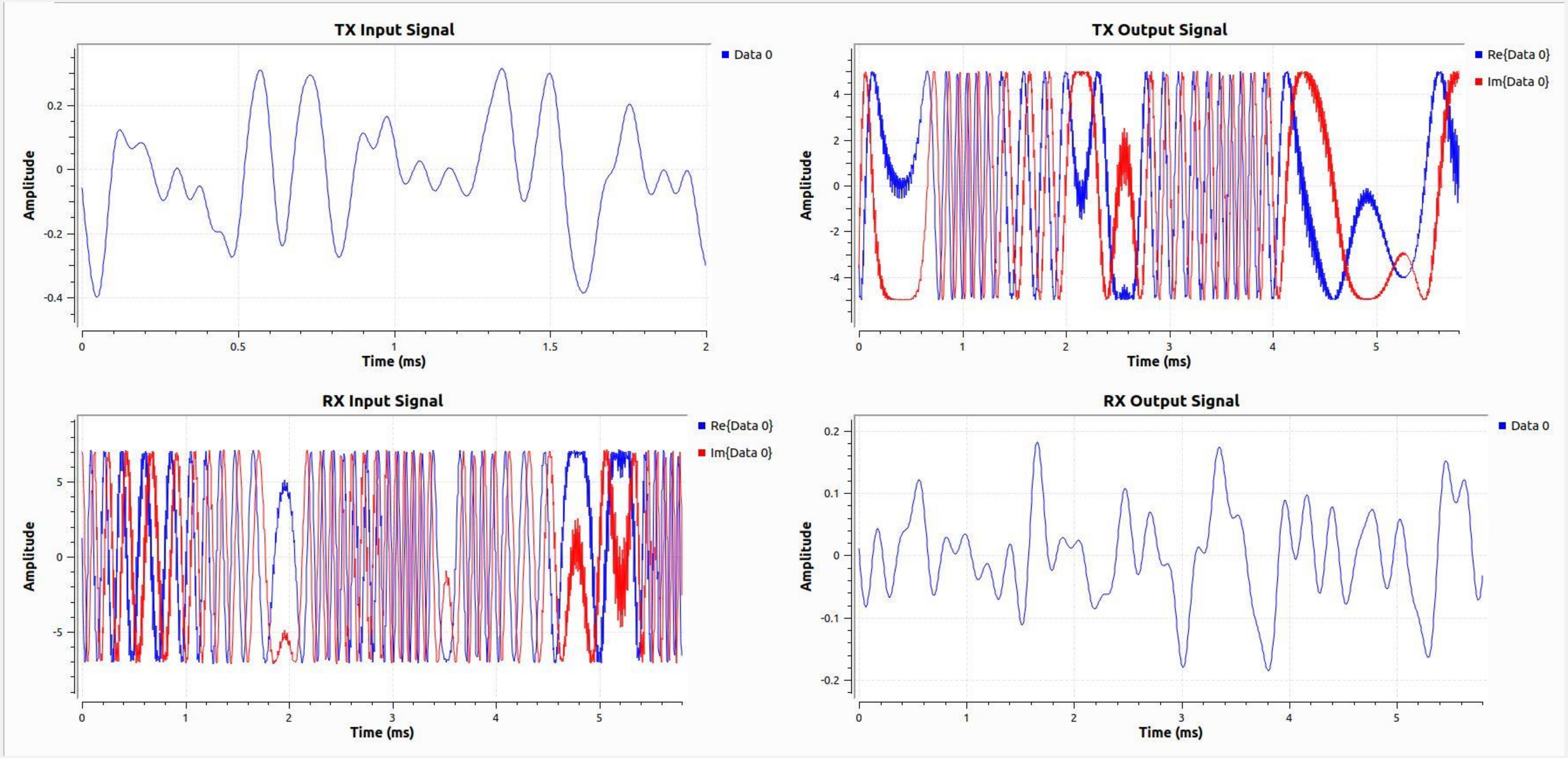


GRC Example for Conventional FM

Receiver’s Flow-Graph:

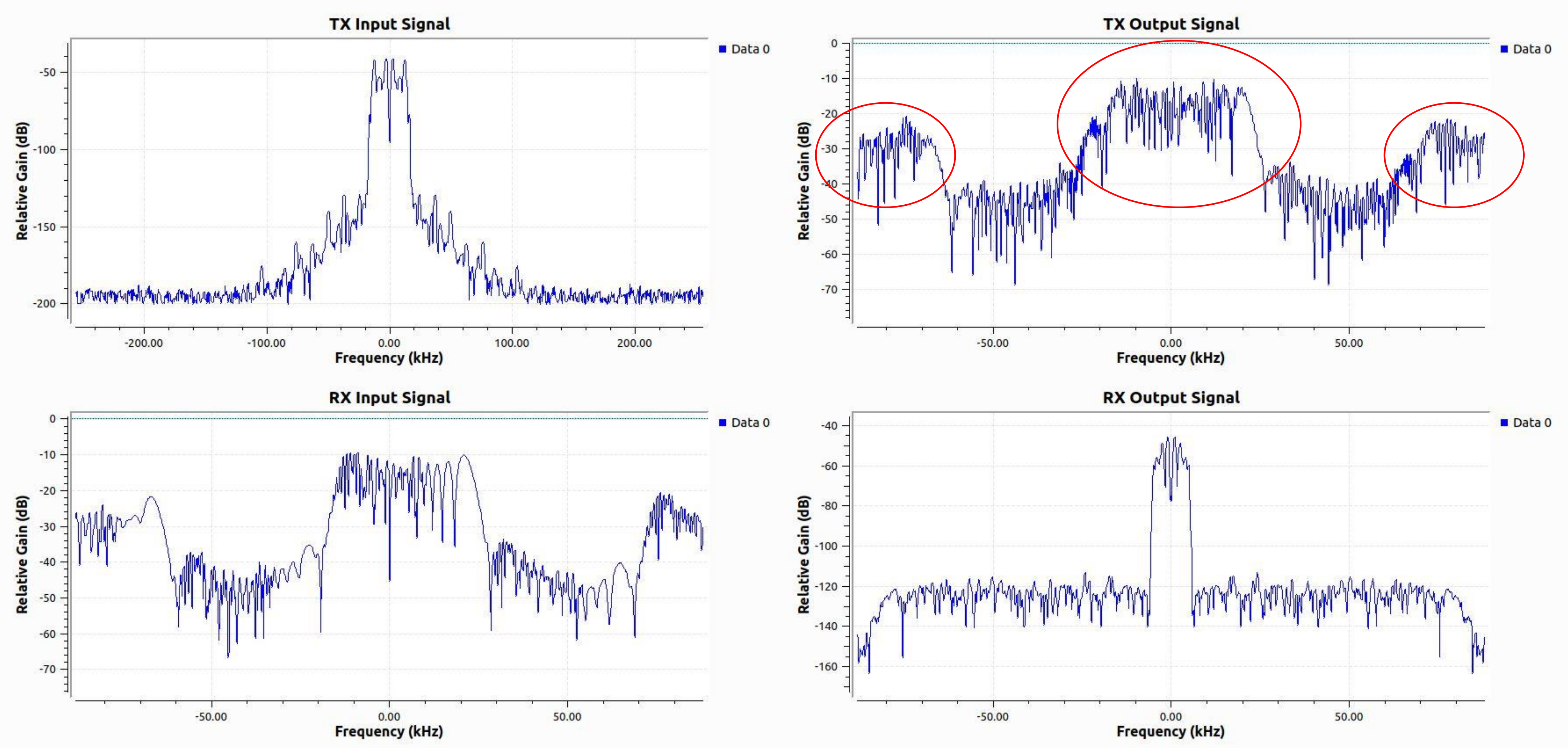
GRC Example for Conventional FM

Signals' Figures in Time Series:



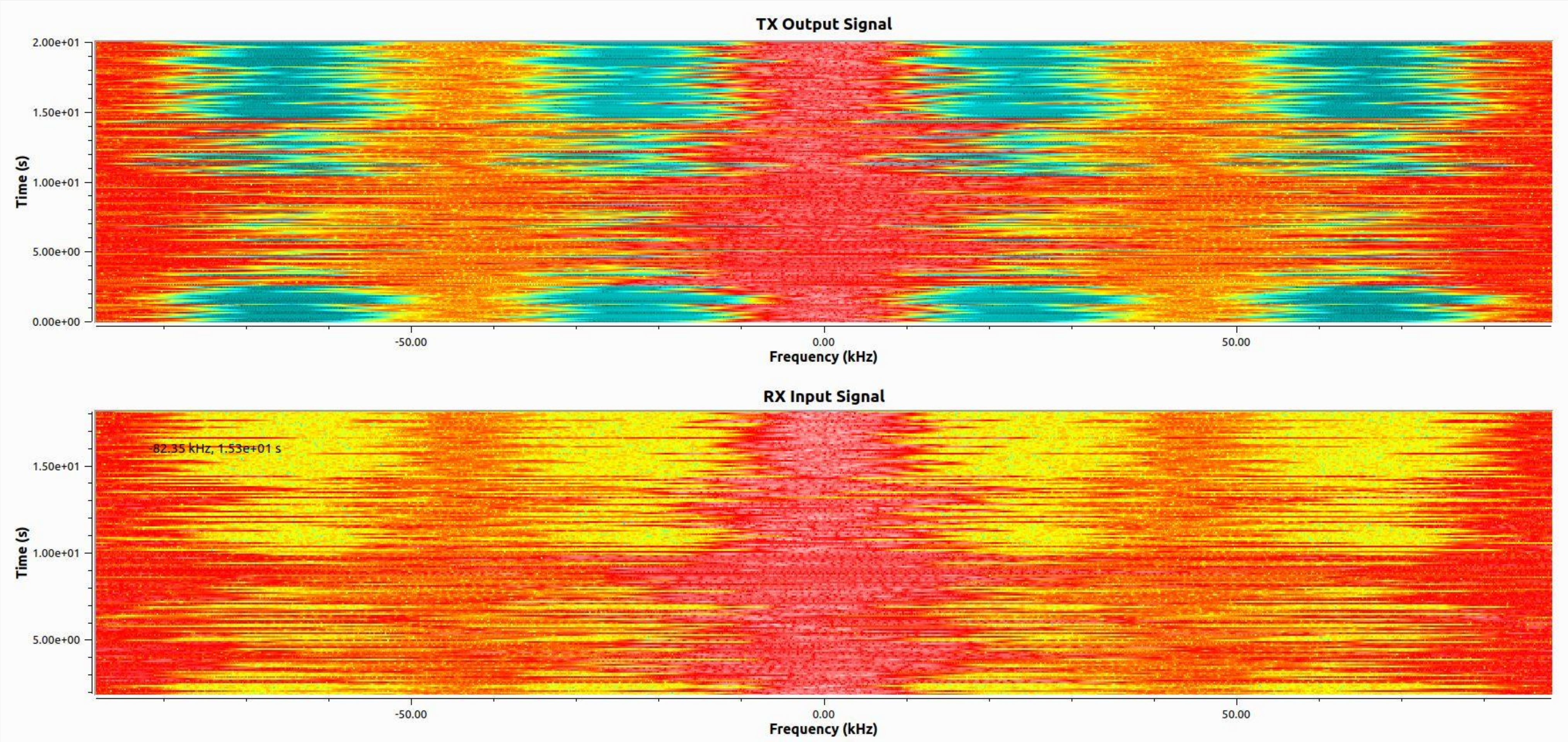
GRC Example for Conventional FM

Signals’ Figures in Frequency Series:



GRC Example for Conventional FM

Signals' Waterfall Figures:



Nooelec NESDR SMArTee v2 SDR

nooelec: We designed this SDR from the ground up in order to develop the best low-cost SDR in existence.

Frequency Range: 25MHz - 1750MHz

Phase noise @1kHz offset: -138dBc/Hz (or better)

Phase noise @10kHz: -150dBc/Hz (or better)

Phase noise @100kHz: -152dBc/Hz (or better)

nooelec

Assignments

Session Two

Problem:

Design AM-SSB via GNU Radio

Due: Oct. 13, 2020

Assignments

Session Three

Problem:

Design Conventional PM via GNU Radio

Due: Oct. 20, 2020