# 16.36: Communication Systems and Networks

## USRP Laboratory 1: Introduction

Igor, Thomas, Vishrant, Jianan and Prof. Eytan Modiano
Laboratory for Information and Decision Systems
Massachusetts Institute of Technology

# Outline

- Goal
  - familiarity with LabVIEW Communications and with the USRP
  - introduce the concept of modulation

- Intro to LabVIEW Communications
  - experiment one: Hello World
  - experiment two: PAM-2 and Power Spectrum Density

- Intro to the USRP
  - experiment three: Send and receive a tone signal

Obs.: A few questions will be made during the lab.

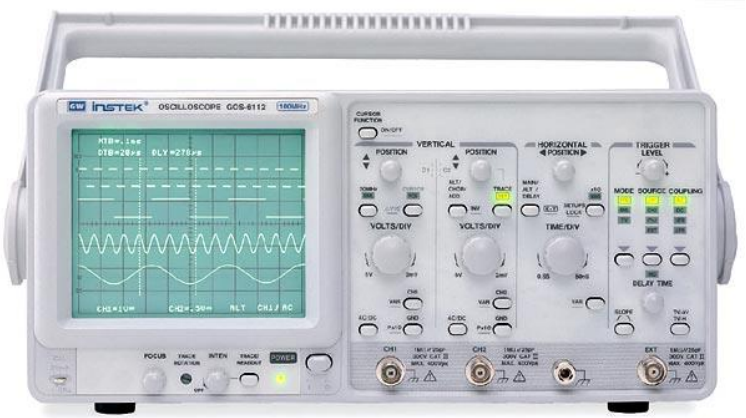
**Each pair of students should turn in the answers!**

# Intro to LabVIEW Communications

- LabVIEW = Graphical Programming Environment

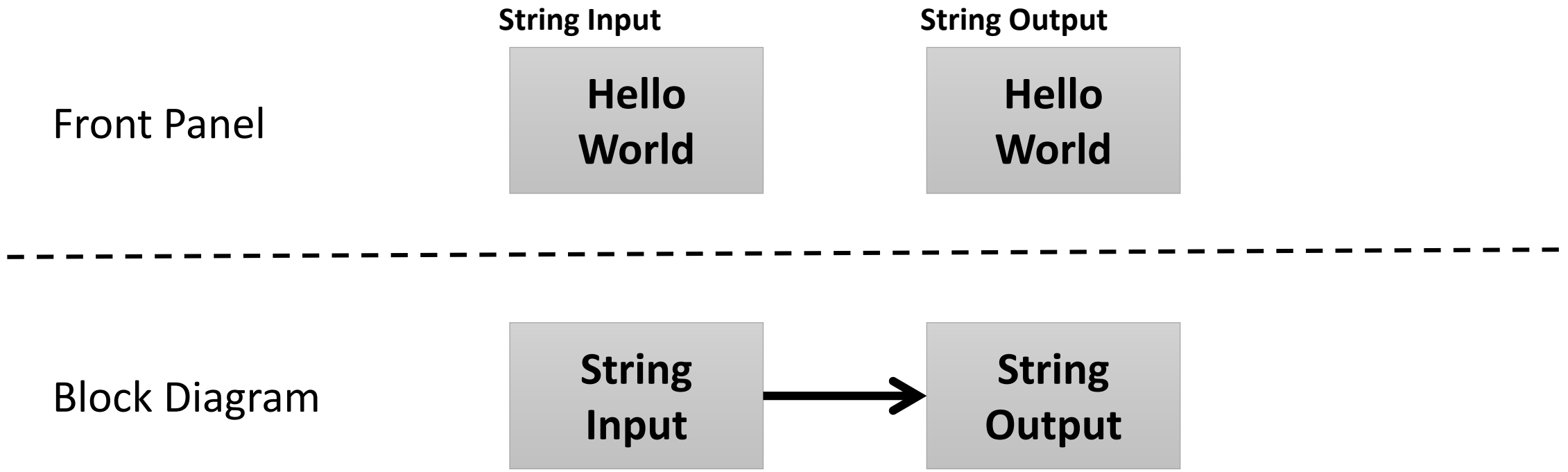
- LabVIEW Program = Virtual Instrument (VI)
  - Front PANEL = **User Interface**
  - Block DIAGRAM = **Graphical Code**

- Software in your workstation:
  - LabVIEW
  - LabVIEW Communications
  - Drivers to the USRP
  - MATLAB



# Experiment ONE: Hello World

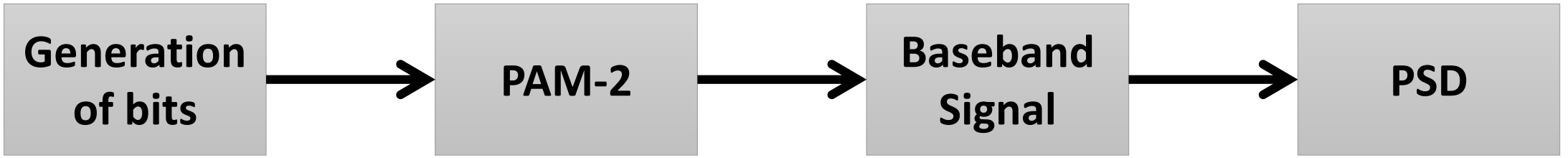
- **Big Picture:** read an input string and copy it to an output string




Laboratory script (~10 minutes). **Wait for instructions on Experiment TWO.**

# Experiment TWO: PAM-2 and PSD

- **Big Picture**: transform a bit sequence into a baseband signal



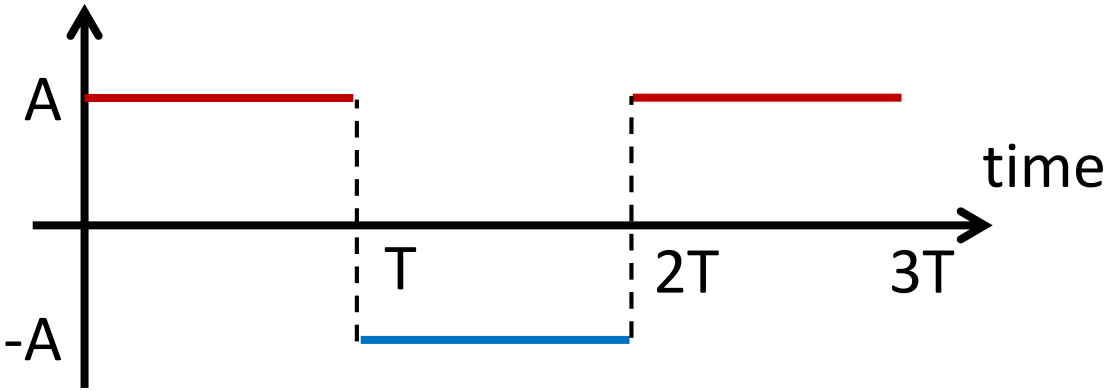

BITS

**1 0 1**

SYMBOLS

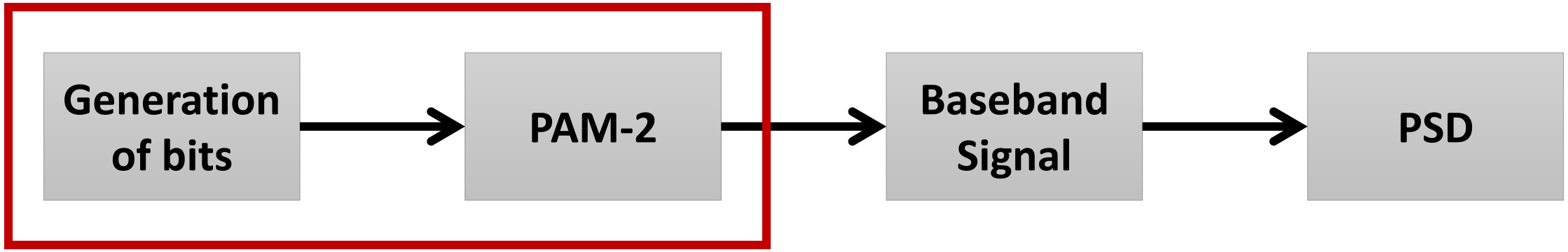
**1 -1 1**

BASEBAND SIGNAL



# Experiment TWO: PAM-2 and PSD

- **Big Picture**: transform a bit sequence into a baseband signal

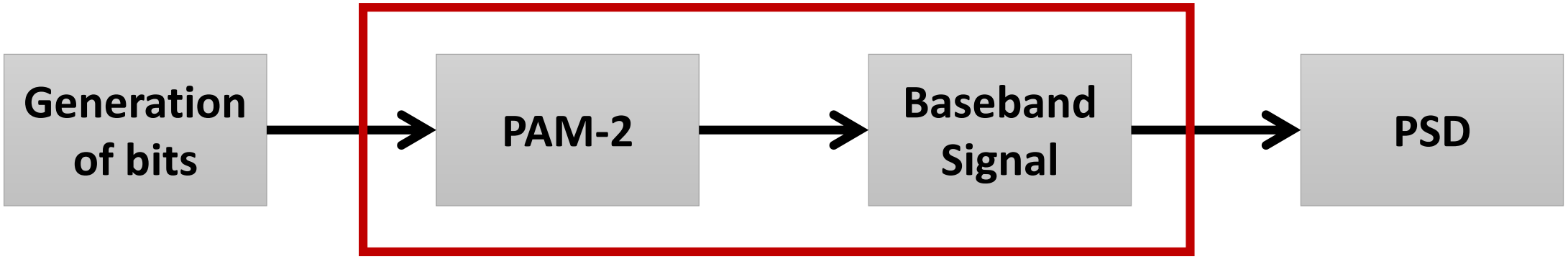



- Question: how to transform a sequence of bits into a sequence of symbols using PAM-2?

- Example: 1110100011100 1 into PAM-2? Answer: 1 1 1 -1 1 -1 -1 -1 1 1 1 -1 -1 1

# Experiment TWO: PAM-2 and PSD

- **Big Picture:**



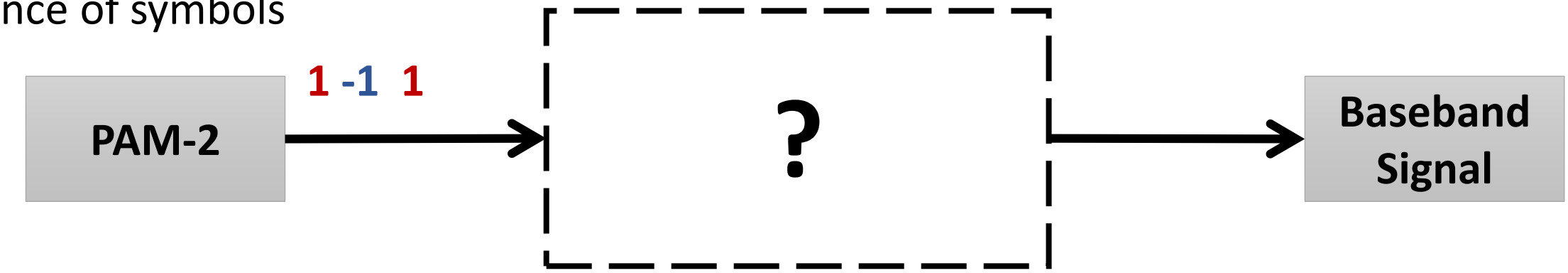

- Question: how to transform a sequence of symbols into a baseband signal?

- Example: 1 1 1 -1 1 -1 -1 -1 1 1 1 -1 -1 1 into a sequence of rectangular pulses?

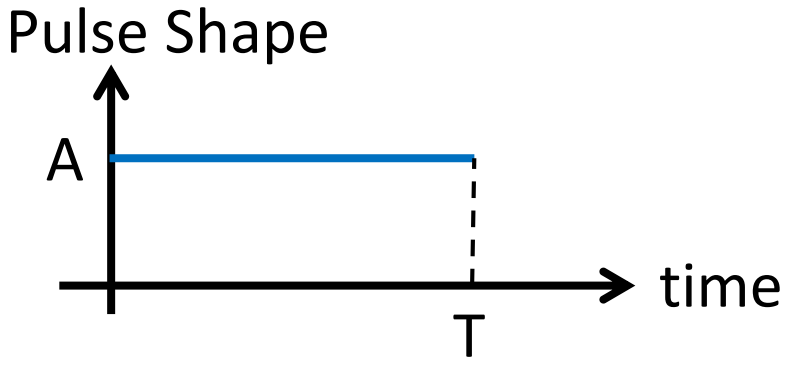
(more specifically…)

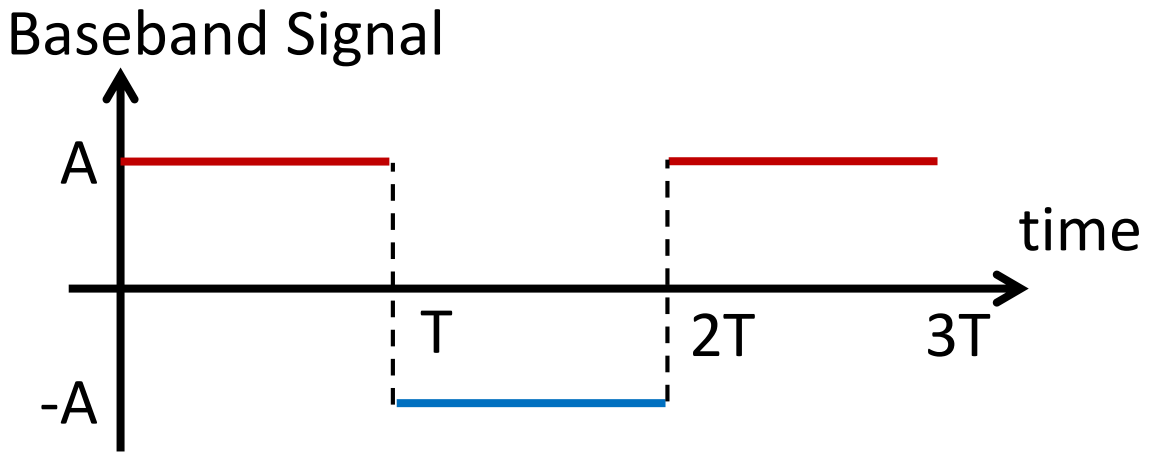
# Experiment TWO: PAM-2 and PSD

Sequence of symbols

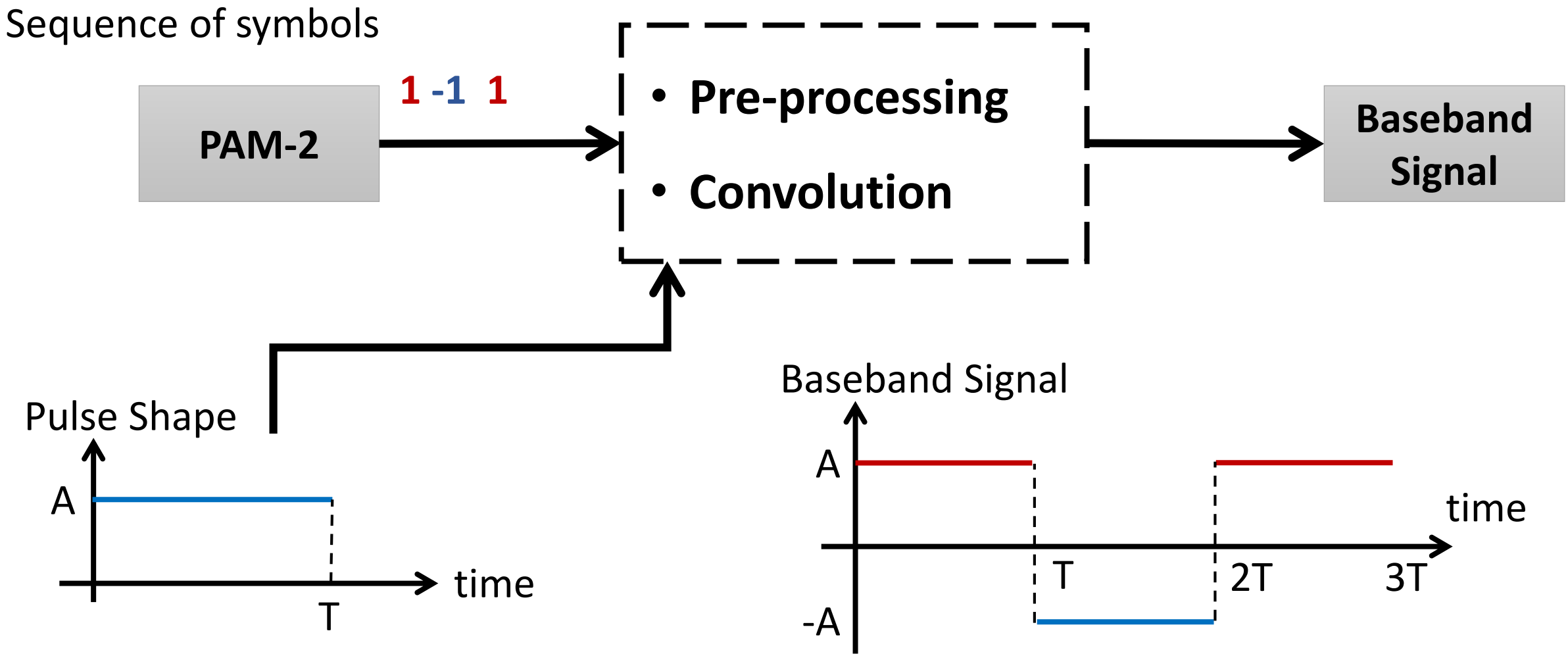



Hint:



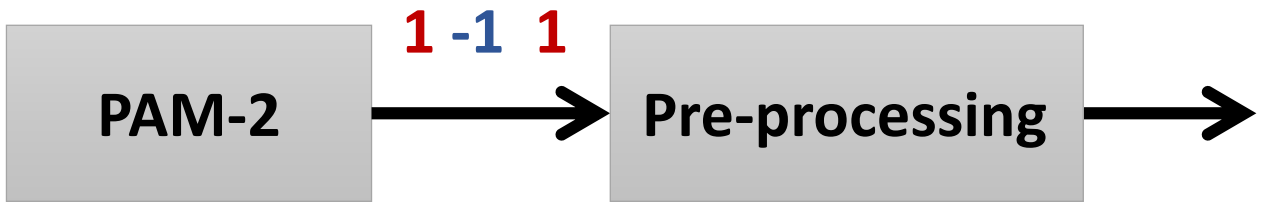



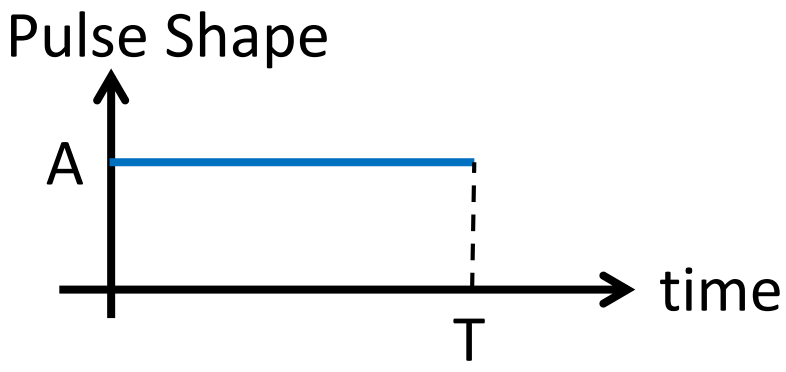
# Experiment TWO: PAM-2 and PSD

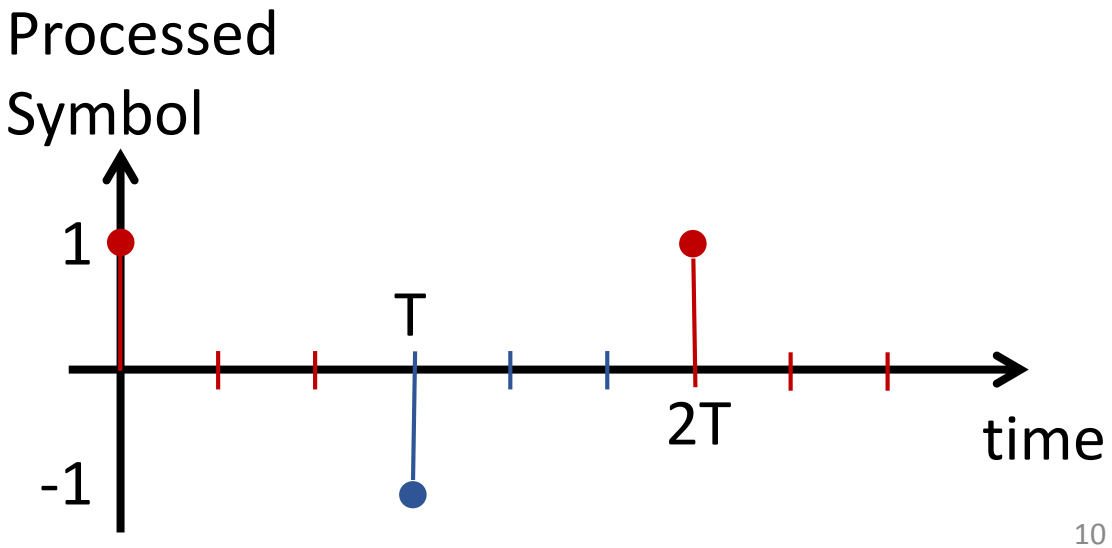


# Experiment TWO: PAM-2 and PSD

Sequence of symbols

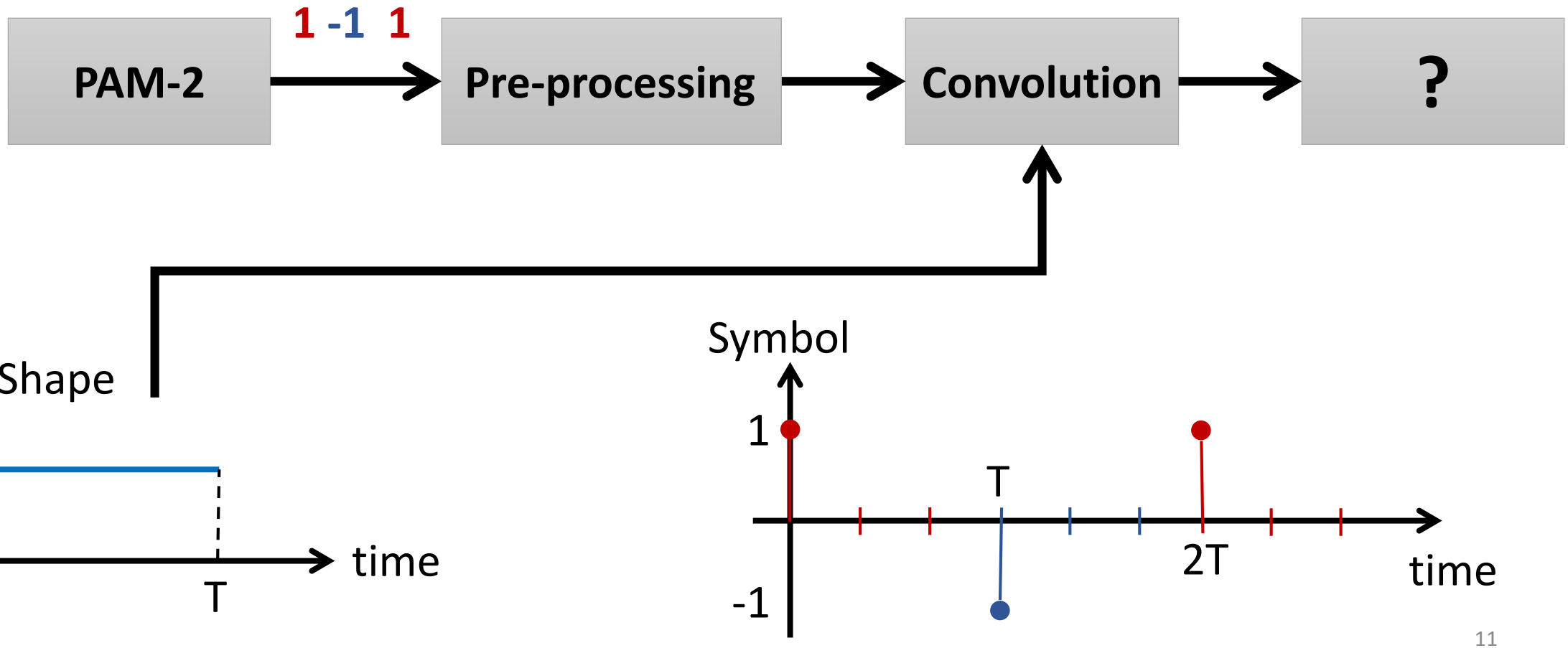


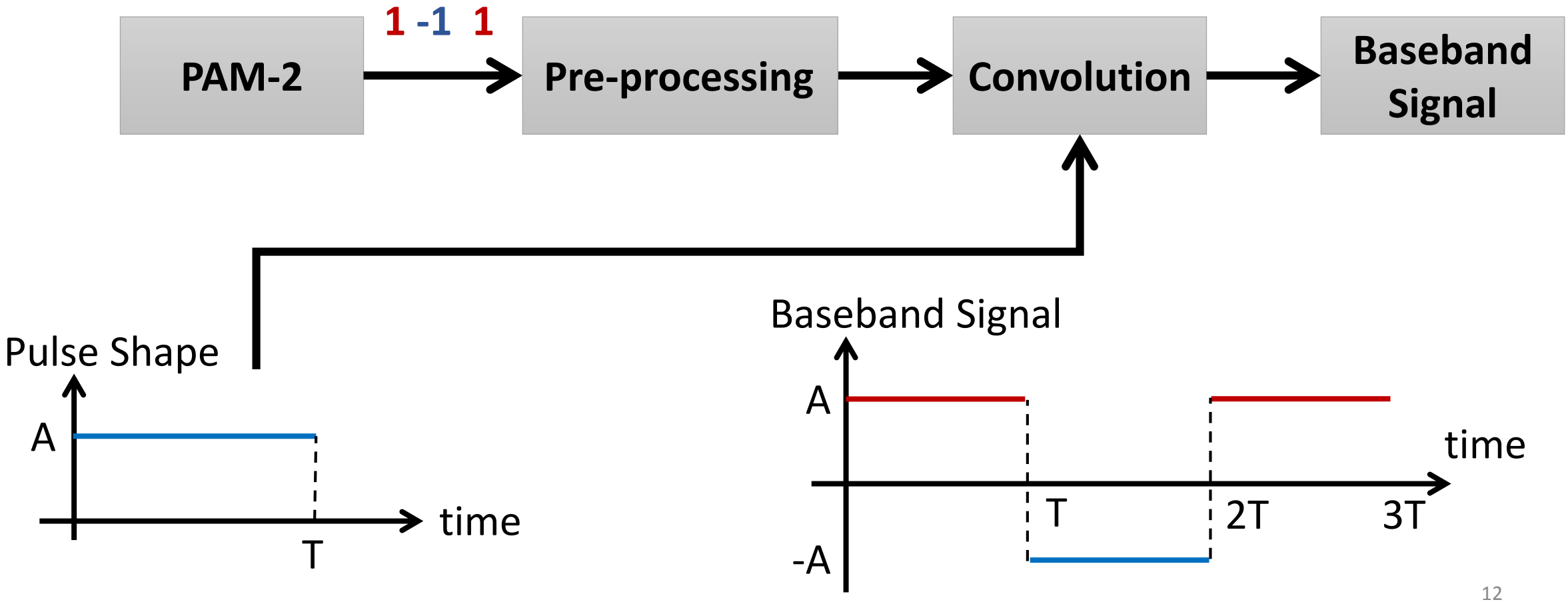
# Experiment TWO: PAM-2 and PSD

Sequence of symbols

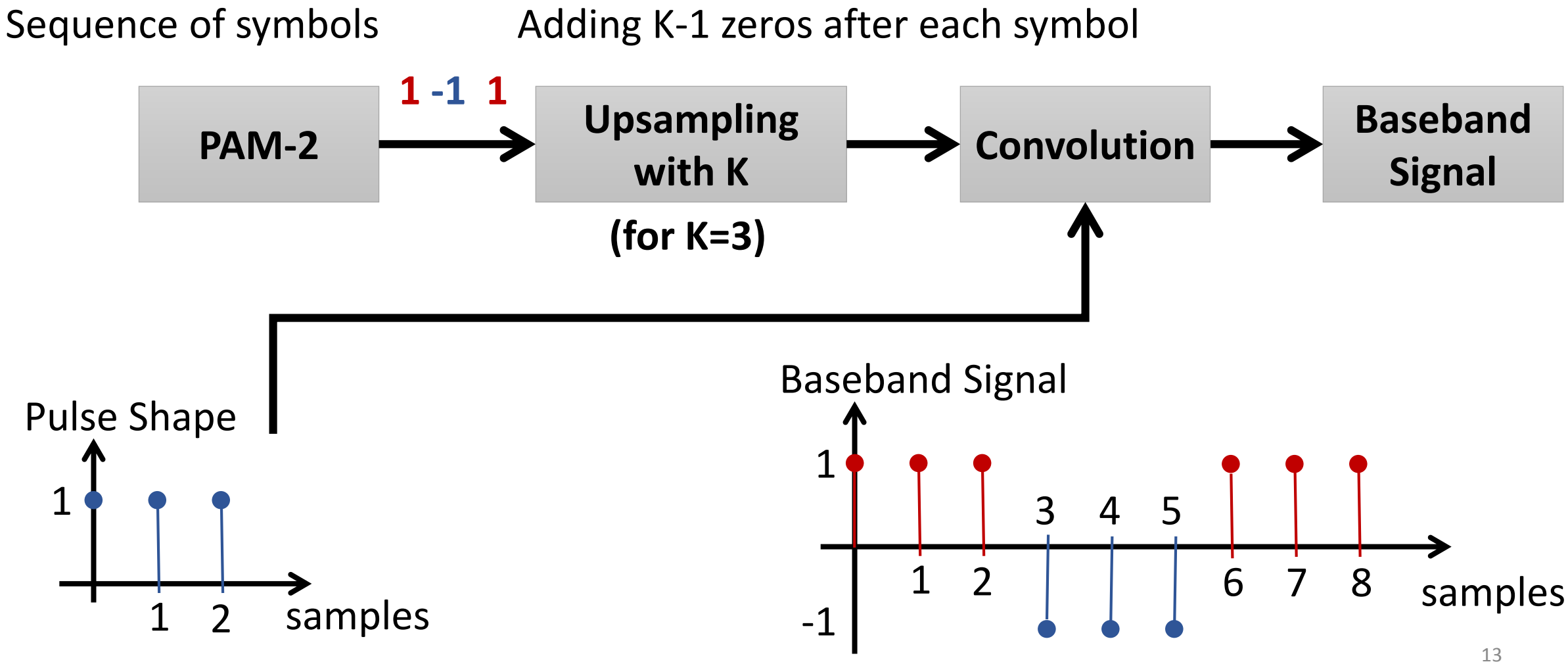


# Experiment TWO: PAM-2 and PSD

Sequence of symbols

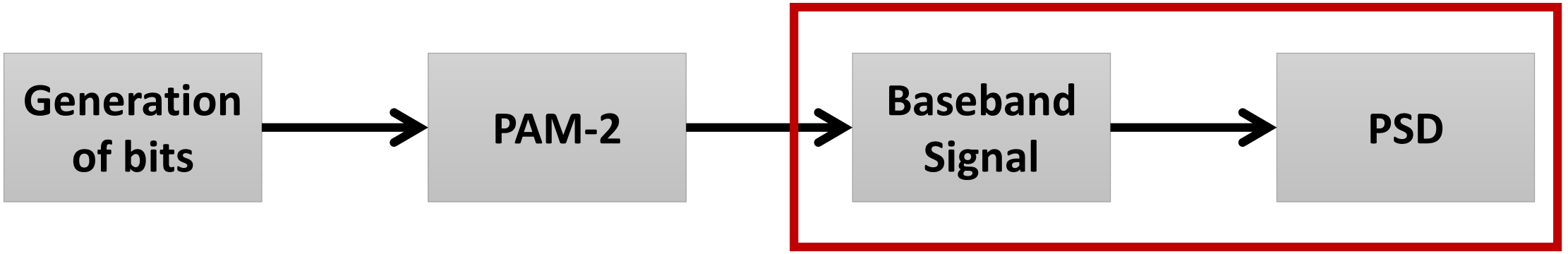


# Experiment TWO: PAM-2 and PSD [Discrete Case]



# Experiment TWO: PAM-2 and PSD

- Big Picture:

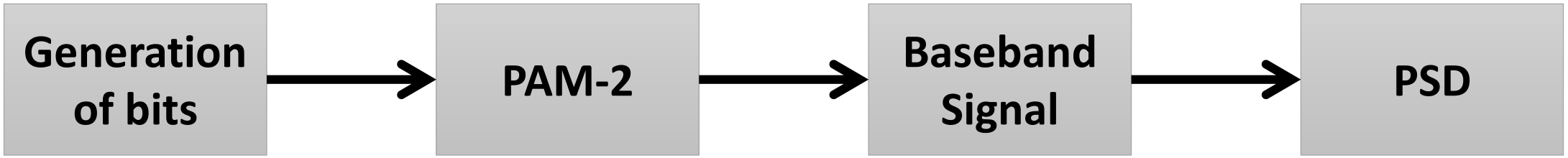



- PSD: Power Spectrum Density of the Baseband Signal:

$P(f_k) = |X(f_k)|^2$, where $X(f_k)$ is the Fourier transform of the baseband signal

# Experiment TWO: PAM-2 and PSD

- Big Picture:




- Experiment TWO:
  - Goal: implement the system above.
  - Please follow the instructions on your laboratory script. (~ 30 minutes)
  - **Stop after finishing**. Wait for instructions on Experiment THREE.

# Experiment THREE: Radio

- **Software Defined Radio**: some components that have been typically implemented in HW are implemented by means of SW

- HW Characteristics:
  - Frequency range 70 MHz to 6 GHz
  - Frequency step <1kHz
  - 56 MHz bandwidth
  - Maximum output power (Pout) 20 dBm
  - Tri-band antennas: 144MHz, 400MHz, 1200MHz

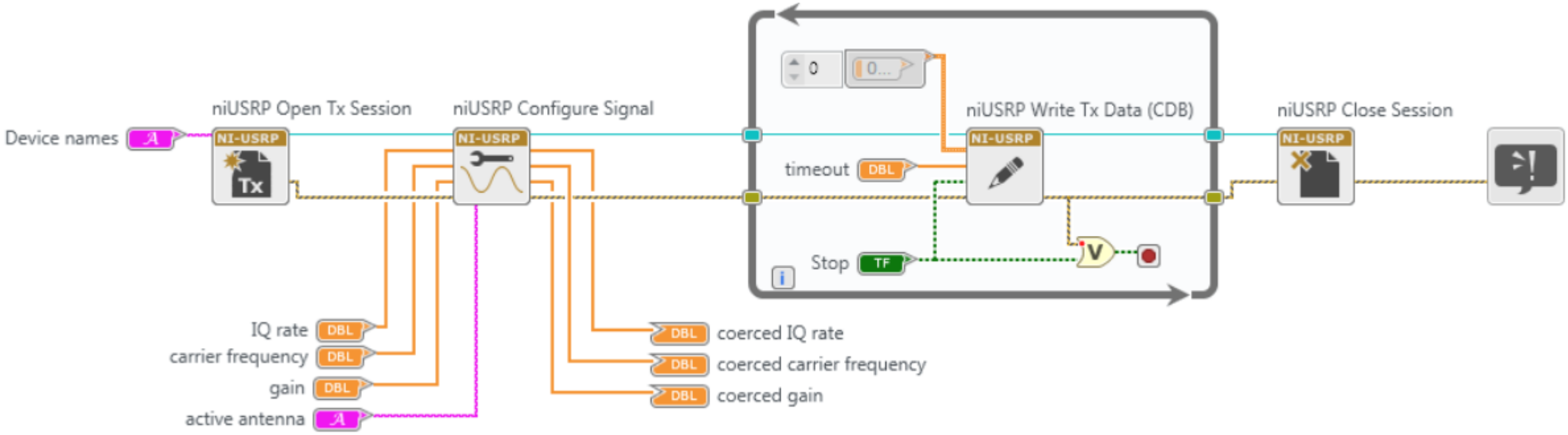
USRP 2900


- Electrostatic Sensitive Devices

Based on the book “Introduction to Communication Systems”, by Bruce A. Black.

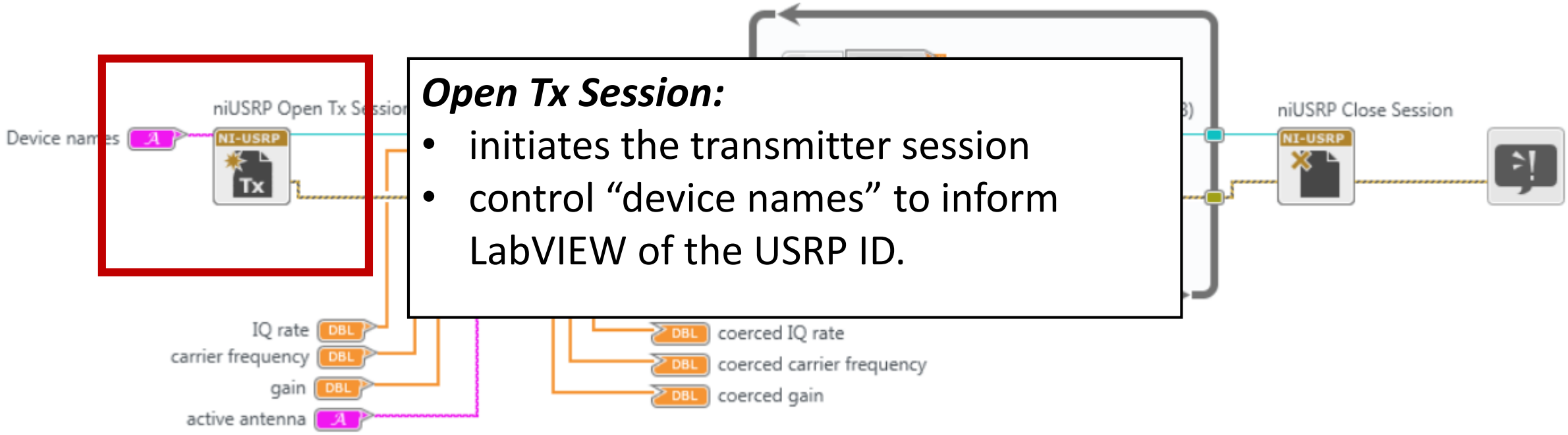
# Experiment THREE: Radio

- LabVIEW interacts with the USRP **TRANSMITTER** by means of four blocks:



# Experiment THREE: Radio

- LabVIEW interacts with the USRP transmitter by means of four blocks:

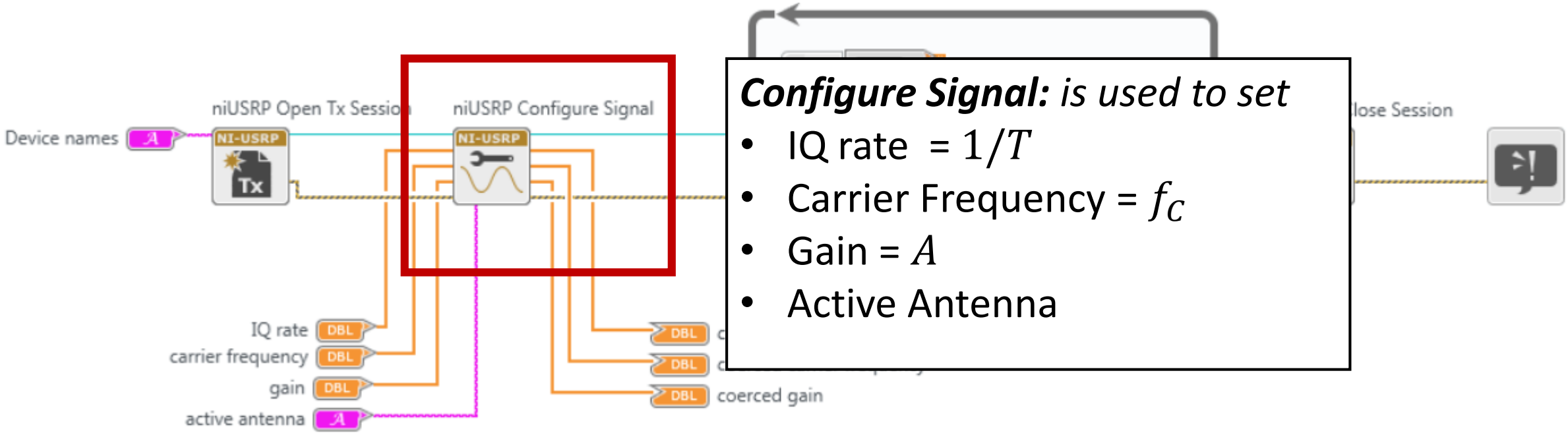



***Open Tx Session:***

- initiates the transmitter session
- control "device names" to inform LabVIEW of the USRP ID.

# Experiment THREE: Radio

- LabVIEW interacts with the USRP transmitter by means of four blocks:

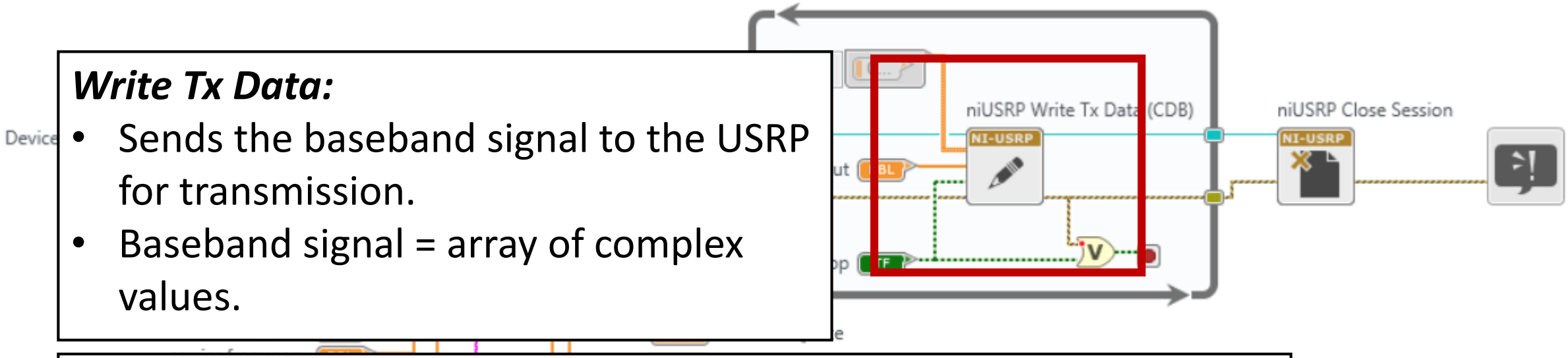



***Configure Signal:*** *is used to set*

- IQ rate = $1/T$
- Carrier Frequency = $f_C$
- Gain = $A$
- Active Antenna

# Experiment THREE: Radio

- LabVIEW interacts with the USRP transmitter by means of four blocks:




***Write Tx Data:***

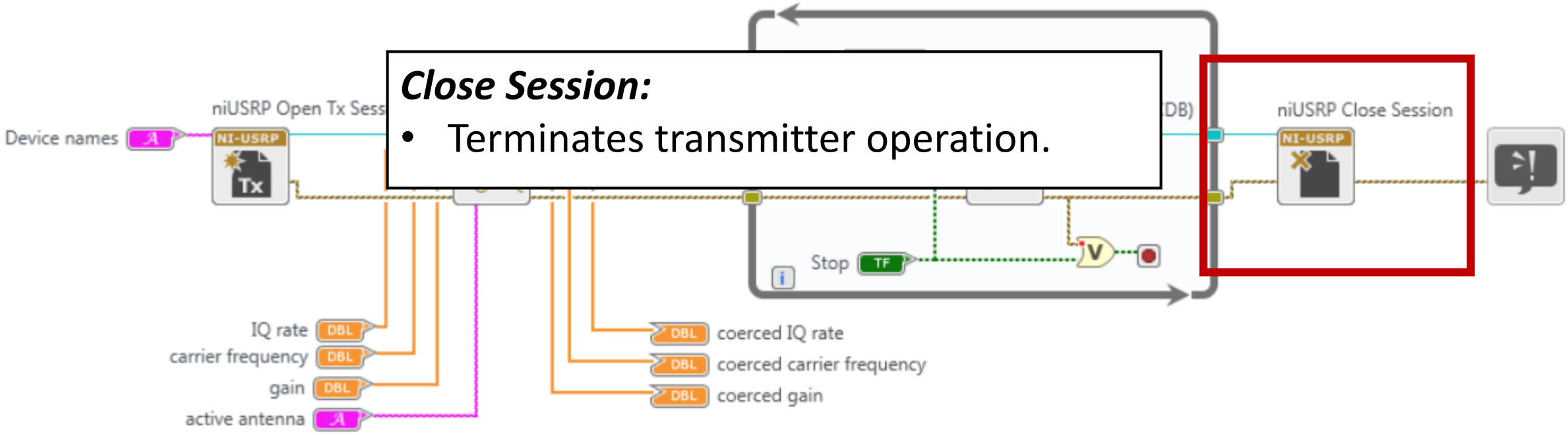
- Sends the baseband signal to the USRP for transmission.
- Baseband signal = array of complex values.

*If we write:* $g_I(nT) + jg_Q(nT)$

*The transmitted signal is:* $Ag_I(t)\cos(2\pi f_c t) - Ag_Q(t)\sin(2\pi f_c t)$

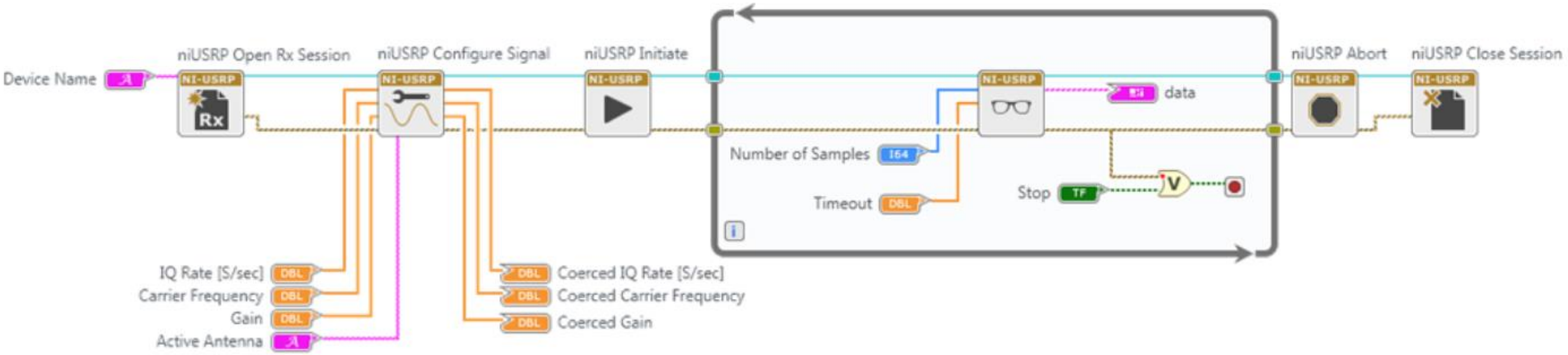
# Experiment THREE: Radio

- LabVIEW interacts with the USRP transmitter by means of four blocks:



# Experiment THREE: Radio

- LabVIEW interacts with the USRP **RECEIVER** by means of five blocks.

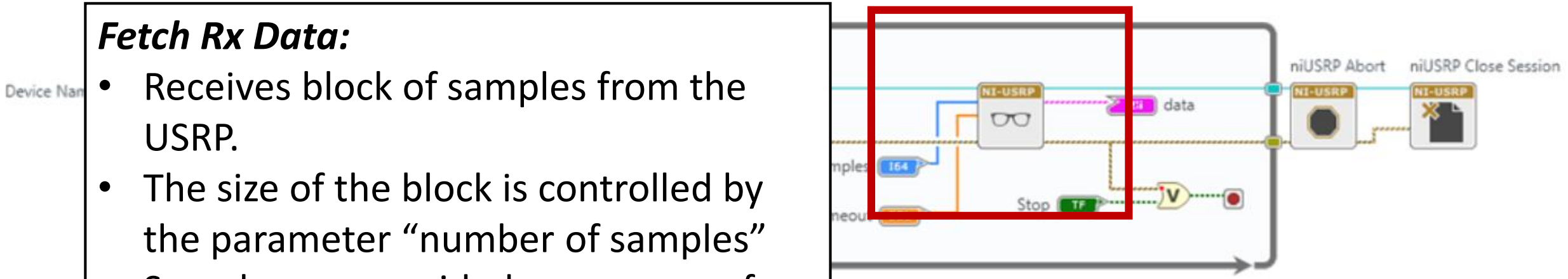


# Experiment THREE: Radio

- LabVIEW interacts with the USRP receiver by means of five blocks.
- Most blocks are analogous. The main difference is:

***Fetch Rx Data:***

- Receives block of samples from the USRP.
- The size of the block is controlled by the parameter “number of samples”
- Samples are provided as an array of complex numbers.



# Experiment THREE: Radio

- **Big Picture:**

**Power Attenuator.**
Used to avoid burning the radio.

- Experiment THREE:
  - Goal: transmit a tone signal using cables and antennas. Compare the results.
  - Please follow the instructions on your laboratory script.
  - **Turn in your answers at the end of the lab!**
  - **Frequency assignments next.**

# Frequency assignment

- Unlicensed Band: from 902 MHz to 928 MHz
- 5 groups → each has 5.2 MHz of available BW
- Central Frequency Assignments:
  - S1_Radio1_TX: 904.6 MHz
  - S2_Radio1_TX: 909.8 MHz
  - S3_Radio1_TX: 915 MHz
  - S4_Radio1_TX : 920.2 MHz
  - S5_Radio1_TX : 925.4 MHz

# Supplementary Slides

# Experiment THREE: Radio

- **Big Picture:**

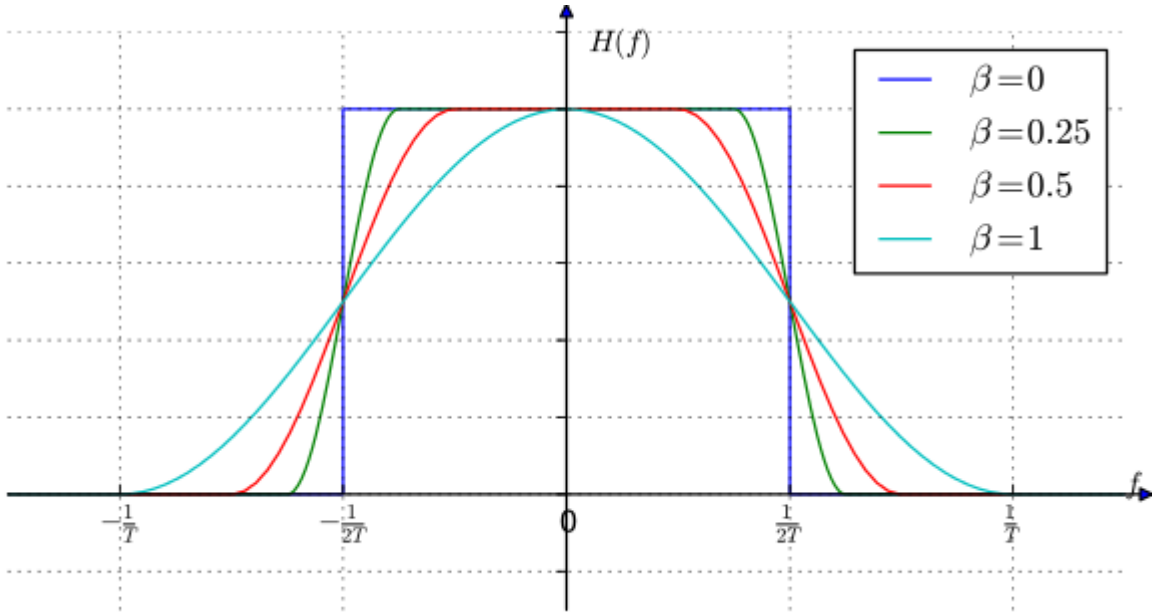
**Power Attenuator.**
Used to avoid burning the radio.

- Experiment THREE:
  - Goal: transmit a tone signal using cables and antennas. Compare the results.
  - Please follow the instructions on your laboratory script.
  - **Turn in your answers at the end of the lab!**

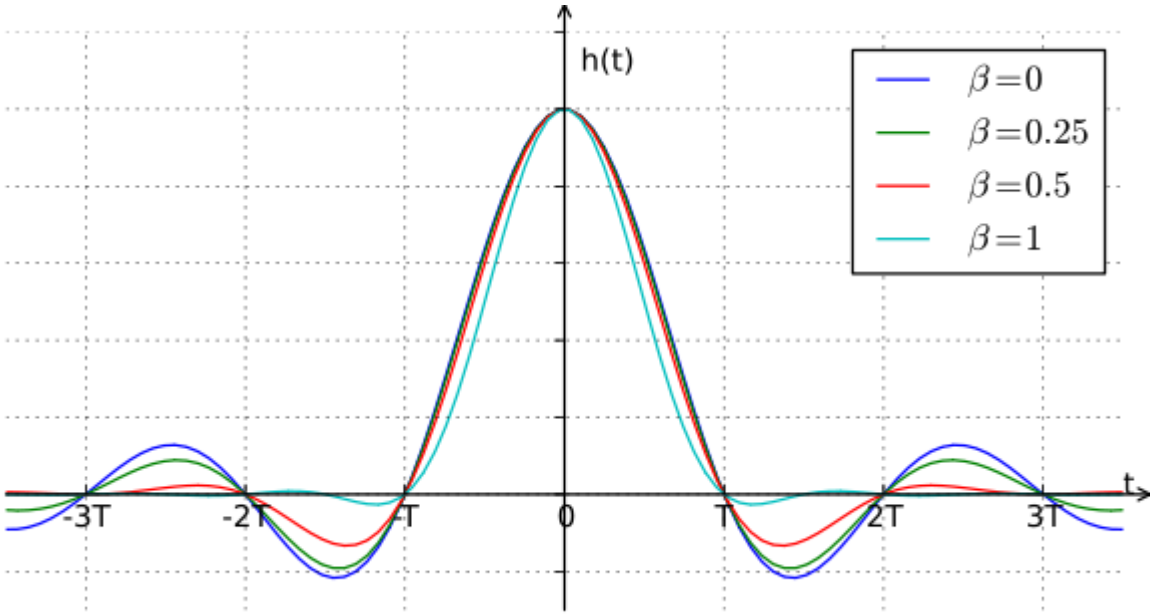
# Experiment TWO: PAM-2 and PSD

- Raised Cosine:

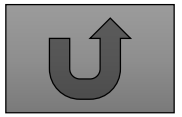
Frequency Response




Time Response




Pictures by [Krishnavedala]



# Experiment TWO: PAM-2 and PSD

- Raised Cosine:

  Frequency Response: $$H(f) = \begin{cases} T, & |f| \leq \frac{1-\beta}{2T} \\ \frac{T}{2}\left[1 + \cos\left(\frac{\pi T}{\beta}\left[|f| - \frac{1-\beta}{2T}\right]\right)\right], & \frac{1-\beta}{2T} < |f| \leq \frac{1+\beta}{2T} \\ 0, & \text{otherwise} \end{cases}$$

- (Squared) Root-Raised Cosine:

  Frequency Response: $$H_{rrc}(f) = \sqrt{H(f)}$$

- Look into *Nyquist ISI Criterion*