
Digital Modulations

Tutorial 1

Course of RF Circuit Design

Electronics Engineering

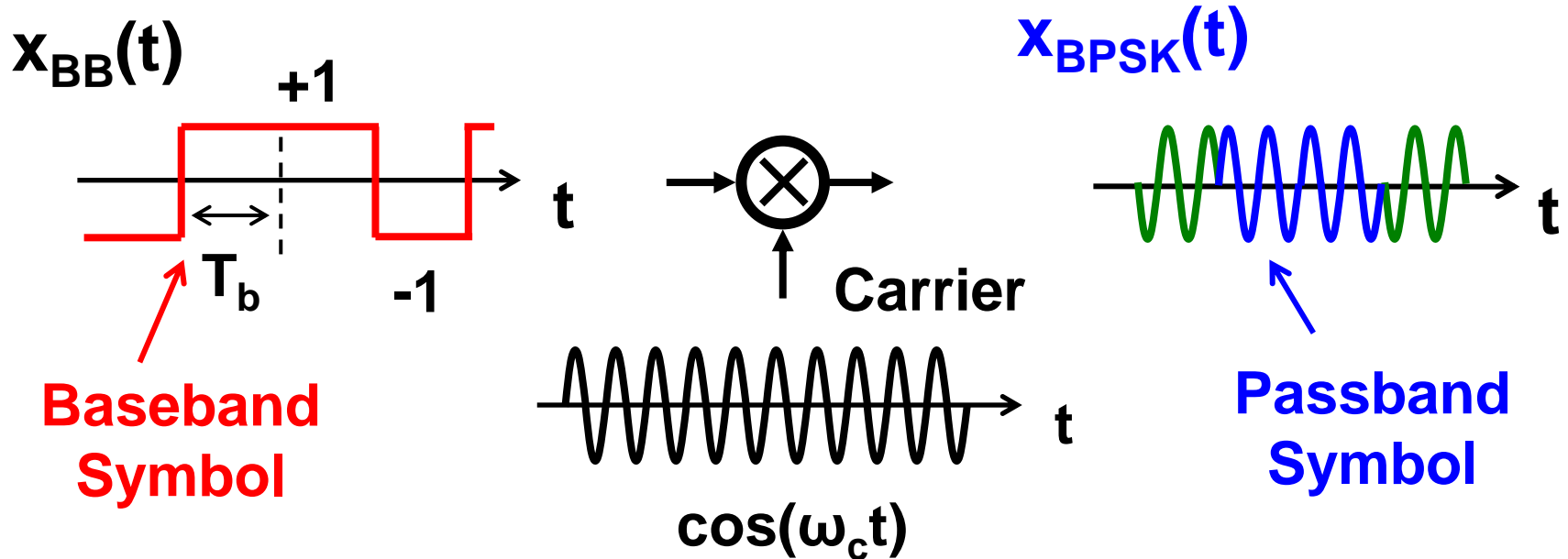
Outline

- **QPSK modulator in Mathworks Matlab**
- **Demodulation in Keysight VSA 89600**
- **Effects of RF transmitter impairments**

Outline

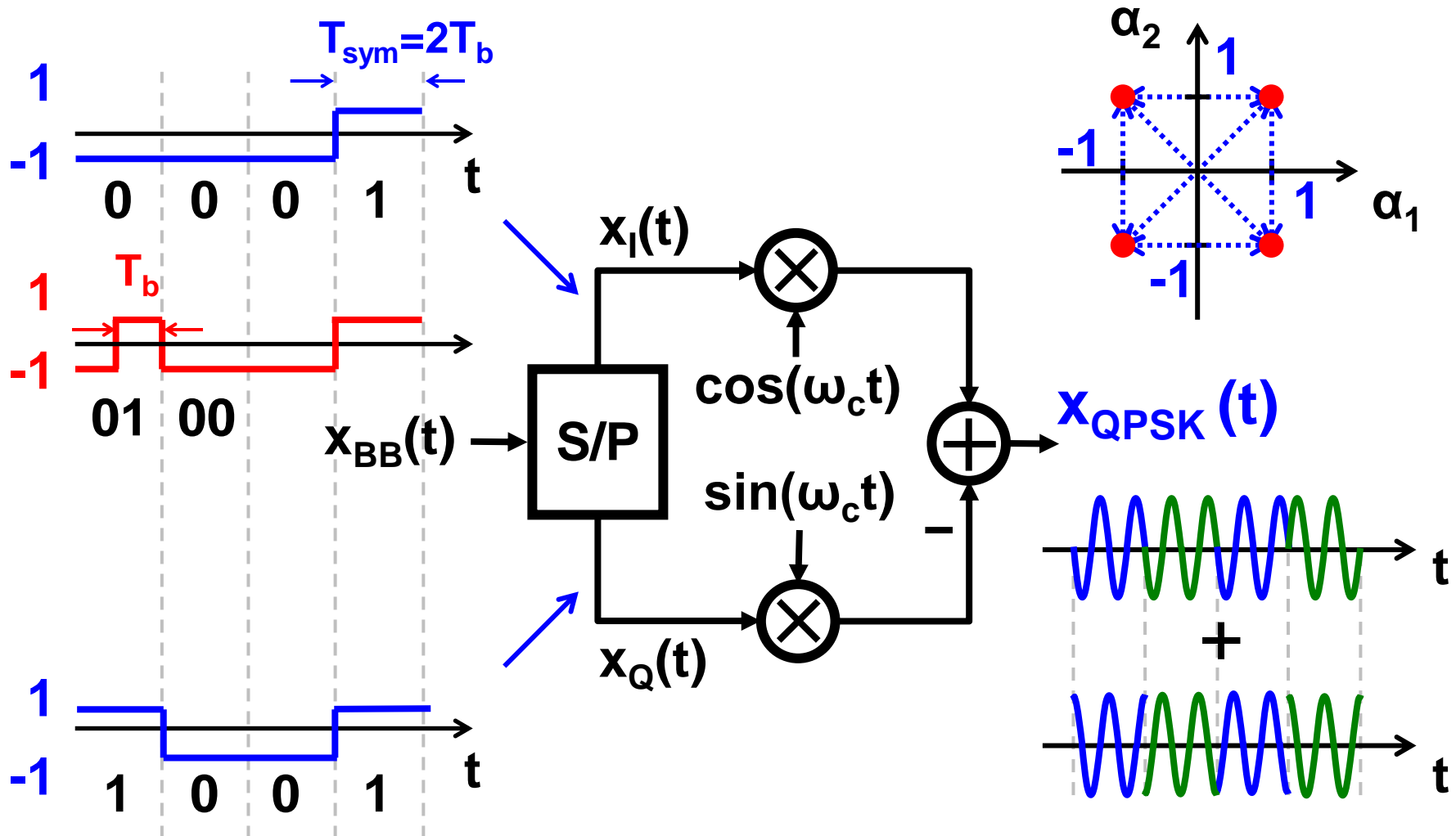
- **QPSK modulator in Mathworks Matlab**
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BPSK Modulator

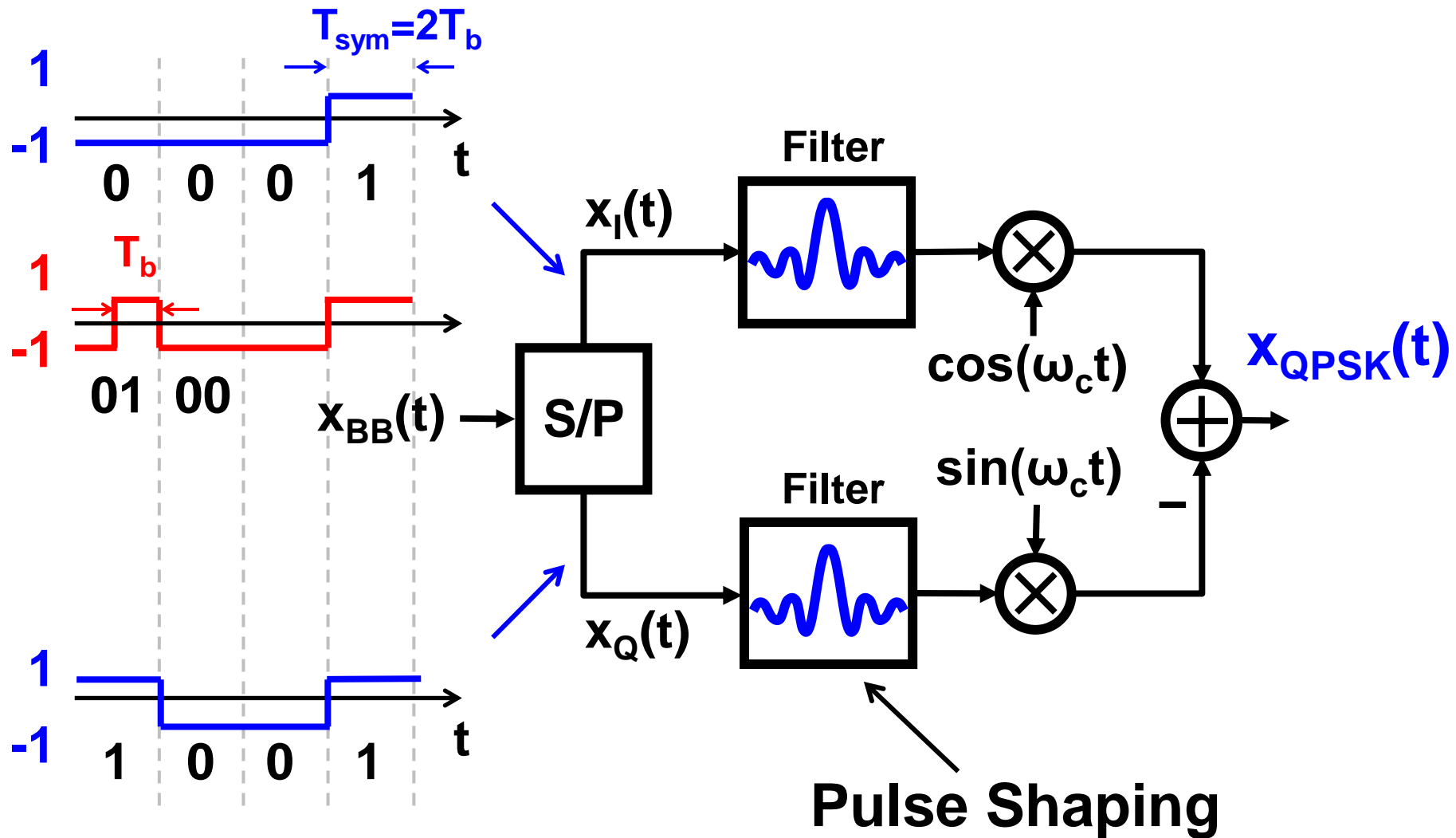


$$x_{BB}(t) = \sum_n b_n p(t - nT_b) \quad b_n = +1, -1$$

QPSK Modulator



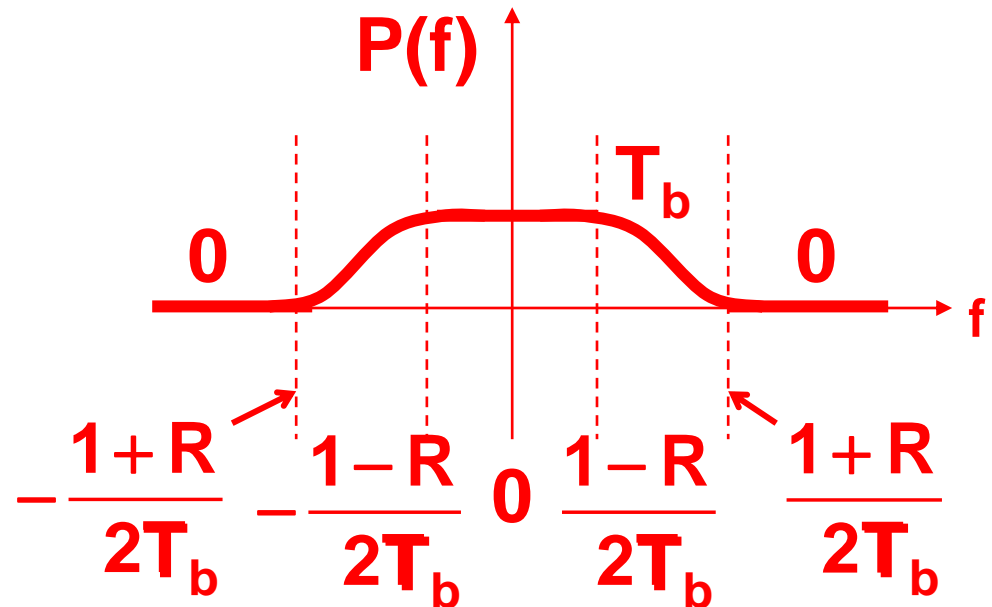
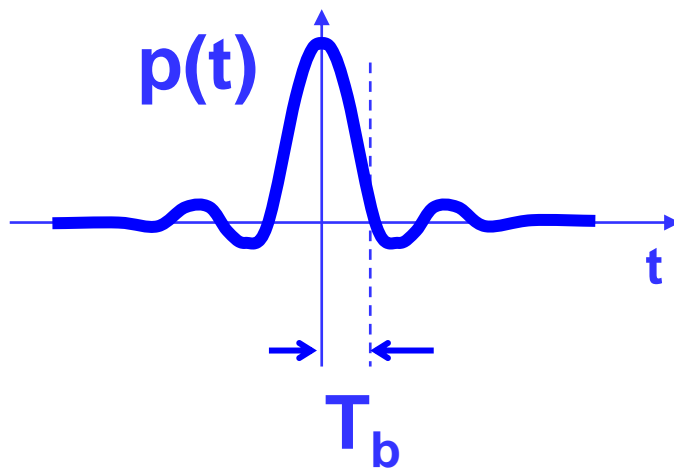
QPSK Modulator with Pulse Shaping



Raised-Cosine Pulse Shape

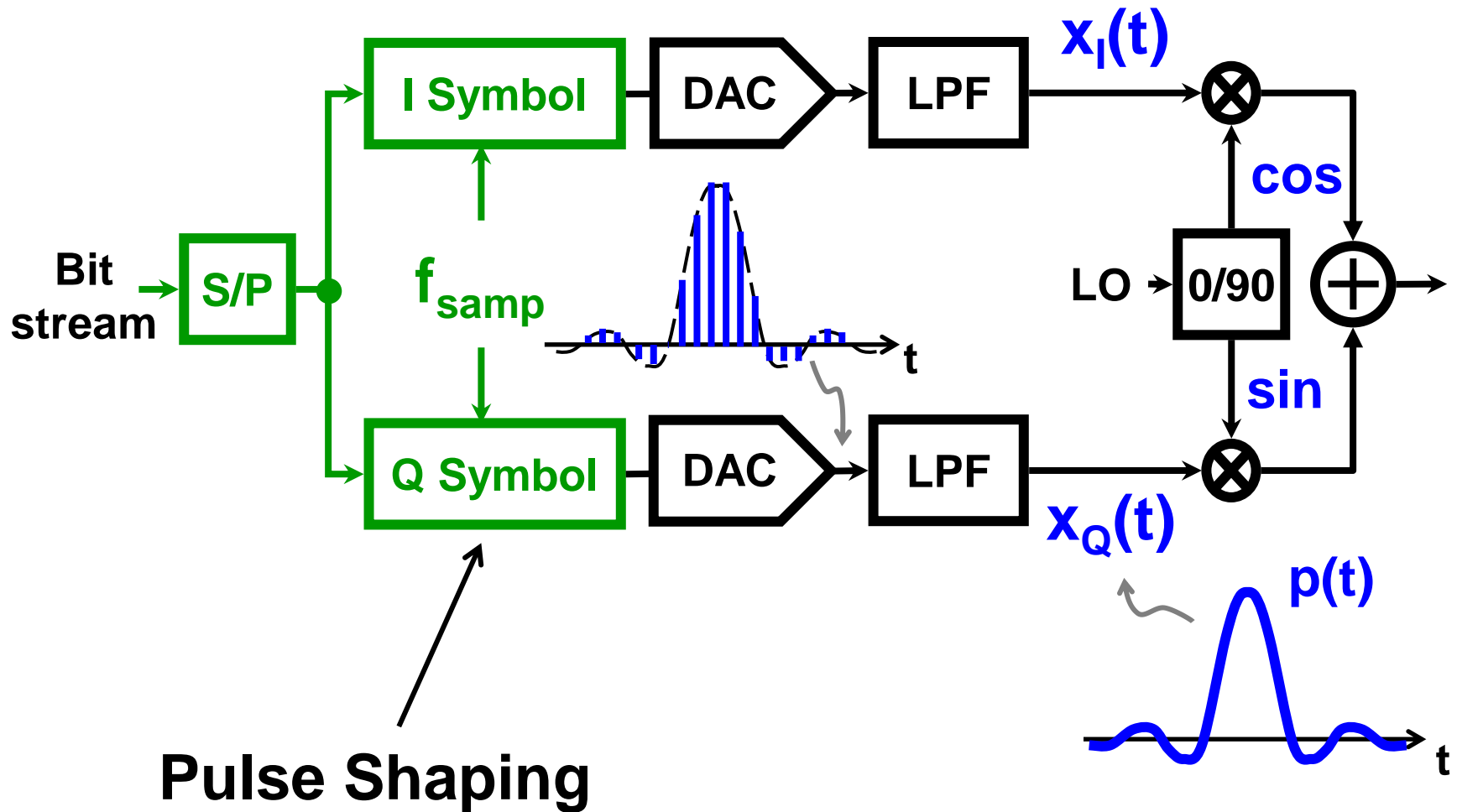
$$p(t) = \text{sinc}\left(\frac{t}{T_b}\right) \frac{\cos\left(\frac{pRt}{T_b}\right)}{1 - \frac{4R^2 t^2}{T_b^2}}$$

$$P(f) = 1 + \cos\left(\frac{pT_b}{R}\right)\left(|f| - \frac{1-R}{2T_b}\right)\frac{T_b}{2}$$

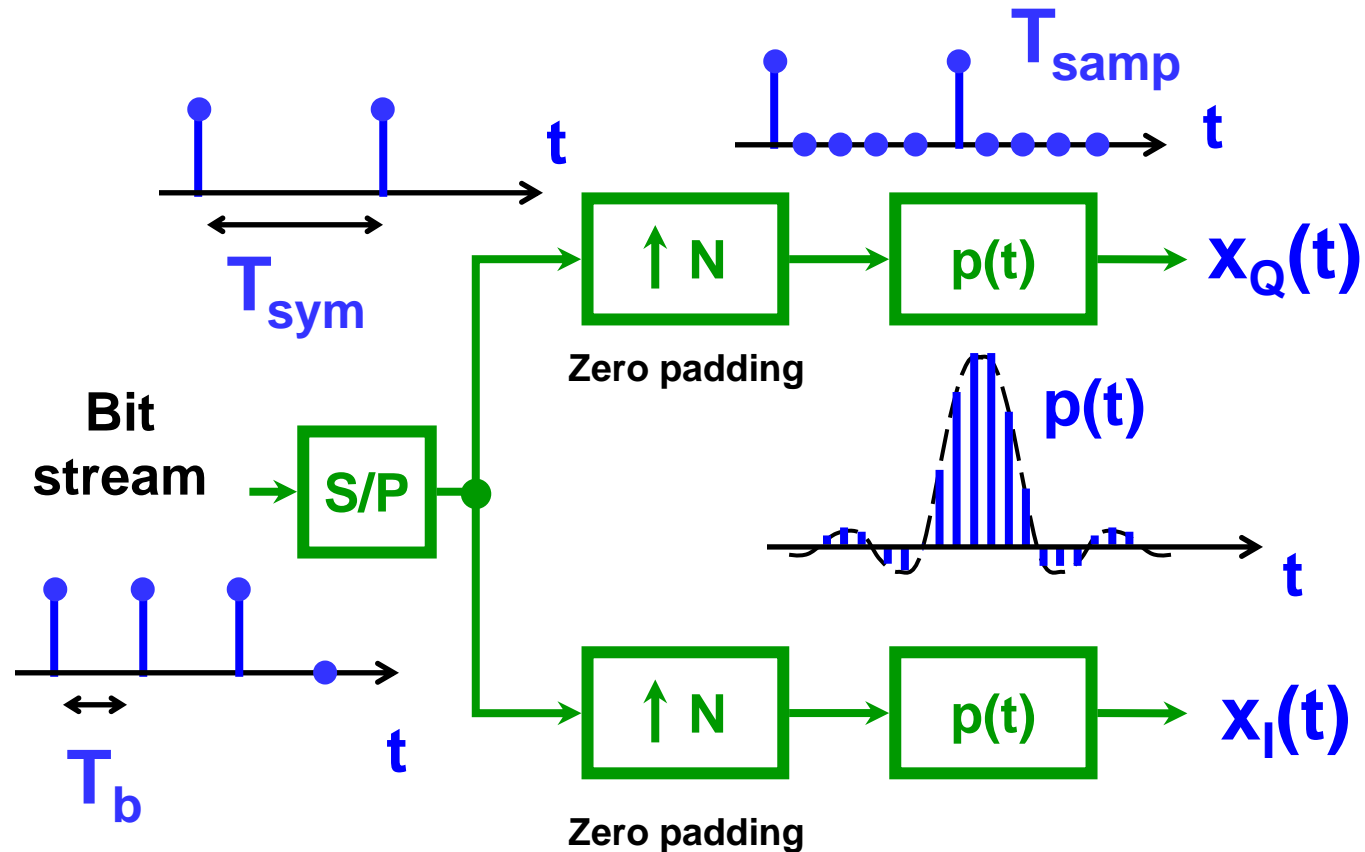


- $R = 0$: Minimum BW (Rectangular spectrum)
- $R = 1$: Maximum BW

Practical Quadrature Modulator



Simulation Model of Transmitter



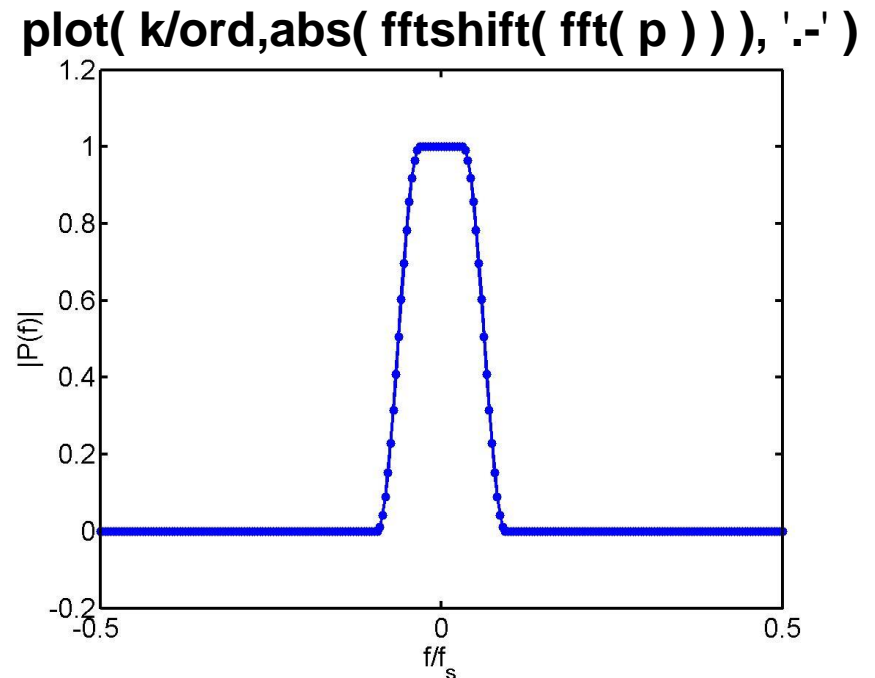
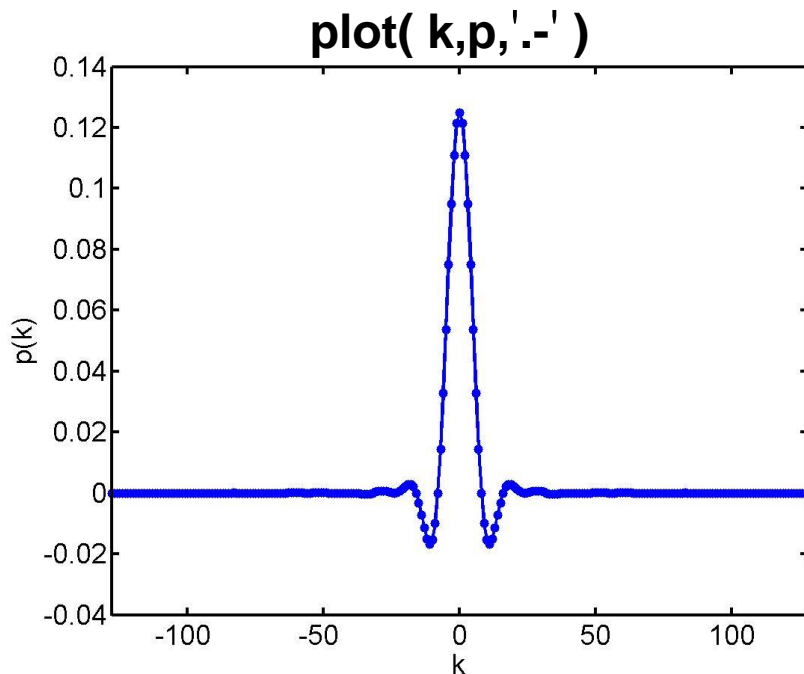
$$T_{\text{sym}} = 2T_b$$

$$T_{\text{samp}} = T_{\text{sym}}/N$$

Raised-Cosine Filter

```
N = 8; ← Number of samples per symbol  
R = 0.5;  
ord = 256; ← Filter order (number of FIR taps)  
p = rcosdesign( R, ord/N, N, 'normal' );  
k = ( -ord/2:1:ord/2 );
```

Matlab code



PRBS Sequence and Pulse Shaping

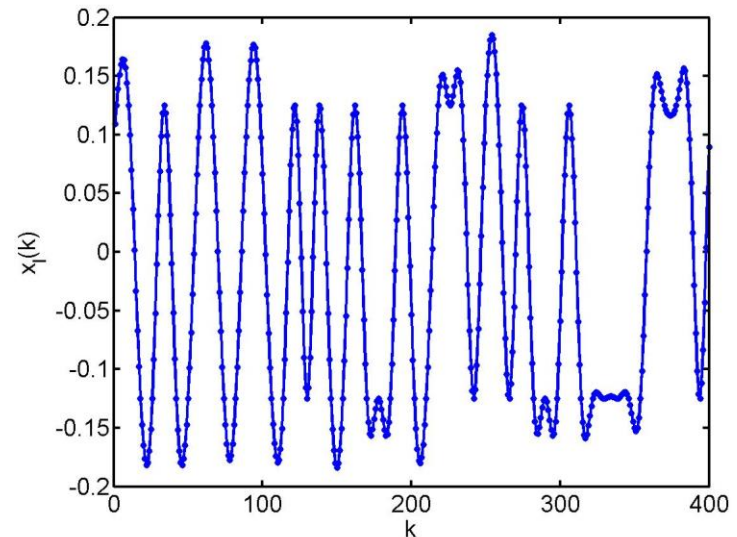
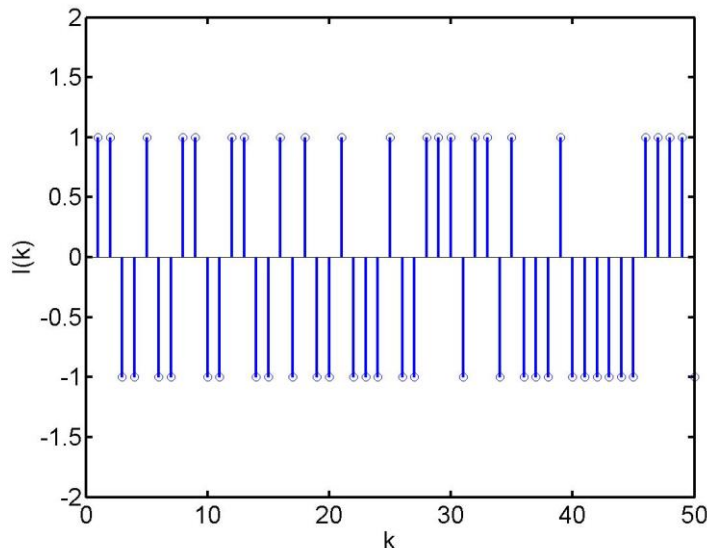
```
Nbit = 3000;  
s = sign( rand( Nbit,1 )-0.5 );  
I = s( 1:2:end );  
Q = s( 2:2:end );  
xl = conv( upsample( I, N ), p );  
xQ = conv( upsample( Q, N ), p );  
xl = xl( ord/2:end-ord/2-1 );  
xQ = xQ( ord/2:end-ord/2-1 );
```

← Pseudo-random bit stream

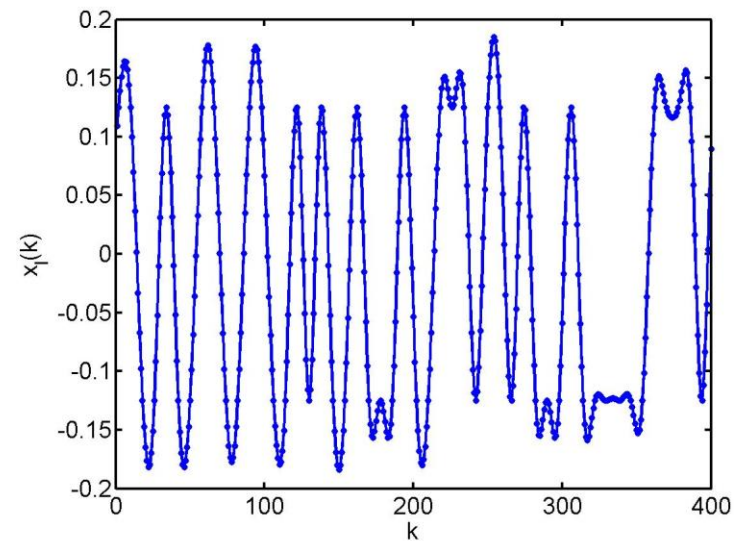
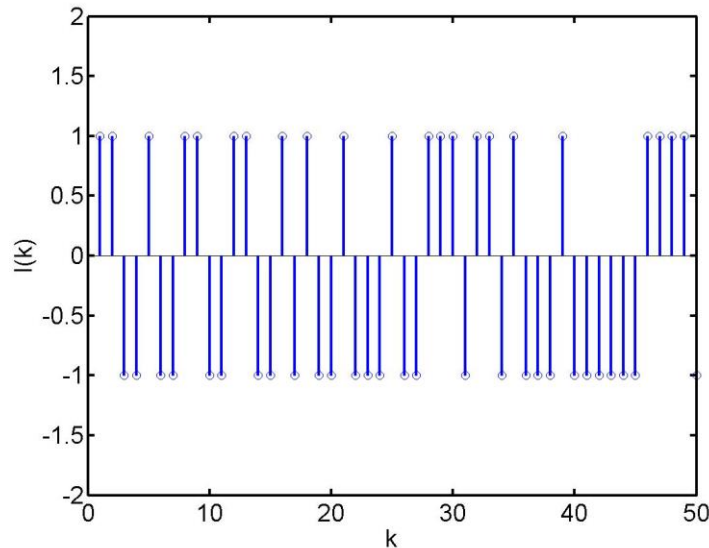
← Symbol stream

← Pulse Shaping

← Eliminating initial and final samples



Save $x_I(t)$ and $x_Q(t)$ Signals



```
file_name='bb.txt';  
save_data=[xI xQ];  
save(file_name,'save_data','-ascii','-tabs')
```

← save I/Q signal

Outline

- QPSK modulator in Mathworks Matlab
- **Demodulation in Keysight VSA 89600**
- Effects of RF transmitter impairments

Keysight (formerly Agilent) 89600 VSA Software

The screenshot shows the Keysight Technologies website for the 89601B - 89600 VSA Software. The page features a navigation bar with links to Products, Services & Support, Industries & Technologies, and About Keysight. The main content area includes a product image, a 'Request Quote' button, and a 'How to Buy or Rent' button. Below the product image, there are links to View Technical Overview, Visit Discussion Forums, Explore YouTube Videos, View Product Demos, and Visit Technical Support. A section titled 'Images' shows a gallery of product images. The 'Document Library' section lists various documents, including 'Signal Analysis Measurement Fundamentals, Optimize Noise Floor, Resolution Bandwidth, and More', '89600 VSA Software - Configuration Guide', '[Automotive Radar] 24, 76, and 79 GHz Band Tx/Rx and Components Evaluation', and 'New Pulse Analysis Techniques for Radar and EW - Application Note'. The right sidebar contains links to the Product Support Center, Related Industries & Technologies, and Training & Events.

KEYSIGHT TECHNOLOGIES

Products Services & Support Industries & Technologies About Keysight myKeysight

Home > Products > ... > Application Software > 89600 VSA and WLA Software > 89601B - 89600 VSA Software

89601B - 89600 VSA Software

Sold By: **Keysight** - Usually arrives in 2 weeks
Authorized Sales Partners - [Check availability](#)

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Prices for: **Italia**
* Prezzi soggetti a variazione. Per una richiesta di offerta contattare il numero 800 599100.

Product Support Center

- Technical Support manuals, drivers, application notes, firmware, software, ...
- Post-Purchase Upgrades

Related Industries & Technologies

- TD-LTE Design and Test Equipment

Training & Events

- RF Design and Test Webcast Series
- Millimeter-wave Challenges Webcast
- RF Fundamentals Part 3 - Signal Generation, Modulation and Vector Signal Analysis

Overview & Features **Standard Configurations** **Options & Accessories** **Trials & Licenses** **Document Library**

Refine the List 1-25 of 61 Sort: [Date](#)

By Type of Content

- Specifications (18)
- Manuals (6)
- Application Notes (12)
- Brochures & Competitive Overviews (4)
- Selection & Configuration Guides (2)
- Demos (13)
- Catalogs (1)
- Press Releases (5)

Signal Analysis Measurement Fundamentals, Optimize Noise Floor, Resolution Bandwidth, and More
Learn measurement fundamentals to optimize your signal analysis for greater insights
Application Note 2017-02-13 PDF 4.07 MB Languages

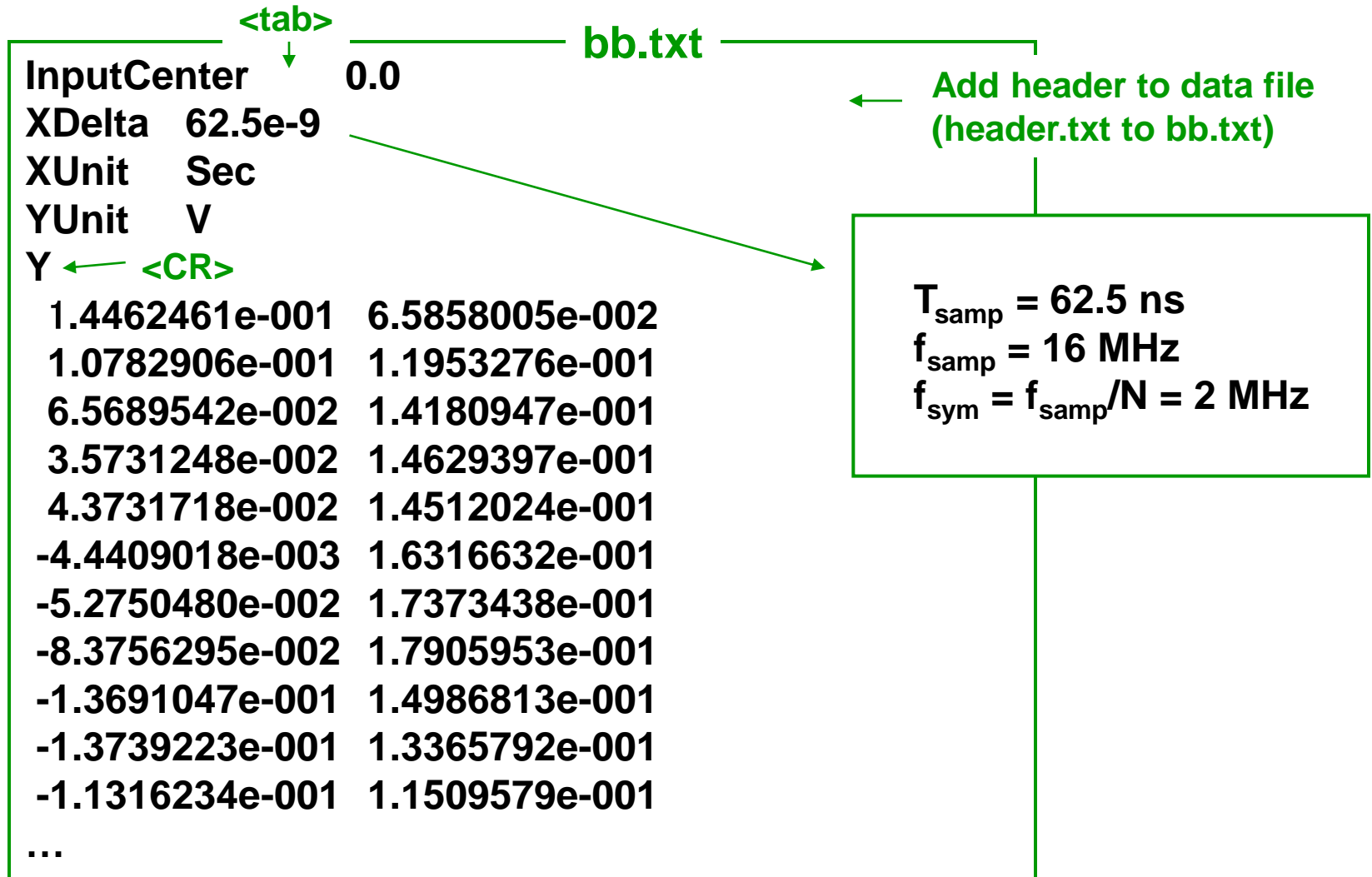
89600 VSA Software - Configuration Guide
This 89600 VSA software configuration guide will help you configure your new or existing 89600 VSA with the measurement options, licenses, and update service subscriptions you need.
Configuration Guide 2017-01-27 PDF 1.06 MB Languages

[Automotive Radar] 24, 76, and 79 GHz Band Tx/Rx and Components Evaluation
For design verification of millimeter wave collision avoidance radar with high resolution and wide viewing angle
Brochure 2016-12-28 PDF 520 KB

New Pulse Analysis Techniques for Radar and EW - Application Note
This app note discusses the best tools for different types of pulse analysis, along with display and analysis techniques for various signals and measurement goals.
Application Note 2016-05-26 PDF 3.93 MB Languages

- Download and install 89600 VSA on Windows OS
- Apply for trial license (use polimi email address)

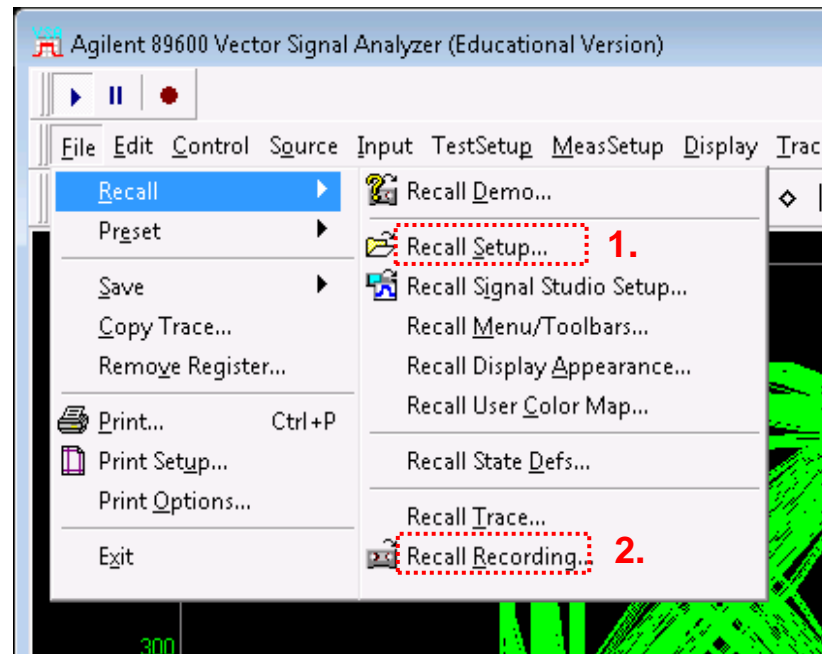
Preparing data file for VSA



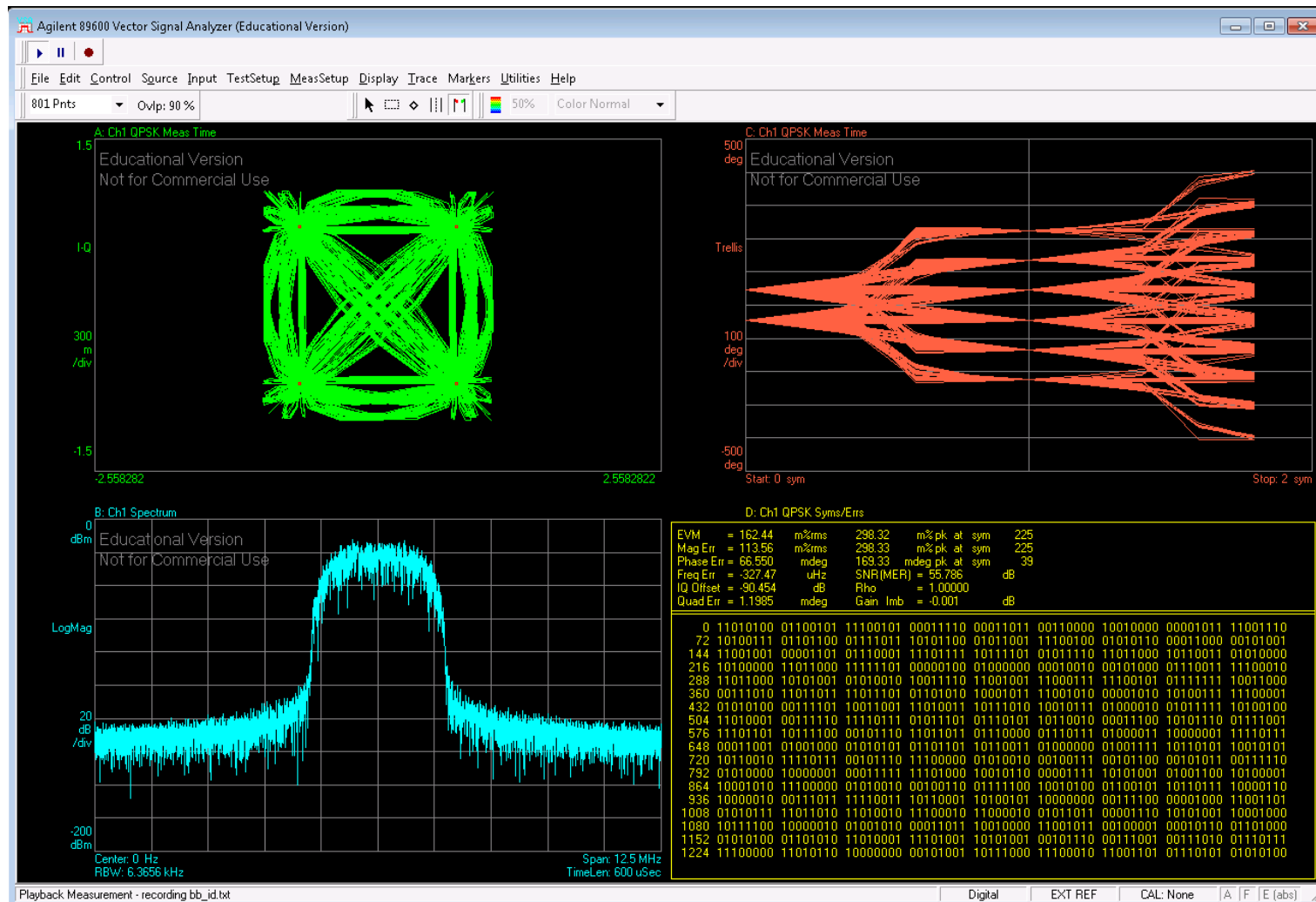
Demodulation with VSA Software

From File menu:

- “Recall setting” (.set file available in Beep website)
- “Recall recording” (.txt file previously saved in Matlab)
- “Play”



Demodulation with VSA Software



Exercise #1

- **What happens in case different values of R ? Try for instance $R = 0.1$ and $R = 1$ and note down how the spectrum and the constellation (and SNR) change**
- **Can you explain the result?**

Exercise #1 – Results

SNR from VSA (at $R = 0.1$) = _____

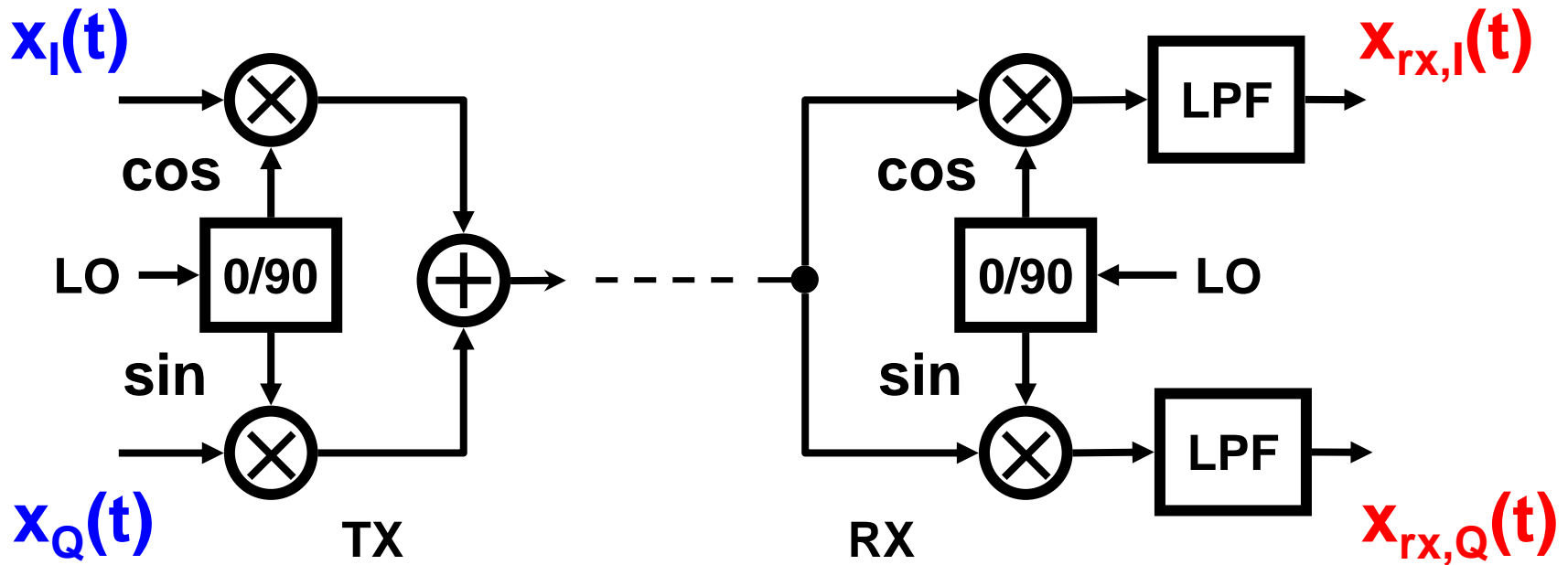
SNR from VSA (at $R = 1$) = _____

Explanation:

Outline

- QPSK modulator in Mathworks Matlab
- Demodulation in Keysight VSA 89600
- **Effects of RF transmitter impairments**
 - **Amplitude/Phase Imbalances**
 - **Phase Noise**

Effect of LO Amplitude and Phase Imbalances



$$x_{LOI}(t) = (1 + \varepsilon/2) \cos(\omega_c t + \theta/2)$$

$$x_{LOQ}(t) = (1 - \varepsilon/2) \sin(\omega_c t - \theta/2)$$



$$\text{SNR}_{\text{TX}} \approx \frac{1}{\frac{\varepsilon^2}{4} + \frac{\theta^2}{4}}$$

Equivalent Error on Base-Band Signals

$$\begin{aligned} & x_I(t) \cos(\omega_c t + \theta/2) + x_Q(t) \sin(\omega_c t - \theta/2) = \\ & = \underbrace{x_I(t) \cos(\theta/2)} \cos(\omega_c t) - \underbrace{x_Q(t) \sin(\theta/2)} \cos(\omega_c t) + \\ & \quad - \underbrace{x_I(t) \sin(\theta/2)} \sin(\omega_c t) + \underbrace{x_Q(t) \cos(\theta/2)} \sin(\omega_c t) \end{aligned}$$

```
theta = 10*pi/180;
```

```
xl = xl*cos( theta /2 ) - xQ*sin( theta /2 );
```

```
xQ = -xl*sin( theta /2 ) + xQ*cos( theta /2 );
```

← 10 deg phase error

← add LO phase error

```
file_name='bb.txt';
```

```
save_data=[xl xQ];
```

```
save(file_name,'save_data','-ascii','-tabs');
```

← save I/Q signal

Exercise #2

- **Compute SNR from theory and from VSA with 10-degree LO quadrature error in TX.**
- **How does the constellation look like? Explain the result.**

Exercise #2 - Results

SNR from VSA **=** _____

SNR from theory **=** _____

Constellation:

Exercise #3

- **Compute SNR from theory and from VSA with 10% LO amplitude error in TX.**
- **How does the constellation look like? Explain the result.**

Exercise #3 - Results

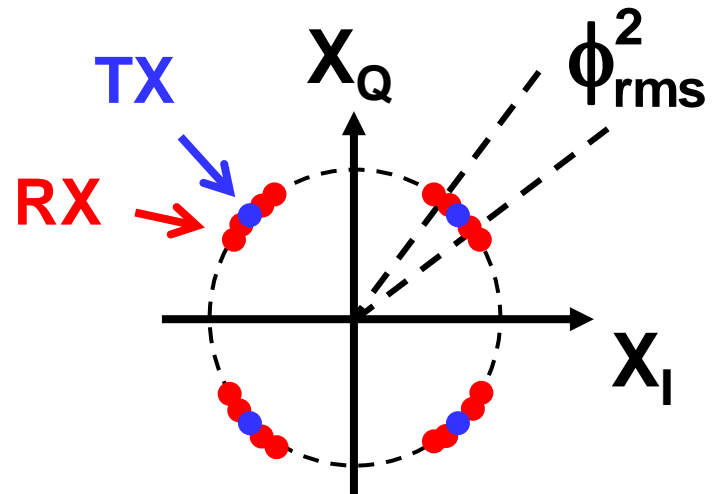
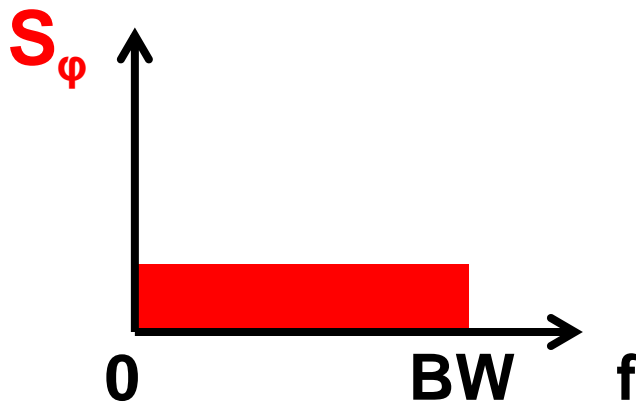
SNR from VSA = _____

SNR from theory = _____

Constellation:

Effect of LO Phase Noise

$$V_{LO}(t) = A_0 \cos[\omega_c t + \phi(t)]$$



$$\phi_{rms}^2 = \int_0^{BW} S_\phi(f) df$$

$$SNR \approx \frac{1}{\phi_{rms}^2}$$

Phase Noise on Base-Band Signals

$$\begin{aligned} x_I(t) \cos(\omega_c t + \phi) + x_Q(t) \sin(\omega_c t + \phi) = \\ = \underbrace{x_I(t) \cos(\phi)} \cos(\omega_c t) + \underbrace{x_Q(t) \sin(\phi)} \cos(\omega_c t) + \\ - \underbrace{x_I(t) \sin(\phi)} \sin(\omega_c t) + \underbrace{x_Q(t) \cos(\phi)} \sin(\omega_c t) \end{aligned}$$

```
phi = 1 * pi/180 * randn( length(xl),1 );  
xl = xl.*cos( phi ) + xQ.*sin( phi );  
xQ = -xl.*sin( phi ) + xQ.*cos( phi );
```

} ← 1 deg-rms Gaussian noise
} ← add LO phase noise

```
file_name='bb.txt';  
save_data=[xl xQ];  
save(file_name,'save_data','-ascii','-tabs')
```

} ← save I/Q signal

Exercise #4

- **Compute SNR from theory and from VSA with 1-degree-rms phase noise of the local oscillator.**
- **How does the constellation look like?**

Exercise #4 - Results

SNR from VSA **=** _____

SNR from theory **=** _____

Constellation:

Exercise #5

- **Combine all the previous LO impairments (10% amplitude error, 10 deg phase error, 1 deg-rms phase noise) and evaluate the SNR at the demodulator**

Exercise #5 - Results

SNR from VSA = _____

SNR from theory = _____