



将 MATLAB 连接到 NI PXI / USRP 加速无线系统设计创新

刘金龙, NI



陈晓挺, MathWorks



MATLAB EXPO

信号检测：一个无线设计需求



Aero/Defense Company



防范措施

信号检测

无人机防御

终点



无线系统架构师
算法开发人员

商用现货软件无线电，如USRPs

1



定制硬件

2



汇报



主要目标：信号检测

- 探索并测试无线系统设计的可行性
- 冻结规范并设计信号检测器的原型

对软件无线电的新需求

当前挑战

- 宽带应用需要高速传输和捕获解决方案
- 无线应用的实时和近实时处理需要
 - 硬件资源的优化利用
 - 智能信号检测与捕获
 - 高效的主机处理
- AI 模型的训练需要大量的实时数据

Wireless Testbench R2022a



高速数据发射与捕获



智能信号检测

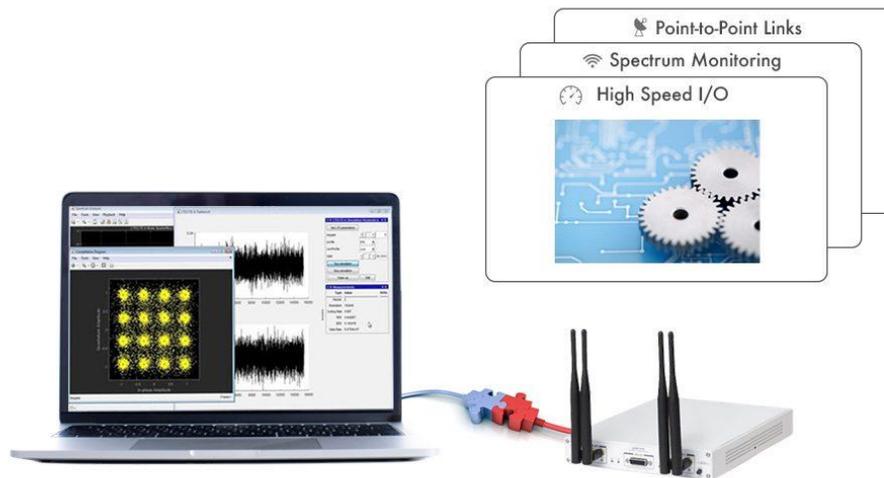
请先下载硬件支持包

Wireless Testbench Support Package for NI USRP Radios

Explore and test **wireless** reference applications on NI USRP radios

The **Wireless Testbench™** Support Package for NI™ USRP™ Radios enables package consists of USRP hardware driver (UHD)

硬件支持



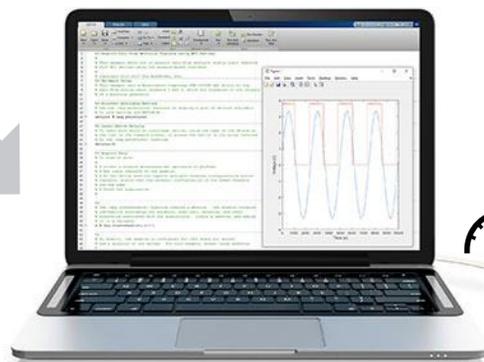
借助高速数据传输和捕获平台探索并测试无线设计

Wireless Testbench workflow1: 高速发射和捕获

- 回环测试
- RF前端验证
- 信道影响
- 端到端
- 收发器设计



基带收发机



基带发射机

- 定制信号
- 噪声
- 干扰波形
- 接收机设计

主要特性

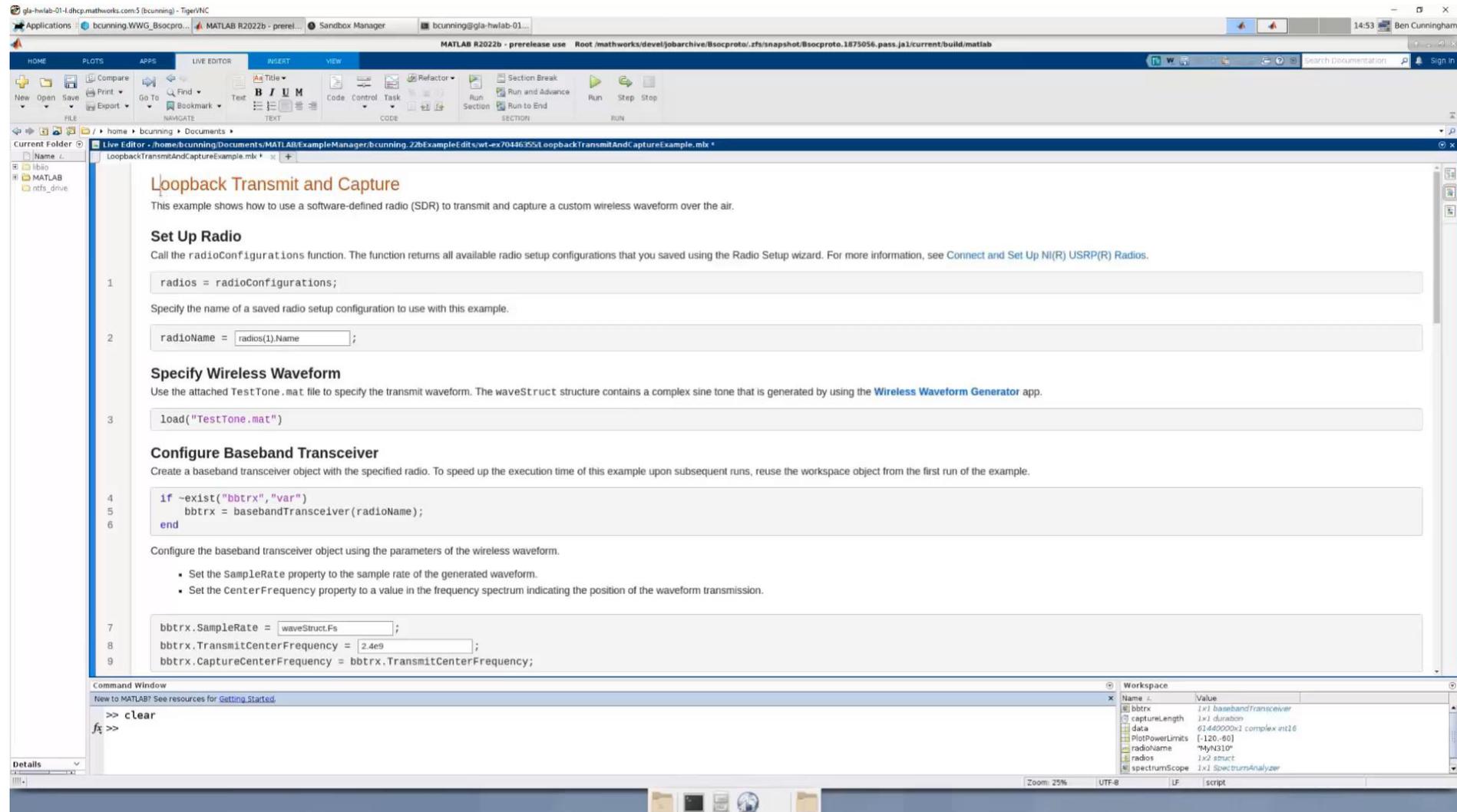
- 全速率传输/捕获（高达 250 MSPS）发送/接收
- 基带接收机、发射机和收发机工作流程



基带接收机

- 5G, WLAN, Satellite Communication
- 定制信号
- 认知无线电
- 频谱感知

高速发射和捕获：基带发射机演示



The screenshot displays the MATLAB Live Editor interface. The main window shows a script titled "Loopback Transmit and Capture" with the following content:

```
1 radios = radioConfigurations;  
2 radioName = radios(1).Name;  
3 load("TestTone.mat")  
4 if ~exist("bbtrx", "var")  
5     bbtrx = basebandTransceiver(radioName);  
6 end  
7 bbtrx.SampleRate = waveStruct.Fs;  
8 bbtrx.TransmitCenterFrequency = 2.4e9;  
9 bbtrx.CaptureCenterFrequency = bbtrx.TransmitCenterFrequency;
```

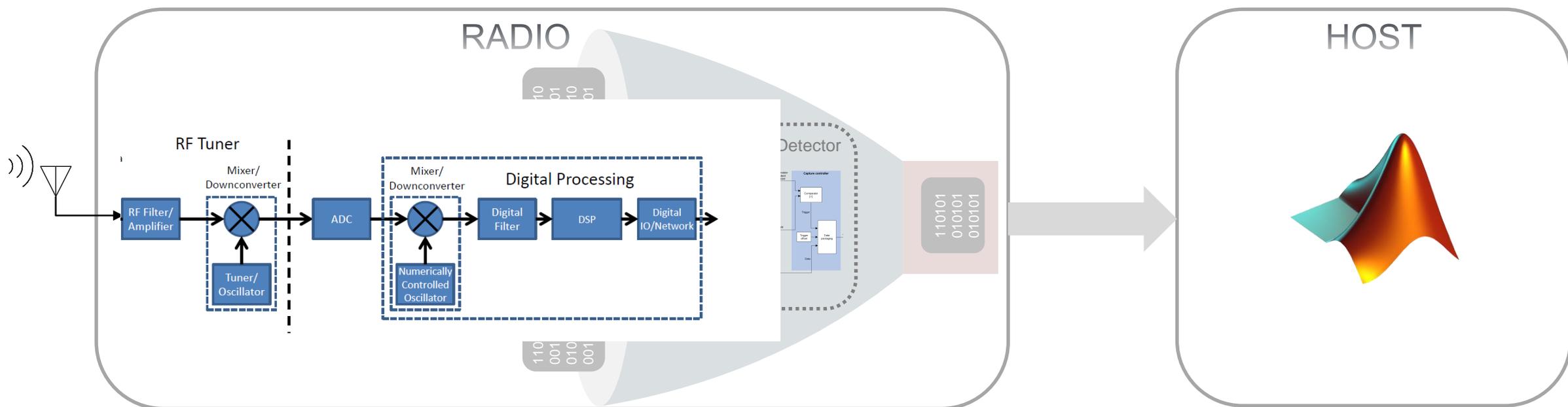
The script is accompanied by explanatory text and instructions. Below the script, the Command Window shows the execution of the following commands:

```
>> clear  
fs >>
```

The Workspace window at the bottom right shows the following variables:

Name	Value
bbtrx	1x1 basebandTransceiver
captureLength	1x1 duration
data	63.449000x1 complex int26
PlotPowerLimits	[-120, 60]
radioName	"MyN310"
radios	1x2 struct
spectrumScope	1x1 SpectrumAnalyzer

Wireless Testbench 工作流程2：智能信号检测和数据采集



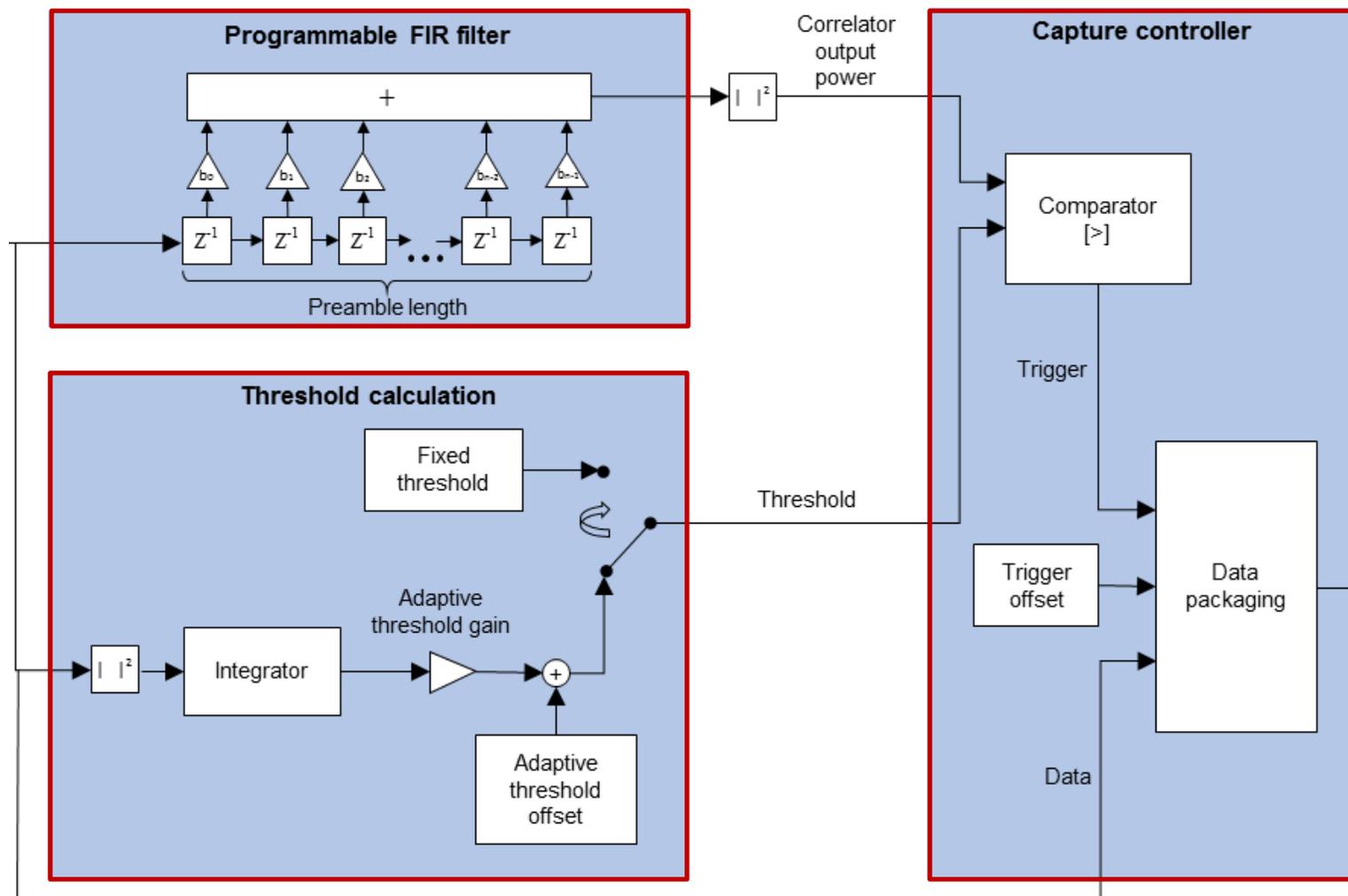
特性

- 智能采集 @ 250 MSPS
- 可编程互相关器
- 预构建的比特流

使用场景

- 频谱一致性
- 信号检测
- 频谱监测
- 信号分类
- 认知无线电
- 雷达

智能信号检测和数据捕获：内部架构



可编程FIR滤波器

- 将输入信号与已知前导序列相关

阈值计算

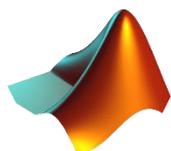
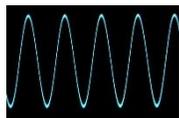
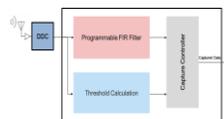
- 固定和自适应阈值

捕获控制器

- 计算触发点
- 延迟触发
- 捕获数据

智能数据检测和捕获：步骤

扫描过程包括5个步骤



配置前导检测器对象 `preambleDetector`



设置前导检测器要扫描的频带和通道



扫描每个指定通道，并在成功检测时捕获波形

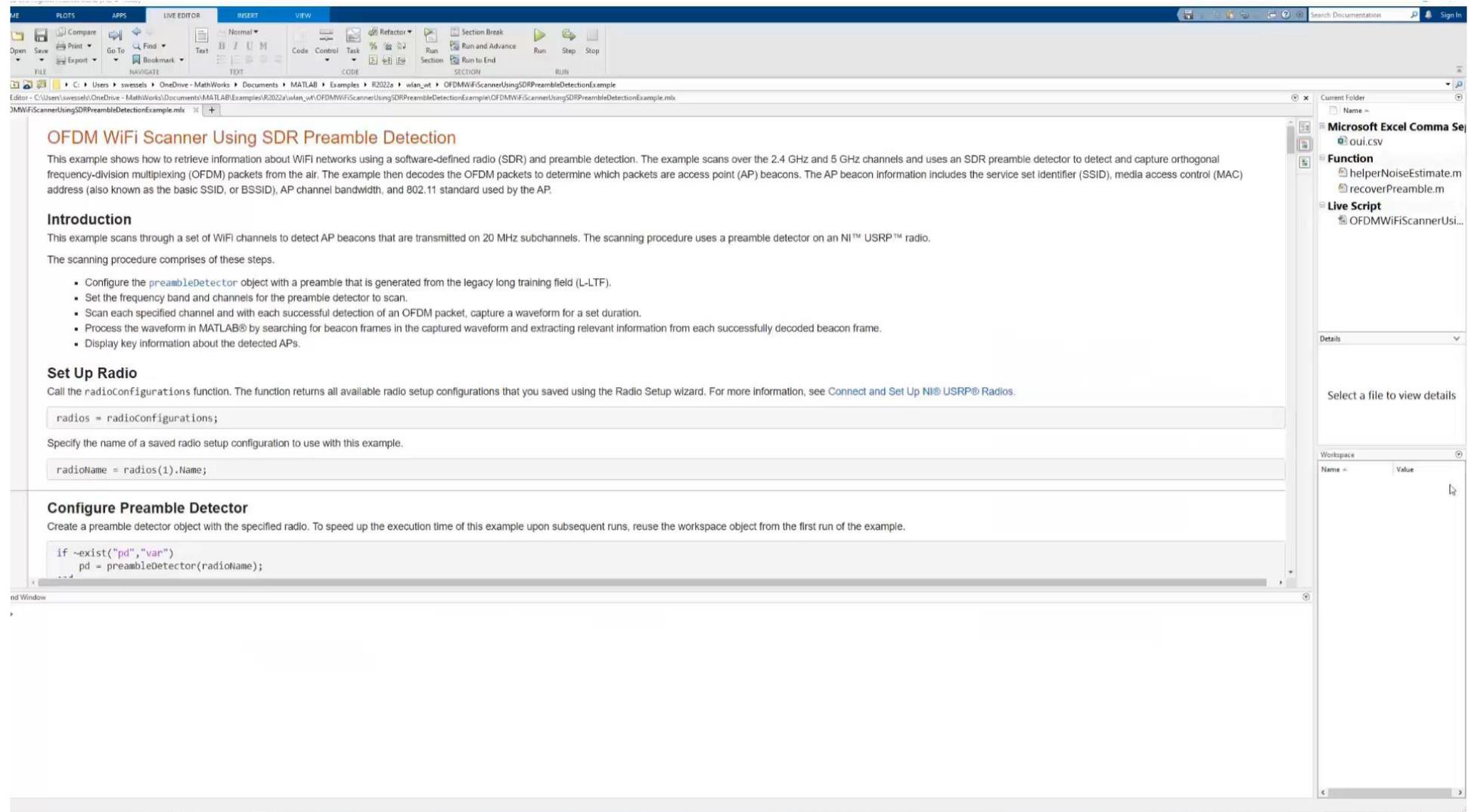


在MATLAB中处理波形



显示信号的关键信息

智能数据检测和捕获：WLAN扫描仪MATLAB示例



OFDM WiFi Scanner Using SDR Preamble Detection

This example shows how to retrieve information about WiFi networks using a software-defined radio (SDR) and preamble detection. The example scans over the 2.4 GHz and 5 GHz channels and uses an SDR preamble detector to detect and capture orthogonal frequency-division multiplexing (OFDM) packets from the air. The example then decodes the OFDM packets to determine which packets are access point (AP) beacons. The AP beacon information includes the service set identifier (SSID), media access control (MAC) address (also known as the basic SSID, or BSSID), AP channel bandwidth, and 802.11 standard used by the AP.

Introduction

This example scans through a set of WiFi channels to detect AP beacons that are transmitted on 20 MHz subchannels. The scanning procedure uses a preamble detector on an NI™ USRP™ radio.

The scanning procedure comprises of these steps.

- Configure the `preambleDetector` object with a preamble that is generated from the legacy long training field (L-LTF).
- Set the frequency band and channels for the preamble detector to scan.
- Scan each specified channel and with each successful detection of an OFDM packet, capture a waveform for a set duration.
- Process the waveform in MATLAB® by searching for beacon frames and extracting relevant information from each successfully decoded beacon frame.
- Display key information about the detected APs.

Set Up Radio

Call the `radioConfigurations` function. The function returns all available radio setup configurations that you saved using the Radio Setup wizard. For more information, see [Connect and Set Up NI® USRP® Radios](#).

```
radios = radioConfigurations;
```

Specify the name of a saved radio setup configuration to use with this example.

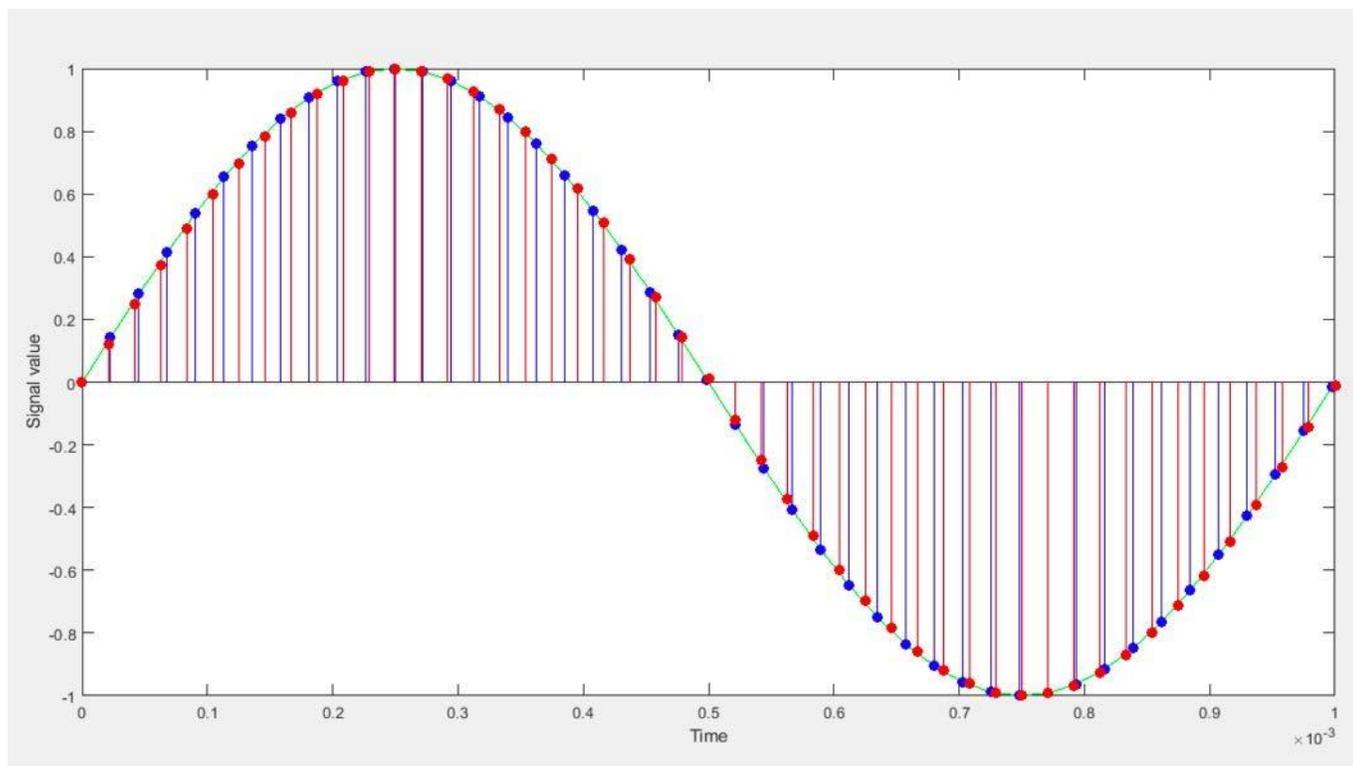
```
radioName = radios(1).Name;
```

Configure Preamble Detector

Create a preamble detector object with the specified radio. To speed up the execution time of this example upon subsequent runs, reuse the workspace object from the first run of the example.

```
if ~exist("pd","var")
    pd = preambleDetector(radioName);
end
```

Wireless Testbench: 任意采样率

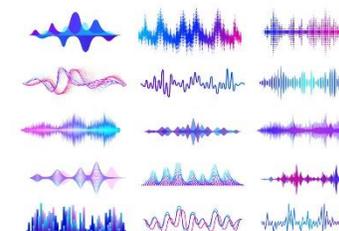


- 任意采样率满足不同应用
- 基于标准和自定义波形
- 重采样在接收路径的FPGA上完成

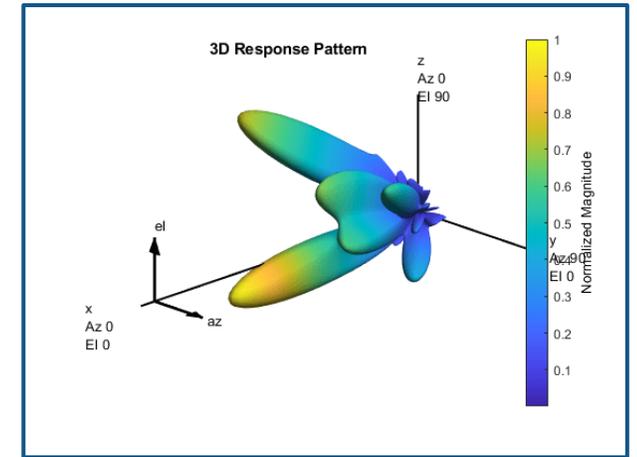
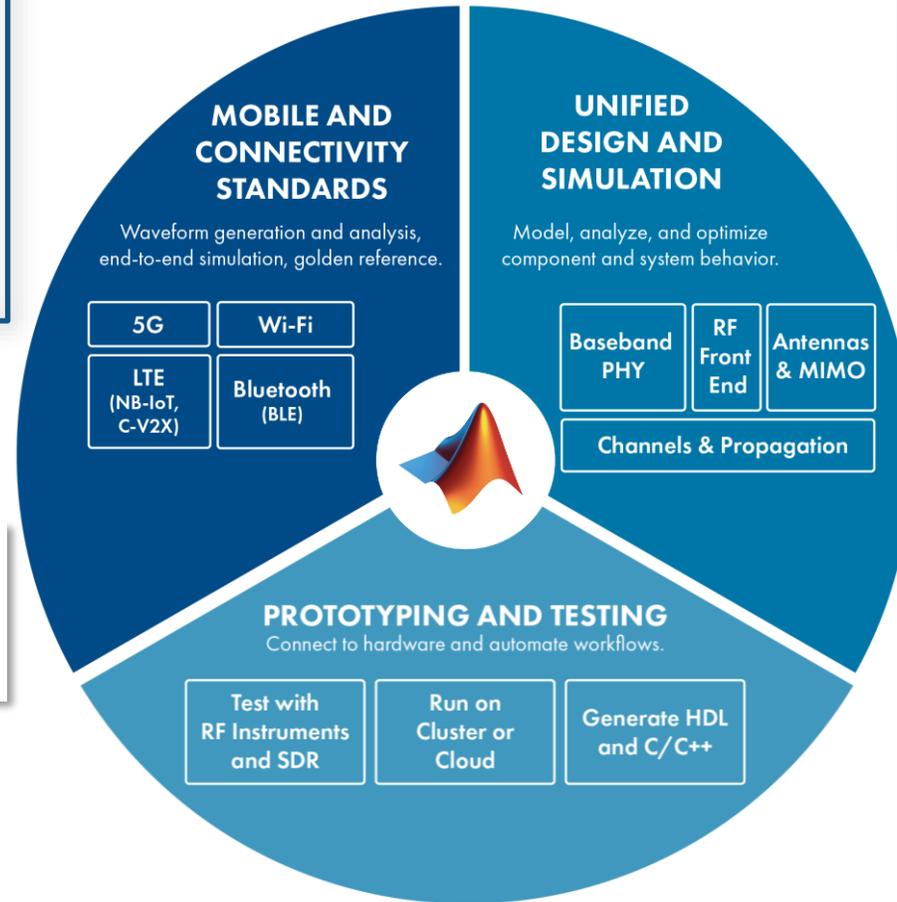
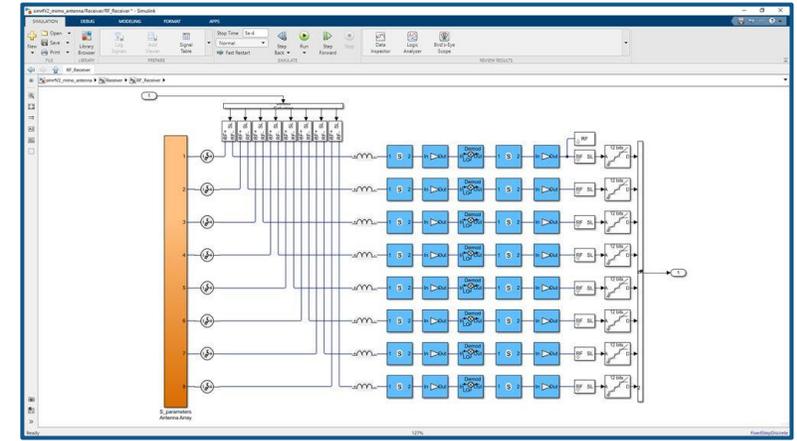
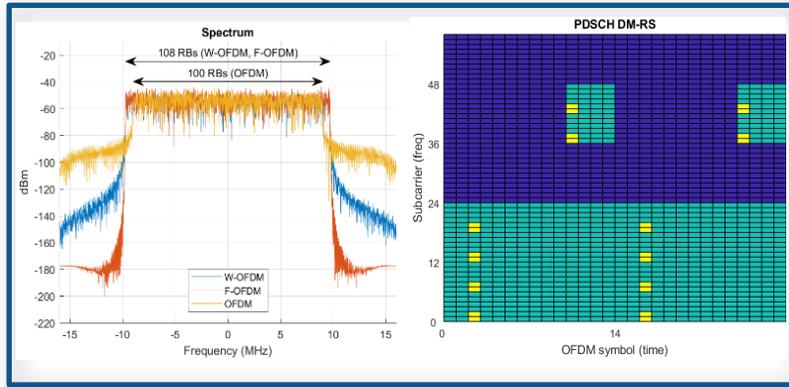
LVDS/S2[®]

5G

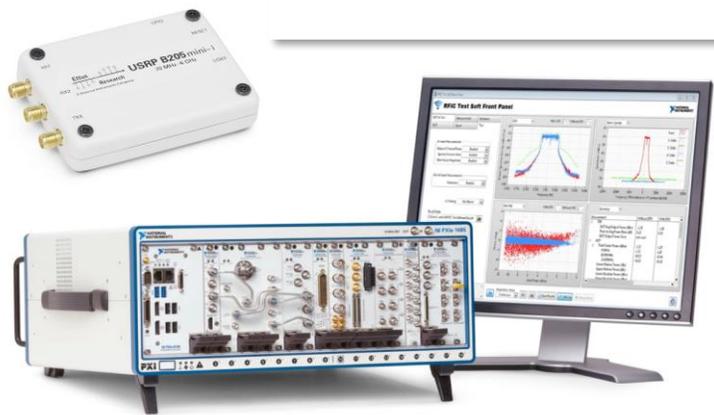
4G LTE



更好的无线设计创新和原型开发 workflow



NI SDR and Instruments





刘金龙
NI亚太区商业航天负责人

将MATLAB连接到PXI/USRP用于无线系统设计

在无线通信中运用MathWorks软件与NI SDR硬件

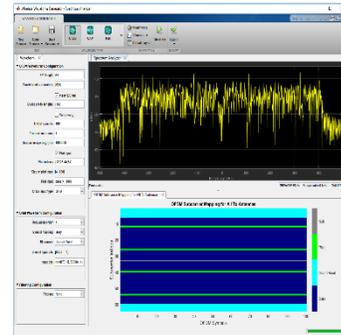
MathWorks 软件

```

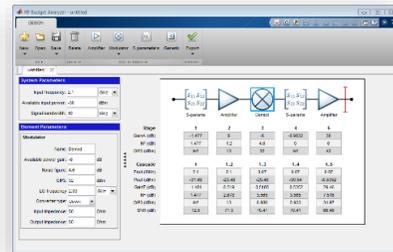
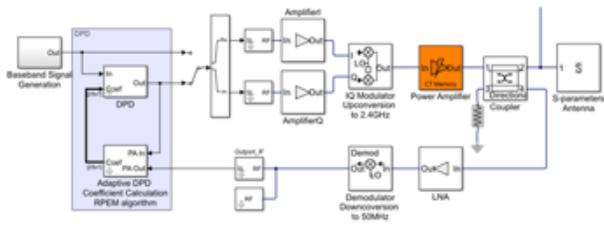
% Establish the number of component carriers.
numCC = length(NDLRB);

% Create transmission for each component carrier
enb = cell(1,numCC);
for i = 1:numCC
    enb{i} = lteRMCDL('R.5');
    enb{i}.NDLRB = NDLRB(i);

```



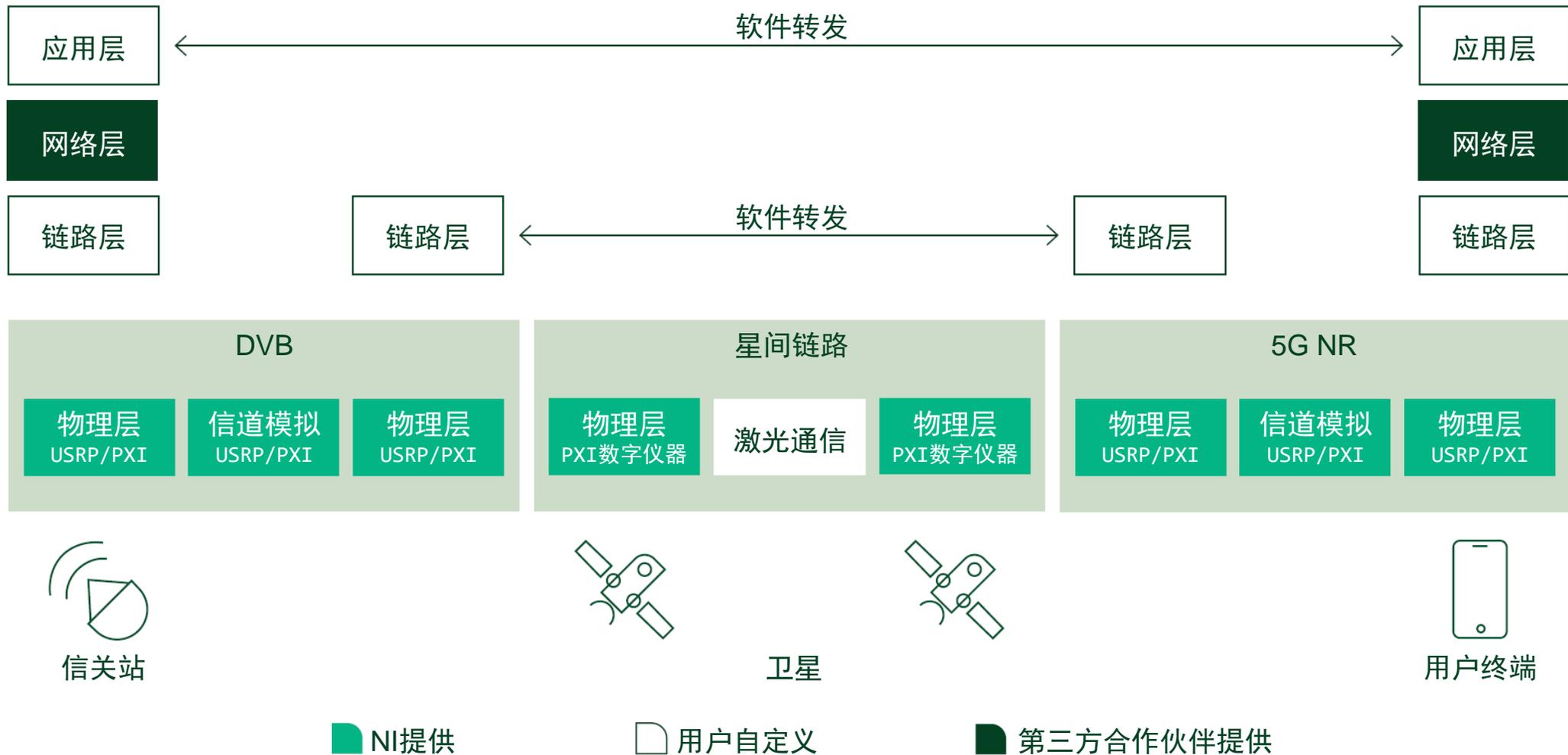
MATLAB®
& SIMULINK®



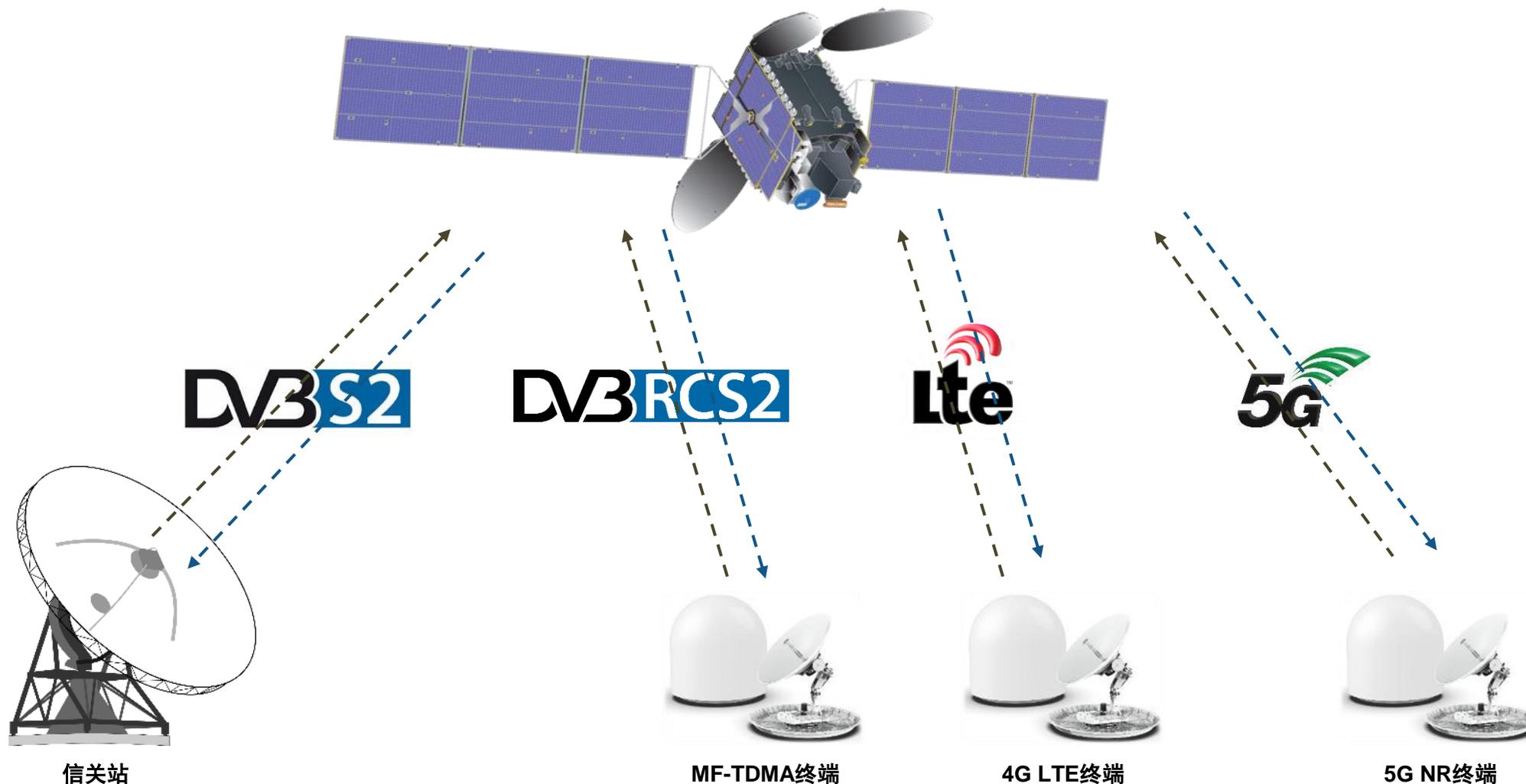
NI SDR 硬件



完整的卫星融合通信仿真原型平台

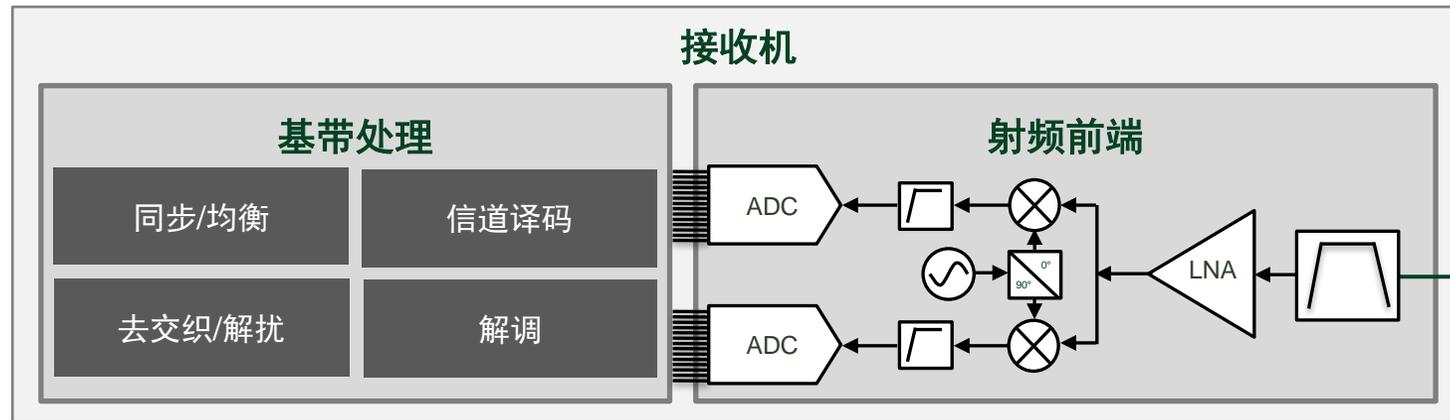
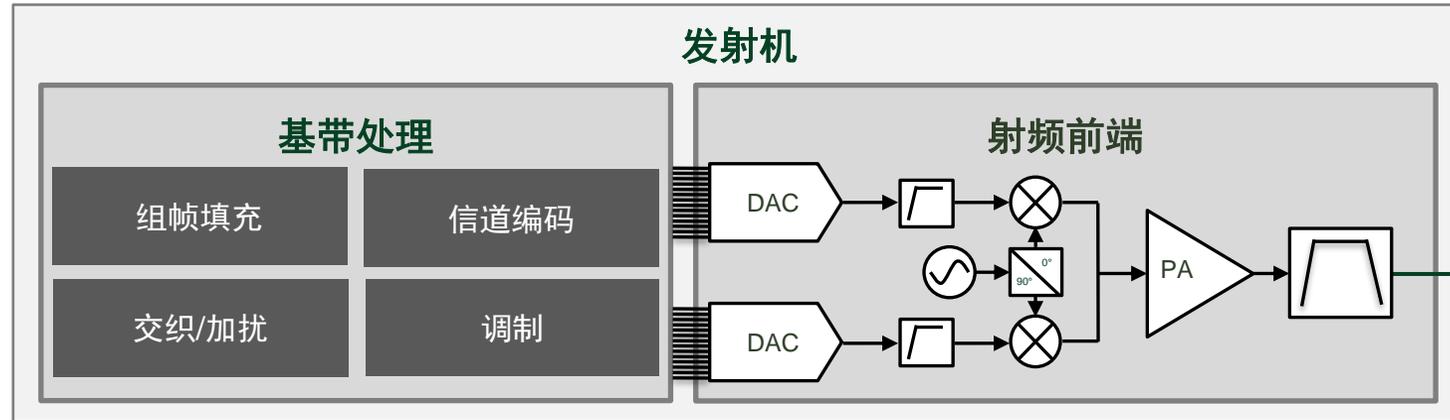
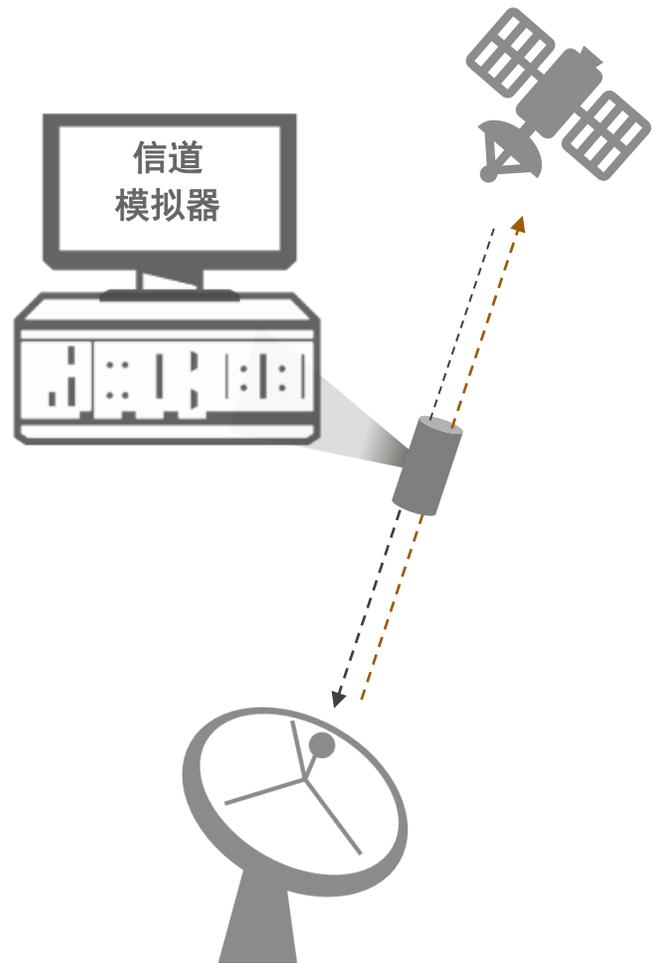


低轨卫星通信与5G融合原型



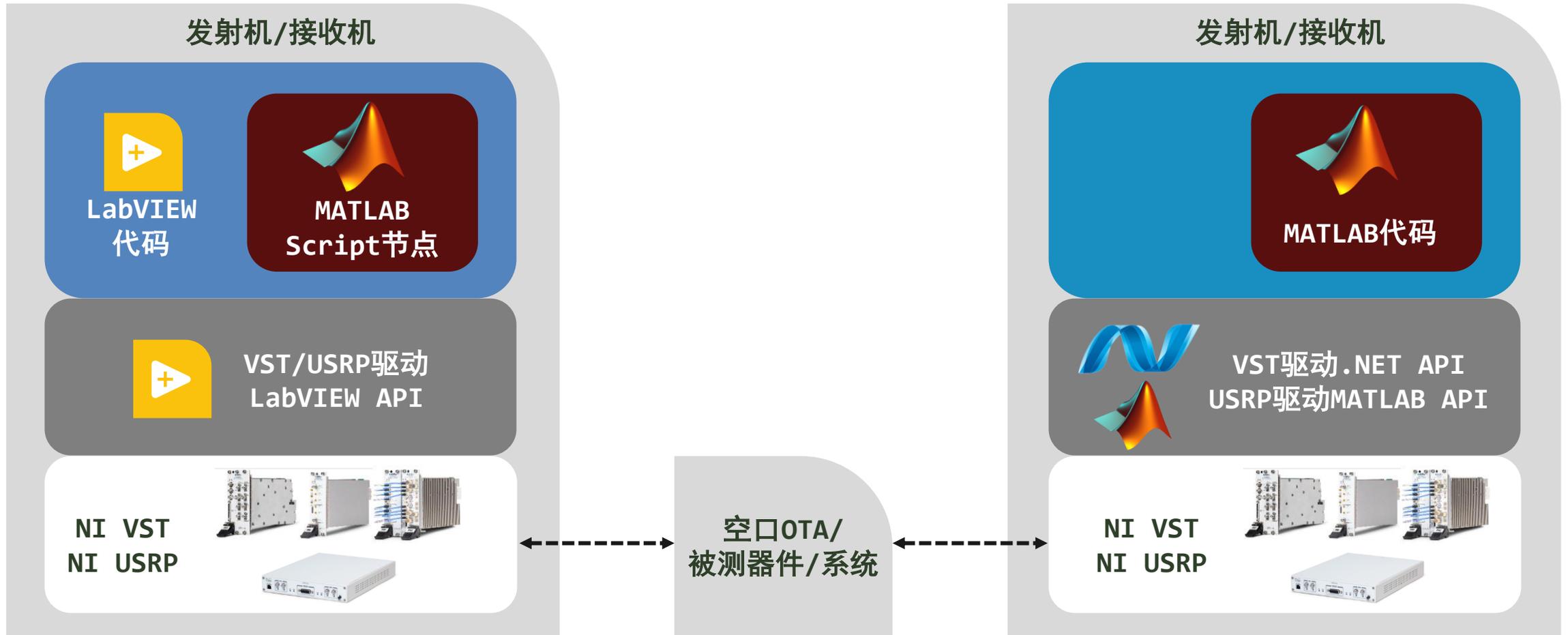
完整的端到端通信链路

基于MATLAB与NI SDR硬件实现全链路的半实物原型验证



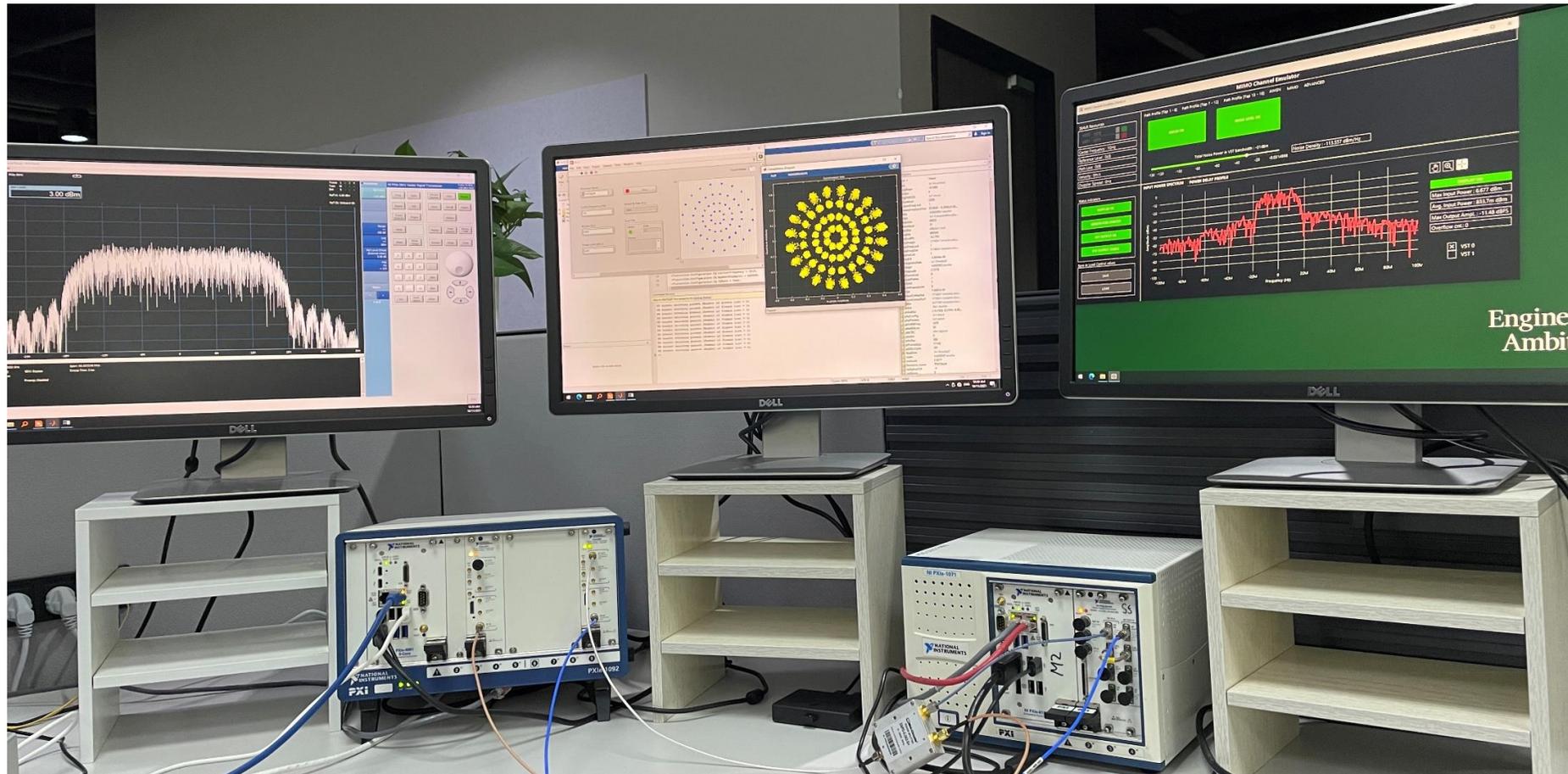
基于MATLAB与SDR硬件的DVB通信半实物原型系统

MATLAB卫星通信工具包



应用案例：DVB端到端半实物通信原型(PXI VST)

信道模拟器充当待测件施加噪声干扰，测试其对链路EVM、频谱等带来的影响



应用案例：DVB端对端半实物通信原型(USRP)

将软件波形快速以空口射频形式传输



5G NR用于卫星通信的关键技术挑战

- **物理层波形、算法**
 - 大多普勒频移
 - 基于多波束的验证
 - 功率受限
- **随机接入过程**
 - 定时提前(TA)
 - 随机接入算法
- **动态调度过程**
 - MAC调度
 - HARQ
 - 干扰信号源
 - 频率管理与干扰
- **定制化设计与修改**
 - ...

基于MATLAB与NI SDR硬件的5G非地面通信半实物原型系统

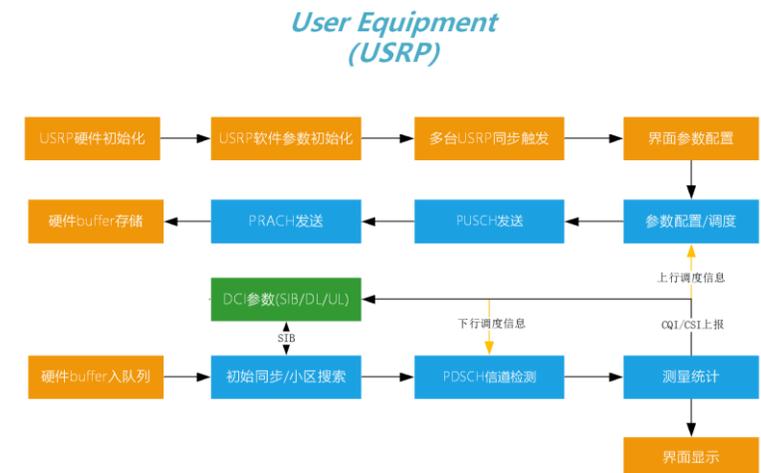
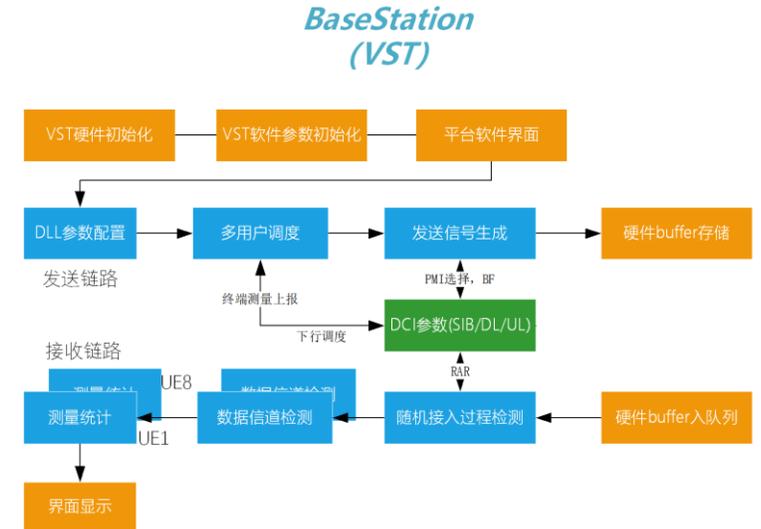
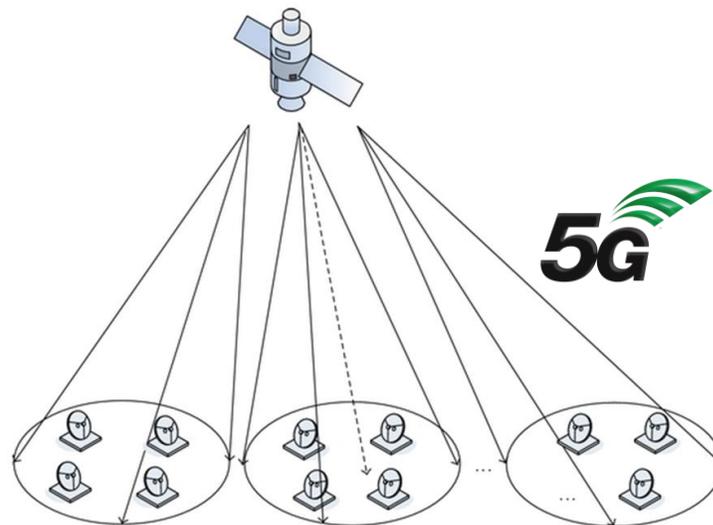
- 基于3GPP 5G NR协议
- 针对卫星通信需求的定制化设计
- 支持多链路（用户）同时收发
- 较为完整的物理层过程实现
- 支持多波束设计与验证
- 模拟多终端(USRP)同基站(PXI VST)的交互过程
- 多用户（多USRP）采用硬件信号触发实现帧同步
- 专用同步信号实现与宽带星地信道模拟器的同步

LabVIEW
代码

MATLAB
Script节点

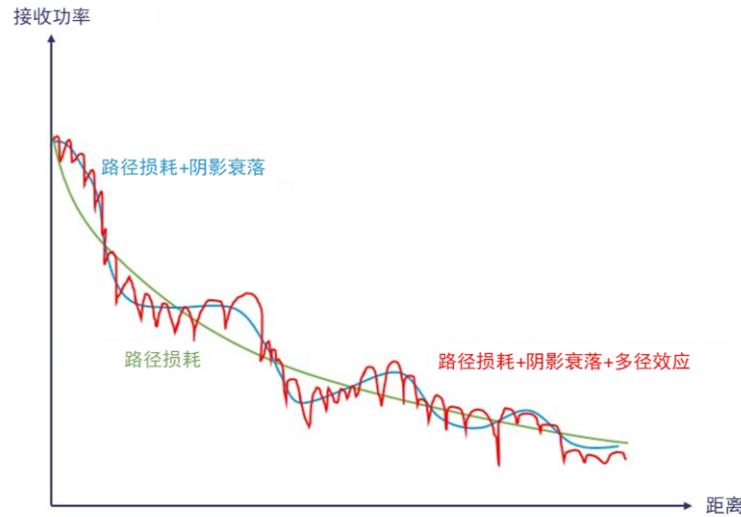
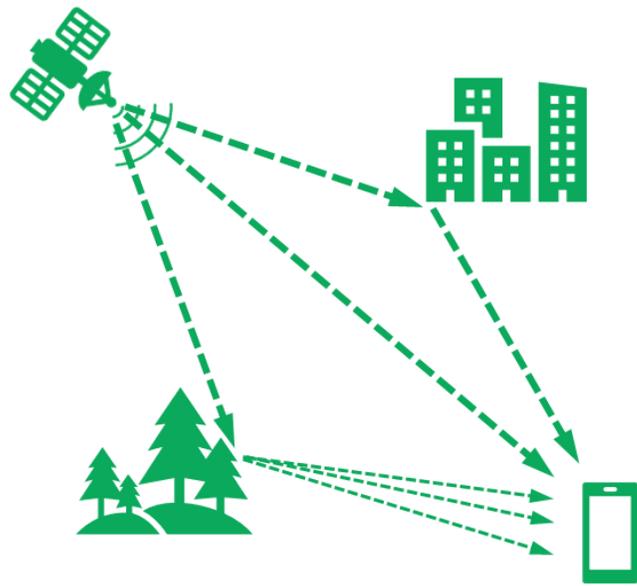
VST/USRP驱动 LabVIEW API

NI VST
NI USRP

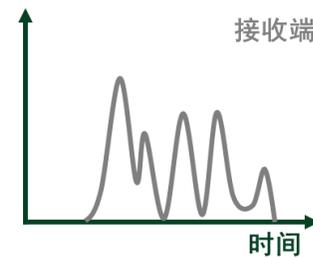
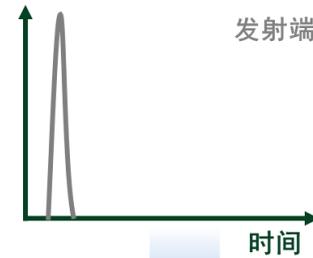


星地信道模拟器

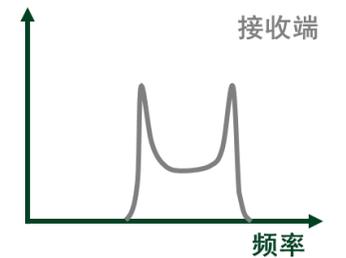
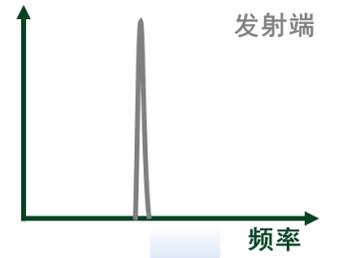
在卫星通信系统的研究开发中，由于条件限制，不能实时进行信道的实际测试，通常采用一个有良好近似效果的星地信道模拟系统来模拟星地信道的特性。星地信道模拟器能在实验室中模拟实际的无线通信信道与样机进行连接，让研究人员不用到现场就能实时测试出通信样机的性能，大幅提高开发与测试工作的效率



大小尺度衰落



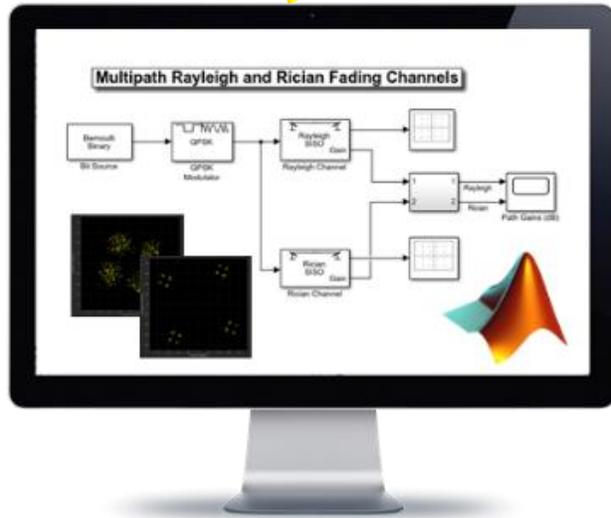
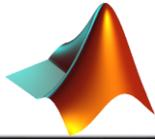
时延扩展



频率色散

信道模拟技术

软件仿真



- 信道建模
- 软件信道模拟



硬件仿真

信道模拟器

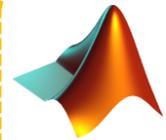
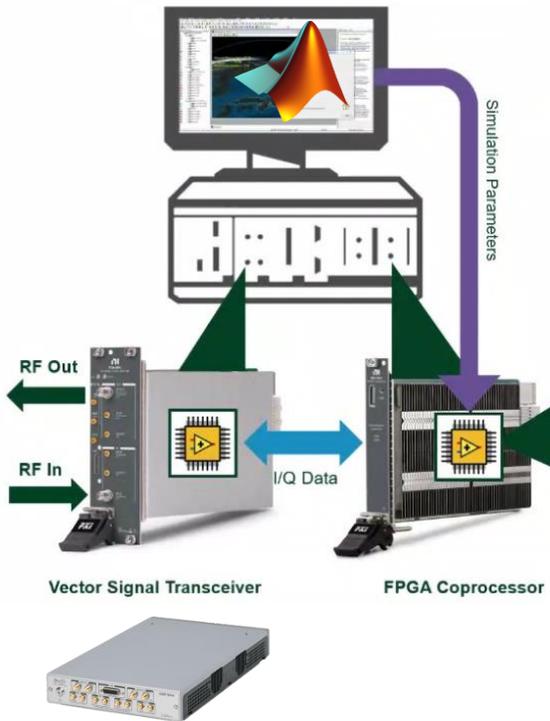
基站/卫星模拟器

终端模拟器



- 连续实时模拟
- 可与硬件样机/待测系统进行射频联调

基于MATLAB与SDR硬件的卫星信道模拟器



Satellite Comm
Toolbox

卫星信道场景产生

轨道动态可视化

模型参数生成 ...



上位机代码

UI交互

模型参数传输

相关系数传输

硬件控制 ...



FPGA代码

实时衰落模型

噪声干扰模型

信道模型施加 ...

基带实时处理

NI SDR硬件

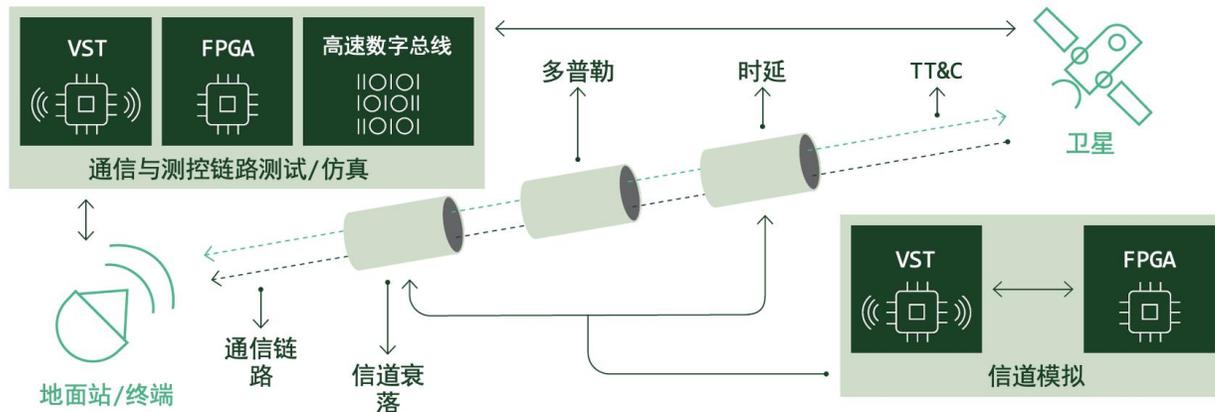


射频信号收发

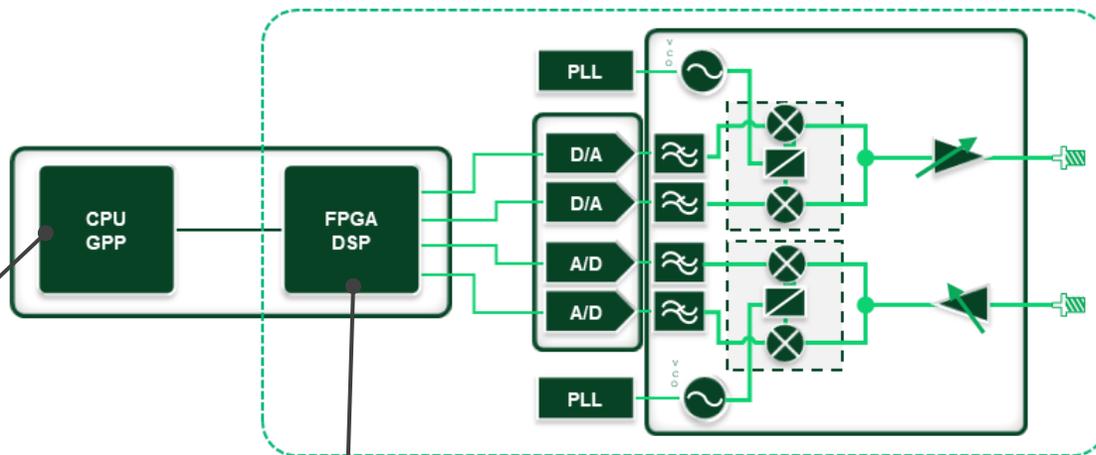
宽带卫星信道模拟器

- 5G非地面网络(NTN)与6G研究验证
- 系统/网络级仿真：
 - 与NI现有端到端通信原型系统 (DVB, MF-TDMA, 4G-LTE, 5G-NR)结合，仿真验证整个网络系统性能
- 链路级仿真：
 - 在实验室内模拟外场环境，验证测试卫星通信载荷或地面终端实际性能

- 通道数量：2收2发，4收4发
- 实时带宽：500 MHz-1GHz
- 最大时延 1000 ms
- 最大多普勒频偏 100 MHz
- 最大多普勒扩展 4 MHz
- 多普勒功率谱：
 - Classical
 - Flat
 - Rounded
 - Jakes
 - Gaussian
- 衰落模型：
 - Rayleigh
 - Rice
 - Nakagami
 - Lognormal



宽带卫星信道模拟器



控制器上位机



PXIe-8881

CPU	Xeon 18-Core
DRAM	64GB DDR4-2666

FPGA处理器



ATCA-3671

FPGA	4 × Vintex-7
逻辑单元	4 × 693,120

射频前端



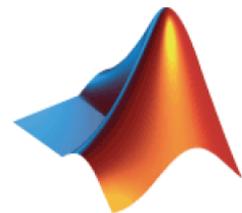
PXIe-5841

频率范围	9 kHz - 6 GHz
瞬时带宽	1 GHz



PXIe-5832

频率范围	5 GHz - 44 GHz
瞬时带宽	1 GHz



MathWorks®

Thank you

MATLAB EXPO