

Satellite Communications Toolbox

Getting Started Guide



MATLAB[®]

R2021a



How to Contact MathWorks



Latest news: www.mathworks.com
Sales and services: www.mathworks.com/sales_and_services
User community: www.mathworks.com/matlabcentral
Technical support: www.mathworks.com/support/contact_us



Phone: 508-647-7000



The MathWorks, Inc.
1 Apple Hill Drive
Natick, MA 01760-2098

Satellite Communications Toolbox Getting Started Guide

© COPYRIGHT 2021 by The MathWorks, Inc.

The software described in this document is furnished under a license agreement. The software may be used or copied only under the terms of the license agreement. No part of this manual may be photocopied or reproduced in any form without prior written consent from The MathWorks, Inc.

FEDERAL ACQUISITION: This provision applies to all acquisitions of the Program and Documentation by, for, or through the federal government of the United States. By accepting delivery of the Program or Documentation, the government hereby agrees that this software or documentation qualifies as commercial computer software or commercial computer software documentation as such terms are used or defined in FAR 12.212, DFARS Part 227.72, and DFARS 252.227-7014. Accordingly, the terms and conditions of this Agreement and only those rights specified in this Agreement, shall pertain to and govern the use, modification, reproduction, release, performance, display, and disclosure of the Program and Documentation by the federal government (or other entity acquiring for or through the federal government) and shall supersede any conflicting contractual terms or conditions. If this License fails to meet the government's needs or is inconsistent in any respect with federal procurement law, the government agrees to return the Program and Documentation, unused, to The MathWorks, Inc.

Trademarks

MATLAB and Simulink are registered trademarks of The MathWorks, Inc. See www.mathworks.com/trademarks for a list of additional trademarks. Other product or brand names may be trademarks or registered trademarks of their respective holders.

Patents

MathWorks products are protected by one or more U.S. patents. Please see www.mathworks.com/patents for more information.

Revision History

March 2021	Online only	New for Version 1.0 (Release 2021a)
------------	-------------	-------------------------------------

About Satellite Communication

1

Satellite Communications Toolbox Product Description	1-2
---	------------

Waveform Generation

2

Waveform Generation Workflow	2-2
Map Standards to Satellite Communications Toolbox Objects	2-3
Create Configuration or System Objects	2-4
Create CCSDS TC Configuration Object	2-4
Create CCSDS TM Object	2-5
Create DVB-S2 Object	2-7
Create a DVB-S2X Object	2-8
Generate Waveforms	2-11
Generate CCSDS TC Waveform	2-11
Generate CCSDS TM Waveform	2-12
Generate DVB-S2 Waveform	2-15
Generate DVB-S2X Waveform	2-16

Satellite Link Budget Analyzer App

3

Get Started with Satellite Link Budget Analyzer App	3-2
Open Satellite Link Budget Analyzer App	3-2
Budget Analyzer Toolstrip	3-2
Customize Input/Output Toolstrip	3-3

Scenario Generation and Visualization

4

Model, Visualize, and Analyze Satellite Scenario	4-2
---	------------

Satellite Scenario Key Concepts	4-6
Coordinate Systems	4-6
Orbital Elements	4-10
Two Line Element (TLE) Files	4-12
Satellite Scenario Basics	4-15

Channel Modeling

5

Earth-Space Propagation Losses	5-2
Earth-Space Propagation Losses	5-2
Outage Probability due to Rain Attenuation with Site Diversity	5-4
Attenuation due to Atmospheric Gases	5-5
Propagation Losses for Specified Range of Elevation Angle	5-6
Propagation Losses with Time Percentage of Exceedance	5-8

About Satellite Communication

Satellite Communications Toolbox Product Description

Simulate, analyze, and test satellite communications systems and links

Satellite Communications Toolbox provides standards-based tools for designing, simulating, and verifying satellite communications systems and links. The toolbox enables you to model and visualize satellite orbits and perform link analysis and access calculations. You can also design physical layer algorithms together with RF components and ground station receivers, generate test waveforms, and perform golden reference design verification.

With the toolbox you can configure, simulate, measure, and analyze end-to-end satellite communications links. You can also create and reuse tests to verify that your designs, prototypes, and implementations comply with satellite communications and navigations standards, including DVB-S2X, DVB-S2, CCSDS, and GPS.

Waveform Generation

- “Waveform Generation Workflow” on page 2-2
- “Map Standards to Satellite Communications Toolbox Objects” on page 2-3
- “Create Configuration or System Objects” on page 2-4
- “Generate Waveforms” on page 2-11

Waveform Generation Workflow

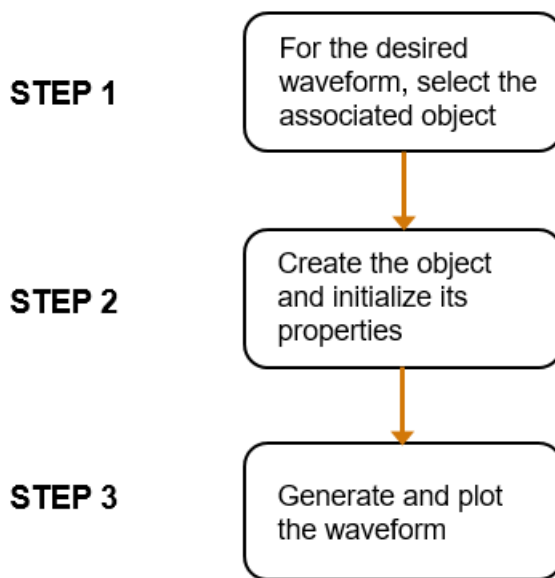
Satellite Communications Toolbox provides standards-based time-domain waveform generation functionalities for Consultative Committee for Space Data Systems (CCSDS) Telecommand (TC), CCSDS Telemetry (TM), Digital Video Broadcasting Satellite Second Generation (DVB-S2), and Digital Video Broadcasting Satellite Second Generation extended (DVB-S2X) standards.

Follow these steps to generate the waveforms.

- Step 1 — Select the associated object for creating the desired waveform. For details, see “Map Standards to Satellite Communications Toolbox Objects” on page 2-3.
- Step 2 — Create the configuration or System object™ for the waveform type.

You can set properties by using either name-value arguments during object creation or dot notation after object creation. For details on this step, see “Create Configuration or System Objects” on page 2-4.

- Step 3 — Use the created object to generate and visualize the desired waveform. For details, see “Generate Waveforms” on page 2-11.



See Also

More About

- “Map Standards to Satellite Communications Toolbox Objects” on page 2-3
- “Create Configuration or System Objects” on page 2-4
- “Generate Waveforms” on page 2-11

Map Standards to Satellite Communications Toolbox Objects

Satellite Communications Toolbox objects define transmission parameters for these standard-based waveforms.

- Consultative Committee for Space Data Systems (CCSDS) Telecommand (TC)
- CCSDS Telemetry (TM) synchronization and channel coding
- CCSDS Flexible advanced coding and modulation schemes for high rate TM applications
- Digital Video Broadcasting Satellite Second Generation (DVB-S2)
- Digital Video Broadcasting Satellite Second Generation extended (DVB-S2X)

Satellite Communications Toolbox objects define and configure format-specific and function-specific properties. The reference page of each object contains descriptions, valid settings, ranges, and other information about the object properties.

This table shows the mapping between these standard-based waveforms and their associated Satellite Communications Toolbox objects.

Standard-Based Waveform	Object
CCSDS TC	ccsdsTCConfig
CCSDS TM synchronization and channel coding	ccsdsTMWaveformGenerator
CCSDS Flexible advanced coding and modulation schemes for high rate TM applications	
DVB-S2	dvbs2WaveformGenerator
DVB-S2X	dvbs2xWaveformGenerator

See Also

More About

- “Waveform Generation Workflow” on page 2-2
- “Create Configuration or System Objects” on page 2-4
- “Generate Waveforms” on page 2-11

Create Configuration or System Objects

Satellite Communications Toolbox configuration and System object initialize, store, and validate object properties. These properties correspond to parameters that define the standards-specific waveforms.

After you create the various objects described here, you can use them to generate waveforms. The functions in the toolbox initialize parameter settings for waveform transmission and reception by using the relevant object properties.

Create CCSDS TC Configuration Object

This example shows how to create a Consultative Committee for Space Data Systems (CCSDS) Telecommand (TC) configuration object. It also shows how to change the default property settings by using dot notation or by overriding the default settings by using `Name, Value` pairs when creating the object.

Create Object and Then Modify Properties

Create a CCSDS TC configuration object with default settings.

```
cfg = ccsdsTCConfig
cfg =
  ccsdsTCConfig with properties:
      DataFormat: "CLTU"
      ChannelCoding: "BCH"
      HasRandomizer: 1
      Modulation: "PCM/PSK/PM"
      PCMFormat: "NRZ-L"
      ModulationIndex: 0.4000
      SubcarrierFrequency: 16000
      SymbolRate: 4000
      SamplesPerSymbol: 10
  Read-only properties:
      SubcarrierWaveform: "sine"
```

Modify the defaults to specify for BPSK modulation scheme.

```
cfg.Modulation = "BPSK"
cfg =
  ccsdsTCConfig with properties:
      DataFormat: "CLTU"
      ChannelCoding: "BCH"
      HasRandomizer: 1
      Modulation: "BPSK"
```

Override Default Property Values During Object Creation

Create a CCSDS TC configuration object, using `Name, Value` pairs to specify LDPC codes with codeword length of 512.

```
cfg = ccsdsTCConfig("ChannelCoding", "LDPC", "LDPCCodewordLength", 512)
```

```
cfg =
  ccsdsTCConfig with properties:
      DataFormat: "CLTU"
      ChannelCoding: "LDPC"
      LDPCCodewordLength: 512
      Modulation: "PCM/PSK/PM"
      PCMFormat: "NRZ-L"
      ModulationIndex: 0.4000
      SubcarrierFrequency: 16000
      SymbolRate: 4000
      SamplesPerSymbol: 10

  Read-only properties:
      SubcarrierWaveform: "sine"
```

Create CCSDS TM Object

This example shows how to create a Consultative Committee for Space Data Systems (CCSDS) Telemetry (TM) System object. It also shows how to change the default property settings by using dot notation or by overriding the default settings by using Name,Value pairs when creating the object.

The System object `ccsdsTMWaveformGenerator` supports these two CCSDS TM standards, depending on the type of input to `WaveformSource` property.

- CCSDS TM synchronization and channel coding standard (CCSDS 131.0-B-3)
- CCSDS flexible advanced coding and modulation scheme for high rate telemetry standard (CCSDS 131.2-B-1)

The default standard for this object is CCSDS TM synchronization and channel coding.

Create Object and Then Modify Properties

Create a CCSDS TM System object with default settings.

```
tmWaveGen = ccsdsTMWaveformGenerator

tmWaveGen =
  ccsdsTMWaveformGenerator with properties:
      WaveformSource: "synchronization and channel coding"
      HasRandomizer: true
      HasASM: true
      PCMFormat: "NRZ-L"

  Channel coding properties:
      ChannelCoding: "RS"
      RSMessageLength: 223
      RSInterleavingDepth: 1
      IsRSMessageShortened: false

  Digital modulation and filter properties:
      Modulation: "QPSK"
      PulseShapingFilter: "root raised cosine"
```

```
        RolloffFactor: 0.3500
    FilterSpanInSymbols: 10
        SamplesPerSymbol: 10
```

Show all properties

Modify the defaults to specify for turbo codes and QPSK modulation.

```
tmWaveGen.ChannelCoding = "turbo";
tmWaveGen.Modulation = "QPSK"
```

```
tmWaveGen =
    ccsdsTMWaveformGenerator with properties:

        WaveformSource: "synchronization and channel coding"
        HasRandomizer: true
            HasASM: true
        PCMFormat: "NRZ-L"

    Channel coding properties:
        ChannelCoding: "turbo"
        NumBitsInInformationBlock: 7136
        CodeRate: "1/2"

    Digital modulation and filter properties:
        Modulation: "QPSK"
        PulseShapingFilter: "root raised cosine"
        RolloffFactor: 0.3500
        FilterSpanInSymbols: 10
        SamplesPerSymbol: 10
```

Show all properties

Override Default Property Values During Object Creation

Create a CCSDS TM System object, using Name,Value pairs, to specify the object for flexible advanced coding and modulation scheme for high rate TM applications standard, and specifying the ACM format as 9.

```
tmWaveGen = ccsdsTMWaveformGenerator("WaveformSource","flexible advanced coding and modulation",
tmWaveGen =
    ccsdsTMWaveformGenerator with properties:

        WaveformSource: "flexible advanced coding and modulation"
        ACMFormat: 9
    NumBytesInTransferFrame: 223

    Digital modulation and filter properties:
        PulseShapingFilter: "root raised cosine"
        RolloffFactor: 0.3500
        FilterSpanInSymbols: 10
        SamplesPerSymbol: 10
            HasPilots: false
        ScramblingCodeNumber: 0
```

Show all properties

Create DVB-S2 Object

This example shows how to create a Digital Video Broadcasting Satellite Second Generation (DVB-S2) System object. It also shows how to change the default property settings by using dot notation or by overriding the default settings by using Name,Value pairs when creating the object.

To create a DVB-S2 System object, you must use MAT-files with LDPC parity matrices. If the MAT-files are not available on the path, download and unzip the MAT-files by entering this code at the MATLAB command prompt.

```
if ~exist('dvbs2xLDPCParityMatrices.mat','file')
    if ~exist('s2xLDPCParityMatrices.zip','file')
        url = 'https://ssd.mathworks.com/supportfiles/spc/satcom/DVB/s2xLDPCParityMatrices.zip';
        websave('s2xLDPCParityMatrices.zip',url);
        unzip('s2xLDPCParityMatrices.zip');
    end
end
addpath('s2xLDPCParityMatrices');
end
```

Create Object and Then Modify Properties

Create a DVB-S2 System object with default settings.

```
s2WaveGen = dvbs2WaveformGenerator
```

```
s2WaveGen =
    dvbs2WaveformGenerator with properties:
```

```
        StreamFormat: "TS"
    NumInputStreams: 1
        FECFrame: "normal"
        MODCOD: 1
        DFL: 15928
        HasPilots: 0
    RolloffFactor: 0.3500
    FilterSpanInSymbols: 10
    SamplesPerSymbol: 4
```

Show all properties

Modify the defaults to specify multi-input generic stream and the data field length (DFL) for each stream.

```
s2WaveGen.StreamFormat = "GS";
s2WaveGen.NumInputStreams = 3;
s2WaveGen.DFL = [44500 51387 42960]
```

```
s2WaveGen =
    dvbs2WaveformGenerator with properties:
```

```
        StreamFormat: "GS"
    NumInputStreams: 3
        UPL: 0
```

```
FECFrame: "normal"  
  MODCOD: 1  
    DFL: [44500 51387 42960]  
  HasPilots: 0  
  RolloffFactor: 0.3500  
FilterSpanInSymbols: 10  
SamplesPerSymbol: 4
```

Override Default Property Values During Object Creation

Create a DVB-S2 System object, using Name,Value pairs for a single-input transport stream with short FEC frame format, and specified modulation scheme and FEC rate (MODCOD).

```
s2WaveGen = dvbs2WaveformGenerator("FECFrame","short","MODCOD",10)
```

```
s2WaveGen =  
  dvbs2WaveformGenerator with properties:
```

```
  StreamFormat: "TS"  
  NumInputStreams: 1  
    FECFrame: "short"  
      MODCOD: 10  
      DFL: 15928  
    HasPilots: 0  
    RolloffFactor: 0.3500  
FilterSpanInSymbols: 10  
SamplesPerSymbol: 4
```

```
Show all properties
```

Create a DVB-S2X Object

This example shows how to create a Digital Video Broadcasting Satellite Second Generation extended (DVB-S2X) System object. It also shows how to change the default property settings by using dot notation or by overriding the default settings by using Name,Value pairs when creating the object.

To create a DVB-S2X System object, you must use MAT-files with LDPC parity matrices. If the MAT-files are not available on the path, download and unzip the MAT-files by entering this code at the MATLAB command prompt.

```
if ~exist('dvbs2xLDPCParityMatrices.mat','file')  
  if ~exist('s2xLDPCParityMatrices.zip','file')  
    url = 'https://ssd.mathworks.com/supportfiles/spc/satcom/DVB/s2xLDPCParityMatrices.zip';  
    websave('s2xLDPCParityMatrices.zip',url);  
    unzip('s2xLDPCParityMatrices.zip');  
  end  
addpath('s2xLDPCParityMatrices');  
end
```

Create Object and Then Modify Properties

Create a DVB-S2X System object with default settings.

```
s2xWaveGen = dvbs2xWaveformGenerator
```

```
s2xWaveGen =
  dvbs2xWaveformGenerator with properties:

    StreamFormat: "TS"
    HasTimeSlicing: false
    NumInputStreams: 1
    PLSDecimalCode: 132
        DFL: 18448
    PLScramblingIndex: 0
    RolloffFactor: 0.3500
    FilterSpanInSymbols: 10
    SamplesPerSymbol: 4

Show all properties
```

Modify the defaults to specify multi-input transport stream with time slicing enabled.

```
s2xWaveGen.NumInputStreams = 4;
s2xWaveGen.HasTimeSlicing = true

s2xWaveGen =
  dvbs2xWaveformGenerator with properties:

    StreamFormat: "TS"
    HasTimeSlicing: true
    NumInputStreams: 4
    PLSDecimalCode: 132
        DFL: 18448
    PLScramblingIndex: 0
    RolloffFactor: 0.3500
    FilterSpanInSymbols: 10
    SamplesPerSymbol: 4
    ISSYI: false

Show all properties
```

Override Default Property Values During Object Creation

Create a DVB-S2X System object, using Name,Value pairs to specify the very low signal to noise ratio (VL-SNR) frame set 2, and specifying the modulation scheme and code rate as BPSK 1/5.

```
s2xWaveGen = dvbs2xWaveformGenerator("PLSDecimalCode",131,"CanonicalMODCODName","BPSK 1/5")

s2xWaveGen =
  dvbs2xWaveformGenerator with properties:

    StreamFormat: "TS"
    HasTimeSlicing: false
    NumInputStreams: 1
    PLSDecimalCode: 131
    CanonicalMODCODName: "BPSK 1/5"
        DFL: 18448
    PLScramblingIndex: 0
    RolloffFactor: 0.3500
    FilterSpanInSymbols: 10
    SamplesPerSymbol: 4
```

Show all properties

References

- [1] TM Synchronization and Channel Coding. *Recommendation for Space Data System Standards*. CCSDS 131.0-B-3. Blue Book. Issue 3. Washington, D.C.: CCSDS, September 2017.
- [2] Flexible Advanced Coding and Modulation Scheme for High Rate Telemetry Applications. *Recommendation for Space Data System Standards*. CCSDS 131.2-B-1. Blue Book. Issue 1. Washington, D.C.: CCSDS, March 2012.

See Also

[ccsdsTCConfig](#) | [ccsdsTMWaveformGenerator](#) | [dvbs2WaveformGenerator](#) | [dvbs2xWaveformGenerator](#)

More About

- “Waveform Generation Workflow” on page 2-2
- “Generate Waveforms” on page 2-11

Generate Waveforms

After you create the necessary objects described in “Create Configuration or System Objects” on page 2-4, you can use these objects to generate the desired waveform. Vary the object parameters and plot the waveforms.

In each section of these examples, you:

- Create a format-specific configuration object or a System object.
- Create a column vector or cell array of column vectors of the information bits for the waveform generation.
- Generate the format-specific waveform and plot it.

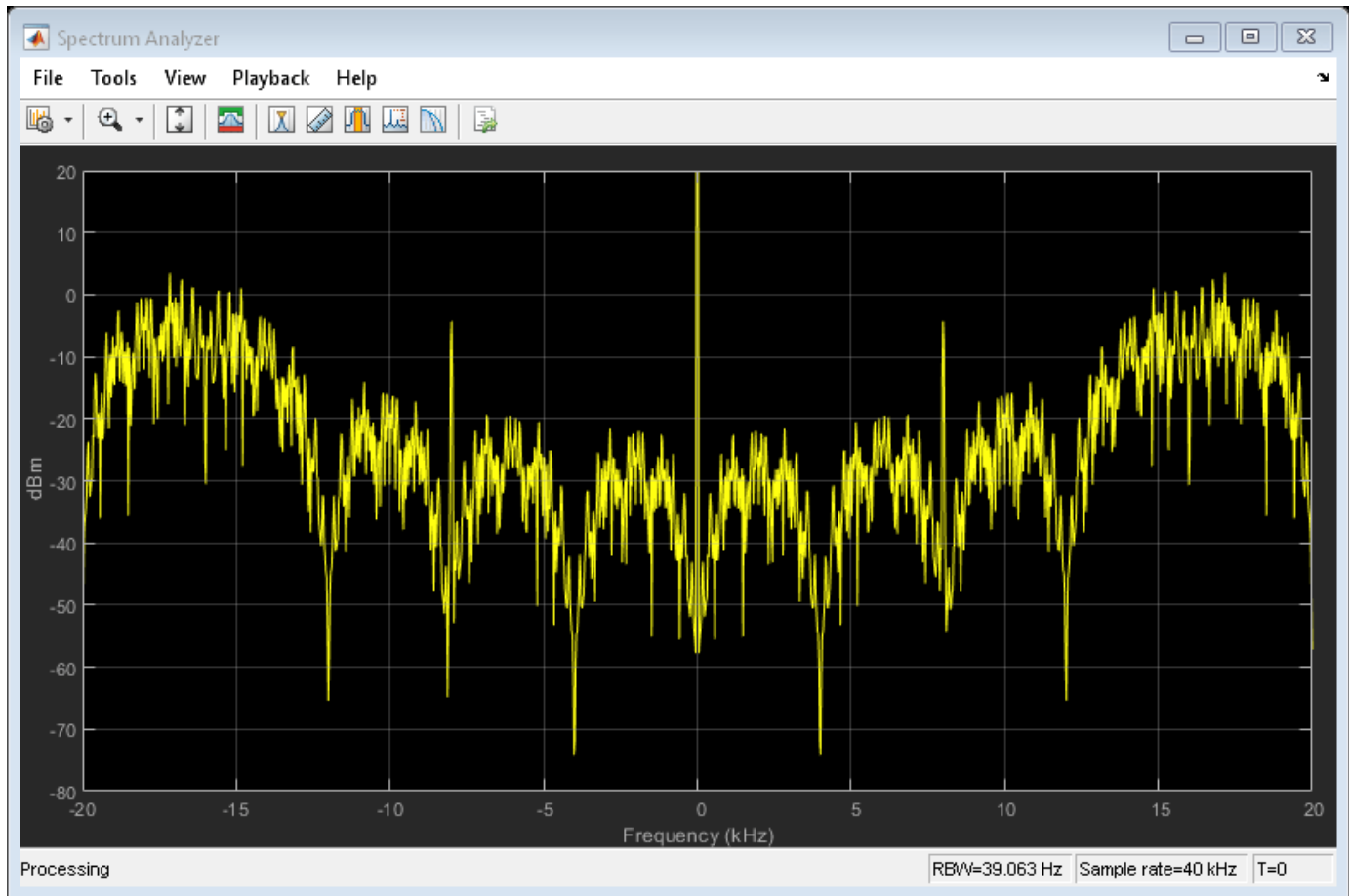
Generate CCSDS TC Waveform

Create a Consultative Committee for Space Data Systems (CCSDS) Telecommand (TC) configuration object and the waveform. Use Name, Value pairs to specify the transmission parameters.

```
cfg = ccsdsTCConfig ('ChannelCoding', "LDPC", 'LDPCCodewordLength', 512);
TFLength = 12; % Transfer frame length
bits = randi([0 1],8*TFLength,1); % Bits in TC transfer frame
waveform = ccsdsTCWaveform(bits, cfg);
```

Create a dsp.SpectrumAnalyzer System object to display the signal spectrum of the generated CCSDS TC waveform.

```
scope = dsp.SpectrumAnalyzer;
scope.SampleRate = cfg.SamplesPerSymbol*cfg.SymbolRate;
scope(waveform)
```



Generate CCSDS TM Waveform

Create a Consultative Committee for Space Data Systems (CCSDS) Telemetry (TM) System object and the waveform.

The object `ccsdsTMWaveformGenerator` supports these two CCSDS TM standards, depending on the type of input to `WaveformSource` property.

- CCSDS TM synchronization and channel coding standard (CCSDS 131.0-B-3)
- CCSDS flexible advanced coding and modulation scheme for high rate telemetry standard (CCSDS 131.2-B-1)

The default standard for this object is CCSDS TM synchronization and channel coding.

Create the System object and Generate Waveform for CCSDS TM Synchronization and Channel Coding Scheme

```
tmWaveGen = ccsdsTMWaveformGenerator % CCSDS TM object with default properties
```

```
tmWaveGen =  
    ccsdsTMWaveformGenerator with properties:
```

```
WaveformSource: "synchronization and channel coding"
  HasRandomizer: true
    HasASM: true
    PCMFormat: "NRZ-L"

Channel coding properties:
  ChannelCoding: "RS"
  RSMessagelength: 223
  RSInterleavingDepth: 1
  IsRSMessagelengthShortened: false

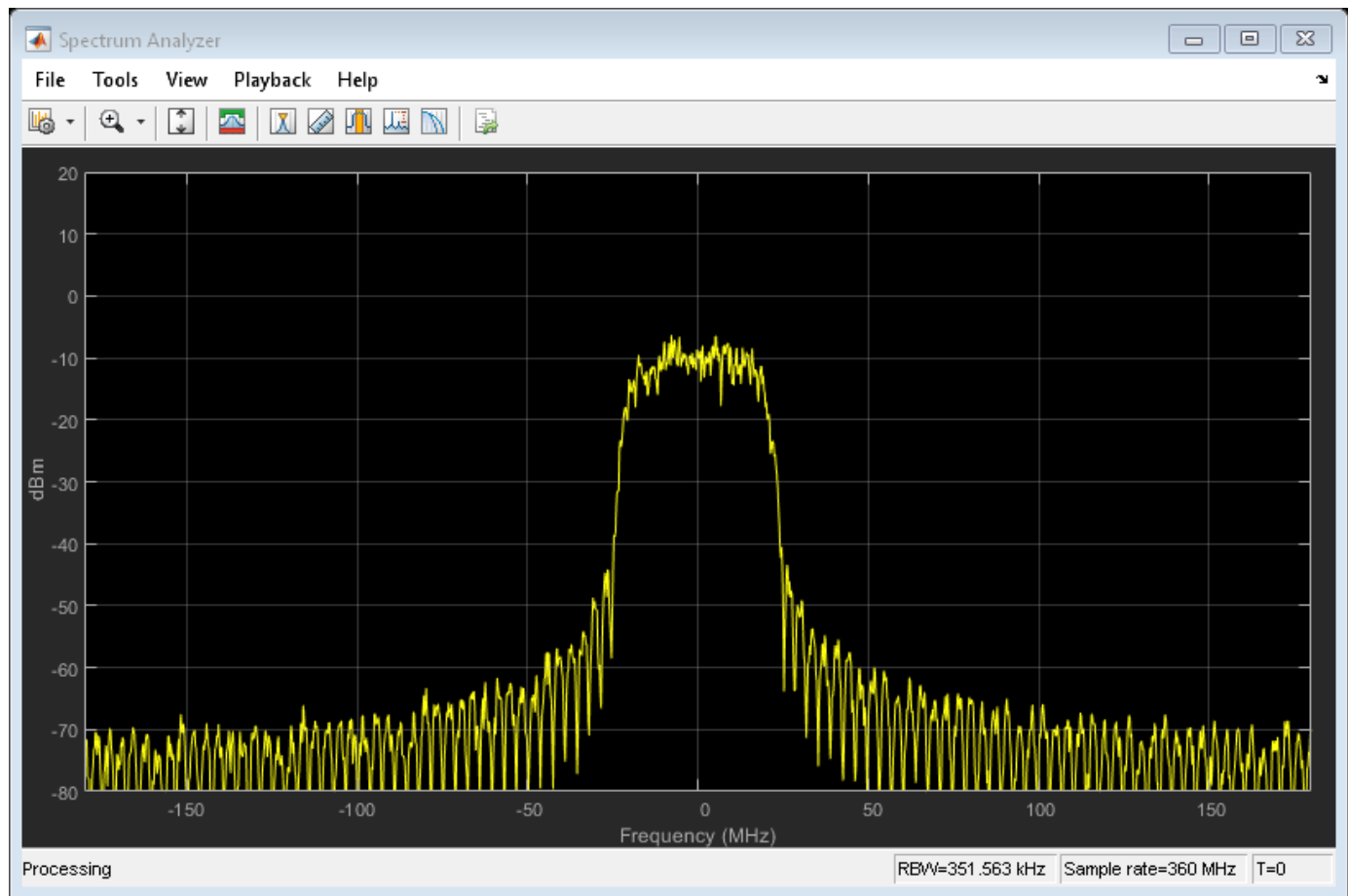
Digital modulation and filter properties:
  Modulation: "QPSK"
  PulseShapingFilter: "root raised cosine"
  RolloffFactor: 0.3500
  FilterSpanInSymbols: 10
  SamplesPerSymbol: 10

Show all properties

bits = randi([0 1], tmWaveGen.NumInputBits,1); % Input information bits
waveform = tmWaveGen(bits);

Create a dsp.SpectrumAnalyzer System object to display the frequency spectrum of the generated
CCSDS TM time-domain waveform.

BW = 36e6; % Typical satellite channel bandwidth
Fsamp = tmWaveGen.SamplesPerSymbol*BW;
scope = dsp.SpectrumAnalyzer('SampleRate',Fsamp,'AveragingMethod','Exponential');
scope(waveform)
```



Create the System object and Generate Waveform for CCSDS TM Flexible Advanced Coding and Modulation Scheme

For this example, use dot notation to specify the transmission parameters.

```
tmWaveGen = ccSDS_TMWaveformGenerator;
tmWaveGen.WaveformSource = "flexible advanced coding and modulation";
tmWaveGen.ACFormat = 14; % 16APSK
```

Calculate the number of transfer frames in one physical layer frame. Generate the waveform using the information bits, data.

```
NumTFInOnePLFrame = tmWaveGen.MinNumTransferFrames*16 % One PL frame consists of 16 codewords, a
```

```
NumTFInOnePLFrame = 192
```

```
waveform = []; % Initialize waveform as null
% Generate waveform
for iTF = 1:NumTFInOnePLFrame
    bits = randi([0 1], tmWaveGen.NumInputBits, 1);
```

```
    waveform = [waveform;tmWaveGen(bits)];
end
```

Generate DVB-S2 Waveform

This example uses MAT-files with LDPC parity matrices. If the MAT-files are not available on the path, download and unzip the MAT-files by entering this code at the MATLAB command prompt.

```
if ~exist('s2xLDPCParityMatrices.zip','file')
    url = 'https://ssd.mathworks.com/supportfiles/spc/satcom/DVB/s2xLDPCParityMatrices.zip';
    websave('s2xLDPCParityMatrices.zip',url);
    unzip('s2xLDPCParityMatrices.zip');
addpath('s2xLDPCParityMatrices')
end
```

Create a Digital Video Broadcasting Satellite Second Generation (DVB-S2) System Object and the waveform. Use Name, Value pairs to specify the transmission parameters.

```
s2WaveGen = dvbs2WaveformGenerator("NumInputStreams",2,"MODCOD",[6 19],"RolloffFactor",0.25 );
disp(s2WaveGen)
```

dvbs2WaveformGenerator with properties:

```
    StreamFormat: "TS"
    NumInputStreams: 2
        FECFrame: "normal"
            MODCOD: [6 19]
            DFL: 15928
        ScalingMethod: "outer radius as 1"
            HasPilots: 0
            RolloffFactor: 0.2500
    FilterSpanInSymbols: 10
    SamplesPerSymbol: 4
    ISSYI: false
```

Show all properties

Initialize the simulation parameters.

```
numFramesPerStream = 1; % Number of PL frames generated per stream
syncBits = [0 1 0 0 0 1 1 1]'; % Sync byte of TS packet (47 HEX)
pktLen = 1496; % User packet (UP) length without sync
numPktsPerStream = s2WaveGen.MinNumPackets*numFramesPerStream; % Number of packets required to fill stream
```

Generate transport stream (TS) packets per stream.

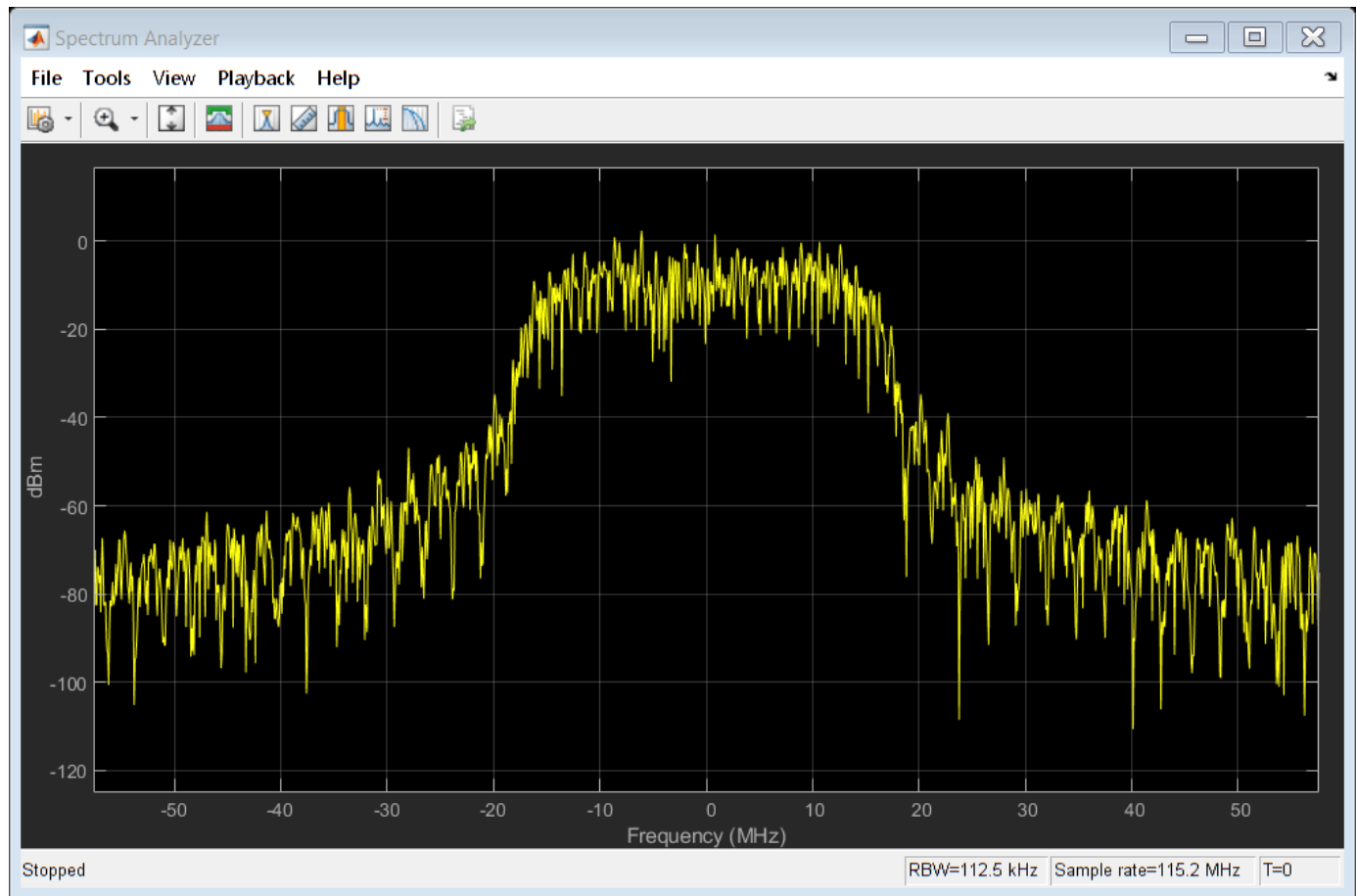
```
data = cell(s2WaveGen.NumInputStreams,1);
for i = 1:s2WaveGen.NumInputStreams
    txRawPkts = randi([0 1],pktLen,numPktsPerStream(i));
    txPkts = [repmat(syncBits,1,numPktsPerStream(i)); txRawPkts];
    data{i} = txPkts(:);
end
```

Generate the DVB-S2 time-domain waveform using the information bits, data.

```
txWaveform = s2WaveGen(data);
```

Create a `dsp.SpectrumAnalyzer` System object to display the signal spectrum of the generated DVB-S2 time-domain waveform.

```
BW = 36e6; % Typical satellite channel bandwidth
Fsym = BW/(1+s2WaveGen.RolloffFactor);
Fsamp = Fsym*s2WaveGen.SamplesPerSymbol;
spectrum = dsp.SpectrumAnalyzer('SampleRate',Fsamp);
spectrum(txWaveform);
release(spectrum);
```



Generate DVB-S2X Waveform

This example uses MAT-files with LDPC parity matrices. If the MAT-files are not available on the path, download and unzip the MAT-files by entering this code at the MATLAB command prompt.

```
if ~exist('s2xLDPCParityMatrices.zip', 'file')
    url = 'https://ssd.mathworks.com/supportfiles/spc/satcom/DVB/s2xLDPCParityMatrices.zip';
    websave('s2xLDPCParityMatrices.zip',url);
    unzip('s2xLDPCParityMatrices.zip');
addpath('s2xLDPCParityMatrices')
end
```

Create a Digital Video Broadcasting Satellite Second Generation extended (DVB-S2X) System object and the waveform.

```
s2xWaveGen = dvbs2xWaveformGenerator % DVB-S2X object with default properties
```

```
s2xWaveGen =
  dvbs2xWaveformGenerator with properties:
```

```
    StreamFormat: "TS"
    HasTimeSlicing: false
    NumInputStreams: 1
    PLSDecimalCode: 132
        DFL: 18448
    PLScramblingIndex: 0
        RolloffFactor: 0.3500
    FilterSpanInSymbols: 10
    SamplesPerSymbol: 4
```

```
Show all properties
```

Initialize the simulation parameters.

```
numFrames = 3; % Number of PL frames generated per stream
syncBits = [0 1 0 0 0 1 1 1]'; % Sync byte of TS packet (47 HEX)
pktLen = 1496; % User packet (UP) length without sync bits is 1496
numPkts = s2xWaveGen.MinNumPackets*numFrames; % Number of packets required to fill data field p
```

Generate transport stream (TS) packets per stream.

```
txRawPkts = randi([0 1], pktLen, numPkts);
txPkts = [repmat(syncBits, 1, numPkts);txRawPkts];
data = txPkts(:);
```

Generate the DVB-S2X time-domain waveform using the information bits, data.

```
txWaveform = s2xWaveGen(data);
```

References

- [1] TM Synchronization and Channel Coding. *Recommendation for Space Data System Standards*. CCSDS 131.0-B-3. Blue Book. Issue 3. Washington, D.C.: CCSDS, September 2017.
- [2] Flexible Advanced Coding and Modulation Scheme for High Rate Telemetry Applications. *Recommendation for Space Data System Standards*. CCSDS 131.2-B-1. Blue Book. Issue 1. Washington, D.C.: CCSDS, March 2012.

See Also

ccsdsTCConfig | ccsdsTCWaveform | ccsdsTMWaveformGenerator |
dvbs2WaveformGenerator | dvbs2xWaveformGenerator

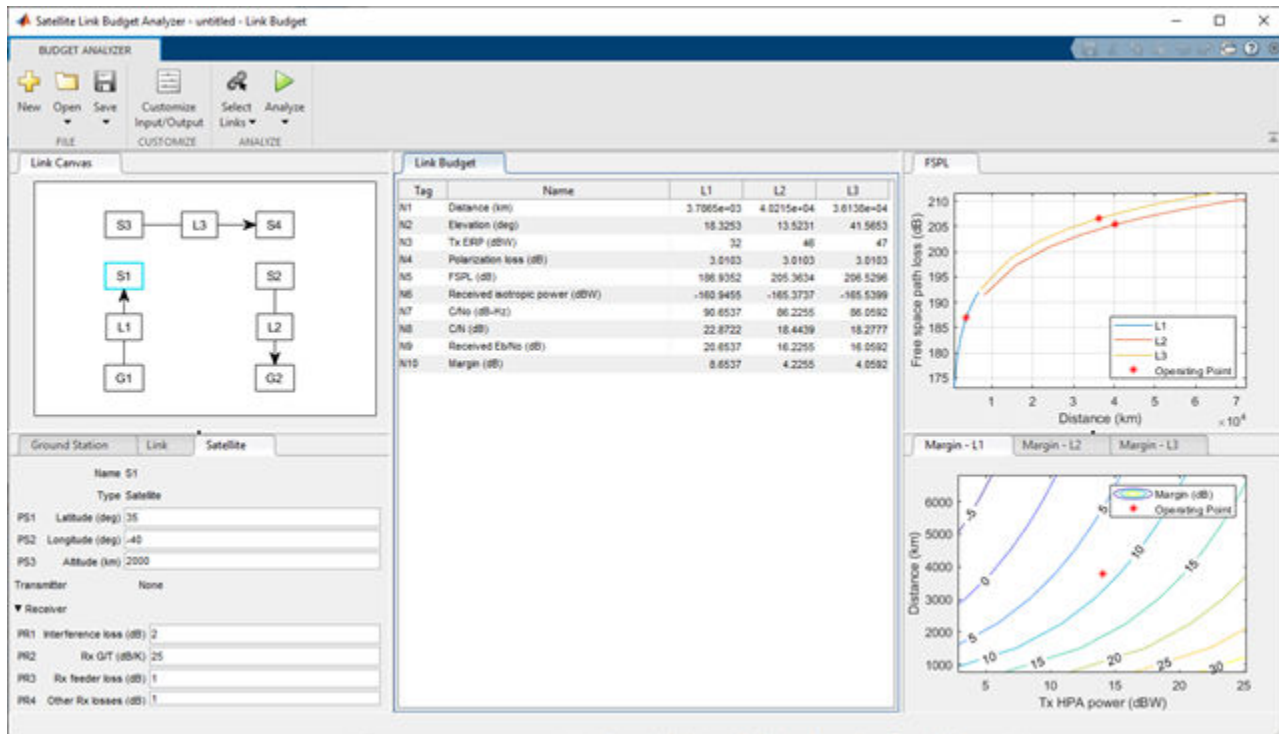
More About

- “Waveform Generation Workflow” on page 2-2
- “Create Configuration or System Objects” on page 2-4

Satellite Link Budget Analyzer App

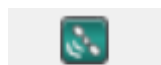
Get Started with Satellite Link Budget Analyzer App

The **Satellite Link Budget Analyzer** app is an interactive tool for creating, configuring, analyzing, and visualizing link budgets for satellite communications. This section describes some of the app features. For more information and examples that demonstrate use of the app, see the **Satellite Link Budget Analyzer** documentation page.



Open Satellite Link Budget Analyzer App

On the **Apps** tab in the MATLAB® Toolstrip, under **Signal Processing and Communications**, click



Satellite Link
Budget Anal...

the app icon. Alternatively, you can open the app by entering `satelliteLinkBudgetAnalyzer` at the MATLAB command prompt.

Budget Analyzer Toolstrip

The app opens to show the **BUDGET ANALYZER** toolstrip and docked tabs. The **BUDGET ANALYZER** toolstrip contains **FILE**, **CUSTOMIZE**, and **ANALYZE** ribbons. The default main work area tabs are arranged to show the link canvas, entity (ground station, link, and satellite) properties, results, and plots. You can move the tabbed panes by dragging to rearrange as desired.

Link Canvas

In the **Link Canvas** pane, you can select an individual ground station, link, or satellite entity to bring it into focus in the associated property pane. The default canvas defines these three satellite communication links.

- Link *L1* is an uplink between ground station *G1* and satellite *S1*
- Link *L3* is a crosslink between satellite *S3* and satellite *S4*
- Link *L2* is a downlink between satellite *S2* and ground station *G2*

Properties

Select the **Ground Station**, **Link**, or **Satellite** tab to view the pane and adjust settings of the input properties for each type of entity. Select the entity of interest in the **Link Canvas** tab to bring focus on that entity in the associated property tab. You can adjust the property settings for the entity in focus only.

Link Budget

When you click **Analyze**, the link budget results are computed and displayed in the **Link Budget** pane. The factory default results compute distance, elevation, transmit effective radiated power (EIRP), polarization loss, free-space pathloss (FSPL), received isotropic power, carrier-to-receiver-noise-density ratio (C/N_0), received E_b/N_0 , and overall link margin.

Click the **Customize Input/Output** button to open the view or customize the configured input properties and output computations.

Visualization Options

View free-space pathloss in 2-D line plots and link margins in 2-D contour plots that characterize the links. When opened the app shows the default scenario, including link budget results and these plots:

- Free-space pathloss in a 2-D line plot labeled **FSPL**
- Link margin for links *L1*, *L2*, and *L3* in individual 2-D contour plots labeled **Margin - L1**, **Margin - L2**, and **Margin - L3**, respectively

Customize Input/Output Toolstrip

On the **BUDGET ANALYZER** toolstrip, click the **Customize Input/Output** button to open the **CUSTOMIZE INPUT/OUTPUT** toolstrip. The **CUSTOMIZE INPUT/OUTPUT** toolstrip enables you to review, add, delete, and customize the properties for entity and the formulas for the computation of results.

In the **ADD NEW PROPERTY** ribbon you can customize the app by defining and adding new properties.

In the **ADD NEW RESULT** ribbon you can customize the app by defining new formulas and adding them as new results.

In the **Properties** pane, you can adjust or delete properties.

In the **Results** pane you can adjust or delete results.

See Also
Satellite Link Budget Analyzer

Scenario Generation and Visualization

- “Model, Visualize, and Analyze Satellite Scenario” on page 4-2
- “Satellite Scenario Key Concepts” on page 4-6
- “Satellite Scenario Basics” on page 4-15

Model, Visualize, and Analyze Satellite Scenario

This example shows how to model satellites in orbit, analyze access between the satellites and the ground stations, and visualize the fields of view and ground tracks of the satellites.

Create a Satellite Scenario

Create a satellite scenario with the start time of 02-June-2020 8:23:00 AM UTC and a stop time of five hours later. Set the simulation sample time to 60 seconds.

```
startTime = datetime(2020,6,02,8,23,0);
stopTime = startTime + hours(5);
sampleTime = 60;
sc = satelliteScenario(startTime,stopTime,sampleTime);
```

Add Satellites to the Scenario

Add satellites to the scenario from the threeSatelliteConstellation TLE file.

```
sat = satellite(sc,"threeSatelliteConstellation.tle");
```

Show the satellites in orbit and plot their ground tracks over 20 minutes.

```
show(sat)
groundTrack(sat,"LeadTime",1200);
```

Return Orbital Elements and Position of the Satellites

Display the orbital elements of each satellite in the scenario.

```
ele1 = orbitalElements(sat(1))
ele1 = struct with fields:
    MeanMotion: 9.1649e-04
    Eccentricity: 1.0000e-03
    Inclination: 55
    RightAscensionOfAscendingNode: 175.0000
    ArgumentOfPeriapsis: 100
    MeanAnomaly: 174.9900
    Period: 6.8557e+03
    Epoch: 02-Jun-2020 18:43:16
    BStar: 1.0000e-04
```

```
ele2 = orbitalElements(sat(2))
ele2 = struct with fields:
    MeanMotion: 8.5025e-04
    Eccentricity: 1.0000e-03
    Inclination: 55
    RightAscensionOfAscendingNode: 350.0000
    ArgumentOfPeriapsis: 90
    MeanAnomaly: 310.0877
    Period: 7.3898e+03
    Epoch: 02-Jun-2020 18:33:26
    BStar: 1.0000e-04
```

```
ele3 = orbitalElements(sat(3))
```

```

ele3 = struct with fields:
    MeanMotion: 8.6605e-04
    Eccentricity: 1.0000e-03
    Inclination: 55
    RightAscensionOfAscendingNode: 270
    ArgumentOfPeriapsis: 95
    MeanAnomaly: 119.9007
    Period: 7.2550e+03
    Epoch: 02-Jun-2020 18:37:40
    BStar: 1.0000e-04

```

Return the latitude, longitude, and altitude of the first satellite at time 02-June-2020 12:30:00 PM UTC.

```

time = datetime(2020,6,02,12,30,0);
pos = states(sat(1),time,"CoordinateFrame","geographic")

pos = 3×1
106 ×

    0.0000
   -0.0001
    1.4212

```

Add Ground Stations

Add the Madrid and Canberra Deep Space Communications Complexes as the ground stations of interest, and specify their latitudes and longitudes.

```

name = ["Madrid Deep Space Communications Complex", ...
        "Canberra Deep Space Communications Complex"];
lat = [40.43139, -35.40139];
lon = [-4.24806, 148.98167];
gs = groundStation(sc,"Name",name,"Latitude",lat, ...
                  "Longitude", lon);

```

Return Azimuth Angle, Elevation Angle, and Range at a Specified Time

Return the azimuth angle, elevation angle and range of the first satellite with respect to the Madrid Deep Space Communications Complex at time 02-June-2020 12:30:00 PM UTC.

```

time = datetime(2020,6,02,12,30,0);
[az,elev,r] = aer(gs(1),sat(1),time)

az = 264.2457

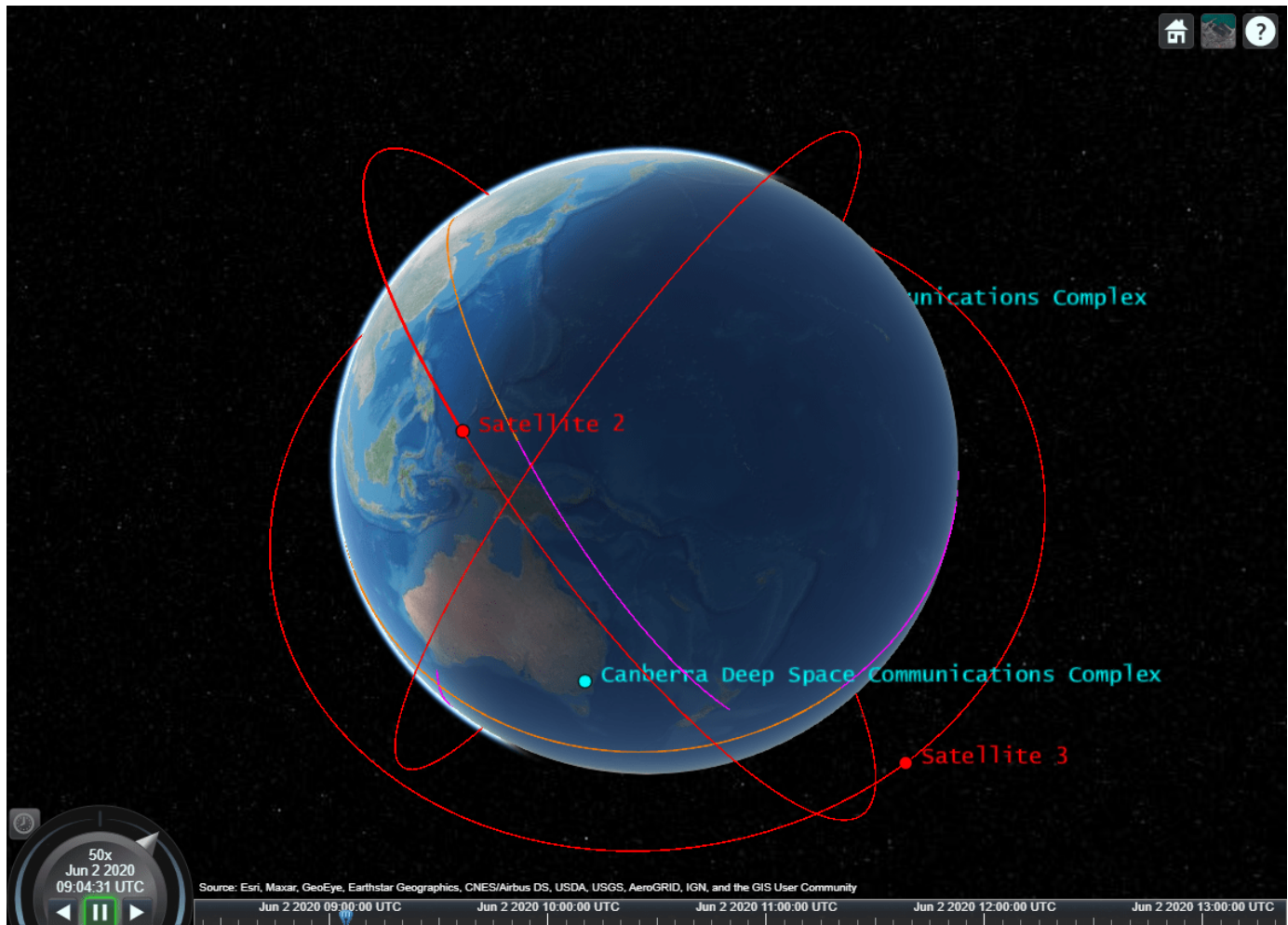
elev = -34.0669

r = 9.3088e+06

```

Play the satellite scenario with the satellites and ground stations.

```
play(sc)
```



See Also

Objects

`access` | `conicalSensor` | `groundStation` | `receiver` | `satellite` | `satelliteScenario` | `satelliteScenarioViewer` | `transmitter`

Functions

`hide` | `play` | `show`

Related Examples

- “Multi-Hop Satellite Communications Link Between Two Ground Stations”
- “Satellite Constellation Access to a Ground Station”
- “Comparison of Orbit Propagators”
- “Modeling Satellite Constellations using Ephemeris Data”
- “Estimate GNSS Receiver Position with Simulated Satellite Constellations”
- “Model, Visualize, and Analyze Satellite Scenario” on page 4-2

More About

- “Satellite Scenario Key Concepts” on page 4-6
- “Satellite Scenario Basics” on page 4-15

Satellite Scenario Key Concepts

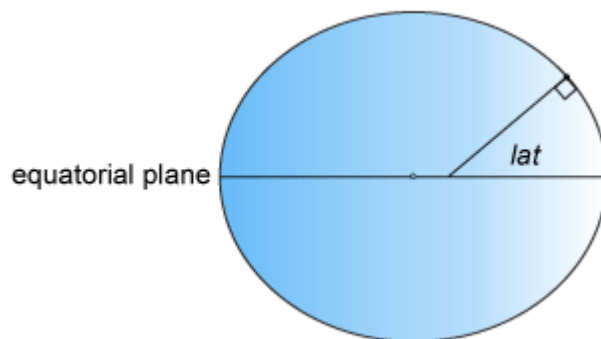
You can use the Satellite Communications Toolbox `satelliteScenario` object provides the ability to model and visualize satellites in orbit, compute access with ground stations, and visualize and analyze communication links. This topic provides an overview of the technical terms frequently encountered in scenario visualization.

Coordinate Systems

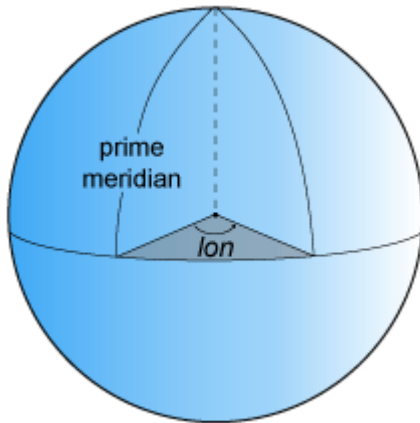
Geodetic Coordinates

A geodetic system uses coordinates (lat, lon, h) to represent position relative to a reference ellipsoid. All geodetic coordinates in satellite scenario use the WGS84 ellipsoid as the reference ellipsoid. The coordinate origin of WGS 84 is meant to be located at the center of mass of the Earth.

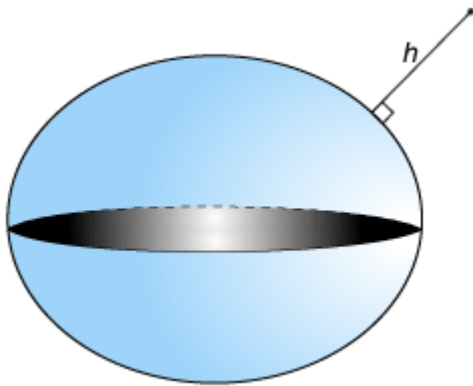
- lat is the latitude, which originates at the equator. More specifically, the latitude of a point is the angle a normal to the ellipsoid at that point makes with the equatorial plane, which contains the center and equator of the ellipsoid. An angle of latitude is in the range $[-90^\circ, 90^\circ]$. Positive latitudes correspond to north and negative latitudes correspond to south.



- lon is the longitude, which originates at the prime meridian. More specifically, the longitude of a point is the angle that a plane containing the ellipsoid center and the meridian containing that point makes with the plane containing the ellipsoid center and prime meridian. Positive longitudes are measured in a counterclockwise direction from a vantage point above the North Pole. Typically, longitude is in the range $[-180^\circ, 180^\circ]$ or $[0^\circ, 360^\circ]$.



- h is the ellipsoidal height, which is measured along a normal of the reference spheroid.



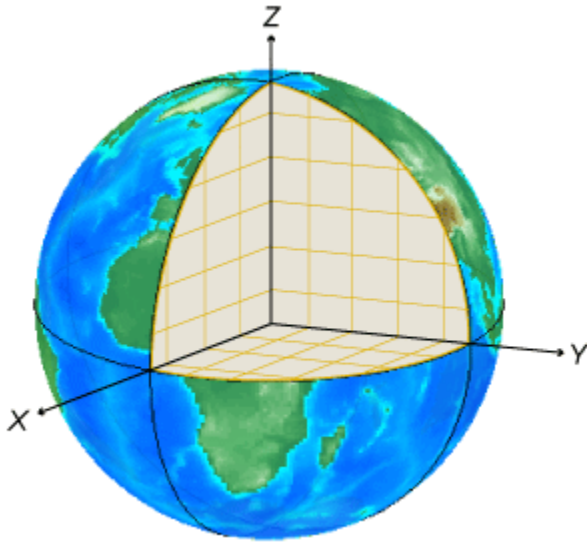
Earth-Centered Earth-Fixed Coordinates

An Earth-centered Earth-fixed (ECEF) system uses Cartesian coordinates (X, Y, Z) to represent position relative to the center of the reference ellipsoid. The distance between the center of the ellipsoid and the center of the Earth depends on the reference ellipsoid.

- The positive X -axis intersects the surface of the ellipsoid at 0° latitude and 0° longitude, where the equator meets the prime meridian.
- The positive Y -axis intersects the surface of the ellipsoid at 0° latitude and 90° longitude.
- The positive Z -axis intersects the surface of the ellipsoid at 90° latitude and 0° longitude (the North Pole).

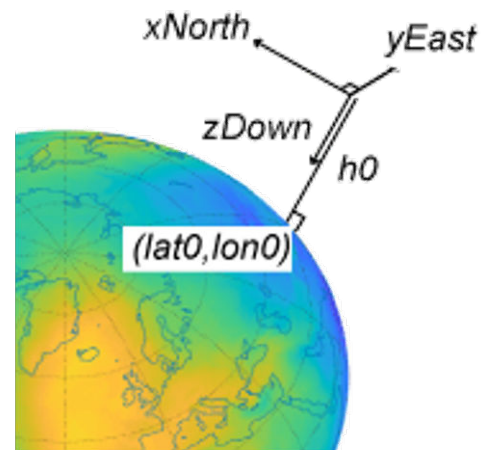
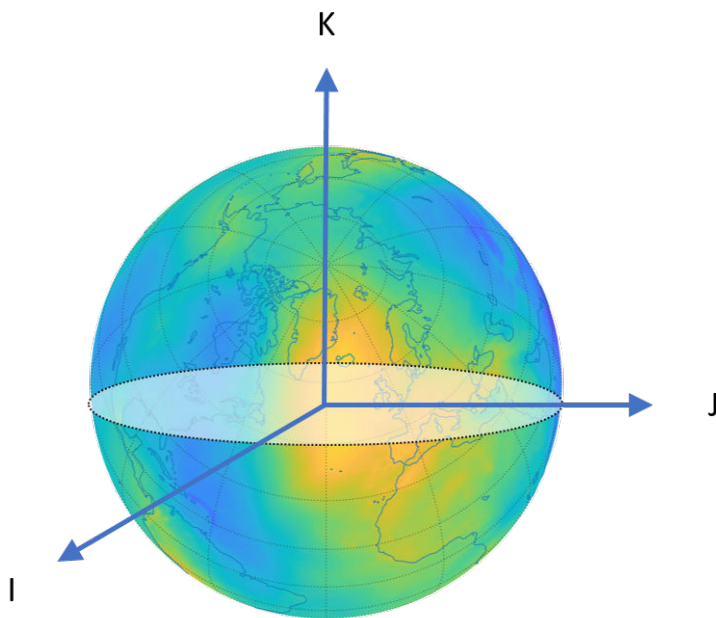
1

1. Alignment of boundaries and region labels are a presentation of the feature provided by the data vendors and do not imply endorsement by MathWorks®.



Frame of Reference and North East Down (NED) Frame

To describe a point in space, you need a frame of reference that does not rotate with respect to the stars. The Geocentric Celestial Reference Frame (GCRF), with the origin at the center of the Earth and orthogonal vectors **I**, **J**, and **K**, is used as the frame of reference while adding `Satellite` objects to a `satelliteScenario` object. The fundamental plane is the **IJ** - plane, which is closely aligned with the equator with a small offset, and **K** aligns closely with the North Pole. You can describe the location of a satellite using a position vector and a velocity vector in the geocentric-equatorial coordinate system.



When referring to the position, velocity, acceleration, orientation, and angular velocity, you must always mention the coordinate system in which these quantities are expressed. Global systems such as GCRF and geodetic systems describe the position of an object using a triplet of coordinates. Local systems such as NED and Azimuth Elevation Range (AER) systems require two triplets of coordinates: one triplet describes the location of the origin, and the other triplet describes the location of the object with respect to the origin.

A NED system uses Cartesian coordinates ($x_{North}, y_{East}, z_{Down}$) to represent position relative to a local origin. The local origin is described by geodetic coordinates (lat_0, lon_0, h_0). Typically, the local origin of an NED system is above the surface of the Earth.

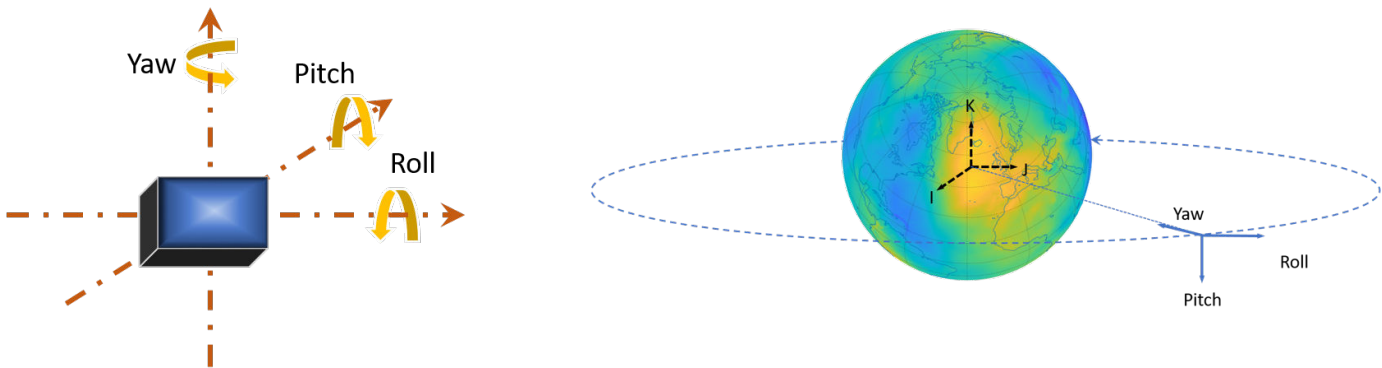
- The positive x_{North} -axis points north along the meridian of longitude containing lon_0 .
- The positive y_{East} -axis points east along the parallel of latitude containing lat_0 .
- The positive z_{Down} -axis points south along the ellipsoid normal.

An NED coordinate system is commonly used to specify location relative to a moving satellite. In this case, the coordinates are not fixed to the frame of the satellite.

Roll, Pitch, and Yaw

Three lines run through a satellite and intersect at right angles at the center of mass of the satellite. These axes move with the satellite and rotate relative to the Earth along with the craft.

- Rotation around the front-to-back axis is called roll.
- Rotation around the side-to-side axis is called pitch.
- Rotation around the vertical axis is called yaw.



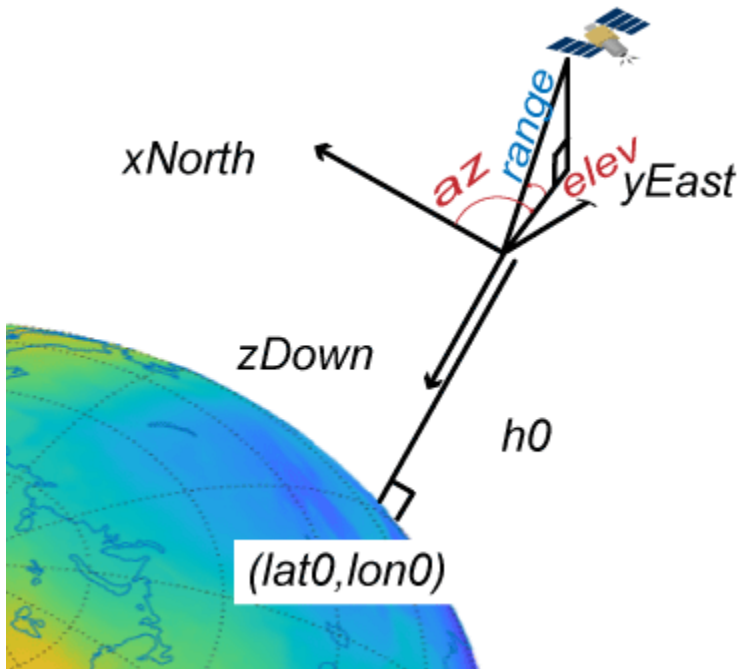
The yaw, pitch, and roll angles of satellites follow an International Organization for Standardization (ISO) convention. These angles have positive clockwise directions when looking in the positive direction of the axes. Unless otherwise specified, by default the Satellite Communications Toolbox uses the yaw-pitch-roll rotation order for these angles.

Azimuth-Elevation-Range (AER) Coordinates

An AER system uses spherical coordinates ($az, elev, range$) to represent position relative to a local origin. The local origin is described by geodetic coordinates (lat_0, lon_0, h_0). Azimuth, elevation, and slant ranges are dependent on a local Cartesian system (for example, an NED system).

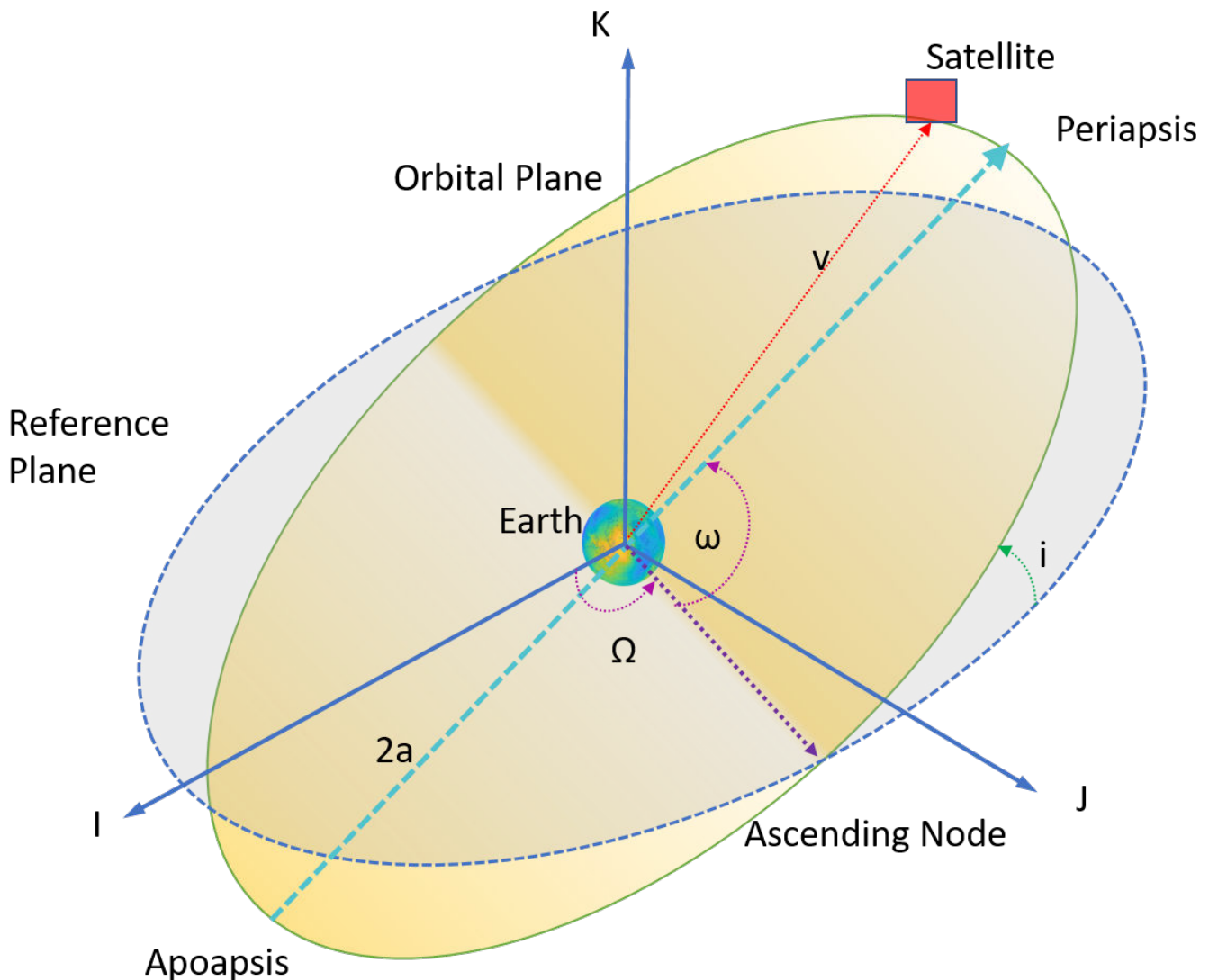
- az is the azimuth, which is the clockwise angle in the (x_{East}, y_{North}) - plane from the positive y_{North} -axis to the projection of the object into the plane.

- *elev* is the elevation, which is the angle from the $(xEast)(yNorth)$ - plane to the object.
- *range* is the slant range, which is the Euclidean distance between the object and the local origin.



Orbital Elements

Orbital elements are parameters required to uniquely identify a specific orbit. Uniquely defining an orbit and the position of a satellite within satellite orbit requires at least six parameters. Three of the parameters describe what the orbital plane looks like and the position of the satellite in the ellipse. The other three parameters describe how that plane is oriented in the celestial inertial reference frame and the location of the satellite in that plane. These six parameters are called the Keplerian elements or orbital elements.



In this diagram, the orbital plane (yellow) intersects a reference plane (gray). For Earth-orbiting satellites, the reference plane is usually the IJ - plane of the GCRF.

These two elements define the shape and size of the ellipse:

- Eccentricity (e) — Shape of the ellipse, describing how elongated it is compared to a circle.
- Semimajor axis (a) — Sum of the periapsis and apoapsis distances divided by two. Periapsis is the point at which an orbiting object is closest to the center of mass of the body it is orbiting. Apoapsis is the point at which an orbiting object is farthest away from the center of mass of the body it is orbiting. For classic two-body orbits, the semimajor axis is the distance between the centers of the bodies.

These two elements define the orientation of the orbital plane in which the ellipse is embedded:

- Inclination (i) — Vertical tilt of the ellipse with respect to the reference plane, measured at the ascending node. The ascending node is the location where the orbit passes upward through the

reference plane (the green angle i in the diagram). The tilt angle is measured perpendicular to the line of intersection between orbital plane and the reference plane. Any three points on an ellipse defines the ellipse orbital plane.

Starting with an equatorial orbit, the orbital plane can be tilted up. The angle it is tilted up from the equator is referred to as the inclination angle, i . Because the center of the Earth must always be in the orbital plane, the point in the orbit where the satellite passes the equator on its way up through the orbit is the ascending node, and the point where the satellite passes the equator on the way down is the descending node. Drawing a line through these two points on the equator defines the line of nodes.

- Right ascension of ascending node (Ω) — Horizontal orientation of the ascending node of the ellipse (where the orbit passes upward through the reference plane) with respect to I-axis of the reference frame.

The rotation of the right ascension of the ascending node (RAAN) can be any number between 0 and 360°.

The remaining two elements are:

- Argument of periapsis (ω) — Orientation of the ellipse in the orbital plane, as an angle measured from the ascending node to the periapsis.
- True Anomaly (v) — Position of the orbiting body along the ellipse at a specific time. The position of the satellite on the path is measured counterclockwise from the periapsis and is called the true anomaly, v .

Two Line Element (TLE) Files

The Satellite Communications Toolbox `satellite` function accepts a TLE file as an input. To download TLE files, see the Space track website.

A TLE set is a data format encoding a list of orbital elements of an Earth orbiting object for a given point in time, the *epoch*. Orbital element parameters can be encoded as text in a variety of formats. The most common format is the NASA/NORAD TLE format. In this format, each satellite has three lines: the first line contains the name of the satellite, and the next two lines are the standard two lines of elements.

Data for each satellite consists of three lines, as this example shows.

```
Satellite 1
1 25544U 98067A 04236.56031392 .00020137 00000-0 16538-3 0 9993
2 25544 51.6335 344.7760 0007976 126.2523 325.9359 15.70406856328906
```

- Line 1 is a eleven-character satellite name.
- Line 2 and 3 are the standard TLE set format identical to that used by NORAD and NASA.

Column	Description	Example
1	Line Number	1
3 — 7	Satellite Number	25544
8	Elset Classification	U
10 — 17	International Designator	98067A

Column	Description	Example
19 – 32	Element Set Epoch (UTC)	04236.56031392
34 – 43	First derivative of the Mean Motion with respect to time	.00020137
45 – 52	Second derivative of the Mean Motion with respect to Time (decimal point assumed)	00000-0
54 – 61	BSTAR Drag Term.	16538-3
63	Element set type	0
65 – 68	Element number	999
69	Check Sum (Modulo 10)	3

This table describes the columns in Line 3.

Column	Description	Examples
1	Line Number of Element Data	2
3 – 7	Satellite Number	25544
9 – 16	Inclination [Degrees]	51.6335
18 – 25	Right Ascension of the Ascending Node [Degrees]	344.7760
27 – 33	Eccentricity (Leading decimal point assumed)	0007976
35 – 42	Argument of Perigee [Degrees]	126.2523
44 – 51	Mean Anomaly [Degrees]	325.9359
53 – 63	Mean Motion [Revs per day]	15.70406856
64 – 68	Revolution number at epoch [Revs]	32890
69	Check Sum (Modulo 10)	6

Depending on the application and object orbit, the data derived from TLEs older than 30 days can become unreliable. Orbital positions can be calculated from TLEs by using the SGP4 and SDP4 algorithms.

References

- [1] "HSF - Orbital Elements." Accessed November 30, 2020. <https://spaceflight.nasa.gov/realdatal/elements/graphs.html>.
- [2] "Celestrak: 'FAQs: Two-Line Element Set Format,'" March 26, 2016. <https://web.archive.org/web/20160326061740/http://celestrak.com/columns/v04n03/>.

See Also

Objects

access | conicalSensor | groundStation | satellite | satelliteScenario

Functions

hide | play | show

Related Examples

- “Multi-Hop Satellite Communications Link Between Two Ground Stations”
- “Satellite Constellation Access to a Ground Station”
- “Comparison of Orbit Propagators”
- “Modeling Satellite Constellations using Ephemeris Data”
- “Estimate GNSS Receiver Position with Simulated Satellite Constellations”
- “Model, Visualize, and Analyze Satellite Scenario” on page 4-2
- “Satellite Scenario Basics” on page 4-15

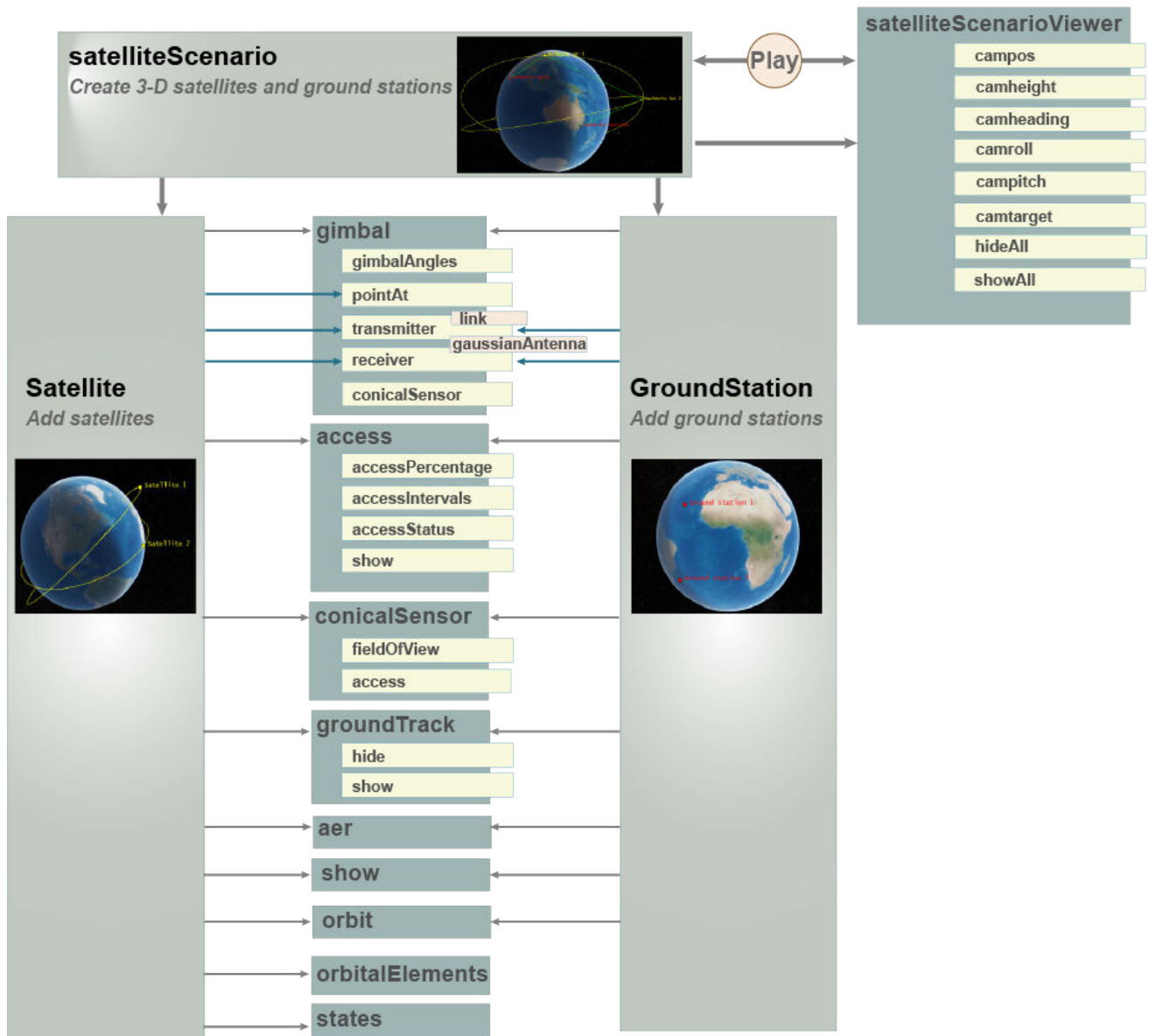
Satellite Scenario Basics

You can build a complete satellite scenario simulation by using the Satellite Communications Toolbox functions and objects. The workflow for satellite scenario simulation consists of these five main components:

- The `satelliteScenario` object represents a 3-D arena consisting of satellites, ground stations, and the interactions between them. Use this object to model satellite constellations, model ground station networks, perform access analysis between the satellites and ground stations, and visualize the results.
- The `satellite` function adds satellites to the scenario using two line element (TLE) files or orbital elements. For more details on orbital elements and TLE files, see “Two Line Element (TLE) Files” on page 4-12.
- The `groundStation` object adds ground stations to the scenario using default parameters or the specified latitude and longitude.
- The `satelliteScenarioViewer` function creates a 3D viewer for the scenario.
- The `play` function simulates the satellite scenario and plays the results in the visualization window specified by `satelliteScenarioViewer`.

This diagram shows the architecture of satellite scenario simulation. Some of the object in the simulation share object functions.

- The `Satellite`, `GroundStation`, and `ConicalSensor` objects share the `access` object function.
- The `Satellite`, `GroundStation`, `GroundTrack`, and `Access` objects share the `show` and `hide` object functions.
- The `Satellite`, `GroundStation`, and `Gimbal` objects share the `conicalSensor` object function.
- The `Satellite` and `GroundStation` objects share the `transmitter` and `receiver` object functions.
- The `Transmitter` and `Receiver` objects share the `link` object function.



See Also

Objects

`satelliteScenario`

Functions

`access` | `conicalSensor` | `groundStation` | `hide` | `play` | `receiver` | `satellite` | `satelliteScenarioViewer` | `show` | `transmitter`

Related Examples

- "Multi-Hop Satellite Communications Link Between Two Ground Stations"

- “Satellite Constellation Access to a Ground Station”
- “Comparison of Orbit Propagators”
- “Modeling Satellite Constellations using Ephemeris Data”
- “Estimate GNSS Receiver Position with Simulated Satellite Constellations”
- “Model, Visualize, and Analyze Satellite Scenario” on page 4-2
- “Satellite Scenario Key Concepts” on page 4-6

Channel Modeling

Earth-Space Propagation Losses

Propagation environments have significant effects on the design of Earth-space links for satellite communications systems. The ionospheric effects on Earth-space links become significant at frequencies below 1 GHz. Effects of the nonionized atmosphere become critical above about 1 GHz and for low elevation angles. Recommendation ITU-R P618 [1] predicts propagation parameters, which are required in the planning of Earth-space systems operating in either the Earth-to-space or space-to-Earth direction. P618 deals with only the effects of the troposphere such as rain attenuation, gaseous attenuation, precipitation and cloud attenuation, and attenuation due to tropospheric scintillation.

In some cases, you might want to provide continuous, high-quality transmission of voice, data, and television signals. In these cases, you can use the `p618Config` object to model tropospheric effects such as rain attenuation, gaseous attenuation, cloud and fog attenuation, and attenuation due to tropospheric scintillation. You can then use the `p618PropagationLosses` function, which initializes configuration parameters settings, to calculate the Earth-space propagation losses, cross-polarization discrimination, and sky noise temperature of the ground station antenna.

Heavy rainfall causes large attenuation values on an Earth-space link. Site diversity enables the rerouting of link traffic to alternate Earth stations, which improves the system reliability. Site diversity systems are classified as one of these options.

- **Balanced:** The attenuation thresholds on the two links are equal.
- **Unbalanced:** The attenuation thresholds on the two links are not equal.

In the case of two Earth stations existing, you can use the `p618SiteDiversityConfig` object to model the parameters required for the calculation of the outage probability due to rain attenuation. Intense rain can cause large attenuation values on an Earth-space link. Then, you can use the `p618SiteDiversityOutage` function, which initializes configuration parameters settings, to calculate the outage probability due to rain attenuation with site diversity.

Earth-Space Propagation Losses

This example requires MAT-files with digital maps from International Telecommunication Union (ITU) documents. If the files are not available on the path, execute these commands to download and untar the MAT-files.

```
if ~exist('ITURDigitalMaps.tar.gz','file')
    url = 'https://www.mathworks.com/supportfiles/spc/P618/ITURDigitalMaps.tar.gz';
    websave('ITURDigitalMaps.tar.gz',url);
    untar('ITURDigitalMaps.tar.gz');
end
```

This example shows how to parameterize and calculate propagation losses for the design of Earth-space systems.

The propagation losses calculated by the `p618PropagationLosses` function are:

- Attenuation by atmospheric gases
- Attenuation by rain
- Precipitation and cloud attenuation
- Attenuation due to tropospheric scintillation

- Total atmospheric attenuation

Earth-space propagation losses are modeled to depend on the frequency, geographic location, and elevation angle. Based on the propagation conditions, at elevation angles above 10°, only the attenuations cause by atmospheric gases, rain, cloud, and tropospheric scintillation are significant.

Configure the Earth-Space Propagation Parameters

Create a default P.618 configuration object. Change property values, and then display the object properties.

```
cfg = p618Config;
cfg.Frequency = 25e9;           % Signal frequency in Hz
cfg.ElevationAngle = 45;
cfg.Latitude = 30;             % North direction
cfg.Longitude = 120;           % East direction
cfg.TotalAnnualExceedance = 0.001; % Time percentage of excess for the total
                                % Attenuation per annum
cfg.AntennaEfficiency = 0.65;
disp(cfg);
```

p618Config with properties:

```
          Frequency: 2.5000e+10
          ElevationAngle: 45
            Latitude: 30
            Longitude: 120
    GasAnnualExceedance: 1
    CloudAnnualExceedance: 1
      RainAnnualExceedance: 1
    ScintillationAnnualExceedance: 1
    TotalAnnualExceedance: 1.0000e-03
    PolarizationTiltAngle: 0
      AntennaDiameter: 1
    AntennaEfficiency: 0.6500
```

Calculate the Propagation Losses in Light Rainfall

Find the propagation losses (pl), cross-polarization discrimination (xpd), and sky noise temperature (tsky) in light rainfall of 1 mm/hr, specifying an Earth station height of 0.5 km.

The fields of propagation losses, pl, describe these attenuations.

- Ag: Gaseous attenuation (in dB)
- Ac: Cloud and fog attenuation (in dB)
- Ar: Rain attenuation (in dB)
- As: Attenuation due to tropospheric scintillation (in dB)
- At: Total atmospheric attenuation (in dB)

```
[pl,xpd,tsky] = p618PropagationLosses(cfg, ...
    'StationHeight',0.5, ...
    'WaterVaporDensity',2.8, ...
    'TotalColumnarContent',1.4, ...
    'RainRate',1)
```

```
pl = struct with fields:
    Ag: 1.6393
```

```
Ac: 1.2010
Ar: 0.0811
As: 0.3010
At: 6.6514
```

```
xpd = 73.1657
```

```
tsky = 214.6132
```

Outage Probability due to Rain Attenuation with Site Diversity

This example requires MAT-files with digital maps from ITU documents. If the files are not available on the path, execute these commands to download and untar the MAT-files.

```
if ~exist('ITURDigitalMaps.tar.gz','file')
    url = 'https://www.mathworks.com/supportfiles/spc/P618/ITURDigitalMaps.tar.gz';
    websave('ITURDigitalMaps.tar.gz',url);
    untar('ITURDigitalMaps.tar.gz');
end
```

This example shows how to calculate outage probability due to rain attenuation with site diversity.

The `p618SiteDiversityOutage` function applies to unbalanced and balanced systems and computes the joint probability of exceeding attenuation thresholds.

Configure P.618 Site Diversity Parameters

Create a default P.618 site diversity configuration object. Change property values, and then display the object properties.

```
cfgSD = p618SiteDiversityConfig;
cfgSD.Frequency = 25e9;           % Signal frequency in Hz
cfgSD.Latitude = [30 60];        % North direction
cfgSD.Longitude = [120 150];     % East direction
cfgSD.PolarizationTiltAngle = [-90 90];
cfgSD.AttenuationThreshold = [7 7]; % Attenuation threshold on the two links
cfgSD.SiteDistance = 50;        % Separation between the two sites
disp(cfgSD);
```

```
p618SiteDiversityConfig with properties:
```

```
    Frequency: 2.5000e+10
    ElevationAngle: [52.4099 52.4852]
    Latitude: [30 60]
    Longitude: [120 150]
    PolarizationTiltAngle: [-90 90]
    SiteDistance: 50
    AttenuationThreshold: [7 7]
```

Calculate Outage Probability

Calculate the outage probability due to rain attenuation for the specified site diversity configuration.

```
outage = p618SiteDiversityOutage(cfgSD, ...
    'RainAnnualExceedances',[0.01 0.01 0.03 0.05 0.1 0.2], ...
    'RainProbability1',0.3, ...
```

```

                                'RainProbability2',0.4);
disp(outage);
0.0030

```

Attenuation due to Atmospheric Gases

This example requires MAT-files with digital maps from ITU documents. If the files are not available on the path, execute these commands to download and untar the MAT-files.

```

if ~exist('ITURDigitalMaps.tar.gz','file')
    url = 'https://www.mathworks.com/supportfiles/spc/P618/ITURDigitalMaps.tar.gz';
    websave('ITURDigitalMaps.tar.gz',url);
    untar('ITURDigitalMaps.tar.gz');
end

```

This example shows how to calculate gaseous attenuation for a specified range of frequencies when designing the Earth-space systems.

Gaseous attenuation is modeled to depend on the signal frequency, elevation angle, Earth station height, and water vapor density. Based on the propagation conditions, gaseous attenuations can be significant with frequencies above 10 GHz and neglected at frequencies below 10 GHz.

Configure P.618 Propagation Parameters

Create a default P.618 configuration object. Change property values, and then display the object properties.

```

cfg = p618Config;
cfg.Latitude = 51.5;           % North direction
cfg.Longitude = -0.14;       % West direction
cfg.GasAnnualExceedance = 10; % Time percentage of excess for the gaseous attenuation per annum
cfg.ElevationAngle = 31.076;

```

Set the signal frequency range to the interval from 5 to 55 GHz.

```
freq_range = 5e9:1e9:55e9;
```

Calculate Gaseous Attenuation

Calculate the attenuation due to atmospheric gases for the specified configuration parameters.

```

gaseous_attenuation = zeros(size(freq_range));
for n = 1:numel(freq_range)
    cfg.Frequency = freq_range(n);
    pl = p618PropagationLosses(cfg, ...
        'StationHeight',0.031, ...
        'Temperature',283.6, ...
        'Pressure',1009.48, ...
        'WaterVaporDensity',13.79);
    gaseous_attenuation(n) = pl.Ag;
end

```

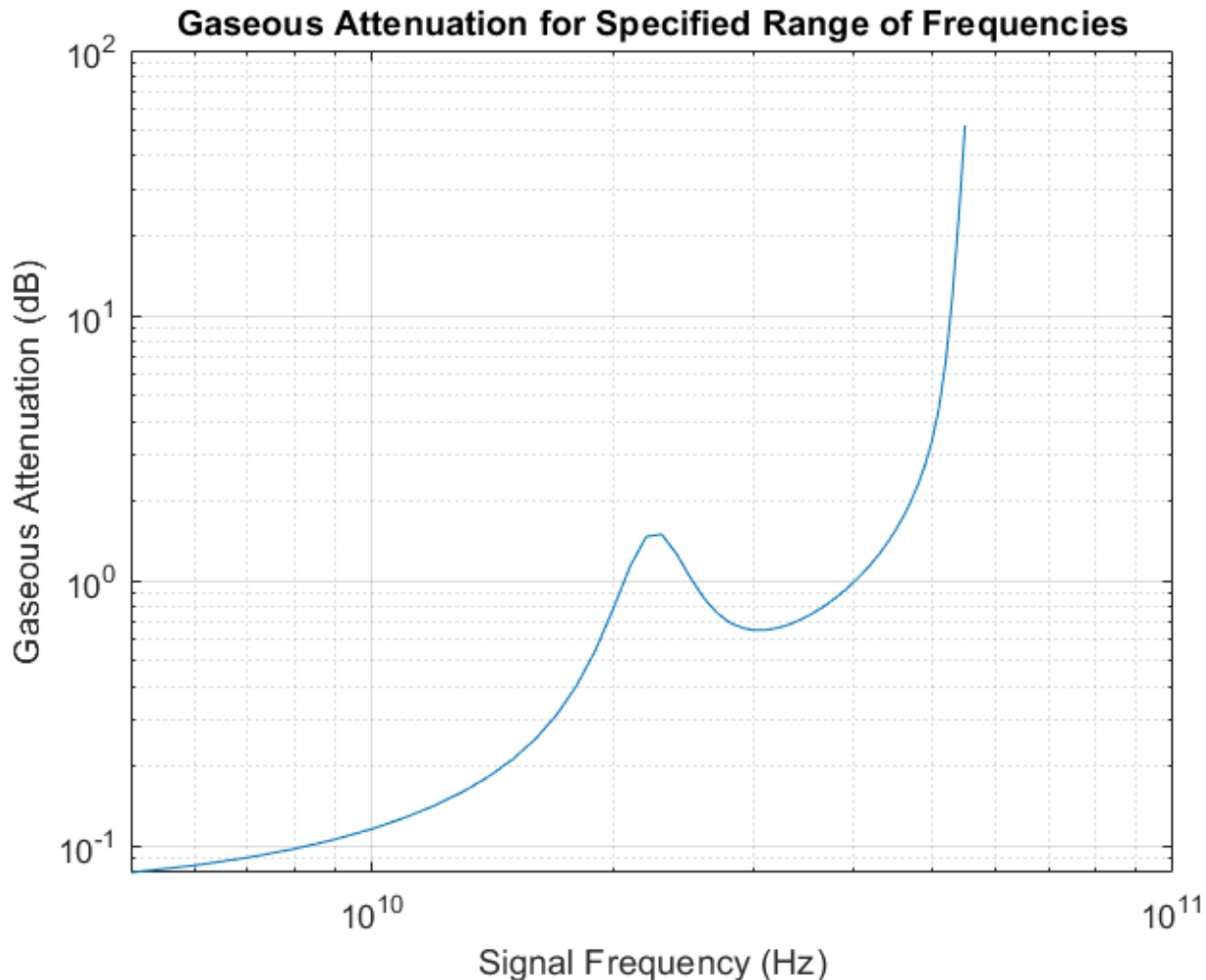
Plot Gaseous Attenuation

On a logarithmic scale, plot the gaseous attenuations for the given range of frequencies.

```

loglog(freq_range,gaseous_attenuation);
grid on;
xlabel('Signal Frequency (Hz)');
ylabel('Gaseous Attenuation (dB)');
title('Gaseous Attenuation for Specified Range of Frequencies');

```



Propagation Losses for Specified Range of Elevation Angle

This example requires MAT-files with digital maps from ITU documents. If the files are not available on the path, execute these commands to download and untar the MAT-files.

```

if ~exist('ITURDigitalMaps.tar.gz','file')
    url = 'https://www.mathworks.com/supportfiles/spc/P618/ITURDigitalMaps.tar.gz';
    websave('ITURDigitalMaps.tar.gz',url);
    untar('ITURDigitalMaps.tar.gz');
end

```

This example shows how to parameterize and calculate Earth-space propagation losses for a specified range of elevation angles when designing Earth-space systems.

Configure P.618 Propagation Parameters

Create a default P.618 configuration object. Change property values, and then display the object properties.

```
cfg = p618Config;
cfg.Frequency = 14.25e9; % Signal frequency in Hz
cfg.Latitude = 51.5; % North direction
cfg.Longitude = -0.14; % West direction
```

Set the elevation angle range to the interval from 5 to 90 degrees.

```
elev_range = 5:5:90;
```

Calculate Earth-Space Propagation Losses

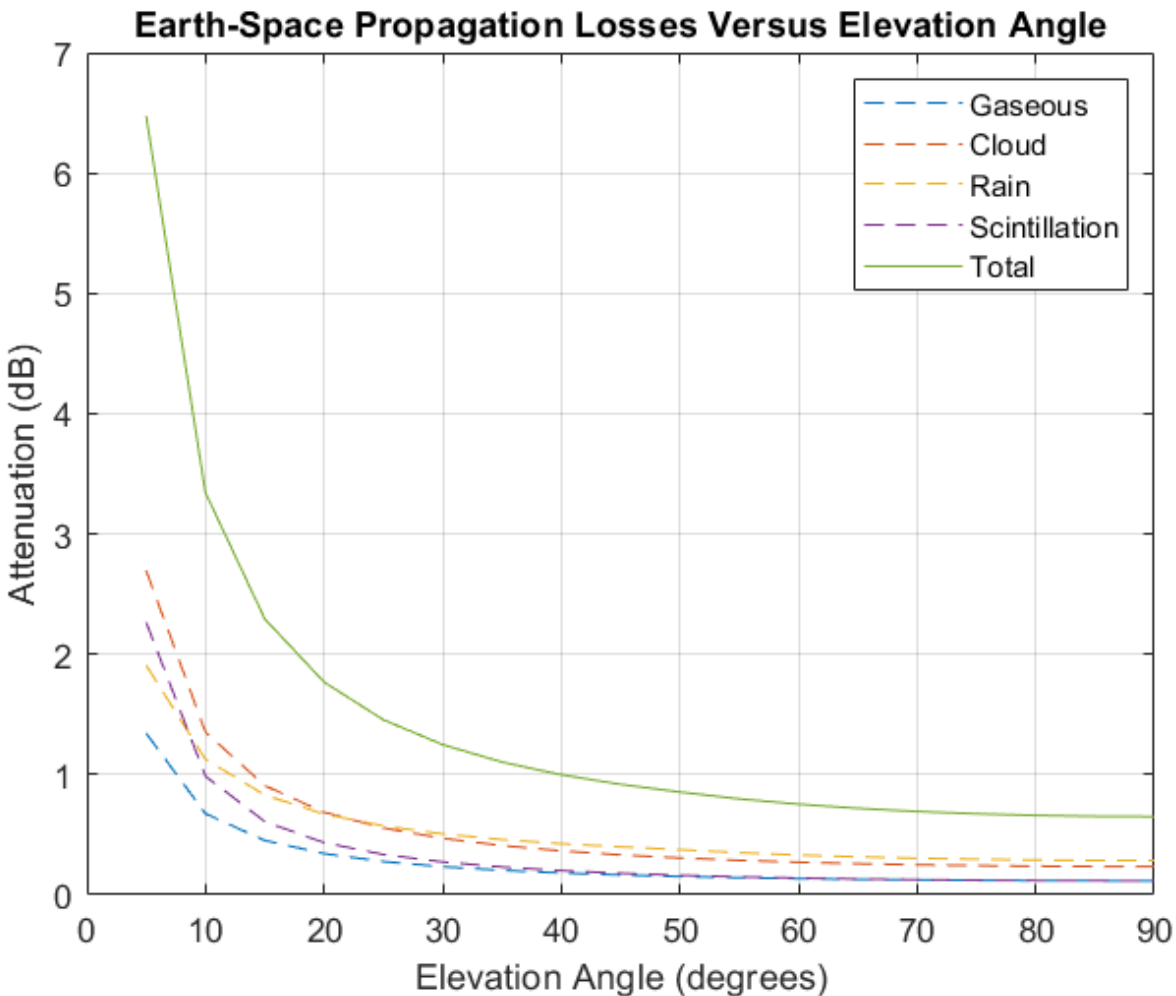
Calculate the Earth-space propagation losses for the specified configuration parameters.

```
elevation_angle = size(elev_range);
gaseous_attenuation = zeros(elevation_angle);
cloud_attenuation = zeros(elevation_angle);
rain_attenuation = zeros(elevation_angle);
scintillation_attenuation = zeros(elevation_angle);
total_attenuation = zeros(elevation_angle);
for n = 1:numel(elev_range)
    cfg.ElevationAngle = elev_range(n);
    pl = p618PropagationLosses(cfg, ...
        'StationHeight',0.031, ...
        'Temperature',283.6, ...
        'Pressure',1009.48, ...
        'WaterVaporDensity',13.79);
    gaseous_attenuation(n) = pl.Ag;
    cloud_attenuation(n) = pl.Ac;
    rain_attenuation(n) = pl.Ar;
    scintillation_attenuation(n) = pl.As;
    total_attenuation(n) = pl.At;
end
```

Plot the Earth-space propagation losses

Plot the various propagation losses (in dB) for the specified range of elevation angles.

```
plot(elev_range,gaseous_attenuation,'--');
hold on;
plot(elev_range,cloud_attenuation,'--');
hold on;
plot(elev_range,rain_attenuation,'--');
hold on;
plot(elev_range,scintillation_attenuation,'--');
hold on;
plot(elev_range,total_attenuation);
legend('Gaseous','Cloud','Rain','Scintillation','Total');
grid on;
xlabel('Elevation Angle (degrees)');
ylabel('Attenuation (dB)');
title('Earth-Space Propagation Losses Versus Elevation Angle');
```



Propagation Losses with Time Percentage of Exceedance

This example requires MAT-files with digital maps from ITU documents. If the files are not available on the path, execute these commands to download and untar the MAT-files.

```
if ~exist('ITURDigitalMaps.tar.gz','file')
    url = 'https://www.mathworks.com/supportfiles/spc/P618/ITURDigitalMaps.tar.gz';
    websave('ITURDigitalMaps.tar.gz',url);
    untar('ITURDigitalMaps.tar.gz');
end
```

This example shows how to parameterize and calculate Earth-space propagation losses when the percentage of time attenuation value is exceeded when designing the Earth-space systems.

Configure Earth-Space Propagation Parameters

Create a P.618 configuration object. Change property values, and then display the object properties.

```
cfg = p618Config;
cfg.Frequency = 19.5e9;           % Signal frequency in Hz
```

```

cfg.ElevationAngle = 36.6142654;
cfg.Latitude = 46.2208;           % North direction
cfg.Longitude = 6.137;          % East direction
cfg.AntennaDiameter = 1.2;
cfg.AntennaEfficiency = 0.65;

```

Set the time percentage of excess for the gaseous attenuation, cloud attenuation, rain attenuation, scintillation, and total atmospheric attenuation.

```
annual_exceedance = [5 3 2 1 0.5 0.3 0.2 0.1 0.05 0.03 0.02 0.01 0.005 0.003 0.002 0.001];
```

Calculate Earth-Space Propagation Losses

Calculate the Earth-space propagation losses for the specified configuration parameters.

```

excess=size(annual_exceedance);
gaseous_attenuation = zeros(excess);
cloud_attenuation = zeros(excess);
rain_attenuation = zeros(excess);
scintillation=zeros(excess);
total_attenuation = zeros(excess);
for n = 1:numel(annual_exceedance)
    exceedance_value = annual_exceedance(n);
    cfg.GasAnnualExceedance = max(exceedance_value,0.1);           % Supported range is 0.1% to
    cfg.CloudAnnualExceedance = max(exceedance_value,0.1);         % Supported range is 0.1% to
    cfg.RainAnnualExceedance = exceedance_value;                   % Supported range is 0.001% to
    cfg.ScintillationAnnualExceedance = max(exceedance_value,0.01); % Supported range is 0.01% to
    cfg.TotalAnnualExceedance = exceedance_value;                  % Supported range is 0.001% to
    pl = p618PropagationLosses(cfg,'StationHeight',0.412);
    gaseous_attenuation(n) = pl.Ag;
    cloud_attenuation(n) = pl.Ac;
    rain_attenuation(n) = pl.Ar;
    scintillation(n) = pl.As;
    total_attenuation(n) = pl.At;
end

```

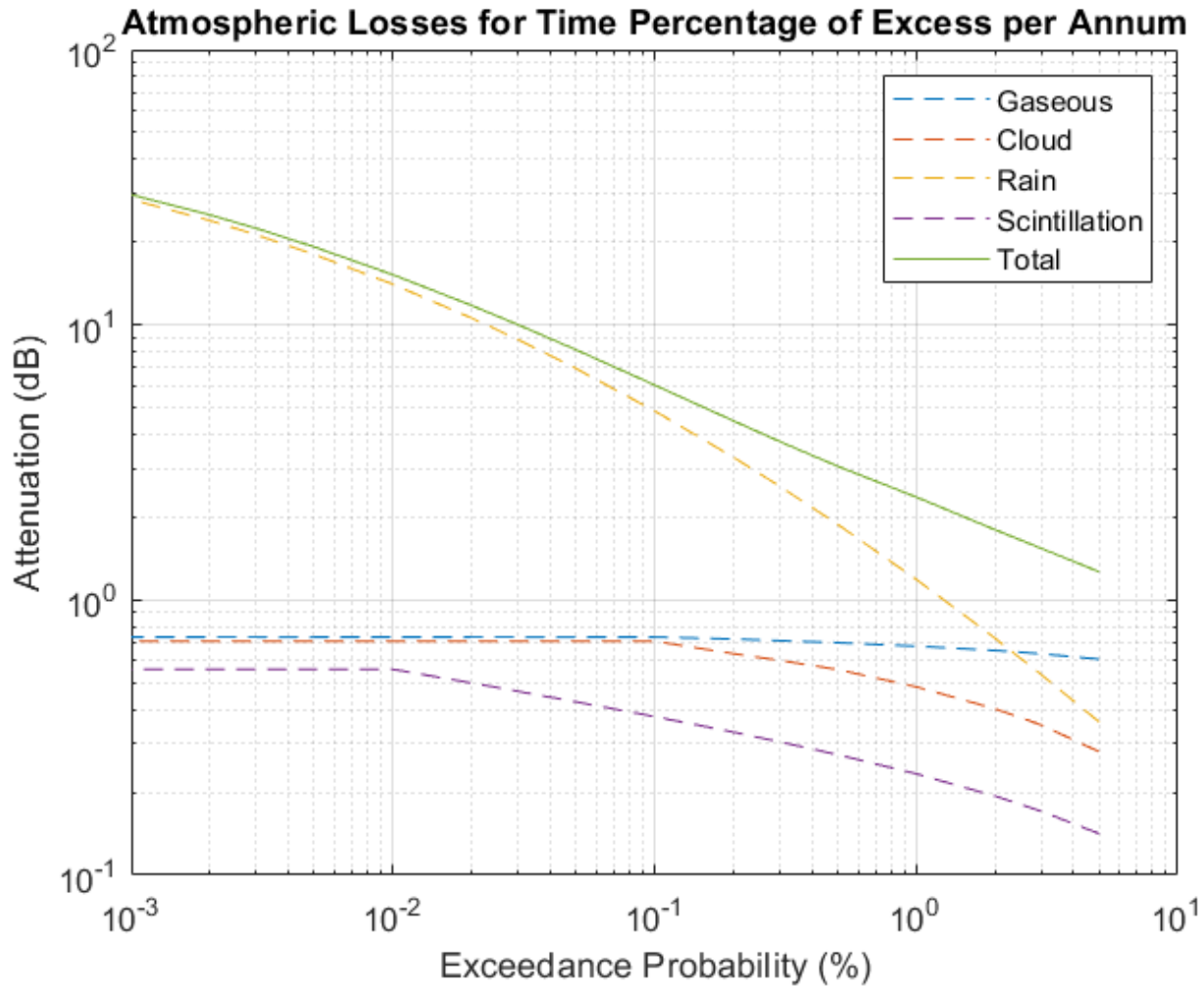
Plot Earth-Space Propagation Losses

Plot the various propagation losses (in dB) when the percentage of time attenuation value is exceeded.

```

loglog(annual_exceedance,gaseous_attenuation,'--');
hold on;
loglog(annual_exceedance,cloud_attenuation,'--');
hold on;
loglog(annual_exceedance,rain_attenuation,'--');
hold on;
loglog(annual_exceedance,scintillation,'--');
hold on;
loglog(annual_exceedance,total_attenuation);
legend('Gaseous','Cloud','Rain','Scintillation','Total');
grid on;
xlabel('Exceedance Probability (%)');
ylabel('Attenuation (dB)');
title('Atmospheric Losses for Time Percentage of Excess per Annum');

```



References

- [1] International Telecommunication Union, ITU-R Recommendation P.618 (12/2017)
- [2] International Telecommunication Union, ITU-R Recommendation P.676 (08/2019)
- [3] International Telecommunication Union, ITU-R Recommendation P.1511 (08/2019)
- [4] International Telecommunication Union, ITU-R Recommendation P.1510 (06/2017)
- [5] International Telecommunication Union, ITU-R Recommendation P.835 (12/2017)
- [6] International Telecommunication Union, ITU-R Recommendation P.836 (12/2017)
- [7] International Telecommunication Union, ITU-R Recommendation P.840 (08/2019)
- [8] International Telecommunication Union, ITU-R Recommendation P.837 (06/2017)
- [9] International Telecommunication Union, ITU-R Recommendation P.453 (08/2019)

[10] International Telecommunication Union, ITU-R Recommendation P.839 (09/2013)

[11] International Telecommunication Union, ITU-R Recommendation P.838 (03/2005)

[12] Validation examples for Study Group 3 Earth-Space propagation prediction methods, Version: 5.0 (P), ITU Radio communication Study Groups.

See Also

Objects

p618Config | p618SiteDiversityConfig

Functions

p618PropagationLosses | p618SiteDiversityOutage

