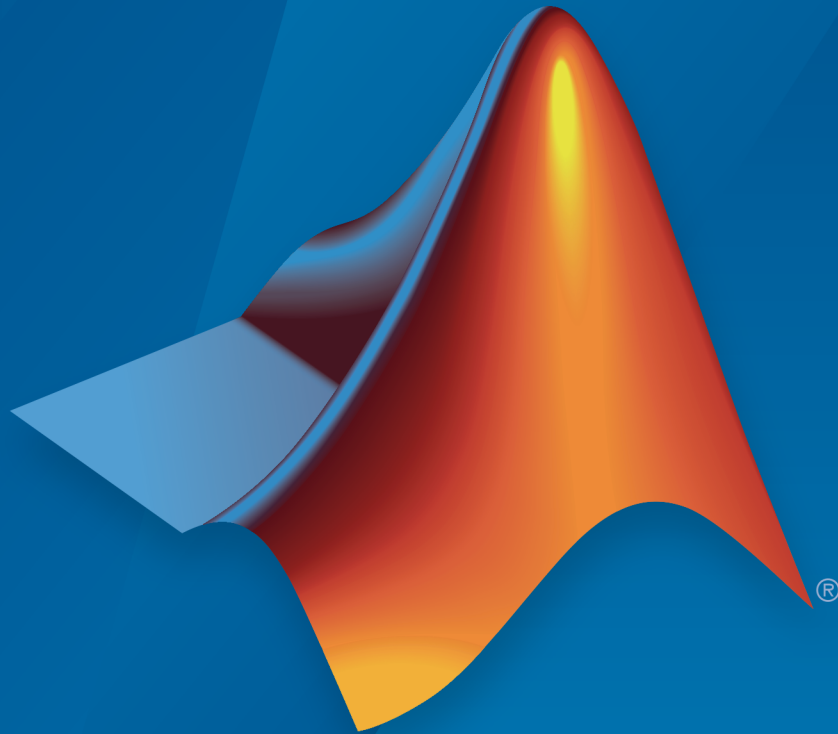


# Phased Array System Toolbox™ Release Notes



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

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# R2016b

**Version: 3.3**

**New Features**

**Bug Fixes**

## Wideband Targets: Model frequency-dependent and angle-dependent RCS

The phased.WidebandBackscatterRadarTarget System object™ models the reflection of wideband signals from targets in monostatic radar simulations. This System object extends to wideband signals the capabilities of the narrowband phased.BackscatterRadarTarget System object.

You can specify angle-dependent radar cross-section (*RCS*) models for nonpolarized fields or scattering pattern models for polarized fields. For nonpolarized signals, you specify the RCS pattern as a MATLAB® array dependent on incident angles and frequency. For polarized signals, you specify a set of three arrays describing the *HH*, *VV*, and *HV* scattering patterns. For the corresponding Simulink® block, you can use Wideband Backscatter Radar Target.

## Multipath Propagation: Model atmospheric effects on narrowband and wideband signals in two-ray channels

The phased.WidebandTwoRayChannel System object models wideband signal propagation when the signal channel includes a planar boundary, such as a flat earth. The wideband two-ray channel propagation model includes atmospheric attenuation caused by fog, rain, or atmospheric gases. This release also adds atmospheric attenuation models to the narrowband signal phased.TwoRayChannel System object. For the corresponding Simulink block, see Wideband Two-Ray Channel.

## 2-D CFAR Detector: Perform constant false alarm rate detection on range-Doppler maps

The phased.CFARDetector2D System object performs constant false alarm rate detection on two-dimensional data. Like the phased.CFARDetector System object, the 2-D CFAR object calculates the detection threshold required to produce a constant false alarm rate. The CFAR threshold is computed by averaging over signal-free training cells in a two-dimensional region surrounding the test cell. For the corresponding Simulink block, use 2-D CFAR Detector.

## MUSIC DOA Estimation: Resolve closely-spaced narrowband sources

This release adds the high-resolution direction-finding algorithm, MUSIC, for resolving closely-spaced narrowband sources. The phased.MUSICEstimator System object

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performs MUSIC estimation on uniform linear arrays. For two-dimensional arrays, use `phased.MUSICEstimator2D`.

For the corresponding Simulink blocks, see `ULA MUSIC Spectrum` for uniform linear arrays and `MUSIC Spectrum` for two-dimensional arrays.

You can also use the `musicdoa` function to compute directions of arrival of signals on ULA arrays based on the sensor covariance matrix.

## **Low Sidelobe Taper: Taylor tapers for circular planar arrays**

Use the `taylortaperc` function to create Taylor tapers, which you can then apply to circular planar apertures. Arrays with Taylor tapers maintain nearly constant sidelobe levels.

## **Periodic and Cross-ambiguity Functions: Compute ambiguity functions for periodic signals**

The `pambgfun` function computes the  $p$ -period ambiguity function for periodic signals. In addition, the enhanced ambiguity function, `ambgfun`, computes the crossambiguity between two signals.

## **Generalized Sidelobe Canceler: Adaptively suppress interference**

The generalized sidelobe canceler (GSC) System object, `phased.GSCBeamformer`, adaptively suppresses directional interference. GSC is an optimized version of the adaptive linear-constrained minimum variance (LCMV) beamformer, whereby the constrained optimization problem is replaced by an unconstrained one. For the corresponding Simulink block, see `GSC Beamformer`.

## **PRF Agility: Dynamically select PRF during simulation**

You can run simulations in *pulse mode* with a dynamically changing pulse repetition frequency (*PRF*). This feature lets you simulate, for example, an MTI radar with staggered PRF waveforms. Pulse mode is available when you use one of the pulsed waveform System objects: `phased.LinearFMWaveform`, `phased.PhaseCodedWaveform`, `phased.RectangularWaveform`, or `phased.SteppedFMWaveform`. To run in pulse mode, specify the waveform `OutputFormat` property as `Pulses`. Then, you can specify the

PRF property as a row vector of varying values. When running a simulation in pulse mode the number of samples per pulse will change when you specify a variable PRF. In contrast, when you specify the `OutputFormat` property as `Samples`, the number of samples is set by the `NumSamples` property and remains fixed. PRF agility also applies to the corresponding Simulink blocks.

## System Objects: Simpler way to call System objects

Instead of using the `step` method to perform the operation defined by a System object, you can call the object with arguments, as if it were a function. The `step` method will continue to work. This feature improves the readability of scripts and functions that use many different System objects.

For example, if you create a `phased.WidebandCollector` System object named `collector`, then you call the System object as a function with that name

```
collector = phased.WidebandCollector('Sensor',array,'SampleRate',fs);  
x = collector(y,incident_ang);
```

The equivalent operation using the `step` method is:

```
collector = phased.WidebandCollector('Sensor',array,'SampleRate',fs);  
x = step(collector,y,incident_ang);
```

When the `step` method has the System object as its only argument, the function equivalent will have no arguments. This function must be called with empty parentheses. For example,

```
waveform = phased.LinearFMWaveform('PulseWidth',10.0e-6);  
wv = step(waveform);  
and
```

```
waveform = phased.LinearFMWaveform('PulseWidth',10.0e-6);  
wv = waveform();  
perform equivalent operations.
```

# R2016a

**Version: 3.2**

**New Features**

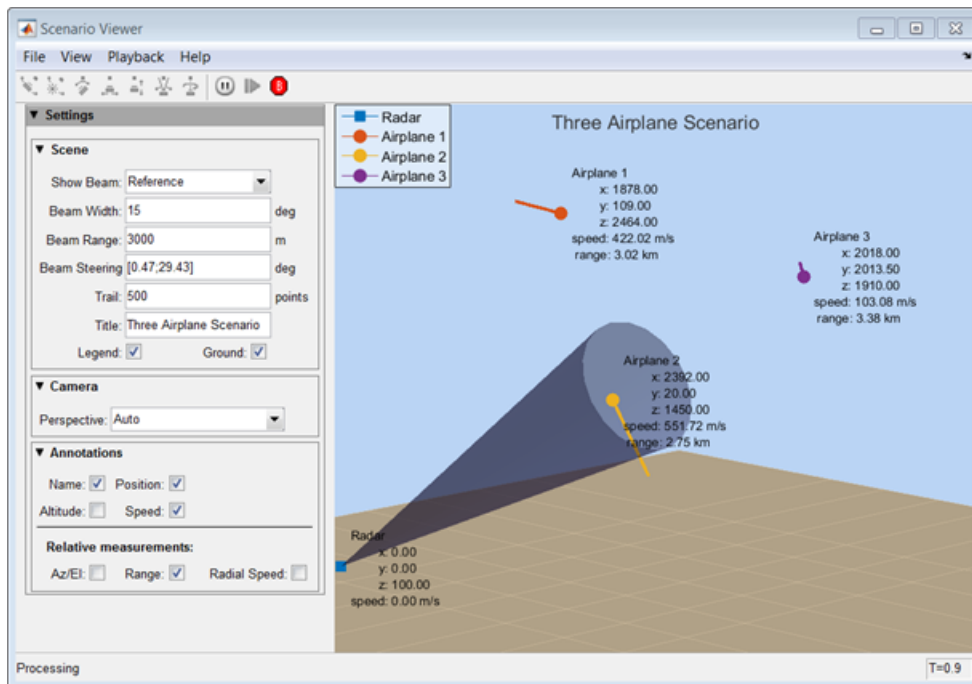
**Bug Fixes**

## Scenario Viewer: Visualize radar and target trajectories

The phased.ScenarioViewer System object is a UI tool for visualizing the trajectories of multiple objects, receivers, and transmitters in radar scenarios. The System object creates a 3-D display showing the motion of radars and targets over time. Use this display to:

- annotate scenario objects with indicators such as position, speed, range, and angle
- toggle the display of radar beams and dynamically alter their pointing directions
- label the scenario objects with custom tags and motion history tracks
- change all parameters during the simulation using the UI panel

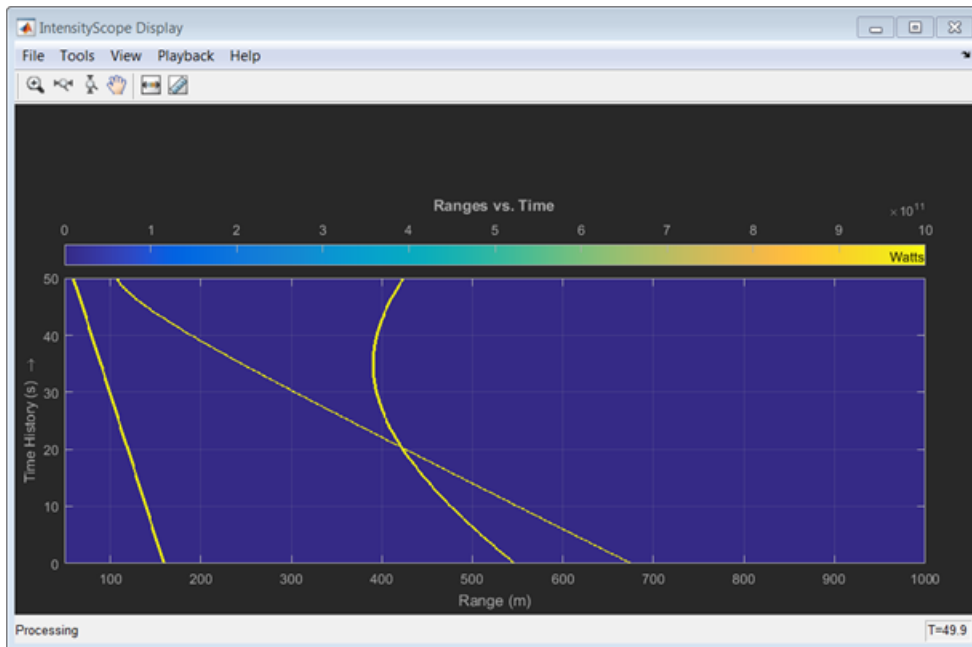
Although designed for radar scenarios, you can also use the UI to visualize sonar and microphone models. You can change all parameters during the simulation by using the UI panel.





## Intensity Scope: Visualize range-time-intensity (RTI) and Doppler-time-intensity (DTI) images

The phased.IntensityScope System object lets you create RTI and DTI displays for radar and sonar. An RTI display shows echo intensity as a function of time and range. A DTI display shows echo intensity as a function of time and Doppler shift, or speed. You can also visualize angle-time-intensity data or display spectrograms.



## Atmospheric Loss: Model rain, fog, and atmospheric gas attenuation of RF signals

The phased.LOSChannel System object lets you simulate line-of-sight (LOS) propagation of narrowband RF signals. The model includes attenuation due to dry air, water vapor, rain, fog, and geometric spreading. The phased.WidebandLOSChannel System object performs the same function for wideband RF signals. These System objects correspond to the phased.FreeSpace and phased.WidebandFreeSpace System objects, which model propagation in vacuum. In addition, the toolbox provides two associated Simulink blocks: LOS Channel and Wideband LOS Channel. When you want to perform analytic

modeling, use the `gaspl` function to simulate attenuation due to atmospheric gases. The `fogpl` and `rainpl` functions let you model attenuation due to fog and rain, respectively.

## Backscattered Radar Target: Model backscattered radiation with angle-dependent, custom RCS patterns

Using the `phased.BackscatterRadarTarget` System object, you can model an angle-dependent radar cross-section (RCS) or scattering pattern model for monostatic radar simulations. For nonpolarized signals, specify the RCS pattern as a single  $M$ -by- $N$  matrix. For polarized signals, you specify a set of three matrices describing  $HH$ ,  $VV$ , and  $HV$  scattering patterns. The entries in the matrices specify the RCS value for each azimuth and elevation angle with respect to the local target coordinate system. The toolbox provides an associated Simulink block, Backscatter Radar Target.

## Phase Shift Quantization: Model effects of quantized beamformer weights on array patterns and responses

In this release, you can model beamformer and steering vector weights to finite precision. This feature appears in the System objects listed in the table and in the corresponding Simulink blocks.

System Objects with Phase Quantization Property	
<code>phased.ADPCACanceller</code>	<code>phased.PartitionedArray</code>
<code>phased.BeamscanEstimator</code>	<code>phased.PhaseShiftBeamformer</code>
<code>phased.BeamscanEstimator2D</code>	<code>phased.ReplicatedSubarray</code>
<code>phased.DPCACanceller</code>	<code>phased.STAPSMIBeamformer</code>
<code>phased.MVDREstimator</code>	<code>phased.SteeringVector</code>
<code>phased.MVDREstimator2D</code>	<code>phased.SumDifferenceMonopulseTracker</code>
<code>phased.MVDRBeamformer</code>	<code>phased.SumDifferenceMonopulseTracker2D</code>

In addition, the steering vector function, `steervec`, the conventional beamformer weights function, `cbfweights`, and the minimum-variance distortionless response weights function, `mvdweights`, include a quantization bit argument.

In analytic models which use ideal components, the phase shifting required for precise array steering and beamforming is computed to infinite precision. In practical

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applications that model real radar components, the element phase shifting is computed to finite precision. Finite precision gives rise to quantization effects that can affect the beamforming and steering performance of an array. In some simulations, it is important to model quantization effects. Quantized phase shifters are categorized by the number of bits in the phase component of the weight vector.

## Array Orientations: Set array pointing direction

Two features in this release give you more options for positioning elements on uniform arrays:

- The `ArrayAxis` property lets you specify the position of ULA elements along the  $x$ -axis,  $y$ -axis, or  $z$ -axis of the local coordinate system. Previously, elements were located only along the  $y$  axis. This property applies to the `phased.ULA` and `phased.HeterogeneousULA` System objects.
- The `ArrayNormal` property lets you place the elements of uniform planar arrays on the  $x$ - $y$ -plane,  $y$ - $z$ -plane, or the  $z$ - $x$ -plane. Previously, elements were located only on the  $z$ - $x$  plane. In these cases, the array normal axis points along the  $z$ ,  $x$ , or  $y$  axes, respectively. This property applies to the `phased.URA`, `phased.UCA` and `phased.HeterogeneousURA` System objects.
- These features appear in the Simulink blocks that use uniform arrays.

To obtain the direction normal vector for the elements of these arrays, use the `getElementNormal` method belonging to each System object.

## Dynamic PRF: Change pulse repetition frequencies

You can change the pulse repetition frequency (PRF) at each call to the `step` method for these pulse waveform System objects: `phased.RectangularWaveform`, `phased.LinearFMWaveform`, `PhaseCodedWaveform`, and `phased.SteppedFMWaveform`. When initializing the waveforms, you specify a vector of PRFs. In the `step` method call, you then specify an index into this vector.

In addition, the `DutyCycle` property lets you specify pulse duration in terms of duty cycle. Previously, you specified pulse duration in the `PulseWidth` property. When you specify `DutyCycle` and `PRF` properties, the System object computes the pulse duration for you. The `DutyCycle` property applies to the `phased.RectangularWaveform`, `phased.LinearFMWaveform`, and `phased.SteppedFMWaveform` waveforms.

## **Short Dipole Orientation: Align dipole direction along any axis**

You can align the dipole direction of the phased.ShortDipoleAntennaElement System object along the  $x$ -axis,  $y$ -axis, and  $z$ -axis.

# R2015b

**Version: 3.1**

**New Features**

**Bug Fixes**

**Compatibility Considerations**

## **Wideband Radiator: Radiate wideband signals from arrays and elements**

The `phased.WidebandRadiator` System object lets you create wideband signals that radiate from an element or array source into different spatial directions. This System object is the wideband counterpart of the narrowband `phased.Radiator` System object. The radiator employs subband frequency processing to generate wideband propagating signals. Subband processing works in the frequency domain by dividing the signal spectrum into frequency bands and processing each band as if it were a narrowband signal.

This release also includes the corresponding Wideband Transmit Array Simulink block.

The `phased.WidebandRadiator` System object is one of several System objects introduced in this release to process wideband signals.

## **Wideband Free Space: Propagate wideband signals through free space**

The `phased.WidebandFreeSpace` System object propagates wideband signals in free space along line-of-sight paths. The System object models time-delay, Doppler, and propagation loss and is the wideband counterpart of the narrowband `phased.FreeSpace` System object. The wideband free-space propagator uses subband frequency processing to propagate signals. Subband processing works in the frequency domain by dividing the signal spectrum into frequency bands and processing each band as if it were a narrowband signal.

This release also includes the corresponding Wideband Free Space Simulink block.

## **Wideband MVDR Beamformer: Perform frequency-domain MVDR beamforming on wideband signals**

The `phased.SubbandMVDRBeamformer` System object performs minimum-variance distortional response beamforming on wideband signals. This System object is the wideband counterpart of the narrowband `phased.MVDRBeamformer` System object. The wideband MVDR System object uses subband frequency processing to beamform a signal. Subband processing works in the frequency domain by dividing the signal spectrum into frequency bands and processing each band as if it were a narrowband signal.

This release also includes the corresponding Subband MVDR Beamformer Simulink block.

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## Wideband DOA Estimator: Estimate the arrival angle of wideband signals using generalized cross-correlation

The phased.GCCEstimator System object estimates the direction of arrival (DOA) of wideband signals on an array. The System object uses the generalized cross-correlation with phase transform (*GCC-PHAT*) algorithm to determine the time delay of coherent signals from a common source arriving between pairs of sensors in an array. The algorithm estimates time delays from the cross-correlation peaks between signals. The direction of arrival follows directly from the computed time delays. The *GCC-PHAT* algorithm improves the sharpness of the correlation peak over ordinary correlation by whitening the signal spectrum.

In addition, the new gccphat function computes the time delay between two coherent signals from a common source arriving at different sensors.

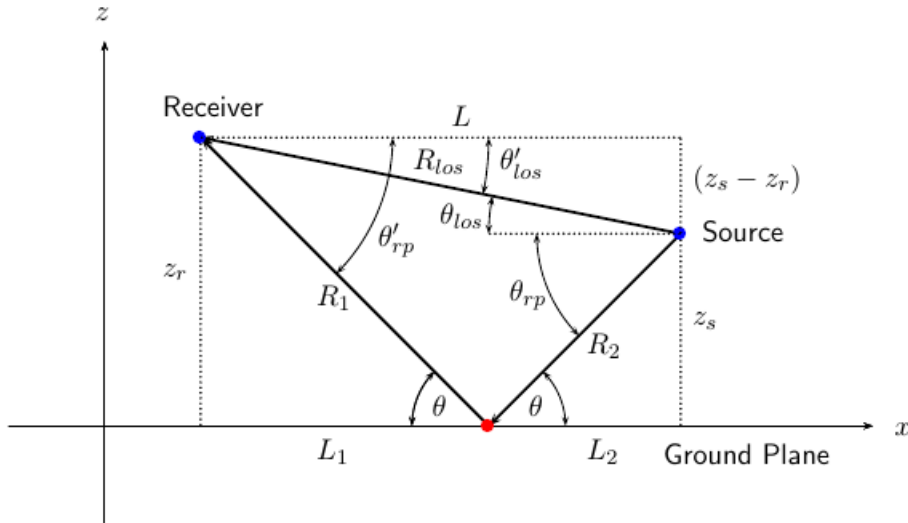
This release includes the corresponding GCC DOA and TOA Simulink block.

## Two-Ray Channel: Propagate signals along line-of-sight and ground-reflected paths

The phased.TwoRayChannel System object propagates signals in a channel with a single reflecting boundary. This type of boundary often occurs with radar signals reflecting from a ground plane or with acoustic signals reflecting from the ocean surface. This System object models the line-of-sight propagation path and the reflected propagation path. The model assumes flat-earth geometry and works with scalar field or polarized electromagnetic fields. To compute reflection loss for scalar fields, you specify a ground reflection loss parameter. For polarized electromagnetic fields, specify the relative dielectric permittivity.

In addition, the rangeangle function now computes the path distance and arrival directions for the line-of-sight and reflected ray paths. The phased.TwoRayChannel System object and rangeangle function work in air or underwater environments provided the signals are non-polarized fields and the propagation speed is appropriate for the medium.

All propagation paths follow straight lines between boundaries. This illustration illustrates line-of-sight (los) and reflected paths (rp) and arrival and emittance angles.



This release also includes the corresponding Two-Ray Channel Simulink block.

## Improved Accuracy of Free Space Propagation: Implement fractional sample-time delay

This release changes how the phased.FreeSpace System object models propagation delays. In previous versions, propagation delays were always an integral number of sample times. This version outputs signals having fractional sample time delays. This change leads to a more accurate estimate of the actual propagation time for a signal.

## Compatibility Considerations

The propagated signal output can differ from the output of previous versions.



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## **Platform Motion: Model acceleration of targets and signal sources**

The `phased.Platform System` object now models platform acceleration in addition to the existing constant-velocity model. Acceleration is also included in the corresponding Motion Platform Simulink block.

## **Wideband Collector: Subband selection changes**

In the `phased.WidebandCollector System` object, when performing subband processing, you can choose the number of frequency subbands. Alternatively, the number of subbands can be automatically calculated. Similarly, you can choose the number of subbands in the corresponding Wideband Receive Array Simulink block.

## **Compatibility Considerations**

The method for computing the default value for the number of frequency subbands has changed, potentially leading to different results. You can minimize the differences by setting the `NumSubbands` property value equal to the signal length.

## **Antenna Toolbox Integration: Changes to field values**

Field values that you generate when using Antenna Toolbox™ antennas in a Phased Array System Toolbox™ array have changed. Previous array computations used the actual field value generated by the antenna. The new computation uses a normalized field value created by dividing the field by its maximum value over all spatial directions. Spatial directions are sampled over a 5° uniform grid in azimuth and elevation.

## **Compatibility Considerations**

Computed values of radiated or received fields are changed. Antenna and array directivity pattern values are not change because they are already normalized quantities.

## **Platform Motion: Changes to orientation dynamics**

In previous versions of the `phased.Platform System` object, the orientation matrix returned by the `step` method remained incorrectly fixed to the value of the `OrientationAxes` property specified during System object construction. (The `step` method returns the platform orientation matrix when the

`OrientationAxesOutputPort` property is set to `true`.) In this release, the returned orientation matrix is properly updated at every call to the `step` method. The orientation axes are rotated if the platform undergoes curvilinear motion. Finally, the name of the `OrientationAxes` property is changed to `InitialOrientationAxes` to emphasize that the property specifies the initial value of the orientation matrix.

## **Compatibility Considerations**

You should replace `OrientationAxes` by `InitialOrientationAxes`. In order to maintain the original behavior, set the `OrientationAxesOutputPort` property to `false` and always use the initial matrix that you specified in `InitialOrientationAxes` for all downstream processing.

# R2015a

**Version: 3.0**

**New Features**

**Bug Fixes**

## **Antenna Toolbox Integration: Use elements from Antenna Toolbox to design antenna arrays**

This release lets you use antenna elements from Antenna Toolbox in your phased array models and simulations. For example, to create a four-element array of helix antennas, enter

```
sAnt = helix('Radius',28e-3,'Width',1.2e-3,'Turns',4);  
sArray = phased.ULA('Element',sAnt,'NumElements',4);
```

just as you would use antennas from Phased Array System Toolbox. Use of Antenna Toolbox requires an additional license. For more information on using this toolbox, go to Antenna Toolbox.

## **Array Calibration: Calibrate array element gain, phase, and position using pilot sources**

This release introduces a function to perform array calibration. You can use the `pilotcalib` function to calibrate individual element gains, phases, and positions. This algorithm implements the pilot source technique and is commonly used for array calibration. The algorithm works by setting up multiple transmitters in known directions and using the array to receive the signals from those transmitters. Because these transmitters are in known directions, you can compute the expected received signal for the array and compare it to the actual received signal. From these differences, you can calibrate the array.

## **Uniform Circular Array: Perform beamforming and root-MUSIC direction-of-arrival estimation**

This release introduces the `phased.UCA` System object to simulate uniform circular arrays (UCA). A uniform circular array has its elements equally spaced around a circle. The element normals point along the outward radius of the array. You can specify the number of elements and the radius of the array. From these two quantities, the object computes the position of the elements. This array accepts any polarized or nonpolarized element types and accepts complex-valued element tapers. You can use a UCA System object as an array for beamforming and direction-of-arrival in System objects such as `phased.PhaseShiftBeamformer` and `phased.LCMVBeamformer`.

In addition, enhancements to the `phased.RootMUSICEstimator` System object let you employ root-MUSIC direction finding algorithms on uniform circular arrays.

---

## Model Simplification: Simulate multiple targets, platforms, and propagation channels using single blocks

Several blocks and System objects have been vectorized to support multitarget scenarios. When simulating multiple platforms and targets, you can combine separate blocks describing target cross-sections, platform motion, or channel propagation into single blocks. This change can simplify complex models. In addition, you can parameterize the number of targets to enable easy modification.

The following blocks and System objects now allow vectorized inputs and outputs:

- Radar Target
- Motion Platform
- Free Space
- phased.RadarTarget
- phased.Platform
- phased.FreeSpace

## Continuous MFSK Waveform: Estimate range and speed simultaneously for multiple targets

This release introduces a Multiple Frequency Shift Keying (MFSK) waveform, `phased.MFSKWaveform` System object and the corresponding Simulink block, `MFSK Waveform`. The continuous MFSK waveform is often used in automotive collision avoidance radar systems where simultaneous range and velocity determination is required. The waveform is constructed by interleaving two stepped sequences of increasing frequency CW waves.

## Pattern methods for antennas, microphones, and arrays

For antenna, microphone, and array System objects, a new `pattern` method replaces the existing `plotResponse` method. In addition, this release introduces two simplified methods for drawing 2-D azimuth and elevation pattern plots: `azimuthPattern` and `elevationPattern`. See, for example, `phased.ULA.pattern`, `phased.ULA.patternAzimuth`, and `phased.ULA.patternElevation`.

This table is a guide for converting your code from using `plotResponse` to using `pattern`. Some of the inputs have changed from input arguments to name-value pair arguments and the converse. The general `pattern` method syntax is

```
pattern(H,FREQ,AZ,EL,'Name1','Value1',...,'NameN','ValueN')
```

plotResponse Inputs	plotResponse Description	pattern Inputs												
H argument	Antenna, microphone, or array System object.	H argument (no change)												
FREQ argument	Operating frequency.	FREQ argument (no change)												
V argument	Propagation speed. This argument is used only for arrays.	'PropagationSpeed' name-value pair. This parameter is only used for arrays.												
'Format' and 'RespCut' name-value pairs	<p>These options work together to let you create a plot in angle space (line or polar style) or <i>UV</i> space. They also determine whether the plot is 2-D or 3-D. This table shows you how to create different types of plots using <code>plotResponse</code>.</p> <table border="1"> <thead> <tr> <th colspan="2">Display space</th> </tr> </thead> <tbody> <tr> <td>Angle space (2D)</td> <td>           Set 'RespCut' to 'Az' or 'El'. Set 'Format' to 'line' or 'polar'.             Set the display axis using either the the 'AzimuthAngle' or 'ElevationAngle' name-value pairs.         </td> </tr> <tr> <td>Angle space (3D)</td> <td>Set 'RespCut'</td> </tr> </tbody> </table>	Display space		Angle space (2D)	Set 'RespCut' to 'Az' or 'El'. Set 'Format' to 'line' or 'polar'.  Set the display axis using either the the 'AzimuthAngle' or 'ElevationAngle' name-value pairs.	Angle space (3D)	Set 'RespCut'	<p>'CoordinateSystem' name-value pair used together with the AZ and EL input arguments.</p> <p>'CoordinateSystem' has the same options as the <code>plotResponse</code> method 'Format' name-value pair, except that 'line' is now named 'rectangular'. The table shows how to create different types of plots using <code>pattern</code>.</p> <table border="1"> <thead> <tr> <th colspan="2">Display space</th> </tr> </thead> <tbody> <tr> <td>Angle space (2D)</td> <td>Set 'CoordinateSystem' to 'rectangular' or 'polar'. Specify either AZ or EL as a scalar.</td> </tr> <tr> <td>Angle space (3D)</td> <td>Set 'CoordinateSystem' to 'rectangular' or 'polar'. Specify both</td> </tr> </tbody> </table>	Display space		Angle space (2D)	Set 'CoordinateSystem' to 'rectangular' or 'polar'. Specify either AZ or EL as a scalar.	Angle space (3D)	Set 'CoordinateSystem' to 'rectangular' or 'polar'. Specify both
Display space														
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Angle space (3D)	Set 'CoordinateSystem' to 'rectangular' or 'polar'. Specify both													

plotResponse Inputs	plotResponse Description		pattern Inputs	
	<b>Display space</b>	<p>to '3D'. Set 'Format' to 'line' or 'polar'.</p> <p>Set the display axis using both the 'AzimuthAngle' and 'Elevation' name-value pairs.</p>	<b>Display space</b>	<p>AZ and EL as vectors.</p> <p><i>UV</i> space (2D) Set 'Coordinate System' to 'uv'. Use AZ to specify a <i>U</i>-space vector. Use EL to specify a <i>V</i>-space scalar.</p>
	<i>UV</i> space (2D)	<p>Set 'RespCut' to 'U'. Set 'Format' to 'UV'. Set the display range using the 'UGrid' name-value pair.</p>	<i>UV</i> space (3D)	<p>Set 'Coordinate System' to 'uv'. Use AZ to specify a <i>U</i>-space vector. Use EL to specify a <i>V</i>-space vector.</p>
	<i>UV</i> space (3D)	<p>Set 'RespCut' to '3D'. Set 'Format' to 'UV'. Set the display range using both the 'UGrid' and 'VGrid' name-value pairs.</p>	<p>If you set <b>CoordinateSystem</b> to 'uv', enter the <i>UV</i> grid values using AZ and EL.</p>	

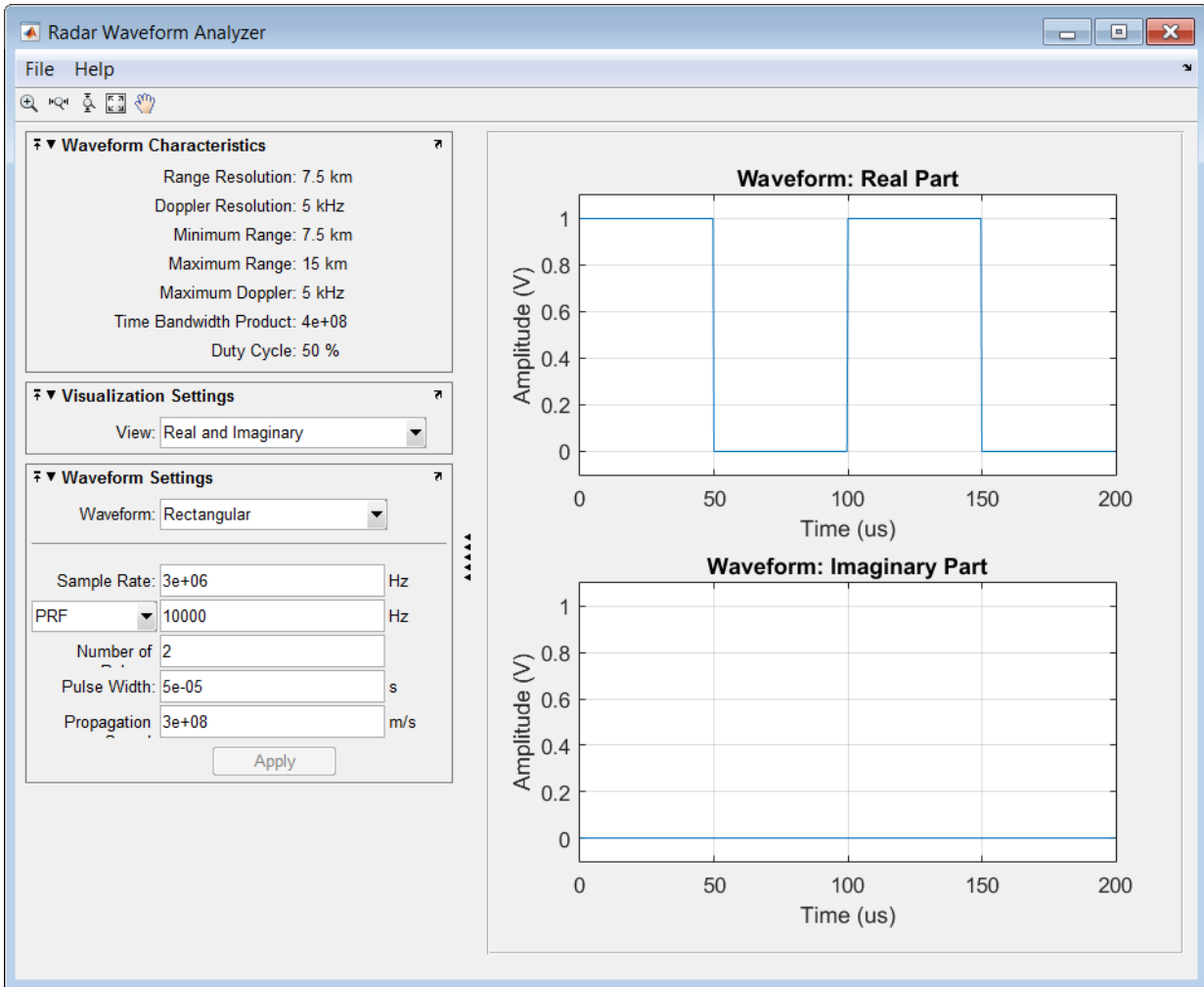
<b>plotResponse Inputs</b>	<b>plotResponse Description</b>	<b>pattern Inputs</b>
'CutAngle' name-value pair	Constant angle at to take an azimuth or elevation cut. When producing a 2-D plot and when 'RespCut' is set to 'AZ' or 'El', use 'CutAngle' to set the slice across which to view the plot.	No equivalent name-value pair. To create a cut, specify either AZ or EL as a scalar, not a vector.
'NormalizeResponse' name-value pair	Normalizes the plot. When 'Unit' is set to 'dbi', you cannot specify 'NormalizeResponse'.	'Normalize' name-value pair. When 'Type' is set to 'directivity', you cannot specify 'Normalize'.
'OverlayFreq' name-value pair	Plot multiple frequencies on the same 2-D plot. Available only when 'Format' is set to 'line' or 'uv' and 'RespCut' is not set to '3D'. The value <code>true</code> produces an overlay plot and the value <code>false</code> produces a waterfall plot.	'PlotStyle' name-value pair plots multiple frequencies on the same 2-D plot.  The values 'overlay' and 'waterfall' correspond to 'OverlayFreq' values of <code>true</code> and <code>false</code> . The option 'waterfall' is allowed only when 'CoordinateSystem' is set to 'rectangular' or 'uv'.
'Polarization' name-value pair	Determines how to plot polarized fields. Options are 'None', 'Combined', 'H', or 'V'.	'Polarization' name-value pair determines how to plot polarized fields. The 'None' option is removed. The options 'Combined', 'H', or 'V' are unchanged.

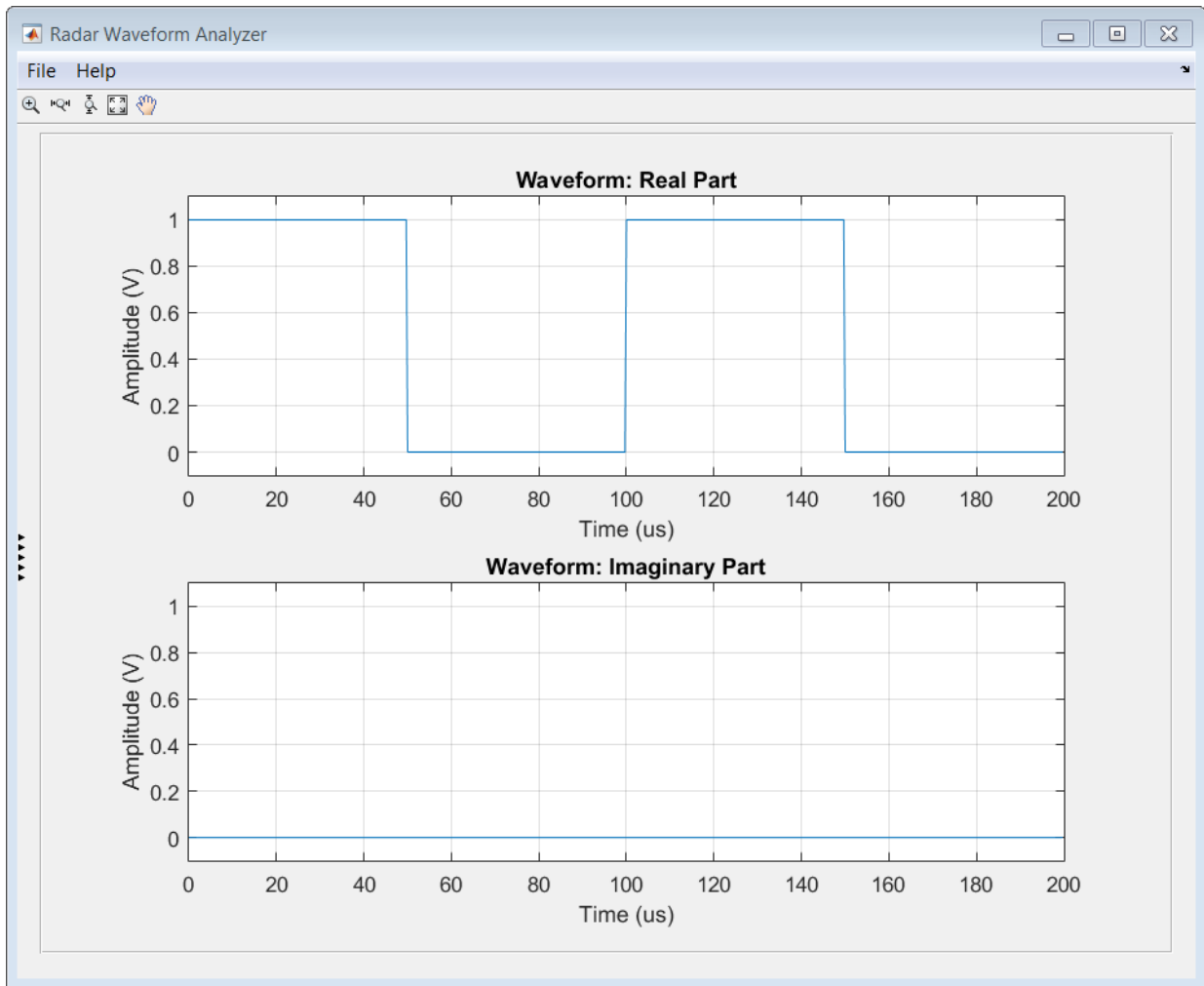


plotResponse Inputs	plotResponse Description	pattern Inputs										
'Unit' name-value pair	Determines the plot units. Choose 'db', 'mag', 'pow', or 'dbi', where the default is 'db'.	'Type' name-value pair, uses equivalent options with different names  <table border="1"> <thead> <tr> <th colspan="2">plotResponse pattern</th> </tr> </thead> <tbody> <tr> <td>'db'</td> <td>'powerdb'</td> </tr> <tr> <td>'mag'</td> <td>'efield'</td> </tr> <tr> <td>'pow'</td> <td>'power'</td> </tr> <tr> <td>'dbi'</td> <td>'directivity'</td> </tr> </tbody> </table>	plotResponse pattern		'db'	'powerdb'	'mag'	'efield'	'pow'	'power'	'dbi'	'directivity'
plotResponse pattern												
'db'	'powerdb'											
'mag'	'efield'											
'pow'	'power'											
'dbi'	'directivity'											
'Weights' name-value pair	Array element tapers (or weights).	'Weights' name-value pair (no change).										
'AzimuthAngles' name-value pair	Azimuth angles used to display the antenna or array response.	AZ argument										
'ElevationAngles' name-value pair	Elevation angles used to display the antenna or array response.	EL argument										
'UGrid' name-value pair	Contains $U$ coordinates in $UV$ -space.	AZ argument when 'CoordinateSystem' name-value pair is set to 'uv'										
'VGrid' name-value pair	Contains $V$ -coordinates in $UV$ -space.	EL argument when 'CoordinateSystem' name-value pair is set to 'uv'										

## Sensor Array Analyzer and Radar Waveform Analyzer configurable layout

You can now hide, rearrange, and undock the configuration panels in the Sensor Array Analyzer and Radar Waveform Analyzer apps. The content and functionality have not changed. These figures show how you can hide the **Waveform Characteristics**, **Visualization Settings** and **Waveform Settings** panes so that you can focus on the waveform shape.

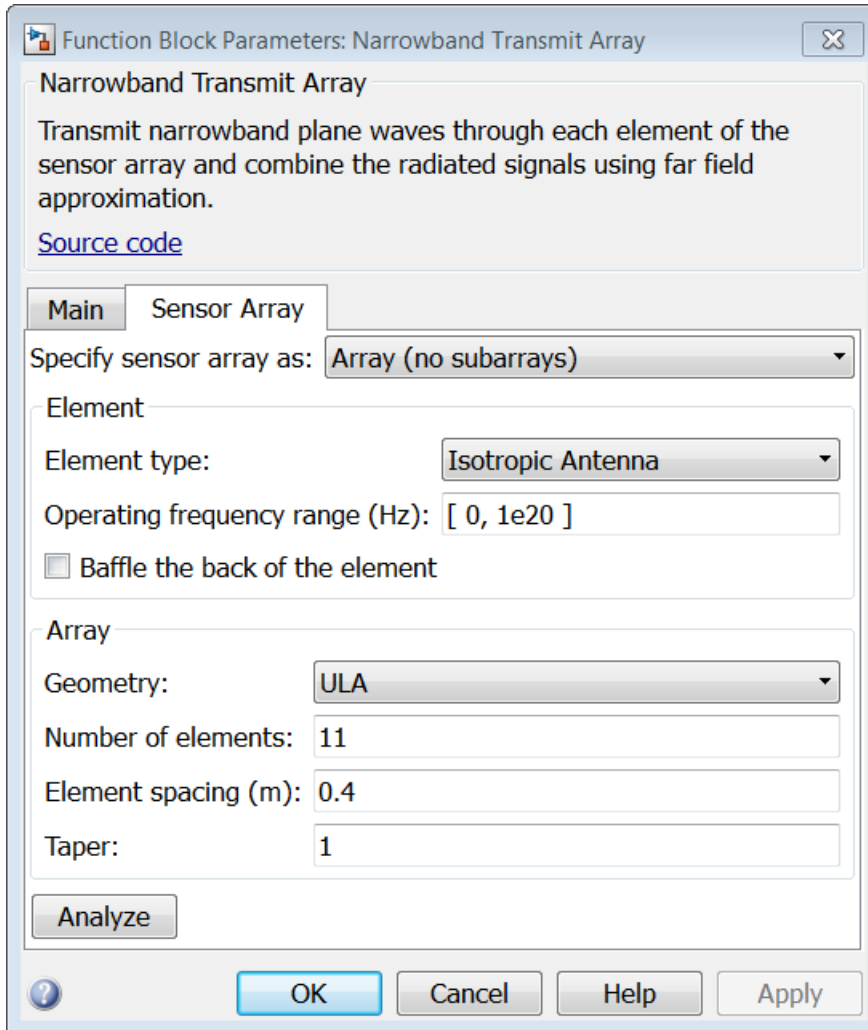




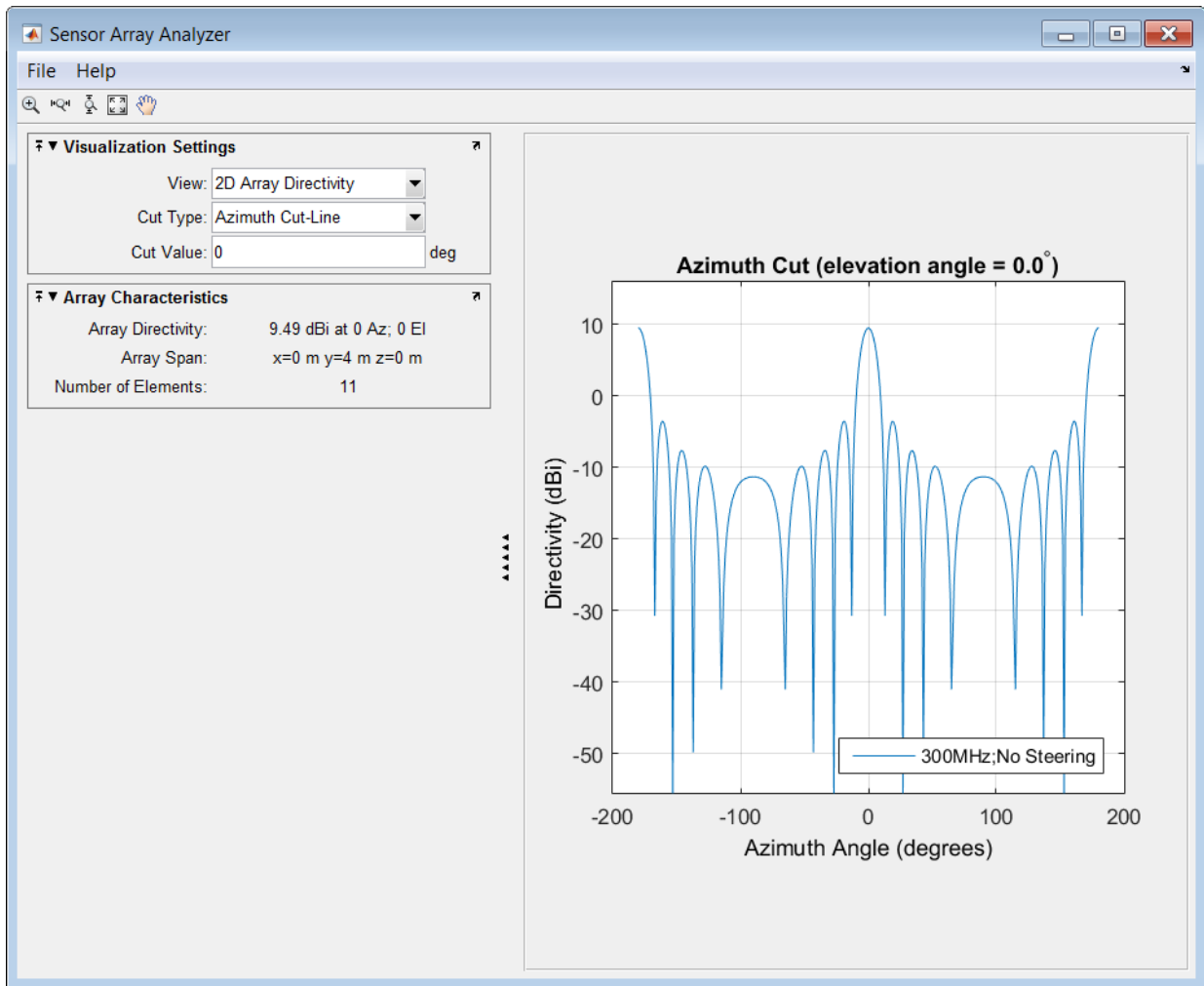
## Launch Sensor Array Analyzer from Tx and Rx blocks

The Narrowband Transmit Array and Narrowband Receive Array blocks let you display and analyze properties of the arrays that you use in your model. You can display an array's shape, its 2-D and 3-D directivities, and its grating lobe structure. To use this feature, on the **Sensor Array** panel of either block, click **Analyze**. As an example, this

Narrowband Transmit Array block dialog models an 11-element ULA with elements spaced 0.4 meters apart with an operating frequency of 300 MHz.



Click **Analyze** to open the Sensor Array Analyzer app and show the array directivity.



## Improvements for creating System objects

- Number of allowable code generation inputs increased to 32
- `isInputSizeLockedImpl` method for specifying whether the input port dimensions are locked

- `matlab.system.display.Action` class, used in the `getPropertyGroupsImpl` method, to define a MATLAB System block button that can call a System object method
- `getSimulateUsingImpl` and `showSimulateUsingImpl` methods to set the value of the `SimulateUsing` parameter and specify whether to show the `SimulateUsing` parameter in the MATLAB System block

## Changed default direction of UCA array normal in Sensor Array Analyzer App

In the Sensor Array Analyzer app, the default direction of the array normal vector for the uniform circular array has changed. The array normal is now along the  $z$ -axis of the local coordinate system. Previously, the array normal was along the  $x$ -axis.

## Compatibility Considerations

If you set the **Array Type** parameter to **Uniform Circular**, the app displays a different array geometry and different array patterns.

## Functionality being removed or changed

Functionality	What Happens When You Use This Functionality?	Use This Instead	Compatibility Considerations
<code>plotResponse</code> methods for all antenna, microphone, and array System objects	Still runs	<code>pattern</code>	Replace all instances of <code>plotResponse</code> with <code>pattern</code> or consider using the new simplified methods <code>patternAzimuth</code> and <code>patternElevation</code> . See “Pattern methods for antennas, microphones, and arrays” on page 4-3 for conversion information.

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<b>Functionality</b>	<b>What Happens When You Use This Functionality?</b>	<b>Use This Instead</b>	<b>Compatibility Considerations</b>
Sensor Array Analyzer app	Still runs		Users will see different a array geometry and different array patterns for uniform circular arrays.





# R2014b

**Version: 2.3**

**New Features**

**Bug Fixes**

**Compatibility Considerations**

## Simulink blocks for phased array system design

This release adds phased array processing to Simulink. You can use Simulink to model from end-to-end the transmission, propagation, reception, and detection of signals from antenna and microphone arrays. Over forty blocks are available in 7 libraries with these capabilities.

Phased Array Library	Purpose
Beamforming	Conventional and adaptive beamformers, such as LCMV and MVDR
Detection	Detection algorithms, including matched filtering and CFAR
Direction of Arrival	DOA algorithms, including beamscan, MUSIC, and ESPRIT
Environment	Clutter models, jammers, and target models
STAP	Space-time adaptive processing
Transmitters and Receivers	Arrays for transmitting and receiving
Waveforms	Signal waveforms, such as Linear FM, FMCW, and rectangular

## Directivity of antennas, microphones, and phased arrays

This release adds directivity methods to each antenna and microphone System object and each array, replicated subarray, and partitioned array System object. Directivity is a useful measure of performance for antenna and microphone elements and arrays of elements. Using these methods, you can calculate the directivity values for different directions and frequencies. For examples using the new methods for several System objects, see these pages.

Phased Array System object	Directivity Method
Cosine Antenna Element	phased.CosineAntennaElement.directivity
Uniform Linear Array	phased.ULA.directivity
Partitioned Array	phased.PartitionedArray.directivity

---

## **Remove NoiseBandwidth property from phased.ReceiverPreamp System object**

The NoiseBandwidth property of the phased.ReceiverPreamp System object is obsolete and may be removed in a future release. This property is not used in any computation. As of this release, a warning message will be displayed when phased.ReceiverPreamp is invoked with the NoiseBandwidth property specified. To suppress this message, type `warning off phased:system:System:NoiseBandwidthWarning` at the command line at any time. Alternatively, you can include this command in your `startup.m` script or other scripts that use phased.ReceiverPreamp.

### **Compatibility Considerations**

To avoid future incompatibility, remove all occurrences of the NoiseBandwidth property.

## **Property value name change for phased.RangeDopplerResponse System object**

In the RangeMethod property of the phased.RangeDopplerResponse System object, the 'Dechirp' value has been renamed to 'FFT' value. This change is a name change only. The 'Dechirp' value name will be removed in a future release.

### **Compatibility Considerations**

When using the RangeMethod property in your code, change all occurrences of 'Dechirp' to 'FFT'.



# R2014a

**Version: 2.2**

**New Features**

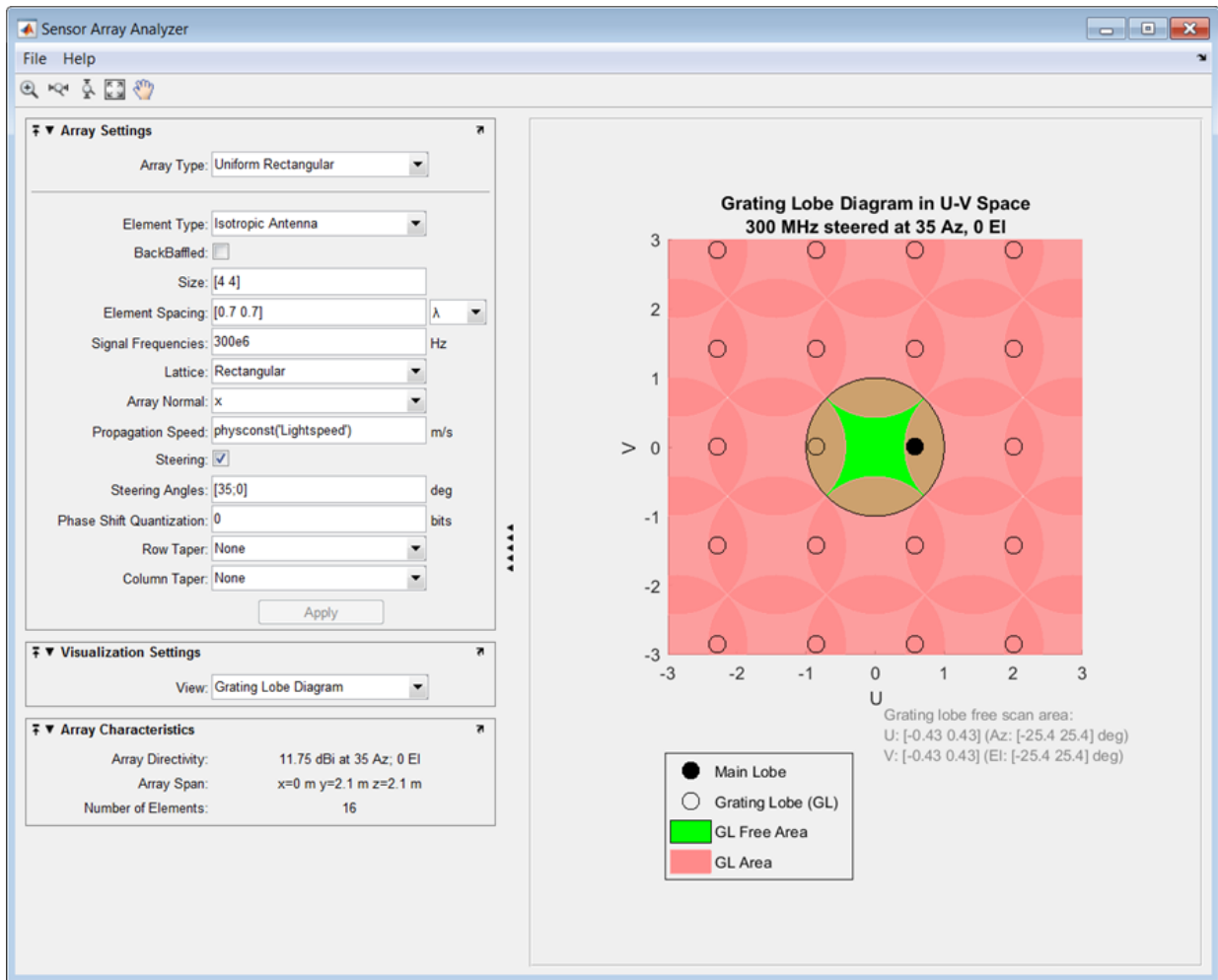
**Bug Fixes**

**Compatibility Considerations**

## Grating lobe diagrams

You can plot the locations of the grating lobes of uniform linear arrays using the new ULA System object method `plotGratingLobeDiagram`. For uniform rectangular arrays, you use the URA System object method `plotGratingLobeDiagram`. Using grating lobe diagrams, you can visualize the grating-lobe-free scan region of the array.

The `sensorArrayAnalyzer` app also provides an option for plotting grating lobe diagrams for uniform linear arrays, uniform rectangular arrays, uniform hexagonal arrays, and circular planar arrays. For example, here is the grating lobe diagram of a spatially undersampled 4-by-4 URA steered towards  $35^\circ$  azimuth.



## Visualization of element and array directivity

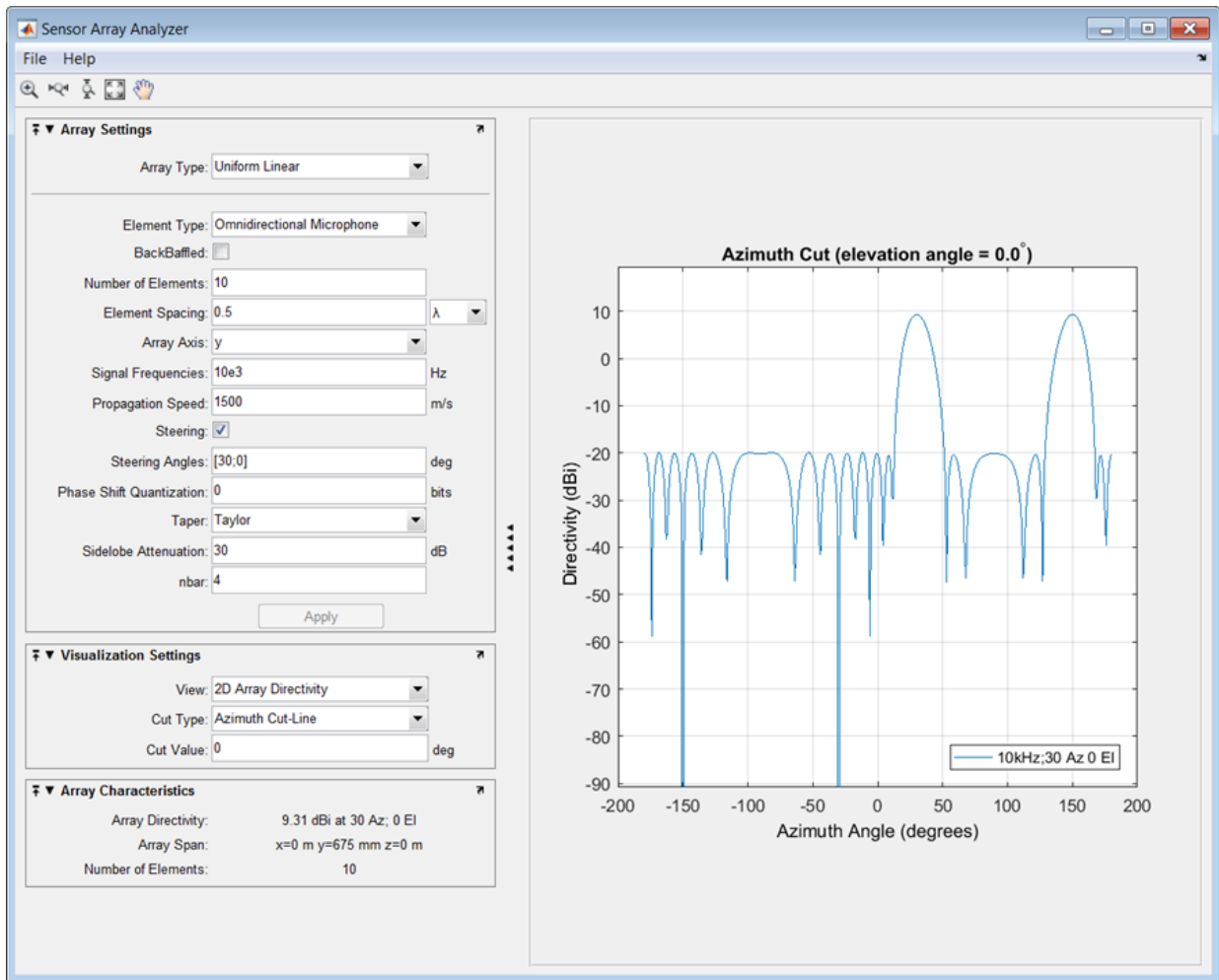
In R2014a, you have a directivity plotting option for all sensor elements, arrays, and subarrays. Directivity patterns help you analyze sensor element and array performance. To plot the directivity, choose 'dbi' for the Unit parameter value of the plotResponse method.

The directivity pattern of an array takes into account the directivity pattern of its constituent sensors. Examples of how to create directivity pattern plots for selected sensor elements, arrays and subarrays can be found here.

Cosine antenna element
Uniform line array
Partitioned uniform rectangular array

The `sensorArrayAnalyzer` app also plots 2D and 3D array directivity patterns. You can plot array directivity patterns for all supported array types by choosing **2D Array Directivity** or **3D Array Directivity** from the **Visualization** drop-down list. When you plot 2D directivities, you can choose the azimuth and elevation angles at which the cuts are taken. These plots replace the 2D and 3D array response plots. Here is an example of a directivity pattern plot of a 10-element uniform linear array.





## Arbitrary geometry and custom element support in the Sensor Array Analyzer app

In R2014a, there are significant modifications and additions to the sensorArrayAnalyzer app.

- You can specify any array geometry by choosing **Arbitrary Geometry** from the **Array Type** drop-down list. Then, you specify the element positions in the **Element Position** field and the element normal angles in the **Element Normal** field. You can enter the element positions and normal angles directly or use MATLAB variables and arrays defined at the command prompt.
- You can define your own antenna type by choosing **Custom Antennas** from the **Element Type** drop-down list. You must supply a radiation pattern in the **Radiation Pattern** field. You must also supply values to the **Frequency Vector**, **Frequency Response**, **Azimuth Angles**, and **Elevation Angles** fields. The azimuth angle dimensions must match the column dimensions of the radiation pattern. The elevation angle dimensions must match the row dimensions of the radiation pattern. You can enter antenna values directly into the app fields or use a MATLAB variable or array defined at the command prompt.
- You can plot array directivity patterns for all supported arrays, as described in “Visualization of element and array directivity” on page 6-3.
- You can plot grating lobe diagrams for several types of arrays, as described in “Grating lobe diagrams” on page 6-2.
- You can apply custom taper weights (also known as shading weights) to the array elements for all array geometries. Specify the weights in the **Taper** field directly or use a MATLAB array defined at the command prompt.
- For convenience, you can use MATLAB variables and arrays as entries into some of the app data fields. Instead of typing numerical values into the fields, you can define the values as variables or arrays at the MATLAB command prompt and use the name of the variable or array in the field.

## Pulse repetition interval parameter for the Radar Waveform Analyzer app

In R2014a, with the `radarWaveformAnalyzer` app, you can specify the temporal spacing between pulses as either the *pulse repetition frequency*, PRF, in hertz, or as the *pulse repetition interval*, PRI, in seconds, where  $PRI = 1/PRF$ .

## Property name change in `phased.PhaseCodedWaveform`

The `Type` property of the `phased.PhaseCodedWaveform` System object has been renamed to `Code` property. This System object creates a phase-coded pulse waveform. The `Code` property specifies the code that you use in phase modulation. This change is a name change only. The `Type` property name will be removed in a future release.

---

## Compatibility Considerations

To avoid future incompatibility, change all instances of this property name to the new name.

## System object templates

The MATLAB® **New > System object** menu now has three new class-definition file templates. The **Basic** template sets up a simple System object. The **Advanced** template includes additional features of System objects. The **Simulink Extension** template provides additional customization of the System object for use in the MATLAB System block.

## System objects infer number of inputs and outputs from `stepImpl` method

When you create a new kind of System object that has a fixed number of inputs or outputs specified in the `stepImpl` method, you no longer need to include `getNumInputsImpl` or `getNumOutputsImpl` in your class definition file. The correct number of inputs and outputs are inferred from the `stepImpl` inputs and outputs, respectively.

## System objects `infoImpl` method allows variable inputs

When you create a new kind of System object, you can use the `info` method to provide information specific to that object. The `infoImpl` method, which you include in your class-definition file, now allows `varargin` as an input argument.

## System objects base class renamed to `matlab.System`

The System object base class, `matlab.system.System` has been renamed to `matlab.System`. If you use `matlab.system.System` when defining a new System object, an error message results.

## Compatibility Considerations

Change all instances of `matlab.system.System` in your System objects code to `matlab.System`.

## **System objects Propagates mixin methods**

Four new methods have been added to the Propagates mixin class. You use this mixin when creating a new kind of System object for use in the MATLAB System block in Simulink. You use these methods to query the input and specify the output of a System object.

- `propagatedInputComplexity`
- `propagatedInputDataType`
- `propagatedInputFixedSize`
- `propagatedInputSize`

# R2013b

**Version: 2.1**

**New Features**

**Compatibility Considerations**

## Code generation for functions and objects

The Phased Array System Toolbox lets you generate C/C++ code from your phased-array MATLAB application code using the MATLAB Coder™. You can create your own standalone C/C++ executables, libraries, and MEX functions directly and automatically from code that you have written that uses phased-array System objects and functions. MATLAB Coder supports basic MATLAB language features such as program control, functions, and matrix operations. See About Code Generation for more information on the use of MATLAB Coder with the Phased Array System Toolbox.

## Visualization of element and array radiation patterns with arbitrary resolution

In this release, the `plotResponse` method now lets you plot the radiation pattern with different display ranges and resolutions. Previously, for example, you could only plot the pattern in one degree increments in azimuth and elevation. New display options, `AzimuthAngles`, `ElevationAngles`, `UGrid`, and `VGrid`, give you freedom to change the display range and resolution of the output in azimuth and elevation or in  $U/V$  space. These new options apply to all antenna and microphone elements, arrays and subarrays. For documentation and usage examples, see `phased.CosineAntennaElement/plotResponse`, `phased.URA/plotResponse`, and `phased.ReplicatedSubarray/plotResponse`.

## Plot response of multiple sets of weights for a single frequency

The `Weights` display option of the `plotResponse` method has a new feature. This applies to all array, replicated subarray and partitioned array System objects. Previously, you could only specify one weight set for multiple frequencies or a different weight set for each frequency. You can now display the response due to multiple sets of weights for a single frequency. For documentation and examples of how to use this properties, see `phased.URA/plotResponse`, and `phased.ReplicatedSubarray/plotResponse`.

## New default frequency limits for antenna and microphone elements

The restriction on the range of valid frequencies for all antenna and microphone elements is effectively eliminated by increasing the maximum frequency value to  $10^{20}$  and setting the minimum value to zero.

---

## Function `delayseq` implements FFT length of power of two

The function `delayseq` now use an internal *FFT* length equal to a power of two.

### Compatibility Considerations

This change in internal logic produces some insignificant numerical differences. No action is required.

### System objects `matlab.system.System` warnings

The `System` object base class, `matlab.system.System` has been replaced by `matlab.System`. If you use `matlab.system.System` when defining a new `System` object, a warning message results.

### Compatibility Considerations

Change all instances of `matlab.system.System` in your `System` objects code to `matlab.System`.

### Restrictions on modifying properties in `System` object Impl methods

When defining a new `System` object, certain restrictions affect your ability to modify a property.

You cannot use any of the following methods to modify the properties of an object:

- `cloneImpl`
- `getDiscreteStateImpl`
- `getNumInputsImpl`
- `getNumOutputsImpl`
- `validateInputsImpl`
- `validatePropertiesImpl`

This restriction is required by code generation, which assumes that these methods do not change any property values. These methods are validation and querying methods that are expected to be constant and should not impact the algorithm behavior.

## Compatibility Considerations

If any of your class definition files contain code that changes a property in one of the above `Impl` methods, move that property code into an allowable `Impl` method. Refer to the System object `Impl` method reference pages for more information.

### **plotResponse method handle graphics property change**

When you use the `plotResponse` method to return a 3-D display of the element or array response in *UV* coordinates, the sample coordinates of the displayed data have changed. The data contained in the handle graphics properties, `'XData'`, `'YData'`, and `'ZData'`, are now sampled uniformly in Cartesian *UV* grid coordinates instead of uniformly in polar grid coordinates. This change applies to the `plotResponse` method for all antenna and microphone element System objects and array System objects.

## Compatibility Considerations

The data is now in uniformly-sampled Cartesian *UV* coordinates. The `plotResponse` display appearance remains unchanged.

### **Single normal vector for conformal arrays**

When you use a conformal array System object, you can specify a single normal direction vector for the case when all the element normal vectors point in the same direction. Previously, the `ElementNormal` property required you to specify a separate normal direction vector for each element. This syntax applies to the `phased.ConformalArray` and `phased.HeterogeneousConformalArray` System objects.



# R2013a

**Version: 2.0**

**New Features**

**Bug Fixes**

**Compatibility Considerations**

## Polarization support for antennas, arrays, and targets that includes transmission, propagation, and reception of polarized signals

A major enhancement to the Phased Array System Toolbox product for R2013a lets you simulate the transmission, propagation and reception of polarized electromagnetic waves. Polarization simulation is turned on by setting a new property `EnablePolarization` in `phased.Radiator`, `phased.Collector`, `phased.WidebandCollector`, `phased.RadarTarget`, `phased.SteeringVector` and `phased.ArrayResponse` System objects. Two new types of antennas specifically for polarized waves are introduced:

- `phased.ShortDipoleAntennaElement` models a short dipole antenna element.
- `phased.CrossedDipoleAntennaElement` models a crossed-dipole antenna element.

You can test whether an antenna or array of antennas can be used to simulate polarization by invoking the `isPolarizationCapable` method. Only `phased.ShortDipoleAntennaElement`, `phased.CrossedDipoleAntennaElement`, and `phased.CustomAntennaElement` support polarization. Polarization properties of arrays depend upon the properties of their constituent antenna elements.

The `phased.CustomAntennaElement` System object has several new properties for polarization. You can use the `SpecifyPolarizationPattern` property to specify whether to use a horizontal or vertical radiation pattern or a combined pattern and then specify `HorizontalMagnitudePattern`, `HorizontalPhasePattern`, `VerticalMagnitudePattern`, and/or `VerticalPhasePattern` to create the pattern itself.

Changes have been made to the `step` and `plotResponse` methods for antenna elements and arrays. With polarization enabled, the `step` method returns a `struct` instead of a data array. The `plotResponse` method plots the horizontal polarization response, the vertical polarization response or a combined polarization response when you set the name-value property `Polarization` to `H`, `V` or `Combined`. This applies to only arrays and antennas that are capable of polarization. When an antenna or array is not capable of polarization, a fourth option, `None`, is required.

The `phased.RadarTarget` System object lets you model the response of a target to a polarized field by invoking the `EnablePolarization` property. The new `Mode` property allows for `monostatic` or `bistatic` antenna-target configurations. You can set the target's complex 2-by-2 radar cross-section matrix using the new `ScatteringMatrix` property. The scattering matrix contains the  $HH$ ,  $HV$ ,  $VH$ , and  $VV$  responses of the target.

## Summary of Phased Array Polarization Capabilities

Category	System Objects	New and Modified Properties	New and Modified Methods
Antennas and Microphone Elements	phased.CosineAntennaEl phased.CustomMicrophor phased.IsotropicAntenna phased.OmnidirectionalM phased.CrossedDipoleAnt (new) phased.ShortDipoleAnten (new)		isPolarizationCapable plotResponse step
	phased.CustomAntennaE	SpecifyPolarizationI HorizontalMagnitud HorizontalPhasePat VerticalMagnitudeP VerticalPhasePatter	
Array Geometries and Analysis	phased.ConformalArray phased.ULA phased.URA phased.PartitionedArray phased.ReplicatedSubarr		isPolarizationCapable plotResponse step
	phased.SteeringVector phased.ArrayResponse	EnablePolarization	
Signal Radiation and Collection	phased.Collector phased.WidebandCollecto phased.Radiator	EnablePolarization	step
Environment and Target Models	phased.RadarTarget	EnablePolarization Mode MeanRCSMatrix	step

To support polarization simulation analysis, this release includes new utility functions:

### Utility Functions

Name	Description
polellip	Parameters of ellipse traced out by tip of a polarized field vector

Name	Description
polratio	Ratio of vertical to horizontal linear polarization components of a field
stokes	Stokes parameters of polarized field
circpol2pol	Convert circular component representation of field to linear component representation
pol2circpol	Convert linear component representation of field to circular component representation
polloss	Polarization loss
polsignature	Radar cross section polarization signature
rotx	Rotation matrix for rotations around $x$ -axis
roty	Rotation matrix for rotations around $y$ -axis
rotz	Rotation matrix for rotations around $z$ -axis
sph2cartvec	Convert vector from spherical basis components to Cartesian components
cart2sphvec	Convert vector from Cartesian components to spherical representation
azelaxes	Spherical basis vectors in 3-by-3 matrix form

## Array tapers for the modeling of magnitude and phase perturbations

This release adds element taper (array weighting) support to `phased.ULA`, `phased.URA`, and `phased.ConformalArray` System objects using the new `Taper` property. Tapers can be complex-valued coefficients. Real-valued tapers are usually used, for example, to reduce sidelobe levels; complex tapers are useful for modeling phase perturbations. A new method, `getTaper`, lets you retrieve the taper values. The method, `viewArray`, has been modified to display the array with taper values shown.

## Arrays with multiple element patterns, enabling the modeling of edge effects and pattern perturbations

Sensor arrays can now be created to have different antenna patterns assigned to different sensors. These are called *heterogeneous arrays*. To enable this capability, three new system objects are being introduced, `phased.HeterogeneousULA`,

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phased.HeterogeneousURA, and phased.HeterogeneousConformalArray. Heterogeneous arrays let you model, for example, cross-element coupling effects or pattern perturbations. You can specify the types of elements you want in the array using the ElementSet property and then assign a type to each sensor location using the ElementIndices property.

## **Radar Equation Calculator, Radar Waveform Analyzer, and Sensor Array Analyzer apps**

R2013a introduces the first three Phased Array System Toolbox apps:

- radarEquationCalculator starts the Radar Equation Calculator which lets you solve for any one of *Target Range*, *Peak Transmit Power*, or *SNR* from the well-known radar equation. Alternatively, you can start Radar Equation Calculator by selecting it from the SIGNAL PROCESSING AND COMMUNICATIONS section of the Apps tab in the MATLAB toolstrip.
- radarWaveformAnalyzer invokes the Radar Waveform Analyzer which can plot the shape of five common waveforms as well as their spectra and ambiguity functions. Alternatively, you can start the Radar Waveform Analyzer app by selecting it from the SIGNAL PROCESSING AND COMMUNICATIONS section of the Apps tab in the MATLAB toolstrip.
- sensorArrayAnalyzer starts Sensor Array Analyzer to display the geometry of eight different common array configurations. It can also plot the 2-D and 3-D array responses. The user can set the number of array elements, element types, and element spacings and other parameters. Alternatively, you can start the Sensor Array Analyzer app by selecting it from the SIGNAL PROCESSING AND COMMUNICATIONS section of the Apps tab in the MATLAB toolstrip.

## **Visualization of radar vertical coverage on Blake charts**

New radar analysis tools, blakechart and radarvcd, plot radar range-height-angle (Blake) charts and vertical coverage diagrams. You can use these radar design tools to predict the maximum radar range. This function employs the CRPL Exponential Reference Atmosphere model of the refractive index of the atmosphere.

## Custom antenna element patterns specified at different frequencies

This new feature of `phased.CustomAntennaElement` lets you specify frequency-dependent antenna patterns. You do so by creating a 3D array containing pattern values for azimuth, elevation and frequency.

## Full GPU support for clutter model, including nonisotropic antennas and subarrays (using Parallel Computing Toolbox)

You can now use the `phased.gpu.ConstantGammaClutter` System object to accelerate clutter simulations with all antenna types not just isotropic. This System object typically runs faster than `phased.ConstantGammaClutter`. However, there is no GPU support for clutter modeling of polarized waves. `phased.gpu.ConstantGammaClutter` requires a license for the Parallel Computing Toolbox™ and a GPU-enabled computer.

## Ordinary functions for narrowband beamformers

These new functions give you tools to compute narrowband beamformer weights without requiring the system object framework:

- `steervec` computes the steering vector for a narrowband conventional 1D, 2D, or 3D beamformer of arbitrary shape. The antenna elements are assumed to be isotropic. Inputs to this function are the element positions in units of wavelength and the directions-of-arrival of the incoming signals.
- `cbfweights` computes the weights for a narrowband conventional 1D, 2D, or 3D beamformer of arbitrary shape. The antenna elements are assumed to be isotropic. Inputs to this function are the element positions in units of wavelength and the directions-of-arrival of the incoming signals. The weights produced by `cbfweights` equal those produced by `steervec` divided by the number of elements in the array.
- `mvdweights` returns the weights for a narrowband minimum variance distortionless response (MVDR) beamformer. Inputs to this function are the element positions in units of wavelength, the directions-of-arrival of the incoming signals, and the sensor covariance matrix.
- `lcmweights` returns the weights for a narrowband linear constraint minimum variance (LCMV) beamformer. Inputs are the signal covariance matrix, the desired responses, and the constraint matrix.
- `sensorcov` returns the received spatial covariance matrix for narrowband plane wave signals arriving at a sensor array. Inputs are the sensor element positions in units of

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wavelength and the directions-of-arrival of the incoming signals. Optional inputs are the sensor noise and signal covariance matrices.

## **Ordinary functions for narrowband signal directions-of-arrival at a uniform line array**

These new functions allow you to compute directions-of-arrival (DOA) of narrowband signals for uniform line arrays without requiring the use of the system object framework.

- `rootmusicdoa` computes, using the Root MUSIC algorithm, a vector of estimated arrival directions of multiple signals. This estimator uses the sensor covariance matrix and requires that the number of signals be a known value.
- `espritdoa` computes, using the TLS ESPRIT algorithm, a vector of estimated arrival directions of multiple signals. This estimator uses the sensor covariance matrix and requires that the number of signals be a known value.
- `aictest` estimates the number of signals arriving at an array using the Akaike Information Criterion test. This estimator uses a set of snapshots taken at each sensor.
- `mdltest` estimates the number of signals arriving at an array using the Minimum Description Length test. This estimator uses a set of snapshots taken at each sensor.
- `spsmooth` performs spatial smoothing (averaging) of a covariance matrix using maximum overlapped subarrays.

## **Deprecated `VisibleRegion` in `phased.ESPRITEstimator`**

The `VisibleRegion` property of the `phased.ESPRITEstimator` System object will be removed in a future release.

## **Compatibility Considerations**

In the future, users will have to remove the use of this property from their code.

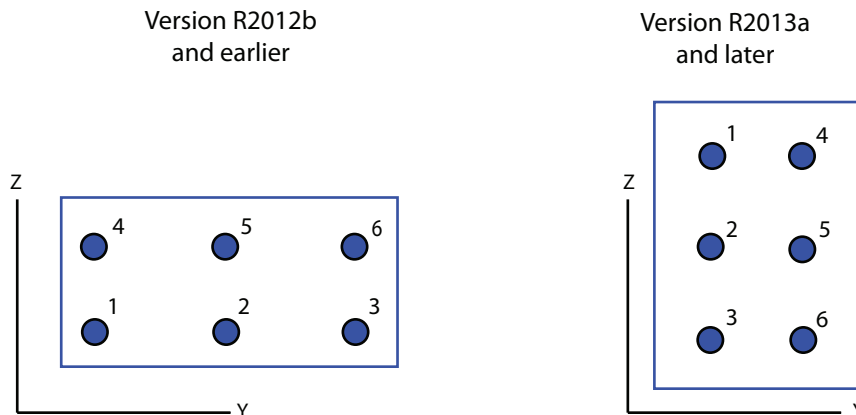
## **Element indexing pattern change for `phased.URA` and `phased.ReplicatedSubarray`**

The index order of the elements of a uniform rectangular array as constructed in `phased.URA` has changed with this release. Instead of row-major order, elements

are stored in column-major order. This has implications for the size and shape of an array. The size of the array is still specified by the `Size` property which is a 1-by-2 integer vector (or a single integer for square arrays). This vector is now interpreted as `[NumberOfRows, NumberOfColumns]`. The corresponding `ElementSpacing` property is a 1-by-2 vector containing the distance between elements (in meters) as `[SpacingBetweenRows, SpacingBetweenColumns]`. If `ElementSpacing` is a scalar, the distance along the columns and rows is the same. The following figure shows how the indexing and shape of an array are changed with this release by using a 6-element rectangular array as an example. Previously, a `[3,2]` array would have three columns and two rows; now it has two columns and three rows.

### New Size and Element Indexing Order for Uniform Rectangular Arrays

Example: `Size = [3,2]`

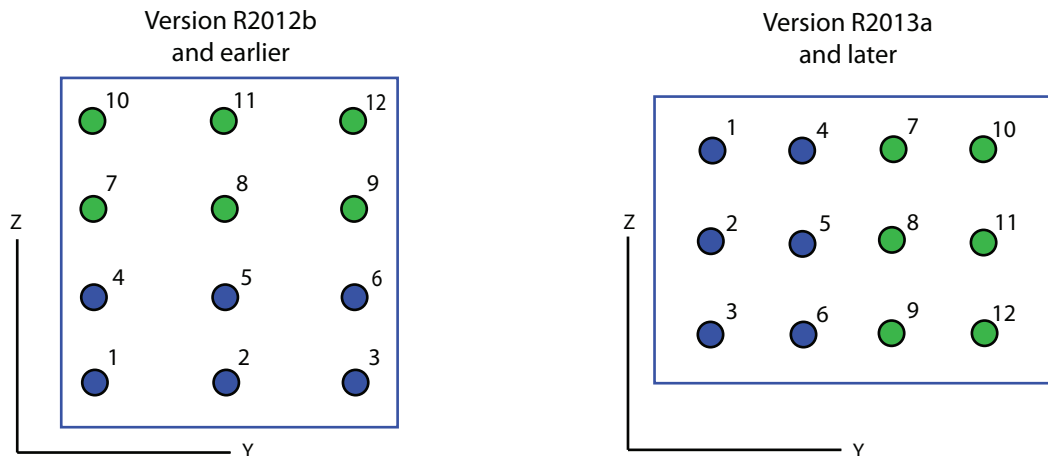


When constructing replicated subarrays using `phased.ReplicatedSubarray`, the `GridSize` and `GridSpacing` properties are used to position the subarrays on a rectangular grid. You specify the dimensions of the grid using the `GridSize` property and the distance between grid points with `GridSpacing` property. As with `phased.URA`, the interpretation of these properties has changed with this release. In this release, `GridSize` is a 1-by-2 vector in the form of `[NumberOfRows NumberOfColumns]` gives



the number of elements along each column (z-axis) and the number of elements along each row (y-axis). If `GridSize` is a scalar, the replicated array has the same number of grid points in each row and column. The `GridSpacing` property can either be 1-by-2 vector in the form of `[SpacingBetweenRows SpacingBetweenColumns]` or a scalar (units are meters). If `GridSpacing` is a scalar, the distance along the rows and columns is the same. The following figure shows how the indexing and shape of a replicated subarray are changed with this release using a `GridSize` of `[1,2]`. This creates a 1-by-2 grid of subarrays as shown on the right-hand side of the figure.

### New Size and Element Indexing Order for Replicated URA [3,2] Subarrays Example: `GridSize = [1,2]`



These changes make antenna array indexing consistent with the MATLAB convention. To insure that the user is aware of this important change, a warning message will be displayed when `phased.URA` are invoked. This message may be suppressed by typing `warning off phased:system:array:SizeConventionWarning` at the command line at any time or by including it in your `startup.m` script and other scripts. A similar warning appears when `phased.ReplicatedSubarray` is invoked. Type `warning off phased:system:array:GridConventionWarning` to suppress this message.

## Compatibility Considerations

Since data is now stored differently, results will generally differ from that of previous releases for the same input. In most cases however, interchanging the order of entries in the `Size` and `ElementSpacing` vectors for `phased.URA` and the `GridSize` and `GridSpacing` vectors for `phased.ReplicatedSubarray` will give the same results. If you need to look at the output of individual array elements, then there will be some differences.

## MATLAB Compiler Support

Phased Array System Toolbox supports the MATLAB Compiler™ for all functions and System objects. Compiler support does not extend to any of the toolbox apps.

## New method for action when System object input size changes

The `processInputSizeChangeImpl` method allows you to specify actions to take when an input to a System object you have defined changes size. If an input changes size after the first call to `step`, the actions defined in `processInputSizeChangeImpl` occur when `step` is next called on that object

# R2012b

**Version: 1.3**

**New Features**

**Compatibility Considerations**

## Acceleration of clutter model simulation with `parfor` or GPUs

A change in the `phased.ConstantGammaClutter` System object facilitates performing Monte Carlo simulations with Parallel Computing Toolbox constructs, such as `parfor`. For details about this change, see the description of random number stream usage that follows.

The new `phased.gpu.ConstantGammaClutter` System object simulates clutter on a GPU. This System object typically runs faster than `phased.ConstantGammaClutter`. Using `phased.gpu.ConstantGammaClutter` requires a license for Parallel Computing Toolbox software.

## FMCW waveforms

The `phased.FMCWWaveform` System object models a frequency modulated continuous wave (FMCW) waveform.

These functions help you determine appropriate property values for `phased.FMCWWaveform`:

- `time2range`
- `range2time`
- `range2bw`

These functions help you simulate and analyze systems that process FMCW waveforms:

- `dechirp`
- `beat2range`
- `range2beat`
- `rdcoupling`

## CFAR detector, supporting SOCA, GOCA, and order statistic thresholds

The `phased.CFARDetector` System object provides a new property named `Method`. Using this property, you can choose among four CFAR detection algorithms: cell averaging (default), smallest-of cell averaging (SOCA), greatest-of cell averaging (GOCA), and order statistic.

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## Compatibility Considerations

In R2012b, if you save a CFAR detector variable in a MAT-file, you cannot load that variable from the MAT-file in an earlier version. Instead, re-create the variable in the earlier version.

## Function to simulate signals received by an array

The new `sensorsig` function simulates plane wave signals received at a phased array. This function facilitates statistical analysis and testing of direction-of-arrival algorithms. The function does not require you to simulate an entire phased array system.

## Range-Doppler estimation

The new `phased.RangeDopplerResponse` System object generates and plots range-Doppler maps.

## Propagation model that now supports intrapulse Doppler modeling

The `phased.FreeSpace` System object models the Doppler shift both within a pulse (fast time) and between successive pulses (slow time). In previous releases, the object modeled only the slow-time Doppler shift.

This enhanced Doppler shift modeling is especially useful for observing range-Doppler coupling in a radar system that uses a linear FM waveform.

## Compatibility Considerations

The `step` method of the `phased.FreeSpace` System object has two additional input parameters:

- `origin_vel`, the velocity of the signal origin
- `dest_vel`, the velocity of the signal destination

To update legacy code that uses this `step` method, use one of these approaches:

- In some cases, the signal origin or signal destination is stationary. If so, set the corresponding velocity input argument to `[0; 0; 0]`.

- In other cases, the signal origin or signal destination is moving, and you are using `phased.Platform` to model the moving platform. In this situation, obtain the velocity vector as an additional output argument from the `step` method of `phased.Platform`. Then, specify this velocity vector as an input argument in the `step` method of `phased.FreeSpace`. For example, compare the R2012a and R2012b versions of an example, and notice the introduction of the `txvel` variable in the R2012b version.

## Visualization of array geometries

You can call `viewArray` on a phased array to plot the positions, normal directions, and element indices of the elements in the array. For arrays containing subarrays, `viewArray` can also graphically highlight one or more of the subarrays.

The System objects affected are:

- `phased.ULA`
- `phased.URA`
- `phased.ConformalArray`
- `phased.ReplicatedSubarray`
- `phased.PartitionedArray`

For more information, see the reference pages for:

- `viewArray` for arrays without subarrays, such as `phased.ULA`
- `viewArray` for arrays containing subarrays, such as `phased.PartitionedArray`

## Random number stream usage for parallel computing

System objects in Phased Array System Toolbox software that rely on a random number generator now behave differently when you set the `SeedSource` property to `'Auto'`:

- The object uses the global stream of random numbers instead of a private stream. This change is useful if you are performing the computations in a set of Monte Carlo trials involving Parallel Computing Toolbox software. In that situation, the global stream is more suitable than a stream that the System object manages internally.
- The `reset` method does not reset the random number generator.

The System objects affected by this change are:

- 
- `phased.BarrageJammer`
  - `phased.ConstantGammaClutter`
  - `phased.ReceiverPreamp`
  - `phased.ReceiverPreamp`
  - `phased.Transmitter`

## Compatibility Considerations

The following compatibility considerations apply to System objects that existed in earlier releases, if your legacy code configures the objects with the `SeedSource` property set to `'Auto'`.

- In operations involving the System objects, the specific random numbers in R2012b differ from the random numbers in earlier releases.
- If your code later performs an arbitrary operation that uses the global random number stream, this operation also uses different random numbers compared to earlier releases.
- In some cases, your code may rely on operations in earlier releases that reset or restore the random number generator while loading, cloning, or resetting objects. If so, you should update your code to reset or restore the global stream yourself.

## save and load for System objects

You can create your own `save` and `load` methods for a System object you create. To do so, use the `saveObjectImpl` and `loadObjectImpl`, respectively, in your class definition file.





# R2012a

**Version: 1.2**

**New Features**

**Compatibility Considerations**

## Replicated Subarrays and Partitioned Array Apertures

A *subarray* is an accessible subset of array elements. The following new System objects enable you to create arrays that contain subarrays:

- `phased.ReplicatedSubarray`
- `phased.PartitionedArray`

The following table lists existing System objects that now support operations on arrays that contain subarrays. Each of the objects in the table has a property called `SensorArray` or `Sensor`. You can set that property to an array object that contains subarrays. Also, some of the objects in the table support subarray steering through a new input argument, `STEERANGLE`, in the `step` method.

System Object	SensorArray or Sensor Can Contain Subarrays	step Syntax Can Include Subarray Steering
<code>phased.AngleDopplerResponse</code>	Yes	Not applicable
<code>phased.ArrayGain</code>	Yes	Yes
<code>phased.ArrayResponse</code>	Yes	Yes
<code>phased.Collector</code>	Yes	Yes
<code>phased.ConstantGammaClutter</code>	Yes	Yes
<code>phased.MVDRBeamformer</code>	Yes	Not applicable
<code>phased.PhaseShiftBeamformer</code>	Yes	Not applicable
<code>phased.Radiator</code>	Yes	Yes
<code>phased.STAPSMIBeamformer</code>	Yes	Not applicable
<code>phased.SteeringVector</code>	Yes	Yes
<code>phased.SubbandPhaseShiftBeamform</code>	Yes	Not applicable
<code>phased.WidebandCollector</code>	Yes	Yes

For more information about using subarrays, see [Subarrays Within Arrays](#).

## Compatibility Considerations

The `IncludeElementResponse` property of the `phased.SteeringVector` System object is no longer tunable in V1.2 (R2012a). This change facilitates support for arrays containing subarrays.

---

You may have code from an earlier version that tunes the value of the `IncludeElementResponse` property of a locked steering vector object. If so, the code will produce an error message in R2012a. You can avoid the error message by calling `release` to unlock the object, or by not changing the value of the `IncludeElementResponse` property.

## Stretch Processing

The following new features help you perform pulse compression on linear frequency modulation (FM) waveforms using stretch processing:

- `phased.StretchProcessor` System object
- `stretchfreq2rng` function
- `getStretchProcessor` method of `phased.LinearFMWaveform` System object

Stretch processing is sometimes called *deramping* or *dechirping*.

For more information about using stretch processing, see [Stretch Processing](#).

## U/V Space and Phi/Theta Angles

Several enhancements facilitate performing operations in the  $u/v$  coordinate system or in a spherical coordinate system that describes angles using  $\phi$  and  $\theta$  instead of azimuth and elevation:

- Visualize radiation patterns in  $u/v$  space using the `plotResponse` method for arrays, antenna elements, and microphone elements. To use this feature, include `'Format'`, `'UV'` in the `plotResponse` syntax.
- Convert coordinates from one coordinate system to another using these new functions:
  - `uv2azel`
  - `azel2uv`
  - `phitheta2azel`
  - `azel2phitheta`
  - `uv2phitheta`
  - `phitheta2uv`
- Convert antenna radiation patterns from one coordinate system to another using these new functions:

- `uv2azelpat`
- `azel2uvpat`
- `phitheta2azelpat`
- `azel2phithetapat`
- `uv2phithetapat`
- `phitheta2uvpat`

For an example, look at *Antenna Radiation Pattern in U/V Coordinates*. For background information about the coordinate systems, see *Spherical Coordinates*.

## Multiple-Beam Beamformers

The following beamformers support multiple beamforming directions:

- `phased.PhaseShiftBeamformer`
- `phased.SubbandPhaseShiftBeamformer`
- `phased.MVDRBeamformer`

You can use this capability to model switched-beam systems.

To indicate multiple beamforming directions, use a matrix instead of a vector for the `Direction` property of the beamformer object or the `ANG` input argument of `step`. In earlier versions, the value required a vector. Now, when you specify multiple beamforming directions, the `Y` and `W` outputs of `step` have an extra matrix dimension.

## Compatibility Considerations

In V1.2 (R2012a), you can create a MAT-file that stores a beamformer variable specifying multiple directions in the `Direction` property. However, you cannot load that variable from the MAT-file in an earlier version. As an alternative, you can re-create the variable in the earlier version and specify only one beamforming direction.

## Support for Wideband Beam Pattern Analysis

The `plotResponse` method for arrays, antenna elements, and microphone elements has enhancements for use with wideband beamforming applications.

- 
- For arrays or elements, `plotResponse` can plot multiple frequency responses in a three-dimensional waterfall plot. To use this feature, include `'OverlayFreq'`, `false` in the `plotResponse` syntax. The `OverlayFreq` argument is new.
  - For arrays, `plotResponse` can apply weights independently to each frequency in the plot. For example, you can use beamformer weights as in Visualization of Wideband Beamformer Performance. To use this feature, include `'Weights'`, `Value` in the `plotResponse` syntax, where `Value` is a vector or matrix. R2011b required that the weights be the same for all frequencies in the plot and that `Value` be a vector.

In the `phased.ArrayResponse` and `phased.ArrayGain` System objects, the `step` method permits the `WEIGHTS` input argument to be a vector or a matrix. In earlier releases, `WEIGHTS` is a vector.

## Beamformer Option to Preserve Power

The phase shift beamformer offers options for normalizing the beamformer weights. To select an option, set the new `WeightsNormalization` property of the `phased.PhaseShiftBeamformer` object to one of these values:

- `'Distortionless'` — The gain toward the beamforming direction is 0 dB. This choice is the default and matches the behavior in earlier versions.
- `'Preserve power'` — The norm of the weights is 1.

## Compatibility Considerations

In V1.2 (R2012a), if you save a phase shift beamformer variable in a MAT-file, you cannot load that variable from the MAT-file in an earlier version. Instead, re-create the variable in the earlier version.

## Symmetric Sweeping of Linear FM Waveform

You can create a linear FM waveform to sweep in an interval that is symmetric about 0 or positive only. To choose the location of the FM sweep interval, set the new `SweepInterval` property of the `phased.LinearFMWaveform` object to one of these values:

- `'Positive'` — The waveform sweeps between 0 and  $B$ , where  $B$  is the sweep bandwidth. This choice is the default and matches the behavior in earlier versions.

- 'Symmetric' — The waveform sweeps between  $-B/2$  and  $B/2$ .

## Toolbox Location of dutycycle Function

The `dutycycle` function in the Signal Processing Toolbox™ product replaces the earlier `dutycycle` function in the Phased Array System Toolbox product. The new function includes both the capabilities of the earlier function and additional new capabilities.

## New System Object Option on File Menu

The File menu on the MATLAB desktop now includes a **New > System object** menu item. This option opens a System object class template, which you can use to define a System object class.

## Variable-Size Input Support for System Objects

System objects that you define now support inputs that change size at runtime.

## Data Type Support for System Objects

System objects that you define now support all MATLAB data types as inputs and outputs.

## New Property Attribute to Define States

R2012a adds the new `DiscreteState` attribute for properties in your System object class definition file. Discrete states are values calculated during one step of an object's algorithm that are needed during future steps.

## New Methods to Validate Properties and Get States from System Objects

The following methods have been added:

- `validateProperties` – Checks that the System object is in a valid configuration. This applies only to objects that have a defined `validatePropertiesImpl` method
- `getDiscreteState` – Returns a `struct` containing a System object's properties that have the `DiscreteState` attribute

---

## **matlab.system.System changed to matlab.System**

The base System object class name has changed from `matlab.system.System` to `matlab.System`.

### **Compatibility Considerations**

The previous `matlab.system.System` class will remain valid for existing System objects. When you define new System objects, your class file should inherit from the `matlab.System` class.





# R2011b

**Version: 1.1**

**New Features**

**Compatibility Considerations**

## Constant Gamma Clutter Modeling

The new `phased.ConstantGammaClutter` System object helps you model surface clutter using the constant gamma model. You can use this object when simulating a radar system or estimating its performance statistically.

For more information, see these resources:

- Clutter Modeling
- `phased.ConstantGammaClutter`

## Clutter Modeling Utilities

These new utility functions can help you implement custom clutter models:

- `billingsleyicm`
- `depressionang`
- `effearthradius`
- `grazingang`
- `horizonrange`
- `surfclutterrcs`
- `surfacegamma`

## Phase-Coded Waveforms

The new `phased.PhaseCodedWaveform` System object generates samples of a phase-coded pulse waveform. This object supports these code types:

- Barker
- Frank
- P1
- P2
- P3
- P4
- Px

- 
- Zadoff-Chu

For more information, see Phase-Coded Waveforms and `phased.PhaseCodedWaveform`.

## Spectrum Weighting Options in Matched Filter

The `phased.MatchedFilter` System object supports spectrum weighting using these window types:

- Hamming
- Chebyshev
- Hann
- Kaiser
- Taylor

You can also specify a custom window. To do so, write a function that takes the window length as an input argument and returns window coefficients in an output argument.

For more information, see Matched Filtering or `phased.MatchedFilter`.

## Compatibility Considerations

If you save a `phased.MatchedFilter` object in a MAT-file in V1.1 (R2011b) and then load the MAT-file in V1.0 (R2011a), the object does not perform spectrum weighting. The Command Window shows this warning:

```
Warning: While loading an object of class 'phased.MatchedFilter':  
No public field SpectrumWindow exists for class phased.MatchedFilter.
```

If you write code in V1.1 (R2011b) that sets or reads any of the following properties of `phased.MatchedFilter` object, the code produces an error message in V1.0 (R2011a).

- `SpectrumWindow`
- `CustomSpectrumWindow`
- `SpectrumRange`
- `SampleRate`
- `SidelobeAttenuation`
- `Beta`

- Nbar

## Expanded Lattice Options in Uniform Rectangular Array

The `phased.URA` System object supports both triangular lattices and rectangular lattices. You use the `Lattice` property to select the lattice type.

In V1.0 (R2011a), `phased.URA` supports only rectangular lattices and does not have a `Lattice` property.

## Compatibility Considerations

If you save a `phased.URA` object in a MAT-file in V1.1 (R2011b) and then load the MAT-file in V1.0 (R2011a), the object uses a rectangular lattice. The Command Window shows this warning:

```
Warning: While loading an object of class 'phased.URA':  
No public field Lattice exists for class phased.URA.
```

If you write code in V1.1 (R2011b) that sets or reads the `Lattice` property of a `phased.URA` object, the code produces an error message in V1.0 (R2011a).

## Enhanced Plots Show Multiple Frequency Responses

The `plotResponse` method can plot multiple frequency responses along an azimuth cut or elevation cut. This method is available for the System objects for array design, antenna elements, and microphone elements. To create a plot of multiple frequency responses, use a `plotResponse` syntax in which:

- `FREQ` is a row vector.
- `RespCut` either does not appear explicitly, or has the value `'Az'` or `'E1'`.

The affected System objects are:

- `phased.ConformalArray`
- `phased.CosineAntennaElement`
- `phased.CustomAntennaElement`
- `phased.CustomMicrophoneElement`
- `phased.IsotropicAntennaElement`

- 
- `phased.OmnidirectionalMicrophoneElement`
  - `phased.ULA`
  - `phased.URA`

In V1.0 (R2011a), `FREQ` must be a scalar. The resulting plot shows one frequency response.

## Custom Antenna Removes Restriction on Radiation Pattern

The `phased.CustomAntennaElement System` object now permits more general radiation patterns. The main beam of the pattern is no longer required to point to 0 degrees azimuth and 0 degrees elevation.

## Storing States When Saving or Cloning Objects

The `save` and `clone` operations now store all states of the `System` objects in the `phased` package. As a result, calling the `step` method on a loaded or cloned object resumes processing from the state where the original object left off. In V1.0 (R2011a), the loaded or cloned object is unlocked and uninitialized.

## Compatibility Considerations

If your legacy code exploits the unlocked, uninitialized state of a loaded or cloned object, you should update the code in V1.1 (R2011b). You can use the `release` method to unlock objects.

## Custom System Objects

You can now create custom `System` objects in MATLAB. This capability allows you to define your own `System` objects for time-based and data-driven algorithms, I/O, and visualizations. The `System` object API provides a set of implementation and service methods that you incorporate into your code to implement your algorithm. See *Define New System Objects* in the *DSP System Toolbox™* documentation for more information.

## Conversion of Error and Warning Message Identifiers

For version 1.1 (R2011b), some error and warning message identifiers have changed in Phased Array System Toolbox software.

## Compatibility Considerations

If you have scripts or functions that use message identifiers that changed, you must update the code to use the new identifiers. Typically, message identifiers are used to turn off specific warning messages, or in code that uses a try/catch statement and performs an action based on a specific error identifier.

For example, the 'phased:phased:RootWSFEstimator:ZeroSourceNumber' identifier and the 'phased:phased:RootMUSICEstimator:ZeroSourceNumber' identifier have both changed to 'phased:phased:doa:ZeroSourceNumber'. If your code checks for one of the earlier values, you must update it to check for 'phased:phased:doa:ZeroSourceNumber' instead.

To determine the identifier for a warning, run the following command just after you see the warning:

```
[MSG,MSGID] = lastwarn;
```

This command saves the message identifier to the variable **MSGID**.

To determine the identifier for an error, run the following command just after you see the error:

```
exception = MException.last;  
MSGID = exception.identifier;
```

---

**Note:** Warning messages indicate a potential issue with your code. While you can turn off a warning, a suggested alternative is to change your code so it runs warning-free.

---

# R2011a

Version: 1.0

New Features

## Introducing the Phased Array System Toolbox

Phased Array System Toolbox provides algorithms and tools for the design, simulation, and analysis of phased array signal processing systems. These capabilities are provided as MATLAB functions and MATLAB System objects. The system toolbox includes algorithms for waveform generation, beamforming, direction of arrival estimation, target detection, and space-time adaptive processing. The system toolbox lets you build monostatic, bistatic, and multistatic architectures for a variety of array geometries. You can model these architectures on stationary or moving platforms. Array analysis and visualization tools help you evaluate spatial, spectral, and temporal performance. The system toolbox lets you model an end-to-end phased array system or use individual algorithms to process acquired data.

### Features

Key features of Phased Array System Toolbox Version 1.0 include:

- Algorithms available as MATLAB functions and MATLAB System objects
- Monostatic, bistatic, and multistatic phased array system modeling
- Array analysis and 3D visualization; physical array modeling for uniform linear arrays, uniform rectangular arrays, and arbitrary conformal arrays on platforms with motion
- Broadband and narrowband digital beamforming functions, including MVDR/Capon, LCMV, time delay, Frost, time delay LCMV, and subband phase shift
- Space-time adaptive processing algorithms, including displaced phase center array (DPCA), adaptive DPCA, sample matrix inversion (SMI) beamforming, and angle-Doppler response visualization
- Direction of arrival algorithms, including MVDR, ESPRIT, Beamscan, Root MUSIC, and monopulse tracking
- Waveform synthesis functions for pulsed CW, linear FM, stepped FM, and staggered PRF signals, and waveform visualization tools for ambiguity function and matched filter response
- Algorithms for TVG, pulse compression, coherent and non-coherent integration, CFAR processing, plotting ROC curves, and estimating range and Doppler