Electronically Scanned Array Antenna for Onboard Weather Radar

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Introduction to Weather Radar

- Airborne weather radar is a type of radar used to provide an indication to pilots of the intensity of convective weather. Modern weather radars are mostly Doppler radars, capable of detecting the motion of rain droplets in addition to intensity of the precipitation

- Typically, the radar antenna is located in the nose of the aircraft. Signals from the antenna are processed by a computer and presented on a screen which is viewed by the pilots. The weather phenomena is indicated on the screen by patterns, colour coded for intensity

- An airborne weather radar provides the pilot with a local (ahead only) weather picture in the cockpit and allows him to identify and avoid specific, undesirable weather formations such as thunderstorm, lightning, hail, turbulence, wind shear etc.

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Basics of Weather Radar Operations

- The radar transmitter sends out pulses of microwave frequency through the antenna, that get reflected from the rain drops within a cloud and are received by the Radar as echo

- The distance to the precipitation is calculated from the round trip time of the echo from the cell. The radar pulses and echoes travel at the speed of light

- The direction of the echo is determined by the direction the antenna is pointing from the nose of the aircraft

$$\text{Range to target(m)} = \frac{(\text{Speed of Light})*(\text{duration from transmit to echo})}{2}$$

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Problem Statement

- On board Weather Radar Antenna is mechanically steered to scan for weather phenomenon in the vicinity of the aircraft

- The limitation of this approach is that slow steering of the antenna limits the total number of targets that can be tracked

- Additionally the mechanical parts facilitating the physical rotation of the antenna add to weight of the aircraft

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Our Solution

- Our Aim is to design a antenna model, which can electronically steer the radiated energy into different directions

- An ESA(*Electronically Scanned Array)* is an antenna, which consists of multiple radiating elements

- Having an electronically steered antenna will also eradicate the mechanical parts that are used for rotating the antenna physically

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Key Highlights of the ESA

- Since the Antenna is electronically steered, the slow steering of the mechanical antenna is eliminated and more weather targets can be tracked simultaneously

- Active ESA comprises of multiple radiating elements each connected to a phase control T/R

- The phase control T/R enables each antenna element to radiate energy at different phase and amplitude which ultimately results in electronic steering of the beam

- Using active ESA allows radiation of pulses on multiple frequencies which will make it compatible with futuristic weather radars that may make use of more than one frequency

Active ESA (AESA)

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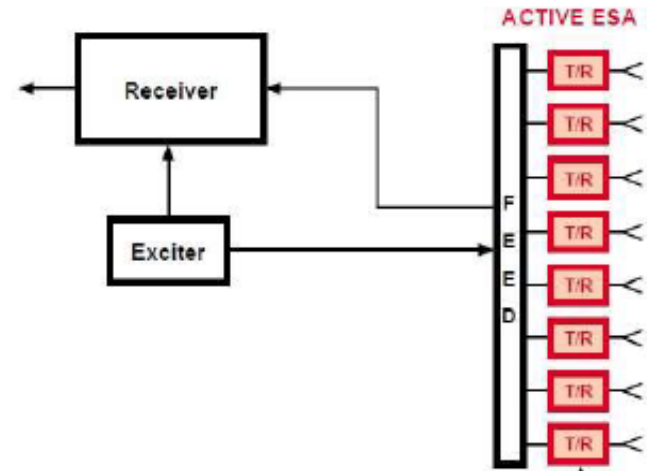
ESA Modelling with our proposed Solution

- Our modelling consists of simulation of monostatic radar antenna system where all the fundamental parts are included i.e. antenna aperture, receiver and combining network, with a model of a simple transmit receive module(T/R module) as a first step and then integrating piece by piece to simulate and develop into a larger and more complex planar array system.

- The first step in modelling the AESA is to model the T/R module where as all the modules of T/R element will be linear and ideal

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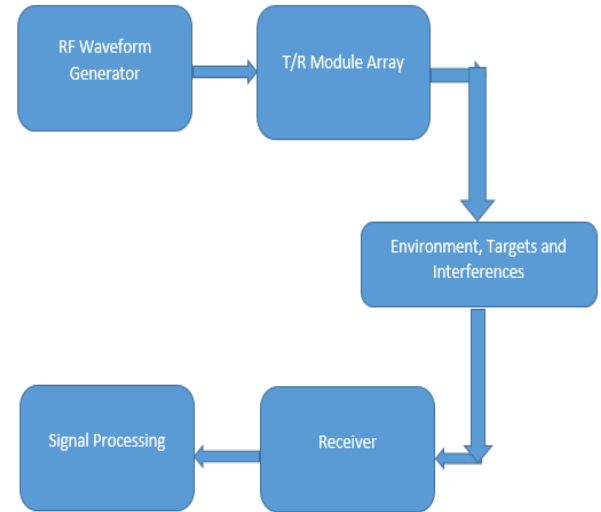
ESA Modelling with our proposed Solution

- The first component of the module will be LNA (low noise amplifier). The phase shifter, which follows after the LNA, is modelled as an exponential function where the phase is manually change by the user. The last component in the T/R module is an attenuator and like the LNA. The signals are transferred to the simulation model using the Waveform generator

- This is an example of one such T/R module, so with 10 or more such T/R modules will provide us the necessary pattern

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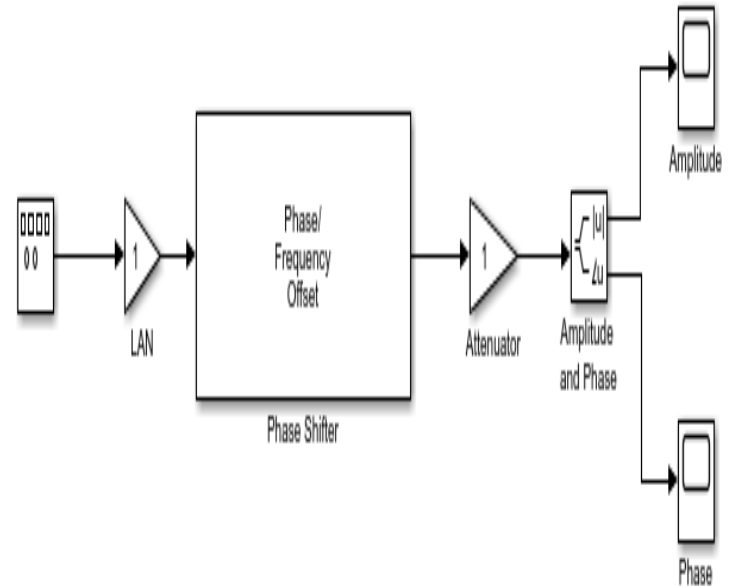
Tools Used

- Used the Simulink blocks from the Commonly used library block, Phase shifters, LNA(Low Noise Amplifier) and scopes to get the model of the T/R block

- Used existing math works example scripts i.e. WeatherRadarExample.m file to generate the Radar, Waveform pattern and Antenna modelling

- Will be using the models present in Phased Array System Toolbox, in Communications Toolbox Pulse Generators has been used to generate square Pulses.

- So combined scripts and Simulink models, design is still in progress

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Example of the required models for ESA

- R/F Waveform: Assuming that the Multi threat Weather Radar operates on X band and must detect targets with a radar cross section that are between 2 km and 100 km

```
fc    = 9.3e9            % Radar carrier frequency (Hz)
c     = 3e8;             % Propagation speed (m/s)
lambda = c/fc;           % Radar wavelength (m)

maxrng = 100e3;          % Maximum range (m)
minrng = 2e3;            % Minimum range (m)
```

Waveform

To satisfy the range requirement, a linear FM waveform with a 1 MHz bandwidth is used. The waveform can be defined as

```
bw     = 1e6;
fs     = 1.5*bw;
prf    = 1/range2time(maxrng,c);
dcycle = 0.1;

wav = phased.LinearFMWaveform('SampleRate', fs, ...
    'DurationSpecification', 'Duty cycle', 'DutyCycle', dcycle, ...
    'PRF', prf, 'SweepBandwidth', bw);
```

The range resolution achievable by the waveform is

```
rngres = bw2range(bw,c)
```

Example of the required models for ESA

- Radar Antenna: The multifunction radar is equipped with a phased array that can electronically scan the radar beams in space. Use a 50-by-50 rectangular array with elements separated by half wavelength

```
arraysz  = 50;
ant      = phased.URA('Size',arraysz,'ElementSpacing',lambda/2);
ant.Element.BackBaffled = true;


arraystv = phased.SteeringVector('SensorArray',ant,'PropagationSpeed',c);
radiator = phased.Radiator('OperatingFrequency',fc, ...
    'PropagationSpeed', c, 'Sensor',ant, 'WeightsInputPort', true);
collector = phased.Collector('OperatingFrequency',fc, ...
    'PropagationSpeed', c, 'Sensor',ant);


beamw = rad2deg(lambda/(arraysz*lambda/2))
```

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Example of the required models for ESA

- Signal Processing: The multifunction radar applies a sequence of operations to the received signal, including matched filtering, time varying gain, monopulse, and detection to generate range and angle measurements of the detected targets

- The simulation results for other Radar Antenna Elements are in progress

```
% matched filter
mfcoeff = getMatchedFilter(wav);
mf      = phased.MatchedFilter('Coefficients',mfcoeff,'GainOutputPort', true);

% time varying gain
tgrid   = unigrid(0,1/fs,1/prf,'[)');
rgates  = c*tgrid/2;
rngloss = 2*fspl(rgates,lambda);
refloss = 2*fspl(maxrng,lambda);
tvg     = phased.TimeVaryingGain('RangeLoss',rngloss,'ReferenceLoss',refloss);

% monopulse
monfeed = phased.MonopulseFeed('SensorArray',ant,'PropagationSpeed',c,...
    'OperatingFrequency',fc,'SquintAngle',1);
monest  = getMonopulseEstimator(monfeed);
```

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References

- Simulation and Evaluation of an Active ElectricallyScanned Array (AESA) in Simulink
  http://publications.lib.chalmers.se/records/fulltext/95362.pdf

- End-to-End Radar System
  https://in.mathworks.com/help/phased/gs/end-to-end-radar-system.html

- Electronic Scanned Array Design by John S. Williams
  https://intranet.birmingham.ac.uk/eps/documents/public/emuw2/SCF01.pdf