LOCALIZER HOLD AUTOPILOT

Prepared by

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- Localizer hold autopilot is one of the important navigational autopilot helps to align the heading of the aircraft with respect to the runway.

- It will be assume that the airplane already has a heading angle control system.

- Some of the aspect of figure must be explained
  - the airplane localizer antenna is assumed to be coincident with c.g
  - The cg is supposed to be driven along the center line of the localizer beam
  - The localizer error angle is sensed by the localizer receiver mounted on board the airplane.

- The airplane heading angle command system is used to keep the airplane on the centerline of the localizer beam. The localizer beam width is typically degree 2.5 degree on both side of center line.

- Any speed and lift changes due to banking is automatically compensated

➢ The localizer guidance and control as treated here is assumed to be independent of any longitudinal control action

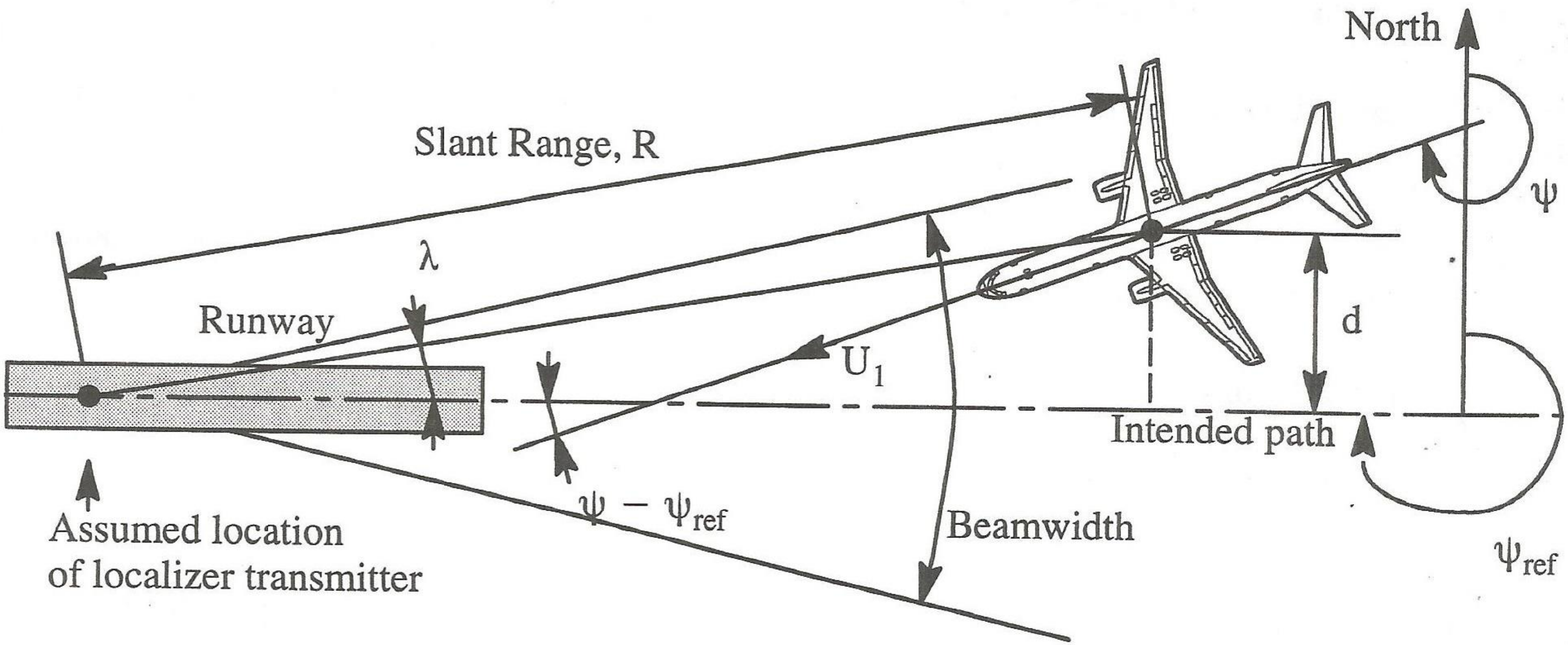


Figure .1 Shows the pertinent flight path geometry for localizer hold mode

From the figure the localizer error angle

$$\lambda \simeq 57.3\frac{d}{R} \qquad R - slant\ range$$

The distance from the centerline $d(s) = \frac{1}{s}\dot{d}(s)$

$$\dot{d} = U_1 \sin\left(\psi - \psi_{ref}\right) \approx U_1\left(\psi - \psi_{ref}\right) \qquad \psi\ in\ radians$$

Taking Laplase on both sides

$$\dot{d}(s) \approx U_1\left\{\psi(s) - \psi_{ref}(s)\right\}$$

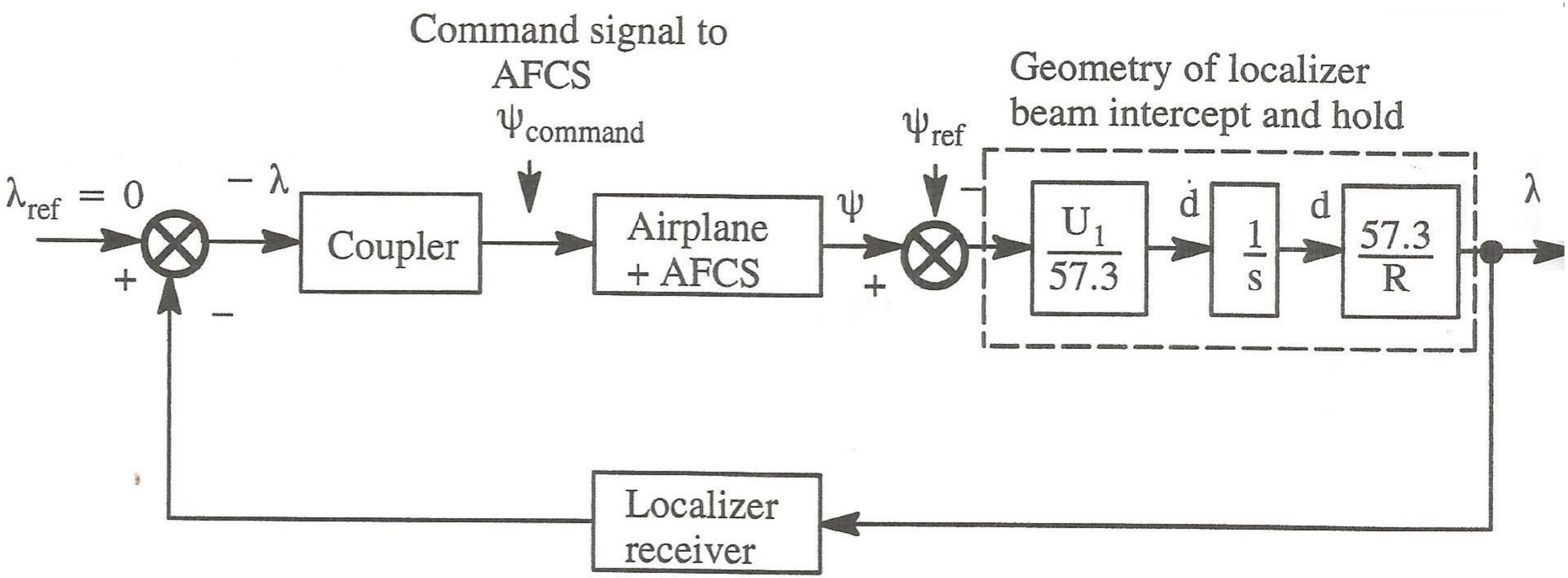
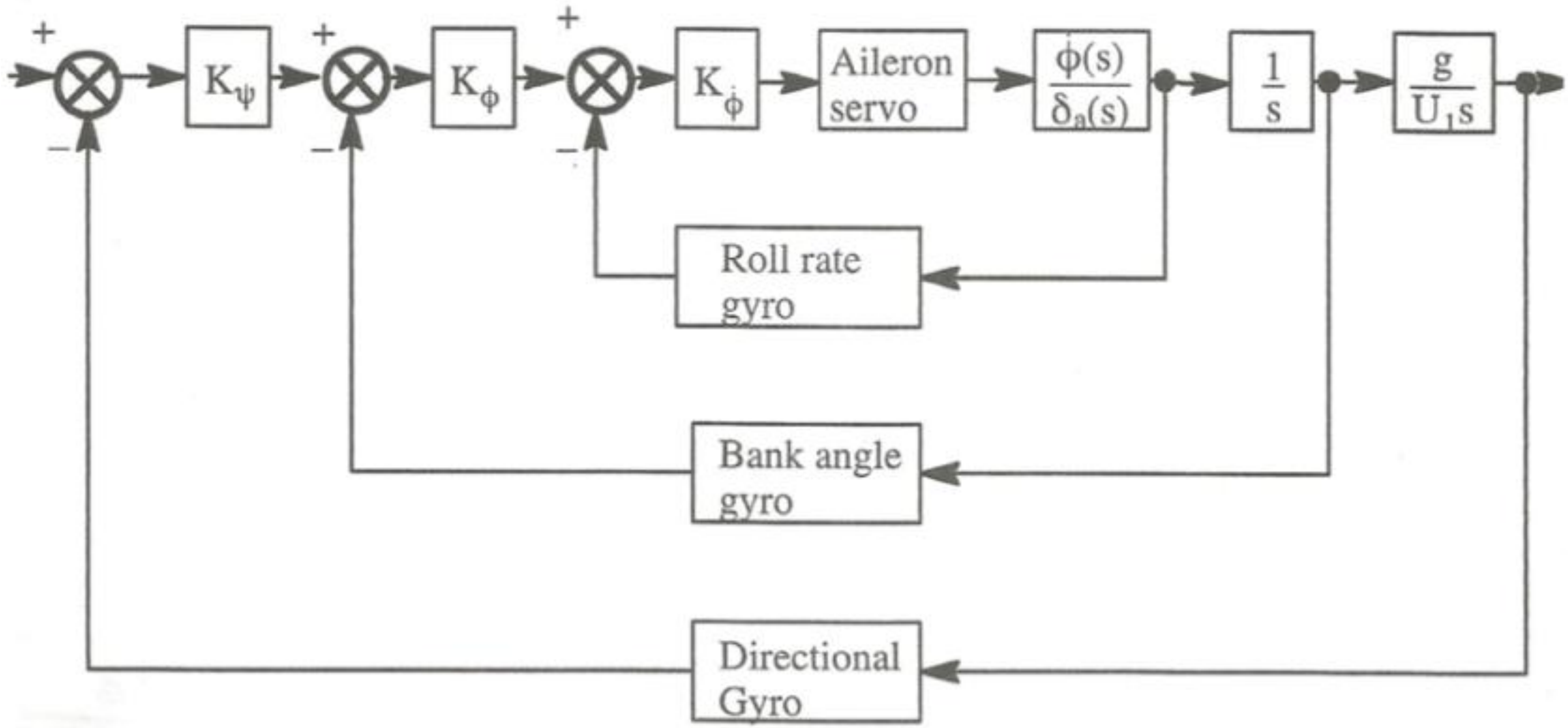
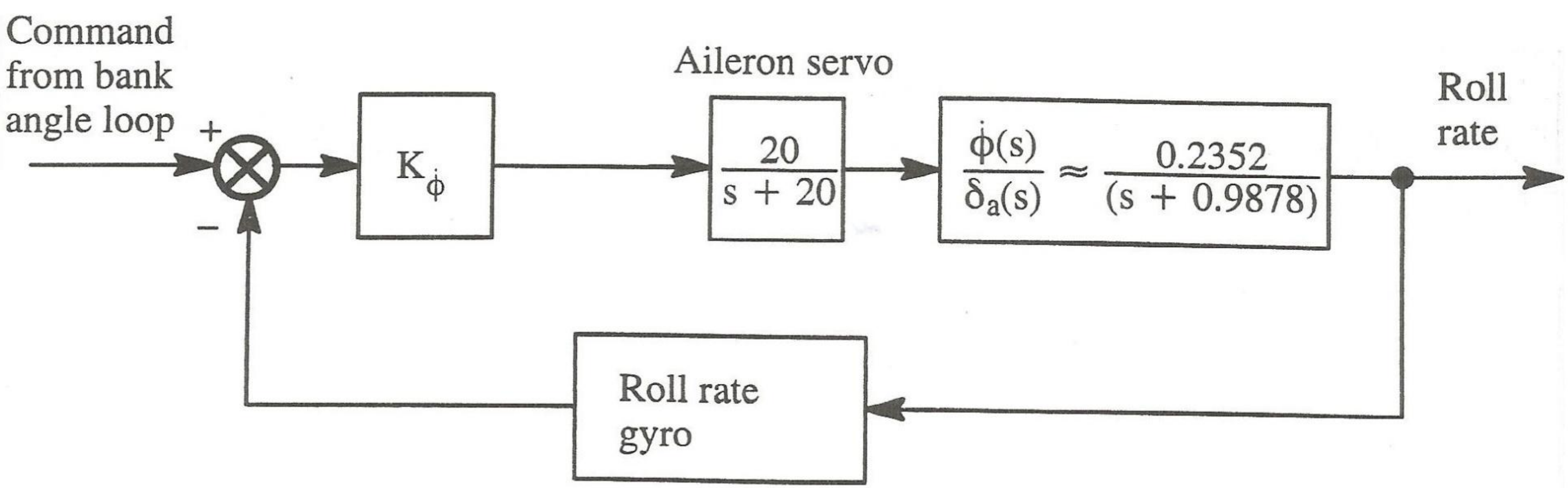
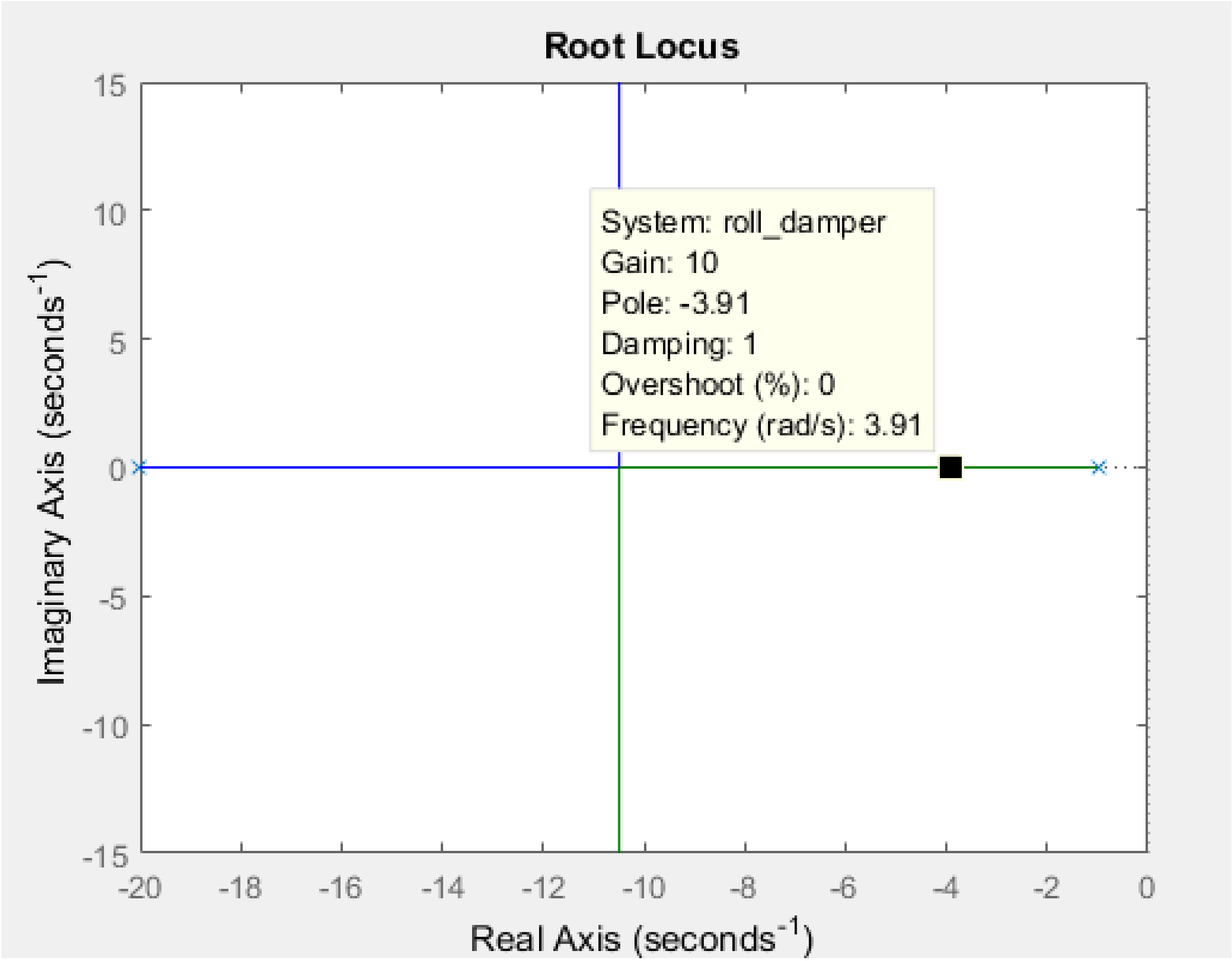


Figure .2 shows a block diagram corresponding to the localizer hold system


+
+
+
−
−
−
K_ψ
K_ϕ
$K_{\dot\phi}$
Aileron servo
$\frac{\dot\phi(s)}{\delta_a(s)}$
$\frac{1}{s}$
$\frac{g}{U_1 s}$
Roll rate gyro
Bank angle gyro
Directional Gyro

Roll rate autopilot




Root Locus
System: roll_damper
Gain: 10
Pole: -3.91
Damping: 1
Overshoot (%): 0
Frequency (rad/s): 3.91
Imaginary Axis (seconds^-1)
Real Axis (seconds^-1)
15
10
5
0
-5
-10
-15
-20
-18
-16
-14
-12
-10
-8
-6
-4
-2
0

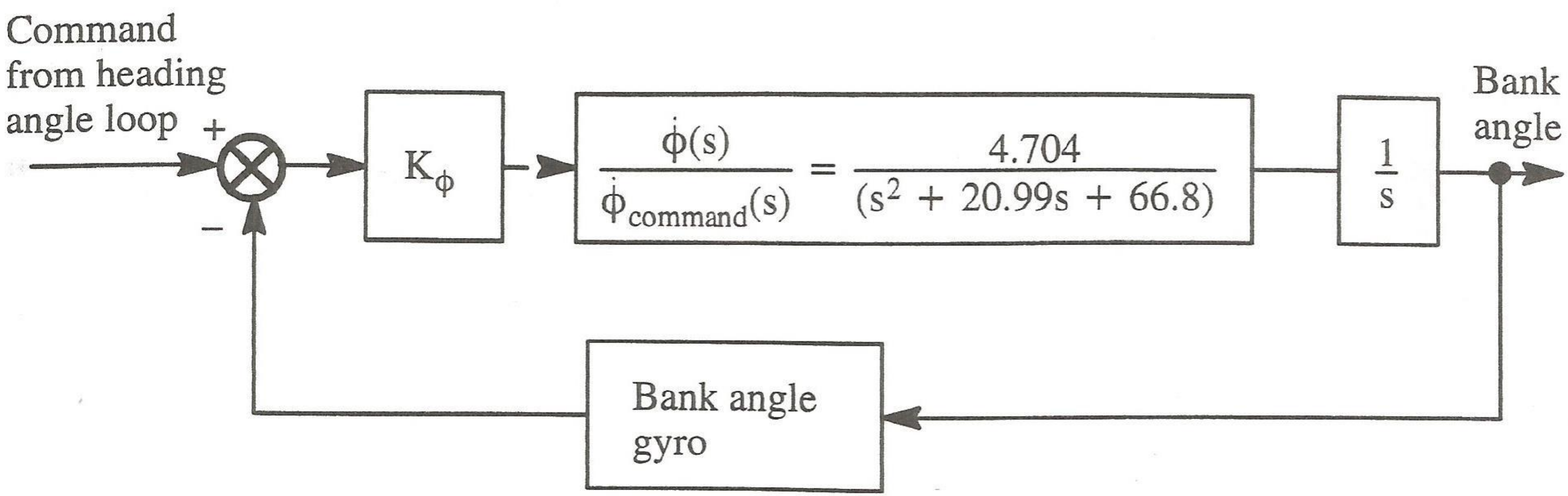
- The roll rate feedback helps to increase the roll out subsidence.

- Increase the closed loop gain helps to move the pole towards the left hand side result in increase in time constant (stability of the system increases).

- Further increasing the gain leads to couple both actuator pole and roll pole in complex plane.

$$For\ this\ case\ \ \tau = \frac{1}{pole} = \frac{1}{3.91} = 0.25575$$

$$0.25575 < 1\ for\ \ Level\ 1\, Category$$



Command
from heading
angle loop
+
−
K_ϕ
$\dfrac{\dot{\phi}(s)}{\dot{\phi}_{command}(s)} = \dfrac{4.704}{(s^2 + 20.99s + 66.8)}$
$\dfrac{1}{s}$
Bank
angle
Bank angle
gyro

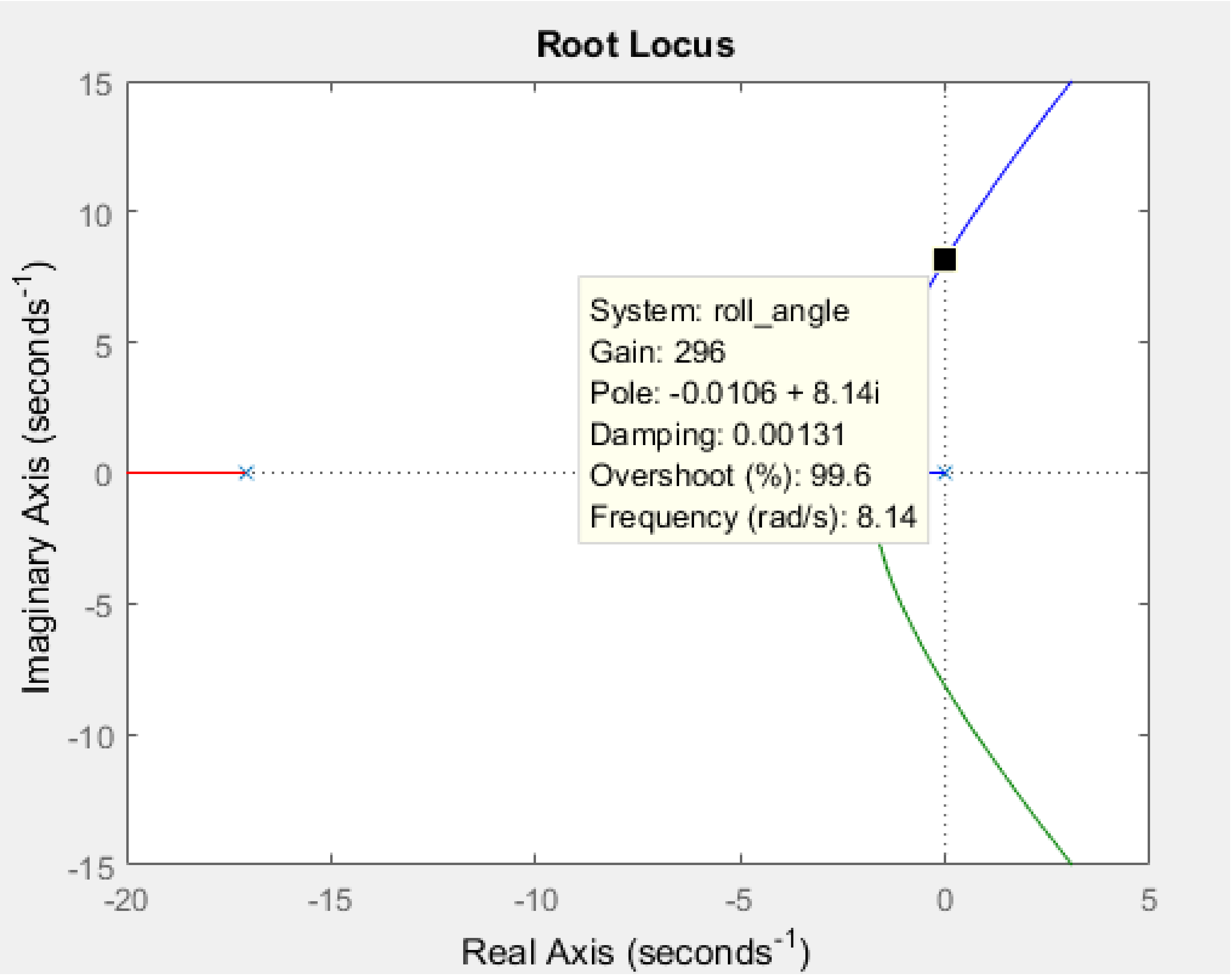
Roll angle Hold autopilot

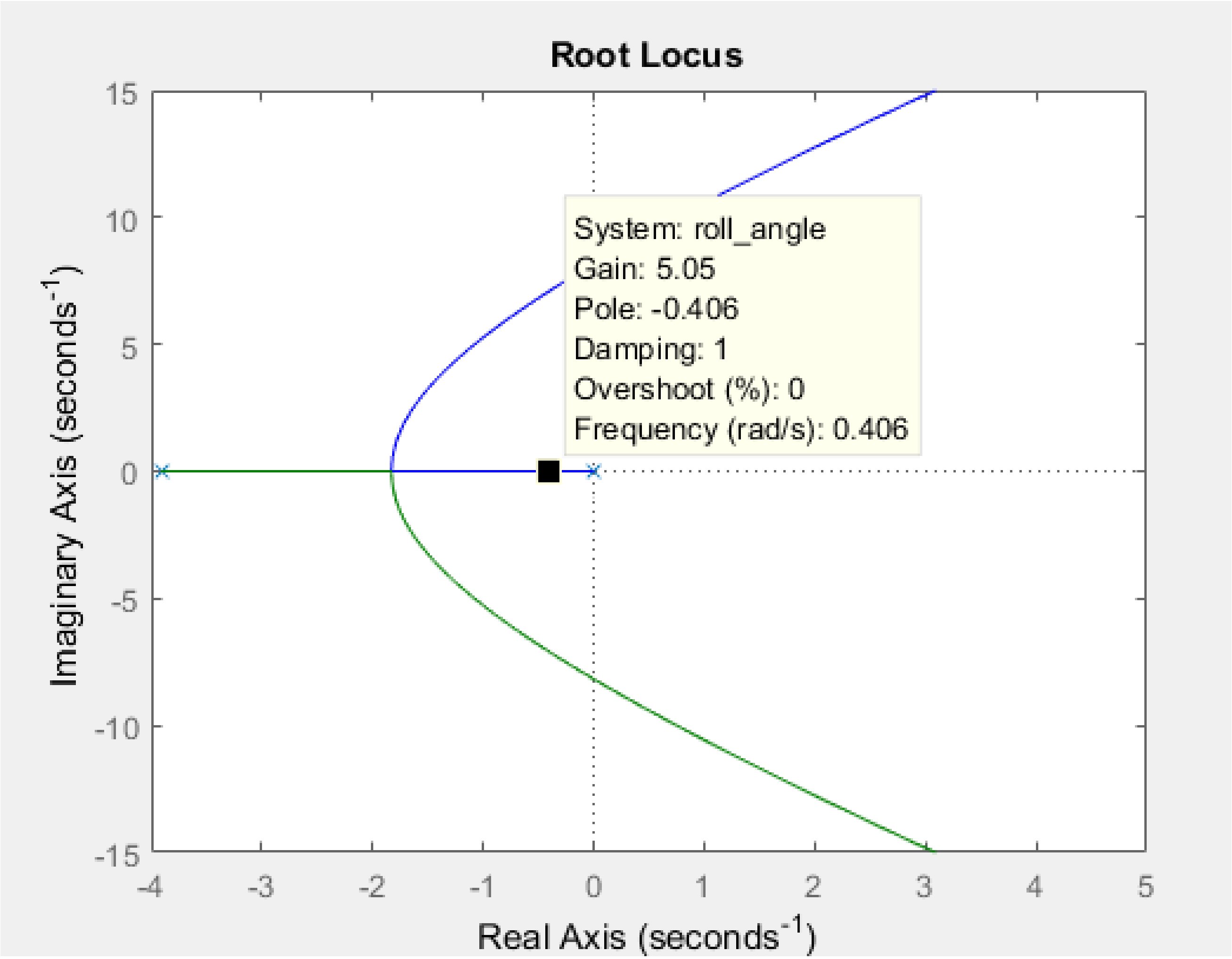
- The bank angle hold autopilot which is sometimes called the "wing leveler", when the commanded bank angle is zero (typical of cruising flight).

- The roll angle feedback helps to increase the spiral stability.

- Increase the closed loop gain helps to move the pole towards the left hand side from the origin or right hand side result in increase in stability of the system.

- Choose the roll pole at a location where the roll out time constant <1.


Root Locus
System: roll_angle
Gain: 296
Pole: -0.0106 + 8.14i
Damping: 0.00131
Overshoot (%): 99.6
Frequency (rad/s): 8.14
Imaginary Axis (seconds-1)
Real Axis (seconds-1)
15
10
5
0
-5
-10
-15
-20
-15
-10
-5
0
5


Root Locus
System: roll_angle
Gain: 5.05
Pole: -0.406
Damping: 1
Overshoot (%): 0
Frequency (rad/s): 0.406
Imaginary Axis (seconds^{-1})
Real Axis (seconds^{-1})
15
10
5
0
-5
-10
-15
-4
-3
-2
-1
0
1
2
3
4
5

Heading angle Hold autopilot

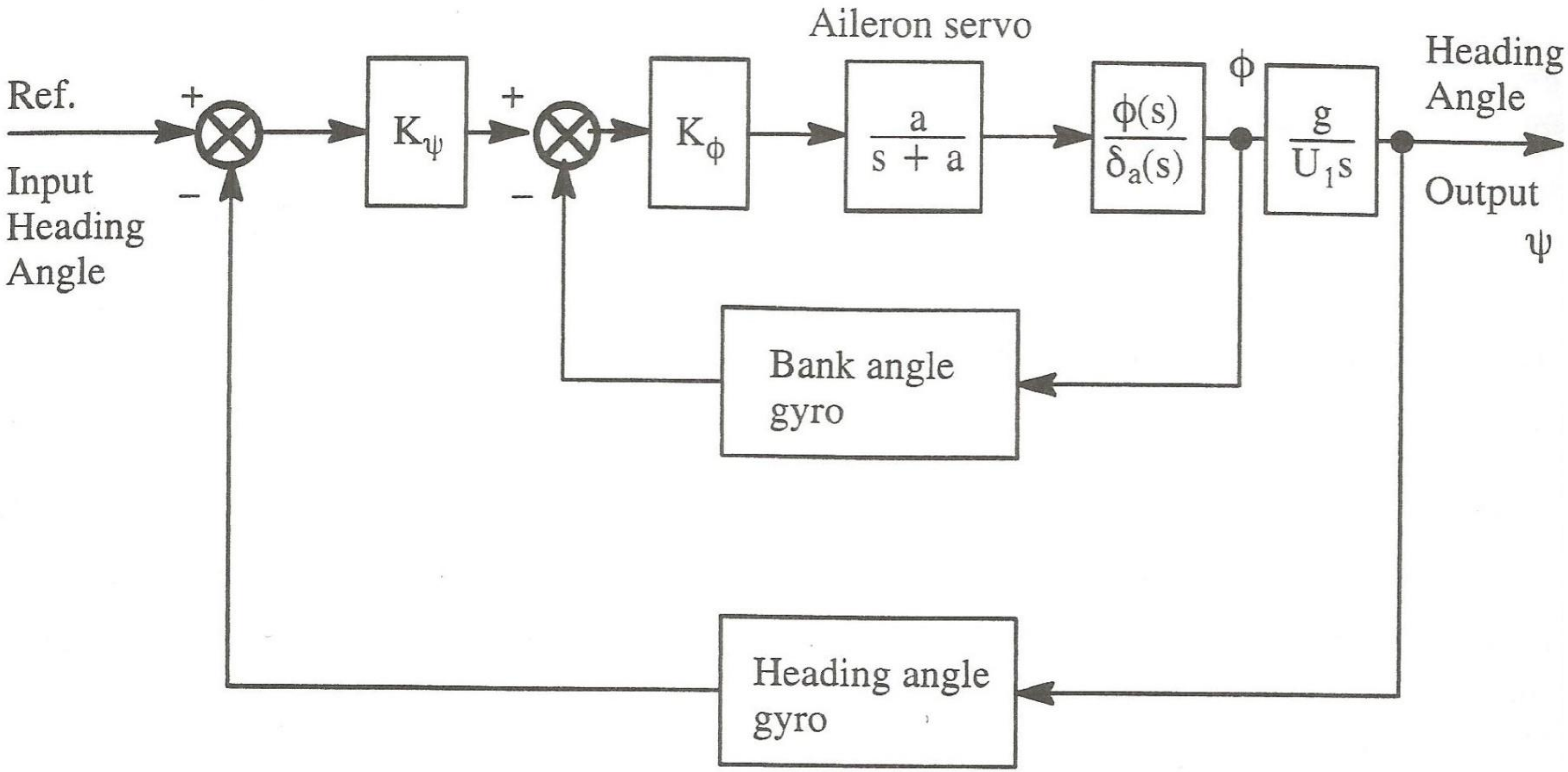
- Autopilot control of aircraft heading is another outer-loop function that can reduce pilot workload.
- Heading corrections are usually made by banking the aircraft at certain angle and hold the angle until the desired heading change is achieved.
- A heading hold system usually involves a multi loop approach with a bank angle hold system used as the inner loop.
- A bank angle gyro and a heading angle gyro are needed in this type of system.

- The relationship between heading angle and bank angle is related by

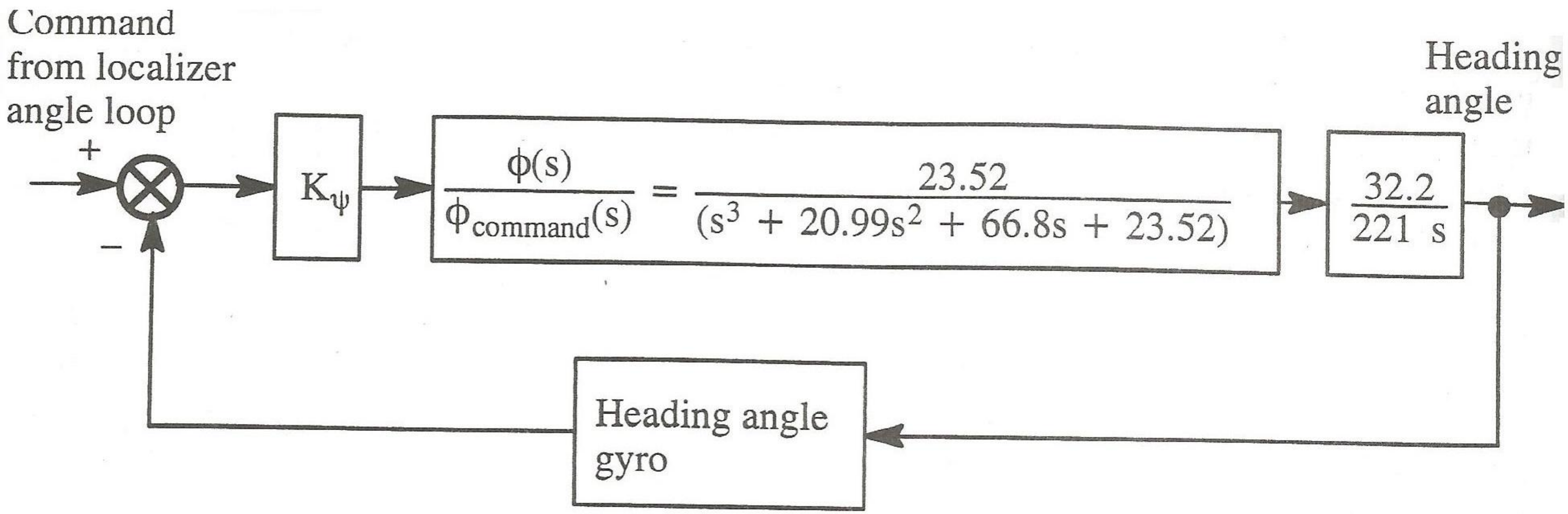
$$\frac{\psi(s)}{\phi(s)} = \frac{g}{U_1(s)}$$

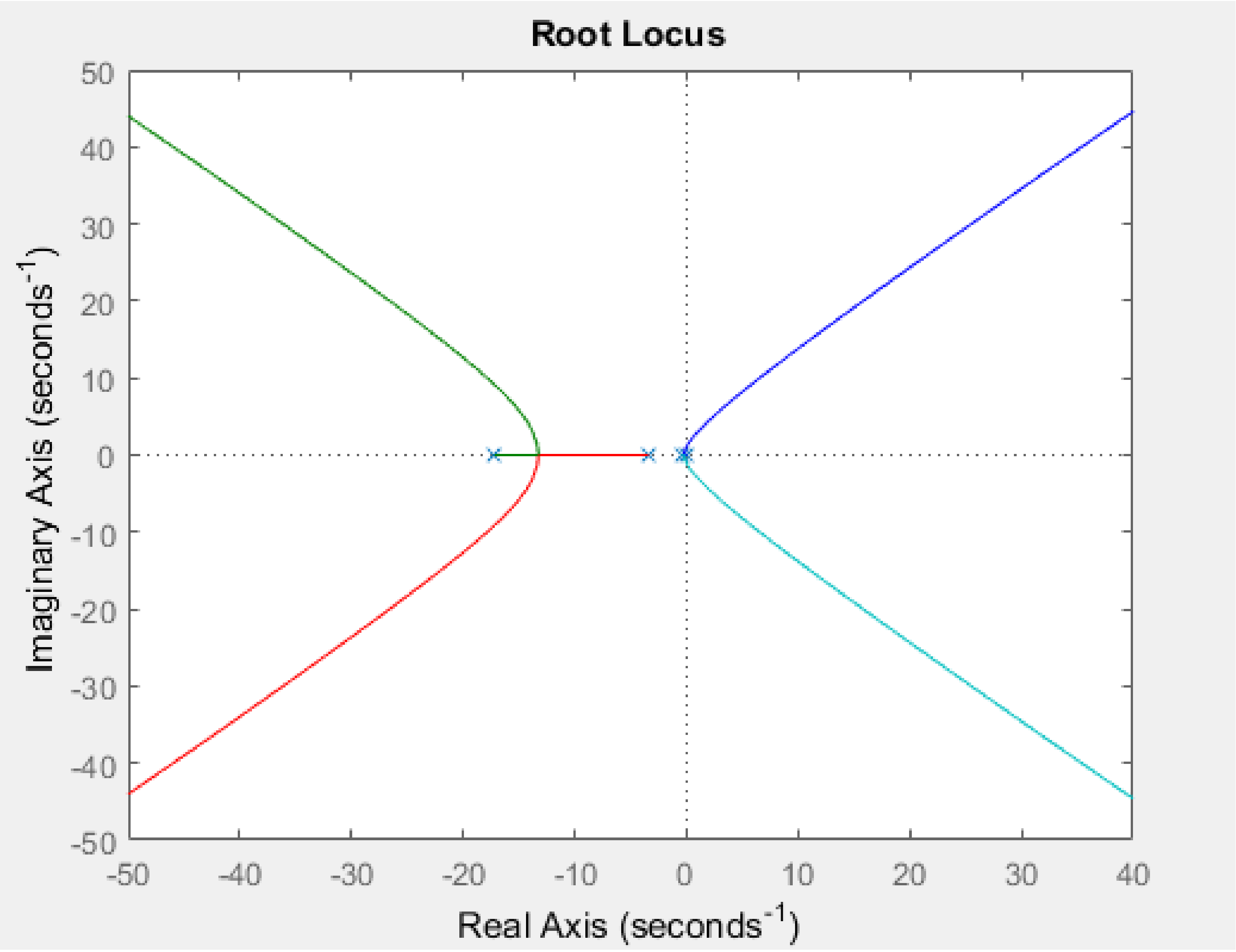
- Another way to command a change in heading is to command turn rate directly.

- When a turn is commanded, the airplane (constant speed and altitude) requires more lift. For an inherently stable plane this increases in lift requires more negative elevator deflection. Also, more drag is produced the pilot have to add thrust (or power). Modern autopilot do all this automatically.

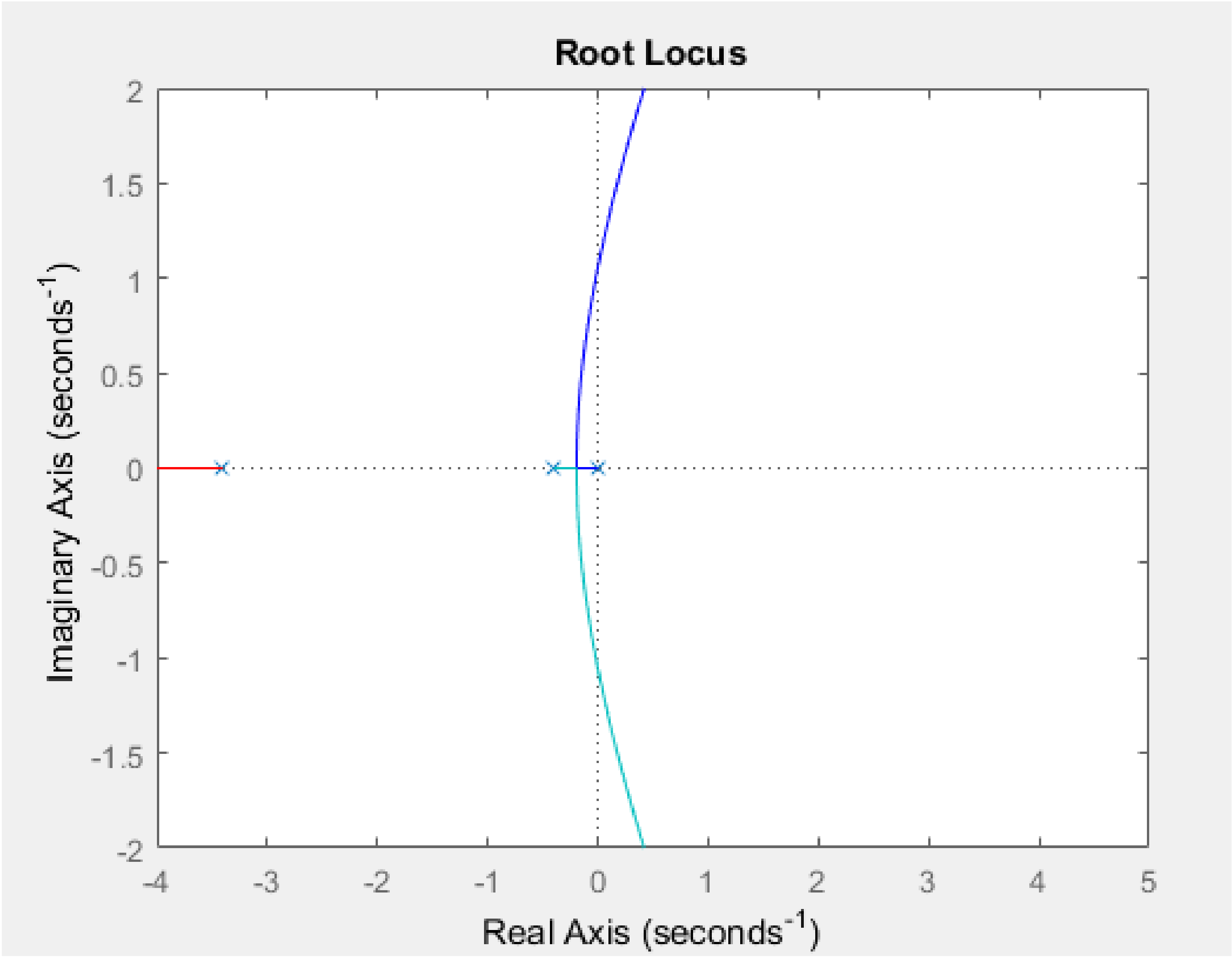


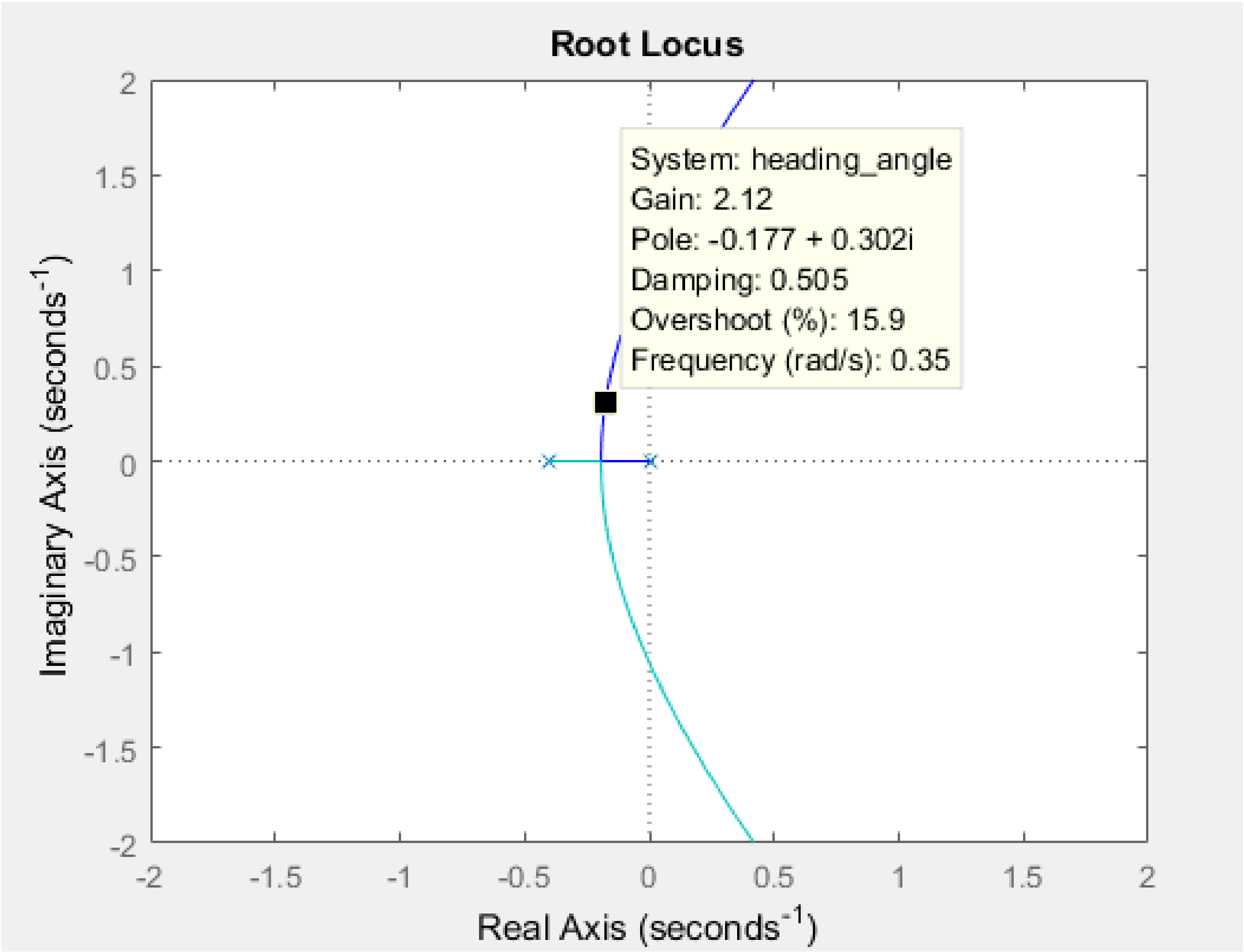
Aileron servo
Ref.
Input
Heading
Angle
+
−
K_ψ
+
−
K_ϕ
$\frac{a}{s + a}$
$\frac{\phi(s)}{\delta_a(s)}$
ϕ
$\frac{g}{U_1 s}$
Heading
Angle
Output
ψ
Bank angle
gyro
Heading angle
gyro


Command
from localizer
angle loop
+
−
K_ψ
$\frac{\phi(s)}{\phi_{command}(s)} = \frac{23.52}{(s^3 + 20.99s^2 + 66.8s + 23.52)}$
$\frac{32.2}{221\ s}$
Heading
angle
Heading angle
gyro

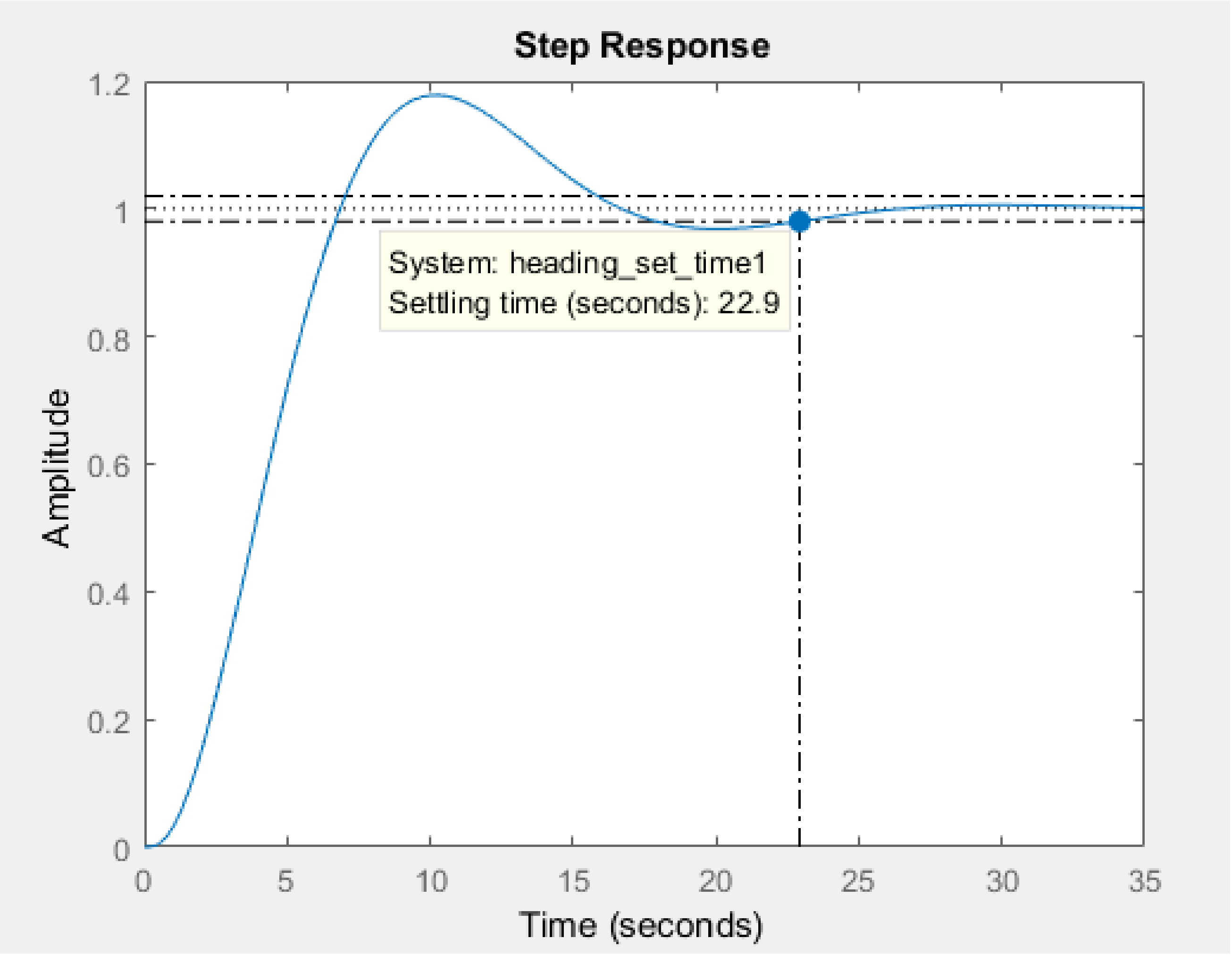


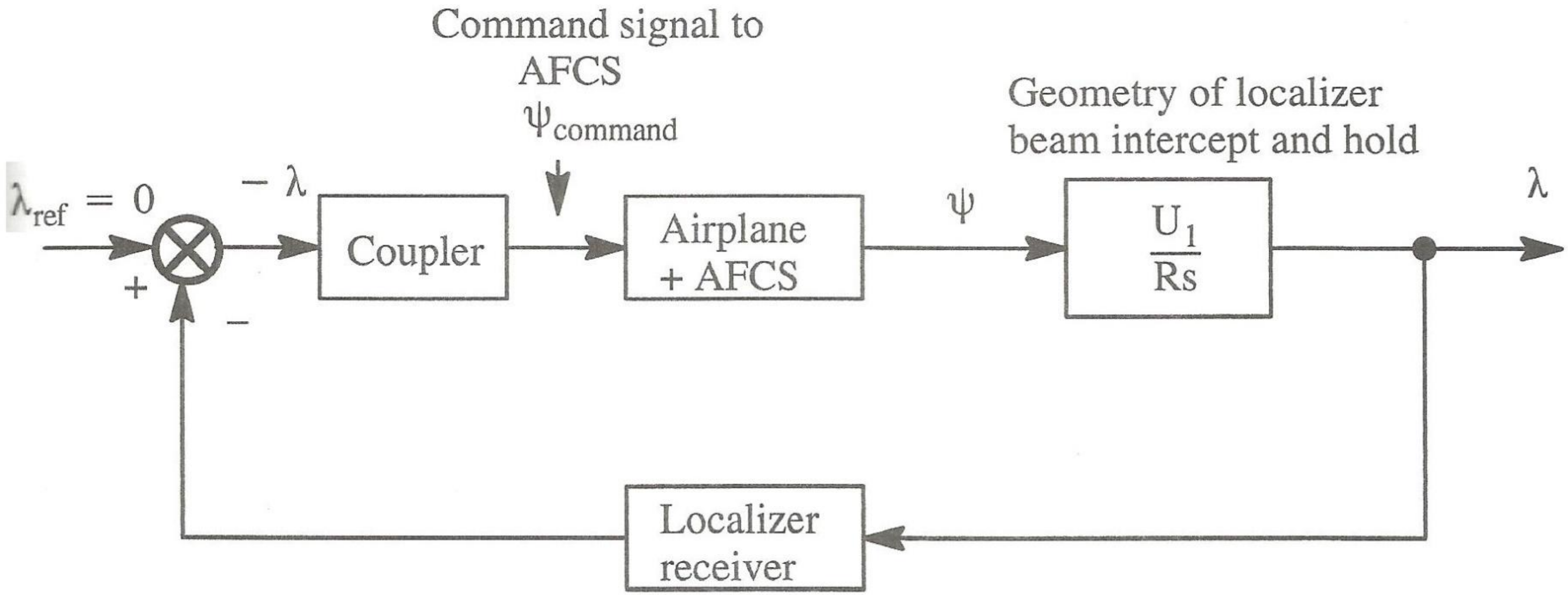
Root locus for heading angle hold autopilot


Root Locus
Imaginary Axis (seconds^{-1})
Real Axis (seconds^{-1})
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-4
-3
-2
-1
0
1
2
3
4
5


Root Locus
System: heading_angle
Gain: 2.12
Pole: -0.177 + 0.302i
Damping: 0.505
Overshoot (%): 15.9
Frequency (rad/s): 0.35
Imaginary Axis (seconds^-1)
Real Axis (seconds^-1)
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2

Time response of heading hold autopilot





Coupler T.F.F: $K_c \dfrac{(s + 0.1)}{s} = 10\dfrac{(s + 0.1)}{s}$

Note: a coupler gain of $K_c = 10$ deg/deg is typical.

Airplane + AFCS T.F.F.: $\dfrac{1514.7}{(221.0s^4 + 4638.8s^3 + 14,762.8s^2 + 5,197.9s + 1,514.7)}$

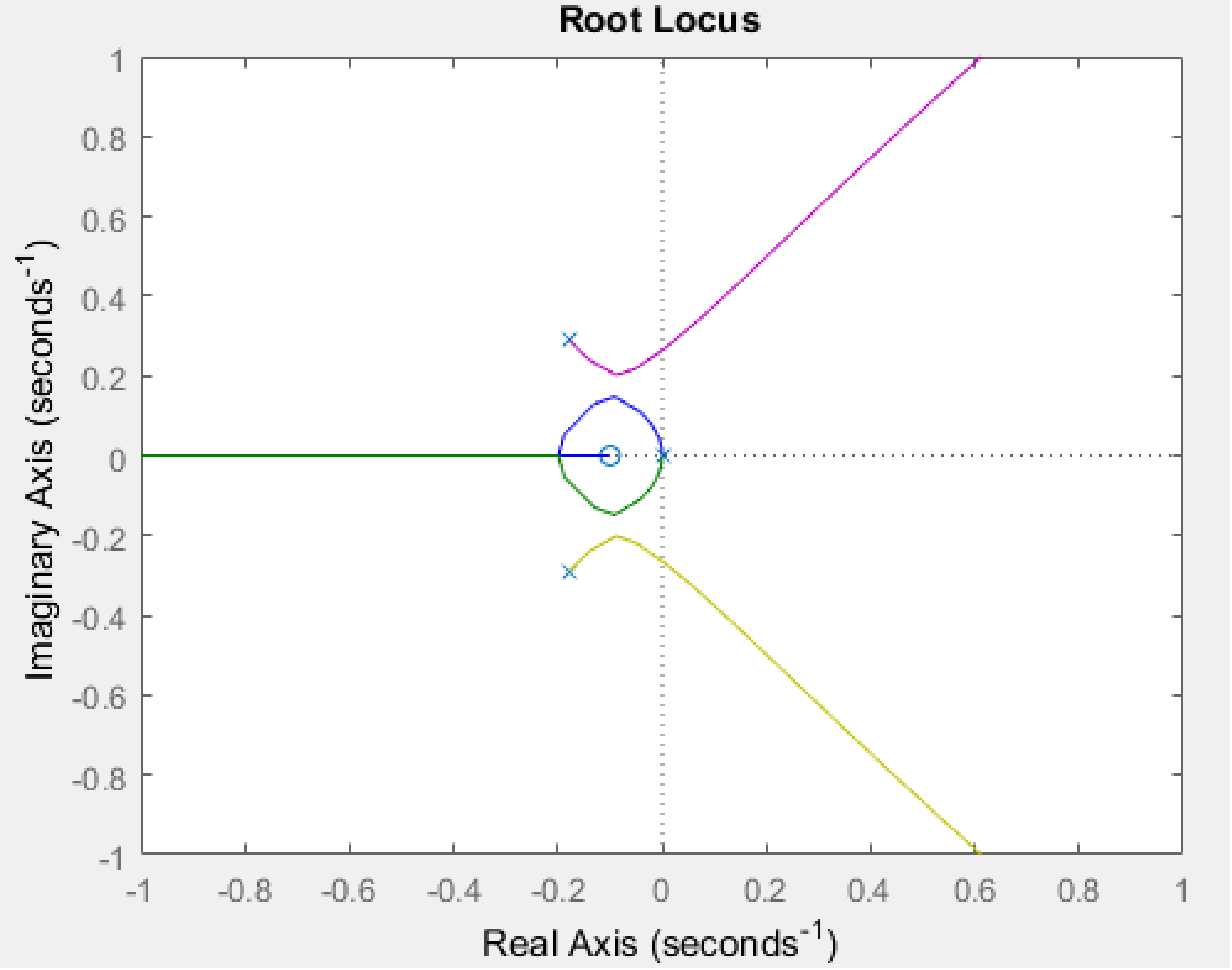
Geometry T.F.F.: $\dfrac{221}{Rs}$, where R is the slant range in ft. Note: 1 nm = 6,076.1 ft)

Localizer receiver T.F.F.: 1.0

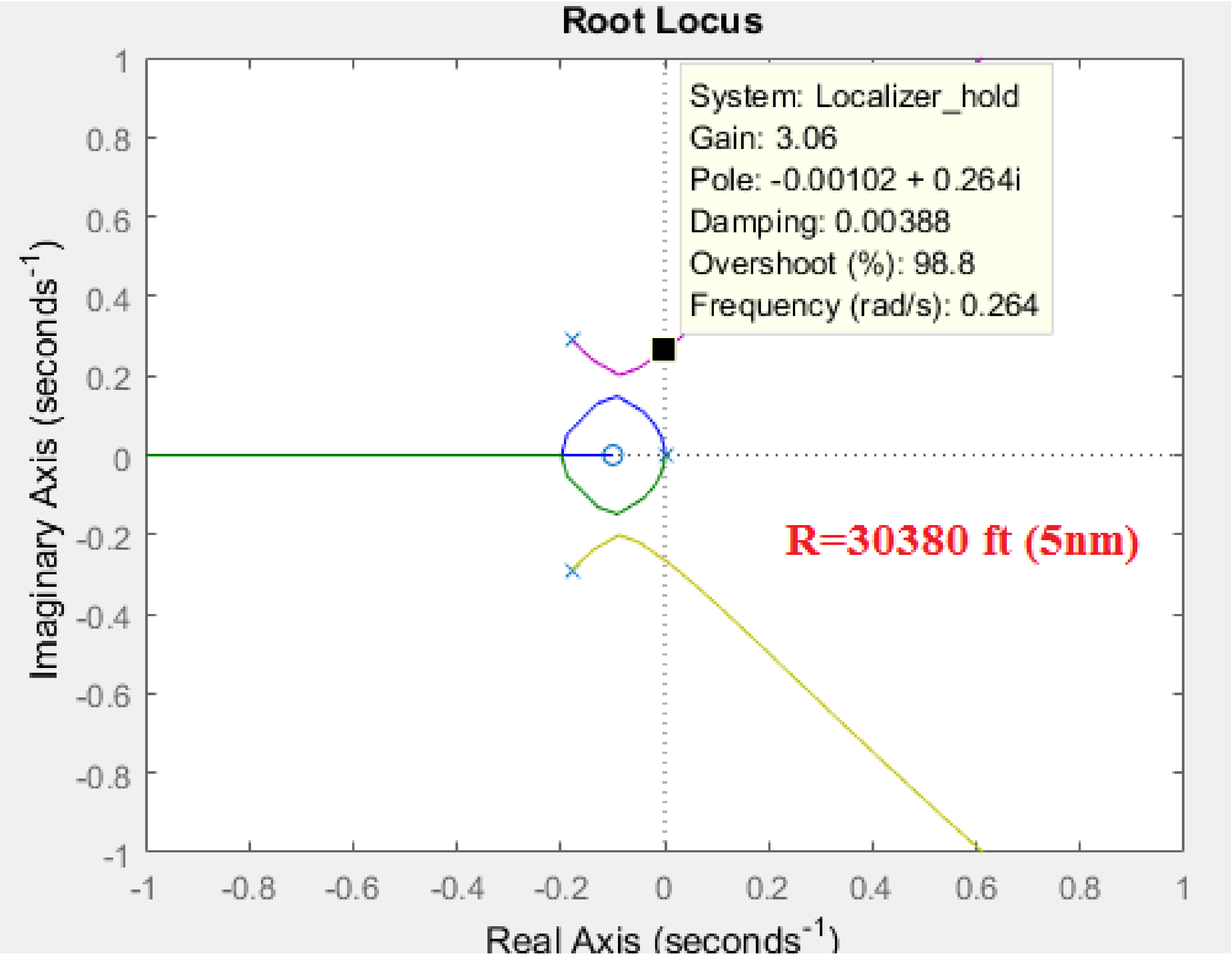
Note : $U_1 = 221$ ft/sec

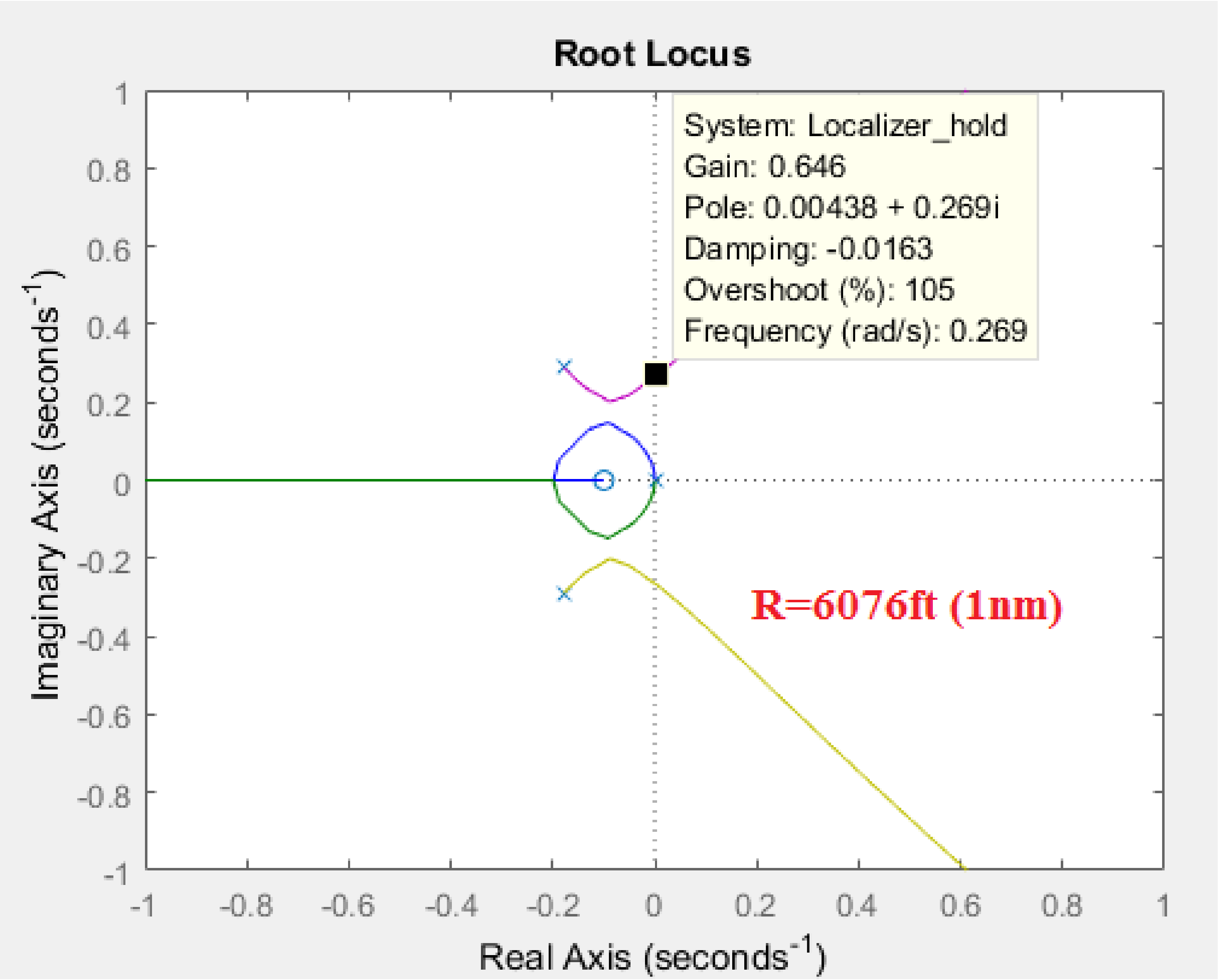
- To simplify the analysis the value of reference heading angle was set to zero.
- A root locus diagram for localizer hold control system is shown in figure.
- The need or choosing of integrator in the forward loop helps to drive the aircraft remains on course in the presence of steady state cross wind.
- The 0.1/s path provides the slow integration process to cope with a steady cross wind. The 0.1 value is selected some what arbitrarily but proves it's a good selection
- The coupler gain was set at 10 deg/deg. The parameter R act as a variable gain in this system.

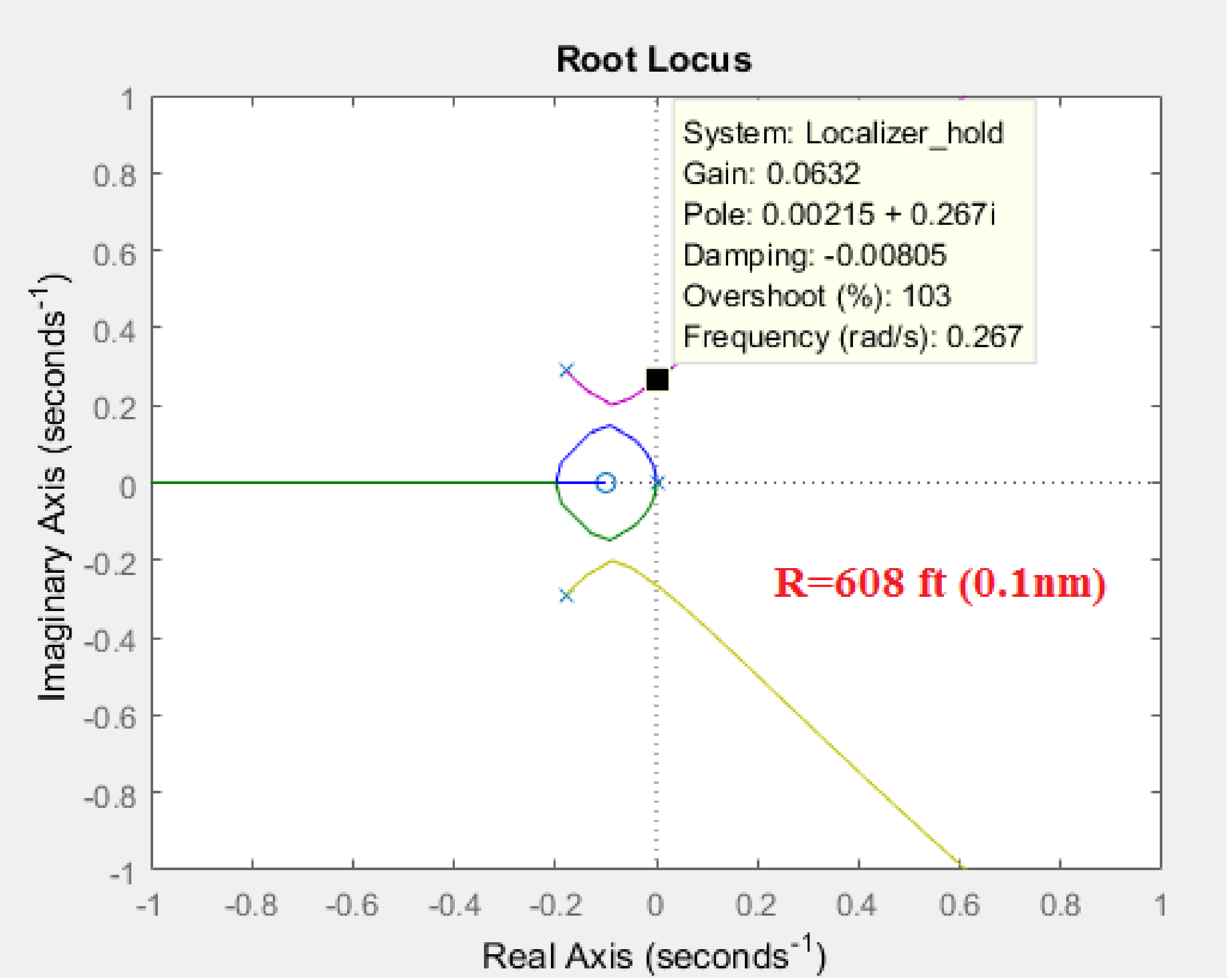
Localizer results



Root Locus
Imaginary Axis (seconds^{-1})
Real Axis (seconds^{-1})
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1


Root Locus
System: Localizer_hold
Gain: 3.06
Pole: -0.00102 + 0.264i
Damping: 0.00388
Overshoot (%): 98.8
Frequency (rad/s): 0.264
R=30380 ft (5nm)
Imaginary Axis (seconds^{-1})
Real Axis (seconds^{-1})
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1

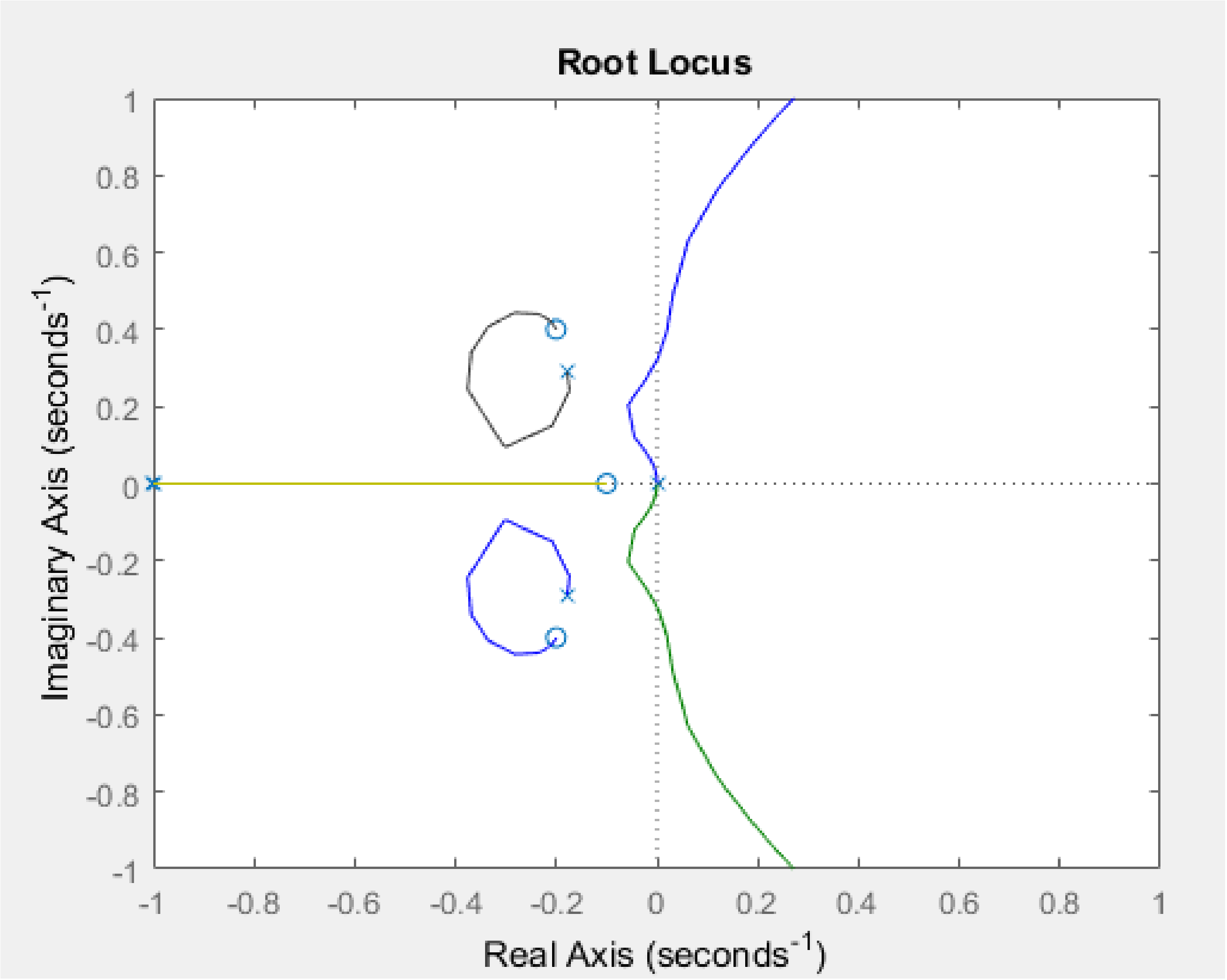

Root Locus
System: Localizer_hold
Gain: 0.646
Pole: 0.00438 + 0.269i
Damping: -0.0163
Overshoot (%): 105
Frequency (rad/s): 0.269
R=6076ft (1nm)
Imaginary Axis (seconds-1)
Real Axis (seconds-1)
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1



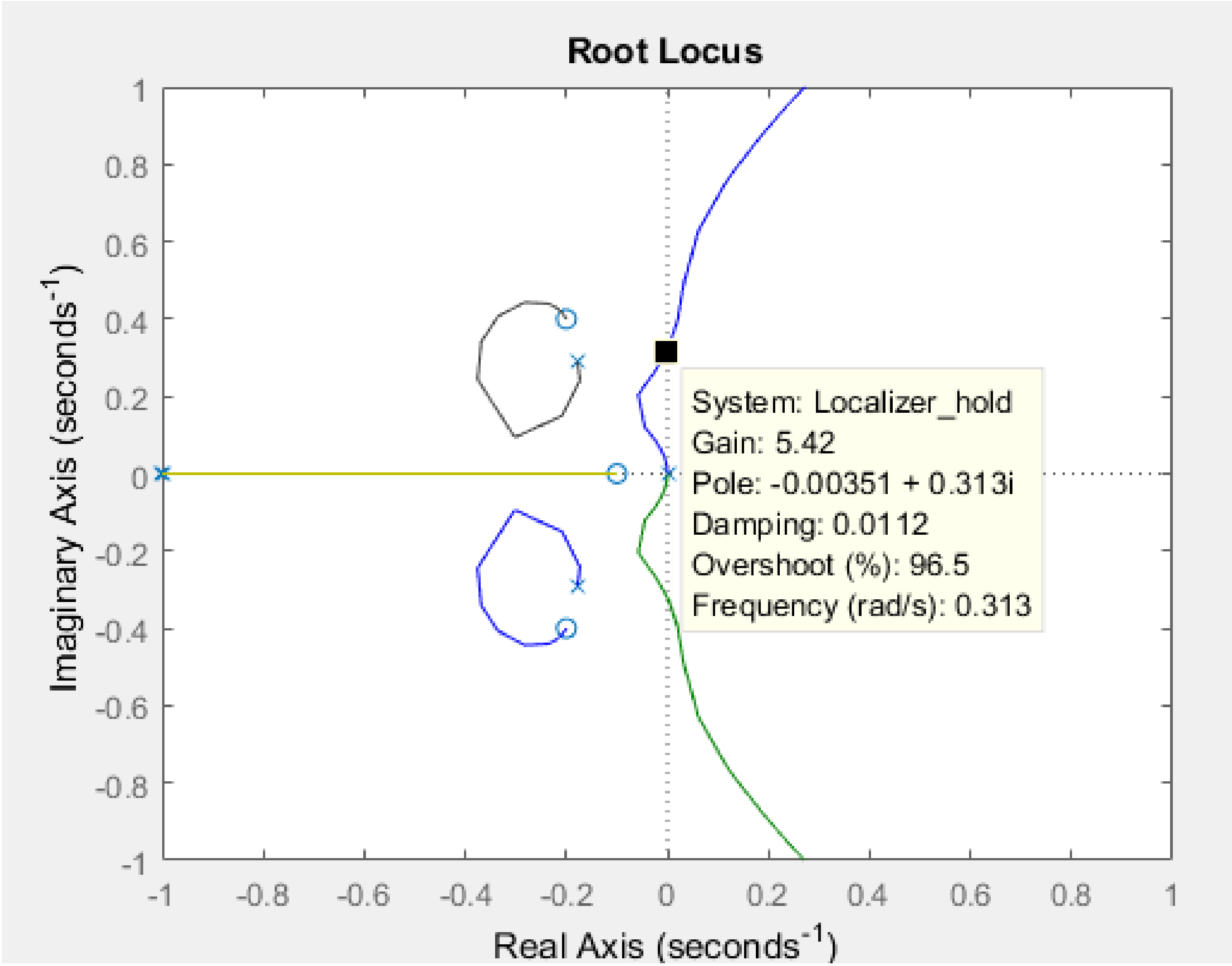
Root Locus
System: Localizer_hold
Gain: 0.0632
Pole: 0.00215 + 0.267i
Damping: -0.00805
Overshoot (%): 103
Frequency (rad/s): 0.267
R=608 ft (0.1nm)
Imaginary Axis (seconds⁻¹)
Real Axis (seconds⁻¹)
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1

- It is noted that the geometry of localizer contribute one pole to the origin where as the coupler also will contribute one more pole to the origin.

- The selection of damping in the heading angle hold mode in such a way, the complex pole should be far from the origin otherwise the system become unstable for all gain values.



$$CompensatingNetwork : \frac{5\left(s^2+0.4s+0.2\right)}{\left(s^2+2s+1\right)}$$



$$CompensatingNetwork : \frac{5\left(s^2+0.4s+0.2\right)}{\left(s^2+2s+1\right)}$$

- The favorable effect of a compensating network (added to the coupler transfer function) on the system is shown in the previous figure with the diamond symbols again representing the system stability at a slant range of R=5nm.

- Since the localizer is far down the runway at a slant range of 1.0 miles the airplane should have already touched down so that the relative stability of the the system at that small a slant range is probably not critical. Better stability can be obtained by adjusting the compensation network.

- It must be noted by varying the coupler gain as a function of slant range, a constant operating point can be obtained. Doing this requires distance measuring equipment (DME) or TACCAN

THANK YOU