1. Answer the following questions with **TRUE** or **FALSE**.

(a) The phase crossover frequency $\omega_p$ is the frequency at which the open loop transfer function’s phase response equals 0 radians.

**FALSE**

(b) The bandwidth $\omega_{BW}$ of a closed loop system is a measure of the speed of response.

**TRUE**

(c) Phase margin is measured at the gain crossover frequency.

**TRUE**

(d) If phase crossover occurs at a lower frequency than gain crossover, then the closed loop system will be stable.

**FALSE**

(e) If the low frequency slope of the magnitude Bode plot is -20db per decade, then the closed loop system is type 1.

**TRUE**
2. Consider the block diagram shown below.

\[ R \rightarrow + \rightarrow D(s) \rightarrow G(s) \rightarrow Y \]

With \( D(s) = D_1(s) \), the closed loop system is type 1 with \( K_c = 10 \) and with dominant closed loop poles at \( s = -5 \pm j3 \). Augment \( D(s) \) with a lag compensator to increase \( K_c \) to 150, while leaving the dominant closed loop poles close to \( s = -5 \pm j3 \).

**Solution:** Set

\[
D(s) = \frac{s + z}{s + p} D_1(s)
\]

with \( z < 5/10 \) and \( p < z/15 \). For example,

\[
D(s) = \frac{s + 0.45}{s + 0.03} D_1(s)
\]
3. Sketch straight line approximations for the magnitude and phase Bode plots for

\[ G(s) = \frac{16s + 5}{s + 20} \]
4. The transfer function $G(s)$ has Bode plot given below. $G(s)$ has no right half plane poles.

For the closed loop system

$$\frac{KG(s)}{1 + KG(s)}$$

(a) determine an upper bound on $K$ for closed loop stability;
(b) determine the crossover frequency, phase margin, and velocity error constant $K_v$ when $K = 1$
(c) determine the crossover frequency, phase margin, and velocity error constant $K_v$ when $K = 10$

**Solution:**
(a) $K < 20\text{db}$ or $K < 10$ (actual limit is a little more than 10).
(b) $\omega_c = 0.9 \text{ rad/sec}, \text{ PM } = 45^\circ$, and $K_v = 1$.
(c) $\omega_c = 0.4 \text{ rad/sec}, \text{ PM } = 0^\circ$ (actually just a little bit bigger), and $K_v = 10$. 
5. Consider the Nyquist plot for $G(s)$ shown below. Assuming that $G(s)$ has one right half plane pole, determine for what values of $K$ the closed loop system

$$\frac{KG(s)}{1 + KG(s)},$$

is stable.

**Solution:** Counting the number of clockwise encirclements for various choices of $K$ to get the value for $N$:

- $1/K > 5 \quad (0 < K < 1/5) \quad N = 0$
- $1/2 < 1/K < 5 \quad (1/5 < K < 2) \quad N = 1$
- $1/K < 1/2 \quad (K > 2) \quad N = -1$

Since $P = 1$ (number of open loop RHP poles), and with $Z = N + P$ the number of closed loop RHP poles, we have $Z = 0$ only for $K > 2$. So,

$K > 2$