Homework Problems

1. Assume we have a feedback system as shown in Fig. 1, and with it open-loop bode diagram as shown in Fig. 2. The controller here is a simple proportional controller with gain K_P, and assume the loop delay of the system is T_d.

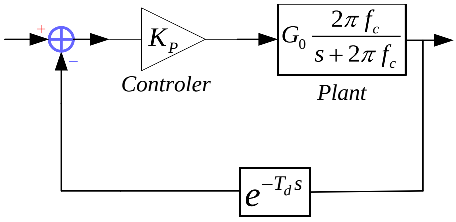

Fig. 1: Simplified block model of a feedback system

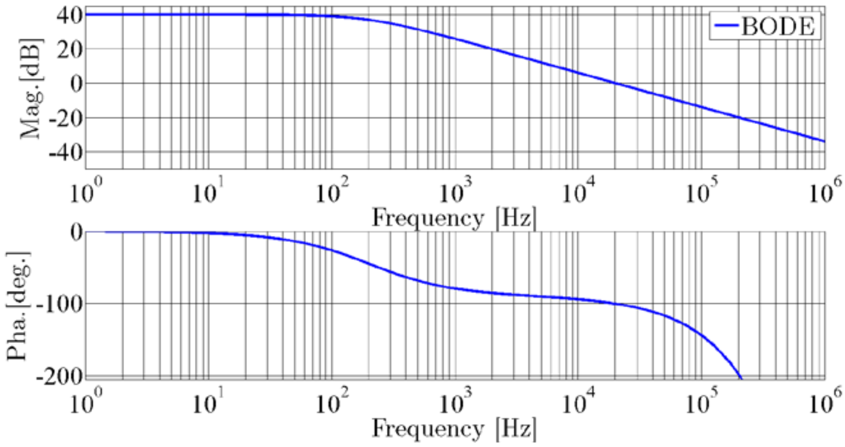

Fig. 2: Open loop bode diagram of Fig. 1

According to Fig. 1 and Fig .2:

a) Assume the gain of plant G_0 is 0.8, please calculate the bandwidth of the plant f_c and controller's gain K_P. **Note: please observe some special point in the Fig.2.**

b) Please approximately calibrate the value of of T_d.

c) The current system in Fig. 2 is stable, but if you increase the loop delay to some value, system may becomes unstable, please estimate the maximum delay we can achieve.

2. Assume we have one first order system which is controlled by a proportional controller (feedback gain is K_P,), the system open loop transfer function is

$$G(s) = \frac{1360}{s+1360}.$$

a) What are the conditions for K_P, to guarantee stability of the closed loop system (assume there is no loop delay).

b) If the loop delay is 1μs, estimate the maximum gain the system can achieve.

c) If we want to reduce the disturbance of the system by 100 times, estimate the limit to the loop delay.

3. Consider only the π mode of the cavity, assume the cavity loaded quality factor is $Q_L = 3\times10^6$, the resonance frequency is f_0 = 1.3GHz, and the shunt impedance is r/Q = 1036Ω. The driving RF power is 200kW.

a) What is the maximum cavity voltage in steady state?

b) If the cavity is detuned by 217 Hz, what is the cavity voltage in steady state? What is the phase difference between the cavity input and output signal?

c) Given a beam current of 8mA (average DC current) with beam phase 0 (on-crest), determine the beam injection time into the cavity (detuning = 0) to achieve a flattop.

4. Same parameters of the cavity as 3, if there is no detuning, we want to fill the cavity voltage to 25MV in 500μs, how much RF power is required? At 500μs, we inject a beam of 5mA (DC current), beam phase is 0, how much RF power is needed to maintain this 25MV flattop. How much power is reflected?

5. If we want the cavity flattop voltage to be 25MV, beam current 8mA, beam phase 30 degree, find out a group of optimized parameters to minimize the klystron power needed.

a) Find an optimized detuning.

b) Find an optimized loaded quality factor.

c) Find the minimum klystron power needed? How much reflection power now?

6*. A disturbance observer-based feedback system is shown in Fig. 3(b). Please compare it with traditional feedback system in Fig. 3(a). **Note: That problem may be difficult but Mason's rule will help, if you do not have time, just ignore it.**

a) Please calculate the transfer function $H_{d\to y}$ from the disturbance $d(t)$ to the plant output $y(t)$ in case a and b.

b) If we have $F(s)=1$, $P_n(s)=1/P(s)$, and $T_n=T_d$, Please simplified the $H_{d\to y}$ of Fig. 3(b)

c) Parameters are same with b). If $Q(s)=1$, concerning $H_{d\to y}$, what is difference between Fig. 3(a) and Fig. 3(b)?

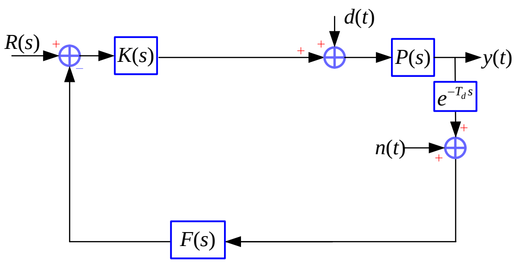

Fig. 3(a). TF of traditional PI control

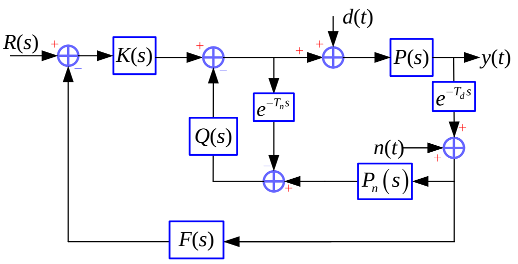

Fig. 3(b). TF of DOB control

7. A cavity probe signal (1.3 GHz) is directly sampled by an ADC (SNR = 78dB), the clock jitter is 0.5 ps RMS. Estimate the phase measurement error. **Note: Convert the noise caused by the clock jitter to dB and compare to ADC noise.**

8. When the klystron power is switched off, the cavity voltage decreases exponentially. If the cavity voltage and phase are given by the functions (decay starts at t=0).

$$V(t) = 25\left(e^{-1260t}\right) \quad (MV),$$

$$\phi(t) = 10 - 120t \quad \text{(Degree)}.$$

Calculate the detuning and loaded quality factor of the cavity.

9*. Assume we are controlling two cavities with vector sum control scheme. The actual RF voltage in the cavities is presented with vectors: V_1 = (100, 200) kV, V_2 = (90, 250) kV. The vector sum calibration of the second cavity has +5% error in amplitude and +5 degree in phase **(Note: that problem is somehow difficult, you can just ignore it if you do not have time, at least I promise you will never find it in this final exam).**

a) What is the vector sum from the measurement? What is the vector sum seen by the beam?

b) If the microphonics generate +3% error in amplitude and +3 degree in phase in the first cavity, and -3% error in amplitude and -3 degree in phase in the second cavity, and assume the feedback control can perfectly compensate the measured vector sum change, how much amplitude and phase errors that will be seen by the beam?

10. Assume the cavity loaded quality factor is $Q_L = 3\times10^6$, the resonance frequency is f_0 = 1.3GHz, and the shunt impedance is r/Q = 1036Ω. The average beam current is 3mA, and the beam pulse width is 30μs. **Note: 30 μs<<τ_{cav}**

a) Calculate the beam induced voltage.

b) If the cavity voltage (raw data from ADC in bits) is presented by the vector of V_{cav} = (3200, 4500), and the beam induced signal (measured by ADC) is V_{beam} = (100, -200). Estimate the cavity voltage in MV and the beam phase.