Homework Problems 2012

1. The differential equation of a second order system is described below

$$\frac{d^2 y}{dt^2} + 2723\frac{dy}{dt} + 6.672 \times 10^{19} y = 4.231 \times 10^{12} u \ .$$

   a) Write out the open loop state space equation of the system.
   b) Draw the block diagram of the open loop system from the result of step a).
   c) Check the stability of the system.
   d) If we use full state feedback algorithm, $u_{fb} = -[K_1 \ K_2] * x$ (x is the state vector), write out the closed loop state space equation.
   e) Add the feedback items into the block diagram that you worked out in step b).
   f) Find out the constraints of K_1 and K_2 to keep the closed loop system stable.
   g) If we want to set the closed loop system bandwidth 4 times larger than the open loop system bandwidth, what value of K_1 and K_2 are required.

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

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

   a) Check the stability of the closed loop system.
   b) If the loop delay is 1µs, estimate the maximum gain the system can achieve.
   c) If we want to reduce the slow (<1Hz) 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 $Q_L = 3 \times 10^6$, the resonance frequency is $f_0 = 1.3$GHz, and the shunt impedance is $r/Q = 1036\Omega$. The driving RF power is 200kW.
   a) What is the maximum cavity voltage in steady state?
   b) If the cavity is detuned by 200Hz, what is the cavity voltage in steady state? What is the phase difference between the cavity input and output signal?
   c) If we have a beam current of 8mA (average DC current) with beam phase 0, when shall we inject the beam into the cavity (detuning = 0) after the RF power is switched on to generate 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. Same parameters of the cavity as 3, 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 cavity is operated in SEL mode, the loop phase of the system is (1000 * 360 + 10) degree @ 1.3GHz, estimate the most possible working frequency of the SEL loop.

7. A cavity probe signal (1.3 GHz) is directly sampled by an ADC with a noise level of -78dB compared to the full scale on the datasheet, the clock jitter is 0.5 ps RMS, estimate the phase/amplitude measurement error.

8. Same parameters of the cavity as 3. When the klystron power is switched off, the cavity voltage decreases exponentially. If the cavity voltage and phase has the functions of (assume the time t = 0 when the decay starts)

$$V(t) = 25\left(1 - e^{-2720t}\right) \ (MV),$$

$$\phi(t) = 10 - 12000t \ \text{(Degree)}.$$

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 field in the cavities is presented with vectors: $V_1 = (100, -200)$, $V_2 = (-50, 300)$. The vector sum calibration of the second cavity has 1% error in amplitude and 1 degree in phase.
   a) What is the vector sum from the measurement? What is the vector sum seen by the beam?
   b) If the microphonics generates 5% error in amplitude and 5 degree in phase in cavity 1, 2% error in amplitude and -3 degree in phase in cavity 2. 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 $Q_L = 3 \times 10^6$, the resonance frequency is $f_0 = 1.3$GHz, and the shunt impedance is $r/Q = 1036\Omega$. The average beam current is 3mA, and the beam pulse width is 30μs.
   a) Calculate the beam induced voltage.
   b) If the cavity voltage (in arbitrary unit) is presented in vector of $V_{cav} = (3200, 4500)$, and the beam induced signal (in arbitrary unit) is $V_{beam} = (100, -200)$. Estimate the cavity voltage in MV and the beam phase.