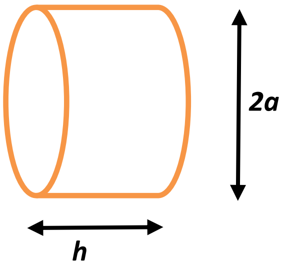
$\mu = \mu_0\, \mu_r$
$\mu_0 = 4\pi \cdot 10^{-7}$ Vs/(Am)
$\varepsilon = \varepsilon_0\, \varepsilon_r$
$\varepsilon_0 = 8.854 \cdot 10^{-12}$ As/(Vm)
$c_0 = 3 \cdot 10^8$ m/s

JUAS 2016 – RF Exam

Name: ___________________________________ Points: ______ of 20 (23 with bonus points)

Utilities: JUAS RF Course 2016 lecture script, personal notes, pocket calculator, ruler, compass, and your brain! (No cell- or smartphone, no iPad, laptop, or wireless devices, no text books or any other tools)

Please compute and write your results clear and readable, if appropriate on a separate sheet of paper. Any unreadable parts are considered as wrong.



1. “Pillbox” Cavity (8 points)

A scaled model of a simple cylindrical “pillbox” cavity is characterized in the RF laboratory (the beam-pipe ports are neglected). The cavity is made out of stainless steel ($\sigma_{ss} = 2 \cdot 10^6$ S/m, $\mu = \mu_0$), and its unloaded E_{010}-mode eigen-frequency measures 600 MHz, with a 3-dB bandwidth of 70 kHz.

a) What is the *Q*-value of the cavity? (1½ points)

b) What are the physical dimensions,
radius (or diameter) and height, of the cylindrical resonator? (2 points)

c) Sketch the *RLC* equivalent parallel circuit, and determine the values of the E_{010}-mode. (Therefore the “geometry factor”, also known as “characteristic impedance” *R/Q*, needs to be calculated, based on the exact formula! Why the approximate expression cannot be applied?) (2 points)

d) The E_{010}-mode is the fundamental eigen-mode of the pillbox cavity,

and its magnetic field has only longitudinal / transverse field components. (½ point)

(Mark the correct answer:) [✓ answer A] answer B

Assuming a ratio height-to-diameter ≅ 0.9, another resonance mode is observed in close proximity of the E_{010} frequency!

e) Which type of higher order mode (HOM) is measured close to 600 MHz? (½ point)
(Hint: The “Mode chart of a Pillbox cavity – Version 1” is a helpful tool!)

E_{011}
H_{111}
H_{112}
E_{010}
E_{110}

f) What dimension needs to be changed, to keep the fundamental mode at 600 MHz, while shifting this higher order mode to higher frequencies, and staying well separated to other HOMs? (½ point)

Increase the diameter
increase the height
decrease the diameter
decrease the height

Bonus points: (the full score can be reached without examining these questions) **(1 points)**

The final version of the resonator is made of of copper, (σ_{Cu} = 58 · 10^6 S/m), with both dimensions reduced by a factor 10. (Hint: Apply the "scaling laws")

g) What is the frequency of the fundamental mode? (¼ point)

h) What values for *Q*-factor and shunt impedance can be expected? (¾ point)

2. S-Parameters (2 points)

Match the ideal S-parameters in matrix form to the corresponding components.

$$\boldsymbol{S_A} = \begin{bmatrix} 0 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix} \quad \boldsymbol{S_B} = \begin{bmatrix} 0 & j0.1 & 0.995 & 0 \\ j0.1 & 0 & 0 & 0.995 \\ 0.995 & 0 & 0 & j0.1 \\ 0 & 0.995 & j0.1 & 0 \end{bmatrix} \quad \boldsymbol{S_C} = \begin{bmatrix} 0 & -j \\ -j & 0 \end{bmatrix} \quad \boldsymbol{S_D} = \begin{bmatrix} 0 & 0 \\ 1 & 0 \end{bmatrix}$$

a) Assign the S-matrices ($\boldsymbol{S_A}$ ... $\boldsymbol{S_D}$) to the components: (1 point)

component	... dB directional coupler	transmission line, electrical length = λ/...	circulator	isolator
S-matrix				

b) Fill the missing dB and λ information (...). (1 point)

3. Resonator analysis in the complex plane (3 points)

A 500 MHz resonator is critically coupled ($Q_0 = Q_{ext}$) by means of a coupling loop to a RF generator of $Z_g = 50\ \Omega$ source impedance. The coupling parameter of the loop coupler is k = 16 (Hint: See the "Equivalent Circuit" on page 50 of the course material).

a) What is the value of the shunt impedance R_p of the resonator? (1 point)

b) With help of compass and ruler, sketch the locus $Z_{resonator}(f)$ of the unloaded resonator in the complex Z-plane. (On the separate sheet provided at the end.)
   - Indicated upper and lower 3-dB points, as well as the points for resonant frequency and frequency limits ($f = 0$, $f \rightarrow \infty$). (1 point)
   - Use the ruler to estimate the value of the impedance Z at f_{3dB}. (½ point)

c) Through a second, very weakly coupled loop the 3-dB bandwidth of the resonator at critical coupling was measured as 1 MHz. Determine Q_0 of the (unloaded) resonator? (½ point)

4. Multiple choice (4 points)

Tick the correct answer(s) like this: ⊗.

1. A sinusoidal RF signal is measured with an oscilloscope, having and internal 50 Ω termination. The cursors display a peak-to-peak voltage of 500 mV. What is the signal power in dBm? (½ point)
   - ○ -1 dBm
   - ○ -2 dBm
   - ○ +4 dBm

2. For a "H"(or "TE") mode, the following is true: (½ point)
   - ○ Its magnetic field has only transverse components
   - ○ Its magnetic field has transverse and longitudinal components
   - ○ Its electric field has only transverse components

3. Changing the height h of a cylindrical cavity oscillating on the E_{010}-mode will: (½ point)
   - ○ change its resonant frequency
   - ○ change its quality factor
   - ○ change its R/Q

4. For which material an AC current flows closest to its surface (assume $\mu_r = 1$)? (½ point)
   - ○ Aluminium ($\sigma = 35 \cdot 10^6$ S/m)
   - ○ Silver ($\sigma = 63 \cdot 10^6$ S/m)
   - ○ Copper ($\sigma = 58 \cdot 10^6$ S/m)

5. What is the limiting factor when using air-filled coaxial lines for transmitting signals of high frequencies? (½ point)
   - ○ There is no frequency limit
   - ○ The propagation of higher order (waveguide) modes
   - ○ Signal leakage (escaping electrons)

6. In a RF accelerating cavity, the transit time factor expresses: (½ point)
   - ○ The time it takes for the energy to transfer from the electric field to the magnetic field
   - ○ The time variation of the accelerating field during the bunch passage
   - ○ The time it takes the bunch to travel through the cavity

7. Which coaxial cable has the highest propagation velocity (for TEM)? (½ point)
   - ○ Filled with Teflon (PTFE) dielectric
   - ○ Filled with Polyethylene (PE) dielectric
   - ○ Filled with air dielectric

8. A gridded tube (triode) operates on the principle of (½ point)
   - ○ Electron density modulation
   - ○ Electron temperature modulation
   - ○ Electron velocity modulation

5. Smith chart (6 points)

a) Indicate points **P_1…P_5** in the Smith chart, assuming a reference impedance $Z_0 = 50\ \Omega$. From the Smith chart, determine the missing Z or Γ, and complete the table. (1½ points)
(Use the provided Smith chart)

Point no.	**P_1**	**P_2**	**P_3**	**P_4**	**P_5**
Z / Ω	∞		**0**		**100 + j 100**
Γ		**0**		**$0.7\angle{-62°}$**	

b) Indicate $|\Gamma| = 0.5$ in the Smith chart. (Hint: It is not a point) (½ point)

c) Point **P_5** represents a complex load impedance Z_{load}.

i. Indicate the normalized z_{load} in the Smith chart, and look up
   - the reflection coefficient, (½ point)
   - the (voltage) standing wave ratio, (½ point)
   - the return loss (in dB), (½ point)
   - the reflection loss (in dB) (½ point)

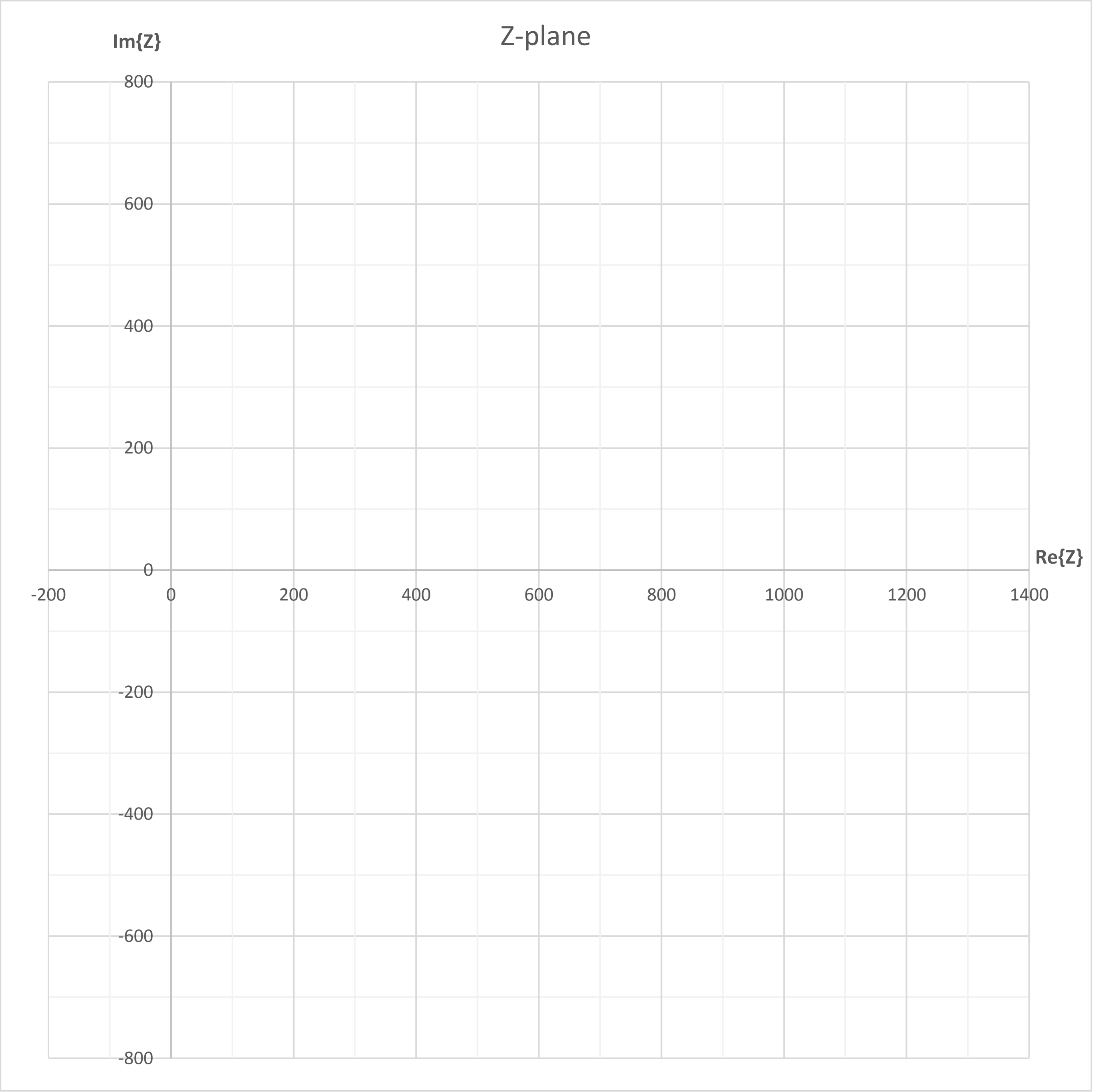
again assuming a reference impedance of $Z_0 = 50\ \Omega$.
(Hint: Use a ruler to determine $|\Gamma|$ of z_{load}, and compare it with value found at the "radially scaled parameters" Smith chart ruler at the bottom.)

Bonus points: (the full score can be reached without examining these questions) **(2 points)**

ii. With help of the Smith chart, design a passive compensation network to match Z_{load} of point **P₅** for *f* = 400 MHz to a 50 Ω source impedance of the RF generator.

- Define the locus path of two circuit elements to route from z_{load} to the normalized reference impedance. (1 point)

  (Hint: Remember the Dellsperger Smith Chart computer exercises, and the Smith chart navigation examples pages 178-180. Only 2 circuit elements are required. Different solutions are possible.)
- Determine the values of the circuit elements, and sketch the circuit of the matching network. (1 points)


Z-plane
Im{Z}
Re{Z}
800
600
400
200
0
-200
-400
-600
-800
-200
0
200
400
600
800
1000
1200
1400