

JUAS 2015 – RF Exam

$$\mu = \mu_0 \mu_r$$

$$\mu_0 = 4\pi \cdot 10^{-7} \text{ Vs/(Am)}$$

$$\varepsilon = \varepsilon_0 \varepsilon_r$$

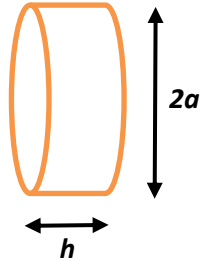
$$\varepsilon_0 = 8.854 \cdot 10^{-12} \text{ As/(Vm)}$$

$$c_0 = 2.998 \cdot 10^8 \text{ m/s}$$

$$\sigma_{\text{copper}} = 58 \cdot 10^6 \text{ S/m}$$

ID #: _____ Points: _____ of 20

Utilities: JUAS RF Course 2015 lecture script, personal notes, pocket calculator, ruler, compass, and your brain! (No cell- or smartphone, no iPad or wireless devices, text books or any other tools)



1. “Pillbox” Cavity

(6 points)

Design a simple “pillbox” (cylindrical) cavity, made out of copper ($\sigma_{\text{copper}} = 58 \cdot 10^6 \text{ S/m}$).

The eigen-frequency of the lowest mode with longitudinal electric field components is 460 MHz.

(The beam-pipe ports are neglected.)

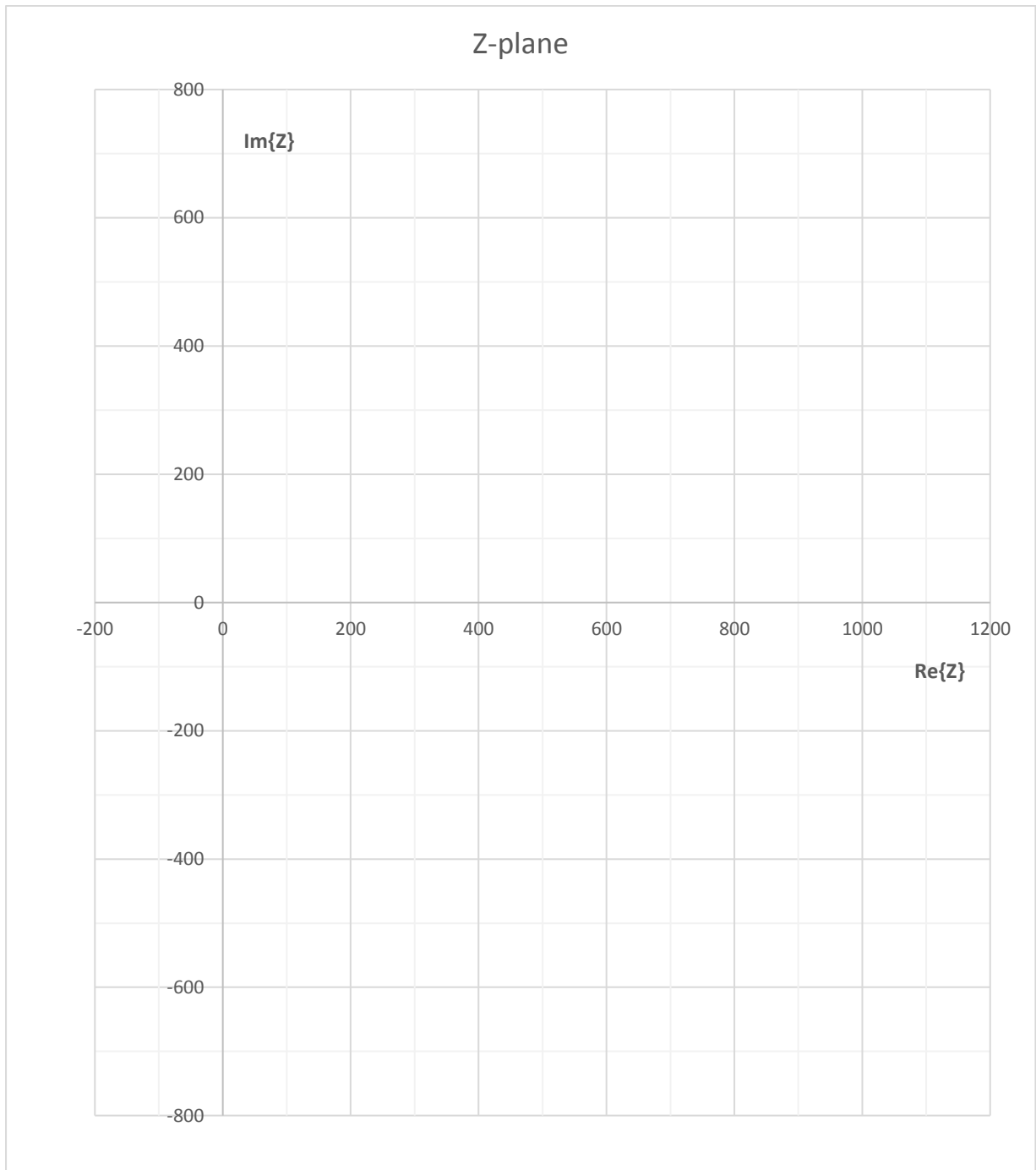
- a) The **magnetic** field if the TM_{010} mode has only **longitudinal** field components.
electric **transverse**
- (Mark the correct answer: **true**) (½ point)
false
- b) What is the radius a of the cavity? (1 point)
- c) What height h of the cavity has to be chosen, to achieve an (unloaded) Q -factor of $Q = 23500$? (2 points)
- d) What is the 3-dB bandwidth of the resonance? (½ point)
- e) Sketch the RLC equivalent circuit of this resonant mode, and determine the values. (1 point)
- f) The cavity is fed from a RF power amplifier with a source impedance of $R_g = 50 \Omega$. What is required transformer ratio of the coupling loop to match the cavity shunt impedance to the generator source impedance? (½ point)
- g) Calculate the necessary RF power for a gap voltage of 1 MV. (½ point)

2. Resonator analysis in the complex plane

(2 points)

At the upper 3-dB point (definition see RF lecture script) of a 1 GHz resonator, the complex impedance measures $|Z(\omega=6.289 \cdot 10^9 \text{ s}^{-1})| = 707 \Omega$.

- a) With help of compass and ruler, sketch the locus of $Z(f)$ in the complex Z -plane
- 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)
 - Estimate the value of the shunt impedance R . (½ point)



b) Determine the Q-value of the resonator.

(½ point)

3. Smith chart

(6 points)

- a) Indicate points $P_1 \dots P_5$ 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)

Point no.	P_1	P_2	P_3	P_4	P_5
Z / Ω	50	0			$R = 75 \Omega, C = 4.25 \text{ pF},$ $(@ f = 500 \text{ MHz})$
Γ			$1 \angle 0^\circ$	$0.5 \angle 45^\circ$	

- b) Indicate $|\Gamma| = 0.75$ in the Smith chart. (Hint: It is not a point) (½ point)
- c) At 400 MHz a complex load impedance measures $Z_{load} = (25 + j67) \Omega$.
- i. Indicate the normalized z_{load} in the Smith chart, and look up
- the reflection coefficient, (¼point)
 - the (voltage) standing wave ratio, (¼ point)
 - the return loss (in dB), (¼ point)
 - the reflection loss (in dB) (¼ point)

for 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.)

- ii. With help of the Smith chart, sketch a lossless matching network, and determine the component values to adapt to a 50Ω source impedance of the RF generator.
- Define the locus path lossless elements to route from Z_{load} to the normalized reference impedance. (1 point)
(Hint: Remember the Dellsperger Smith Chart computer exercises, only 2 lossless elements are required. Different solutions are possible.)
 - Determine the values of the lossless circuit elements. (2 points)

4. S-Parameters

(2 points)

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

$$S_A = \frac{1}{2} \begin{bmatrix} 0 & 1 & 1 \\ 1 & 0 & 1 \\ 1 & 1 & 0 \end{bmatrix} \quad S_B = \frac{1}{10} \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} \quad S_C = \frac{1}{\sqrt{2}} \begin{bmatrix} 0 & j & 1 & 0 \\ j & 0 & 0 & 1 \\ 1 & 0 & 0 & j \\ 0 & 1 & j & 0 \end{bmatrix} \quad S_D = \begin{bmatrix} 0 & -1 \\ -1 & 0 \end{bmatrix}$$

a) Assign the S-matrices ($S_A \dots S_D$) to the components: (1 point)

component	... dB directional coupler	transmission line, length = λ/\dots	... dB resistive power divider	... dB attenuator
S-matrix				

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

5. Multiple choice

(4 points)

Tick the correct answer(s) like this: .

(Except for questions 7. and 8., only one answer is correct)

- A coaxial line is filled homogeneous with a dielectric material, e.g. PTFE ("Teflon"). The signal velocity of a coaxial line of same physical length, but filled with air is (½ point)
 - identical
 - higher
 - lower
- TEM stands for (½ point)
 - Transient Electro-Magnetics
 - Transverse Electro-Magnetic mode
 - Turbo Electric Motor
- For a cylindrical ("pillbox") cavity, the eigen-frequencies are independent of the cavity height h dimension: (½ point)
 - False, for any eigen-mode the resonance frequency depends on height h and radius a
 - True only for the fundamental mode
 - True only for TM_{010} and TM_{110} modes
- When comparing with a charged particle passing the cavity gap with infinite velocity, the integrated field in the cavity gap, seen by a particle of finite velocity is (½ point)
 - increased due to
 - reduced due to
 - independent of the transit time factor.

5. Critical coupling (match at resonance) between resonator and generator occurs at (½ point)
- $Q_L = Q_{ext}$
 - $Q_L = Q_0/2$
 - $Q_L = 2 Q_0$
6. A 10 W RF generator is connected via a 20-dB attenuator to a 50 Ω load impedance. At the load we measure: (½ point)
- 1 W
 - -20 dBW
 - +20 dBm
7. What is true for 2-conductor transmission-lines? (½ point)
- Ideal for broadband (down to DC), low level signal transmission.
 - The signal transmission is based on “modes”.
 - Low losses at high frequencies, therefore ideal for high power RF transmission.
8. What is true for waveguides? (½ point)
- Ideal for broadband (down to DC), low level signal transmission.
 - The signal transmission is based on “modes”.
 - Low losses at high frequencies, therefore ideal for high power RF transmission.