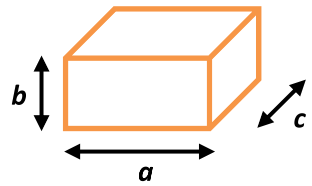
JUAS 2017 – RF Exam

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

Name: ________________________________ Points: ______ of 20 (25 with bonus points)

Utilities: JUAS RF Course 2017 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. "Brick-style" Cavity (5 points)

Design a "brick"-shaped, rectangular cavity with relative dimensions $c = 0.7 \cdot a$ and $a/b = 2$, operating at the fundamental mode of 500 MHz.

a) Of what type is the fundamental mode? (½ point)

b) What are the physical dimensions a, b and c of the cavity? (1½ points)
Hint: Free-space wavelength and frequency are linked through the speed-of-light: $\lambda_0 = \frac{c_0}{f}$

c) What is the (unloaded) *Q*-value of the cavity if it is made out of copper? (1 point)
($\sigma_{Cu} = 58.5 \cdot 10^6$ S/m)

d) Determine the Q-value if the cavity is made out of stainless steel. (½ point)
($\sigma_{SS} = 1.35 \cdot 10^6$ S/m)

e) What are the mode types and frequencies of the next two higher order modes? (1½ points)

2. Smith chart (5 points)

a) Indicate points **P1**…**P6** in the Smith chart, assuming a reference impedance Z_0 = 50 Ω.
From the Smith chart, determine the missing *Z* or *Γ*, and complete the table. (1 point)
(Use the provided Smith chart)

Point no.	P1	P2	P3	P4	P5	P6
Z / Ω	∞		0		50 + j 50	50 - j 100
Γ		0		0.7∠-62°		

b) Draw the locus of |*Γ*| = 0.5 in the Smith chart. (½ point)

c) Points **P5** and **P6** represent a complex load impedance Z_{load}.
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 Ω.
(Hint: Use a ruler to determine |*Γ*| of z_{load}, and compare it with value found at the "radially scaled parameters" Smith chart ruler at the bottom.)

d) With a simple loss-less matching circuit, a single reactive element, the complex loads represented by points **P5** and **P6** (two independent cases!) can be matched to the reference impedance of Z_0 = 50 Ω.

- Indicate the matching as graph in the Smith chart. (½ point)
- Sketch the matching circuit. (½ point)
- Evaluate the element value, assuming an operation frequency of *f* = 500 MHz. (½ point)

3. S-Parameters (2 points)

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

$$\boldsymbol{S_A} = \begin{bmatrix} 0 & 0.5 & 0.5 \\ 0.5 & 0 & 0.5 \\ 0.5 & 0.5 & 0 \end{bmatrix} \quad \boldsymbol{S_B} = \begin{bmatrix} 0 & \frac{j}{\sqrt{2}} & \frac{1}{\sqrt{2}} & 0 \\ \frac{j}{\sqrt{2}} & 0 & 0 & \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} & 0 & 0 & \frac{j}{\sqrt{2}} \\ 0 & \frac{1}{\sqrt{2}} & \frac{j}{\sqrt{2}} & 0 \end{bmatrix} \quad \boldsymbol{S_C} = \begin{bmatrix} 0 & -1 \\ -1 & 0 \end{bmatrix} \quad \boldsymbol{S_D} = \begin{bmatrix} 0 & 0 \\ 1 & 0 \end{bmatrix}$$

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/...	resistive power divider	isolator
S-matrix				

b) Fill the missing dB (coupler) and λ (transmission-line) information (...). (1 point)

4. Multiple choice (5 points)

Tick ***one*** correct answer like this: ☒.

1. Using an electromagnetic simulation software, the mesh cells in regions with electric field concentration should be made: (½ point)
   - ○ smaller
   - ○ larger
   - ○ doesn't matter
2. A sinusoidal RF signal is measured with an oscilloscope, having and internal 50 Ω termination. The cursors displays a peak-to-peak voltage of 500 mV. What is the signal power in dBm? (½ point)
   - ○ -1 dBm
   - ○ -2 dBm
   - ○ +4 dBm

3. For a "E"(or "TM") 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

4. Changing the height *h* of a cylindrical cavity operating on the TM_{110} dipole-mode will **NOT** change: (½ point)
   - its resonant frequency
   - its quality factor
   - its R/Q

5. The GSM standard specifies a minimum sensitivity requirement of -100 dBm for the signal reception, while the output power of the cell phone transmitter is typically in the order of 1 W. This corresponds to how many orders of magnitude in power? (½ point)
   - 5
   - 10
   - 13

6. A 4-port directional coupler has 10 dB coupling and 20 dB directivity. What is the relative level between the desired coupled output and the input signal? (½ point)
   - -10 dB
   - +20 dB
   - -30 dB

7. 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

8. Examples of TEM transmission lines are: (½ point)
   - Waveguides operating below cut-off frequency
   - Coaxial cables
   - Resonant cavities with input and output coupler

9. Critical coupling (impedance match at resonance) between resonator and generator occurs at (½ point)
   - $Q_L = Q_{ext}$
   - $Q_L = Q_0/2$
   - $Q_L = 2 \cdot Q_0$

10. A network analyser is used to (½ point)
    - Analyse signals in the frequency domain
    - To characterize the S-parameters of an RF element (DUT = device under test)
    - Measure and calibrate signals from the internet communication structure.

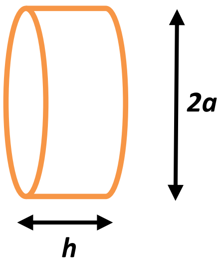
5. Skin-Effect (3 points)

A beam pipe with circular cross-section is given. It has a diameter of 10 cm and is made out copper (σ_{Cu} = 58.5 · 10^6 S/m), with a wall thickness of 2 mm.

a) Determine the skin depth at f = 1 GHz. Determine the real part of the impedance per meter at this frequency. (1½ points)
(Hint: This is the surface resistance as defined for lossy coaxial cables.)

b) Now assume the beam pipe is made from a stainless steel, which has a 43 times higher bulk resistivity compared to copper. (½ point)
What are the skin depth and the surface resistance (= resistance per unit square) now?

c) At which frequency (case: stainless steel) the wall thickness equals the skin depth? (1 point)



6. "Pillbox" Cavity (5 bonus points)

Analyze a simple cylindrical "pillbox" cavity (the beam-pipe ports are neglected). The cavity is made out of copper (σ_{Cu} = 58.5 · 10^6 S/m), has a dimension ratio h/a = 0.2 (a = radius, h = height), and operates at 200 MHz for the fundamental mode (TM_{010} = E_{010}).

a) Calculate the R/Q of the cavity! (½ point)

b) What is the is radius a of this resonator? (½ point)

c) Determine the lumped elements R, L, and C of the equivalent parallel R-C-L circuit. (1½ points)

d) Now assume that this cavity is made from a stainless steel, which has a 43 times higher resistivity than copper. For the same geometrical dimensions, re-compute the resonance frequency, R/Q, and the unloaded Q-value. Which values of the parallel equivalent circuit has changed? (1½ points)

e) The copper cavity is now scaled to a resonance frequency of 100 MHz. Indicate the scaling ratio of all linear dimensions. What is the new Q-value? (1 point)