JUAS 2004 RF-Technology
Question 1 (6 points)

Name:

A TM_{010} mode copper pillbox cavity has a resonance frequency of 500 MHz. For this mode the r/Q is 100 Ω. The value of the elementary charge $e = 1.6*10^{-19}$ As.

1. Determine the diameter (2a) and the full height (2h) of the cavity. (1 point)
2. Calculate the Q factor. (1 point)
3. Determine the values of the elements r, L and C of the equivalent circuit. (2 points)
4. The nominal parameters of the LHC proton beam at injection are
   - particles per bunch: $1.1*10^{11}$
   - DC beam current: 0.56 A
   - Bunch duration (r.m.s): 0.28 ns (short as compared to 500 MHz period)
   - Energy: 7 TeV (highly relativistic, assume $\beta = v/c = 1$)

   What would be the voltage induced in the pillbox cavity by a single bunch? (1 point)
   In the worst case, what would be the stationary end value of the cavity voltage? (1 point)

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Question 2 (5 points)

Each correct cross: 0.5 points, each incorrect cross: -0.5 points, minimum number of points per question: 0 points.

1. Which mode is the fundamental mode (lowest cut-off frequency) in a cylindrical waveguide of circular cross-section *without* inner conductor? (check 1)
   - o TE
   - o TEM
   - o TM
2. Which mode is the fundamental mode in a cylindrical waveguide *with* inner conductor (coaxial line)? (check 1)
   - o TE
   - o TEM
   - o TM
3. Adding capacitive loading to a cavity (check 1)
   - o lowers the resonance frequency
   - o does not affect the resonance frequency
   - o increases the resonance frequency
4. Advantages of a nose cone cavity compared to an ordinary pill box cavity of same dimension (check 1)
   - o Smaller skin depth
   - o Higher r/Q
   - o Higher Q
5. Superconducting cavities usually do not have nose cones because (check 2)
   - o Superconductors are expensive, so don't waste them for nose cones
   - o Nose cones are sensitive to multipactoring, which causes excessive heating and must therefore be avoided
   - o The shunt impedance is so high that it can't be increased any more by changing the geometry
   - o Superconductors can't stand the high electric field around the nose cones
6. When doing numerical simulations, geometrical symmetries are exploited in order to (check 2)
   - o ensure convergence of the simulation algorithms for resonant structures
   - o reduce calculation time
   - o account for the transit time factor
   - o rule out certain higher order modes
7. The GSM standard specifies a minimum sensitivity requirement of about -100 dBm, while the maximum output power is in the order of 1 W. This corresponds to how many orders of magnitude in power? (check 1)
   - o 5
   - o 8
   - o 13

   (Exact values: -102 dBm minimum sensitivity, 1 to 5 W maximum output power)
8. When you cover then antennna of your mobile with your hand while using it, the attenuation caused is in the order of 20 dB. Human tissue is a rather good absorber, so you can neglect reflections for this calculation. How many percent of the mobile's output power stay in the head and hand? (check 1)
   - o 9
   - o 99
   - o 99.99

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Question 3 (4 points)

The S matrices of four RF components are given: an amplifier, a 3 dB attenuator, an ideal isolator and a special component. An isolator serves for seperating a generator from a load. The power can just go from the generator at port 1 to the load at port 2, but not back to the generator.
Identify the components! (2 points)

$$[S_1] = \begin{bmatrix} 0 & \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} & 0 \end{bmatrix}$$

$$[S_2] = \begin{bmatrix} 0.63e^{3.07j} & 0.061e^{0.93j} \\ 5.3e^{1.43j} & 0.17e^{-1.81j} \end{bmatrix}$$

$$[S_3] = \begin{bmatrix} 0.28 & 0.96 \\ 0.96 & -0.28 \end{bmatrix}$$

$$[S_4] = \begin{bmatrix} 0 & 0 \\ 1 & 0 \end{bmatrix}$$

An n-port is *matched* if the reflection coefficients S_{kk} at all ports are 0.

An n-port is *reciprocal* if the transmission between any two ports is equal in amplitude and phase in forward and in backward direction. The reflection coefficients need not to be equal. Mathematically speaking, the condition is $S_{kl} = S_{lk}$.

An n-port is *lossless*, if the S matrix is unitary, $[S^*]^T \cdot [S]=1$. For a 2-port this gives the three conditions

$$|S_{11}|^2 + |S_{21}|^2 = 1$$
$$|S_{12}|^2 + |S_{22}|^2 = 1$$
$$S_{11}^* \cdot S_{12} + S_{21}^* \cdot S_{22} = 0$$

If at least one of the three equations above is not met, then the n-port is not lossless.

Check each of the components above in terms of match and reciprocity! (2 points)

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Bonus question:

- Which one of the 2-ports is lossless? (1 point)
- What could the special component be? (1 point)

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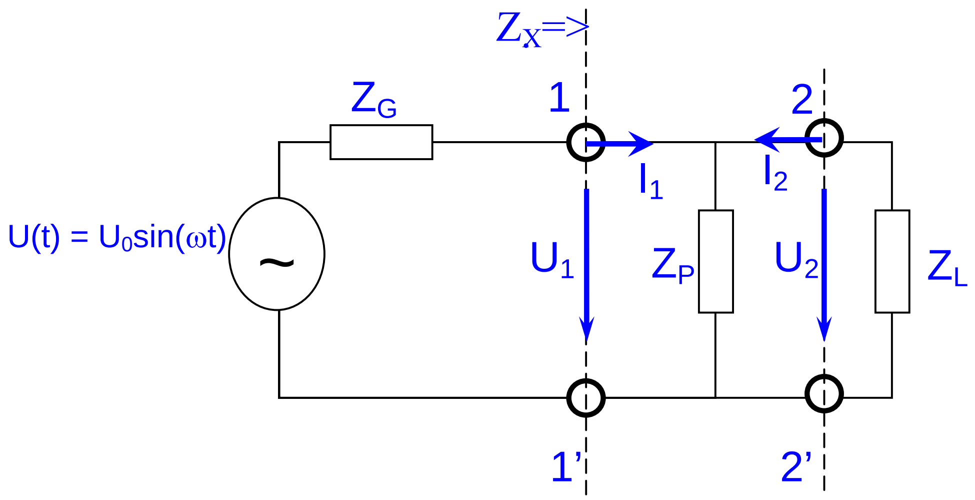
Question 4 (5 points)

Name:

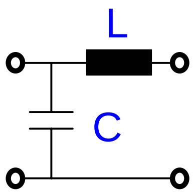
An RF generator with generator impedance $Z_G = 50\Omega$ and f = 100 MHz is feeding a resistive load impedance with $Z_L = 50\Omega$. Between these two elements a scattering 2-port, modeled by a parallel impedance of $Z_P = 25\Omega$ is connected as sketched below.



1. Calculate the impedance Z_X seen from the generator in the plane 1-1'. (1 point)
2. Complete the S matrix of the 2-port constituted by Z_P. (2 points)
   Hint: You may exploit the symmetry...

$$[S] = \begin{bmatrix} . & . \\ 0.5 & . \end{bmatrix}$$

3. In order to avoid power being reflected back to the generator, a lossless matching circuit shall be inserted in the plane 1-1'. After several meetings a standard matching circuit has been chosen: the resonant match (see picture). Illustrate this matching in the Smith chart! (Mark the locus of Z_X and show how we get to the center of the Smith Chart) (2 points)



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4. Bonus question: determine the values of L and C! (2 points)