# JUAS 2004 RF-Technology
# Solutions

## 1 Pillbox cavity

1. $\lambda = \frac{c}{f} = 2.61a = 0.6m \Rightarrow 2a = \frac{2\lambda}{2.61} = 0.46\text{m}$
2. $\frac{r}{Q} = 370\frac{h}{a} \Rightarrow 2h = 2a\frac{r}{Q}\frac{1}{370} = 0.124\text{m}$
3. The skin depth $\delta = \sqrt{\frac{2}{\omega\sigma\mu}} = 2.96\mu\text{m}$ with $\omega = 2\pi f$, $\sigma = 58\text{MS/m}$ for copper and $\mu = \mu_0 = 4\pi \cdot 10^{-7}$.
   $Q = \frac{0.383\lambda}{\delta}\left(1 + \frac{0.192\lambda}{h}\right)^{-1} = 27200$
4. $r = \frac{r}{Q}Q = 2.72M\Omega$
   $L = \frac{1}{\omega}\frac{r}{Q} = 32\text{nH}$
   $C = \frac{1}{\omega}\frac{1}{\frac{r}{Q}} = 3.2\text{pF}$
5. $\Delta U = \frac{q}{C} = \frac{1.1 \cdot 10^{11} e}{C} = 5.54\text{kV}$
   $U_{end} = 2rI_0 = 3.05\text{MV}$ (!!)

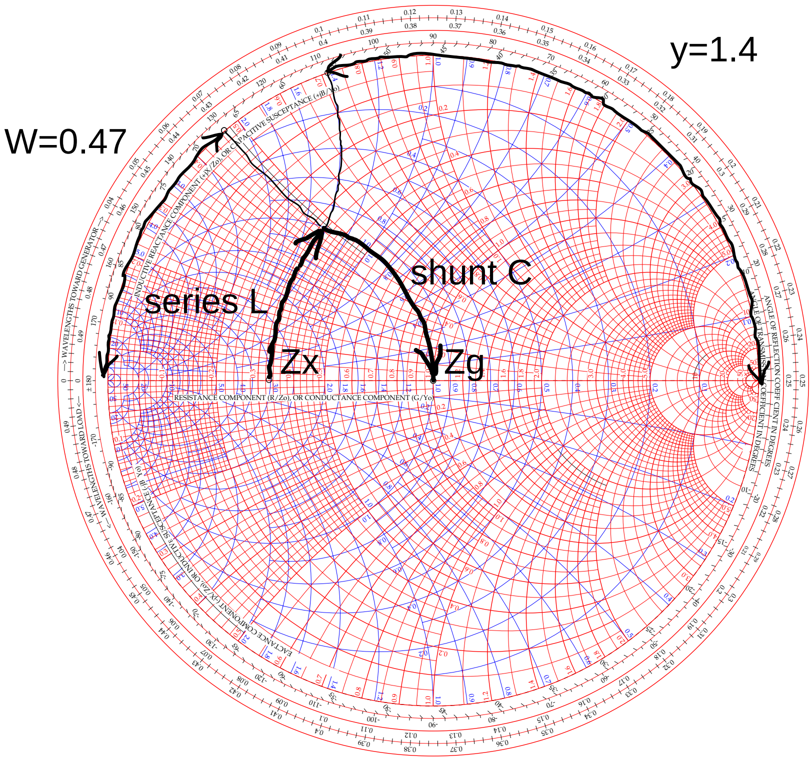
## 3 S-matrices

$[S_1]$ : $S_{21} = S_{12} = -3$ dB $\Rightarrow$ 3 dB attenuator, matched, reciprocal, lossy (not lossless)
$[S_2]$ : $|S_{21}| > 1 \Rightarrow$ amplifier, not matched, nonreciprocal, active component (not lossless)
$[S_3]$ : special component, not matched, reciprocal, lossless
$[S_4]$ : $S_{21} = 1$, all the other matrix elements zero $\Rightarrow$ isolator, matched, nonreciprocal, lossy

Bonus question: $[S_3]$ is lossless and reciprocal. The transmission coefficient is much higher than the reflection coefficient. This indicates that it could be an abrupt change in characteristic impedance in a transmission line. An example would be a cross-section change in a waveguide or a transition between coaxial lines with different dielectrics.

## 4 Scattering 2-port

1. $Z_P$ and $Z_L$ are in parallel $\Rightarrow \frac{1}{Z_X} = \frac{1}{Z_P} + \frac{1}{Z_L}$, giving $Z_X = 16.7\Omega$.
2. $S_{11} = \Gamma$ is the reflection coefficient at port 1. $\Gamma = \frac{Z_X - Z_G}{Z_X + Z_G} = -0.5$. Since the 2-port $Z_P$ is symmetric, we have $S_{22} = S_{11}$ and $S_{12} = S_{21}$. The complete S-matrix is then
$$[S] = \begin{pmatrix} -0.5 & 0.5 \\ 0.5 & -0.5 \end{pmatrix} \quad (1)$$
3. See Smith Chart!




4. Bonus question:
From the Smith Chart we find for the normalized impedance of the inductor $W = 0.47$. After denormalization, we get $Z = W * Z_0 = 0.47 * 50\Omega = 23.5\Omega$. The value of the series inductance is given by $Z = \omega L \Rightarrow L = \frac{Z}{\omega} = 37\text{nH}$.
The normalized admittance $y$ was found to be 1.4. Denormalization yields $Y = y/Z_0 = 1.4/50\Omega = 0.028S$. We have to *divide* by the system impedance $Z_0$ since we are working with an admittance. Finally, with $Y = \omega C$ we find $C = \frac{Y}{\omega} = 45\text{pF}$.

# 2 Multiple Choice

1. Which mode is the fundamental mode (lowest cut-off frequency) in a cylindrical waveguide of circular cross-section *without* inner conductor? (check 1)
   - [x] TE
   - [ ] TEM
   - [ ] TM
2. Which mode is the fundamental mode in a cylindrical waveguide *with* inner conductor (coaxial line)? (check 1)
   - [ ] TE
   - [x] TEM
   - [ ] TM
3. Adding capacitive loading to a cavity (check 1)
   - [x] lowers the resonance frequency
   - [ ] does not affect the resonance frequency
   - [ ] increases the resonance frequency
4. Advantages of a nose cone cavity compared to an ordinary pill box cavity of same dimension (check 1)
   - [ ] Smaller skin depth
   - [x] Higher r/Q
   - [ ] Higher Q
5. Superconducting cavities usually do not have nose cones because (check 2)
   - [ ] Superconductors are expensive, so don't waste them for nose cones
   - [x] Nose cones are sensitive to multipactoring, which causes excessive heating and must therefore be avoided
   - [ ] The shunt impedance is so high that it can't be increased any more by changing the geometry
   - [x] 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)
   - [ ] ensure convergence of the simulation algorithms for resonant structures
   - [x] reduce calculation time
   - [ ] account for the transit time factor
   - [x] 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)
   - [ ] 5
   - [ ] 8
   - [x] 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)
   - [ ] 9
   - [x] 99
   - [ ] 99.99