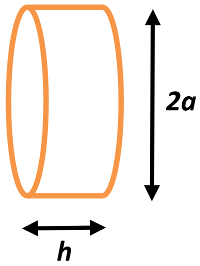
$\mu = \mu_0 \, \mu_r$
$\mu_0 = 4\pi \cdot 10^{-7}$ Vs/(Am)
$\varepsilon = \varepsilon_0 \, \varepsilon_r$
$\varepsilon_0 = 8.854 \cdot 10^{-12}$ As/(Vm)
$c_0 = 2.998 \cdot 10^{8}$ m/s
$\sigma_{copper} = 58 \cdot 10^{6}$ S/m

JUAS 2015 – RF Exam

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 ($\sigma_{copper} = 58 \cdot 10^{6}$ 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 / electric field if the TM_{010} mode das only longitudinal / transverse field components.

(Mark the correct answer: true / false) (½ point)

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)

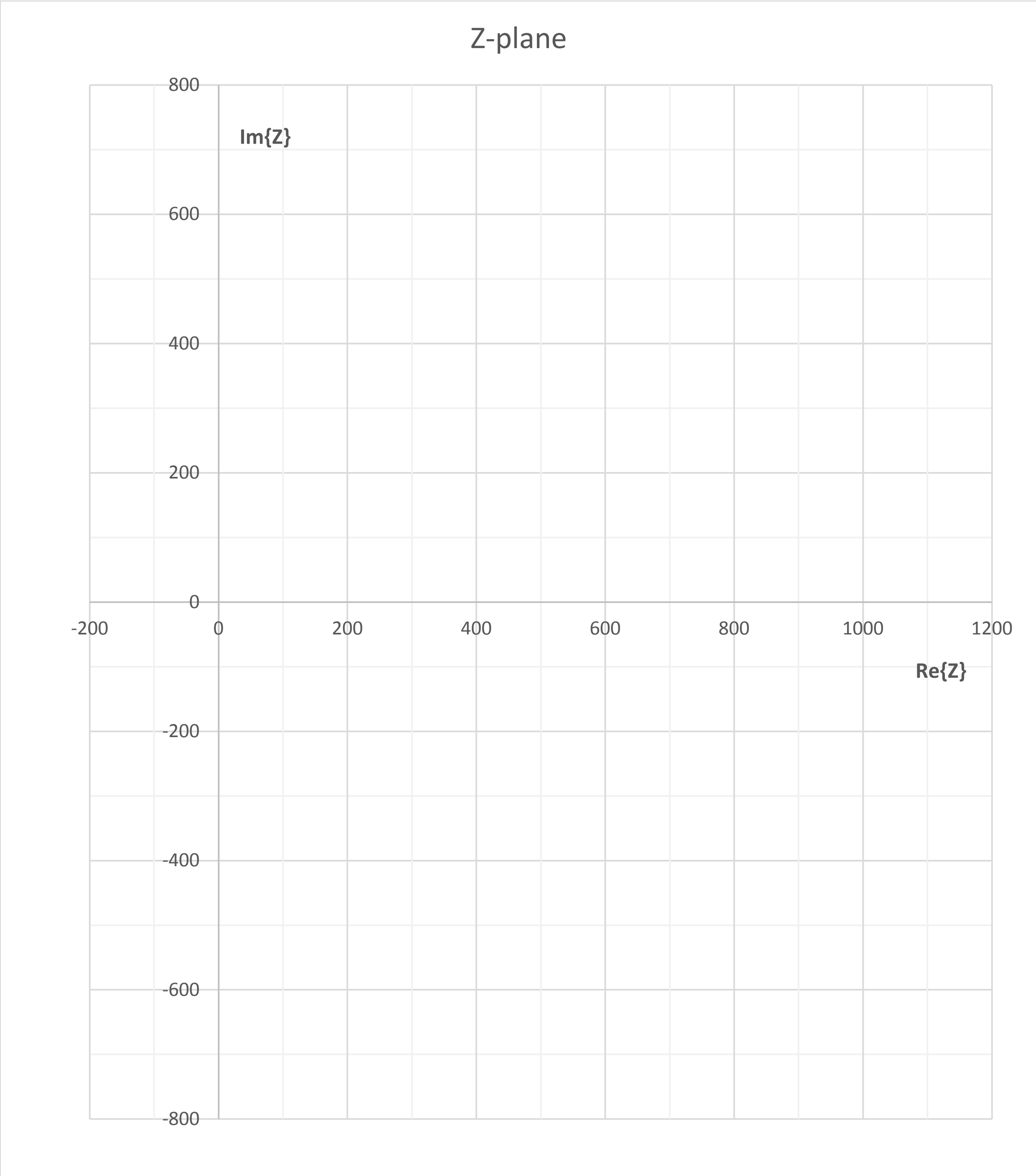
f) The cavity is fed from a RF power amplifier with a source impedance of R_g = 50 Ω. What is required transformer ratio of the coupling loop to match the cavity shunt impedance to the generator source impedance? (½ point)

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 $|Z(\omega=6.289\ 10^{9}\text{s}^{-1})| = 707\ \Omega$.

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 **P1…P5** 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. (1½ points)

Point no.	**P1**	**P2**	**P3**	**P4**	**P5**
***Z* / Ω**	**50**	**0**			*R* = 75 Ω, *C* = 4.25 pF, (@ *f* = 500 MHz)
Γ			**1∠0°**	**0.5∠45°**	

b) Indicate \|*Γ*\| = 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) Ω.

i. Indicate the normalized z_{load} in the Smith chart, and look up

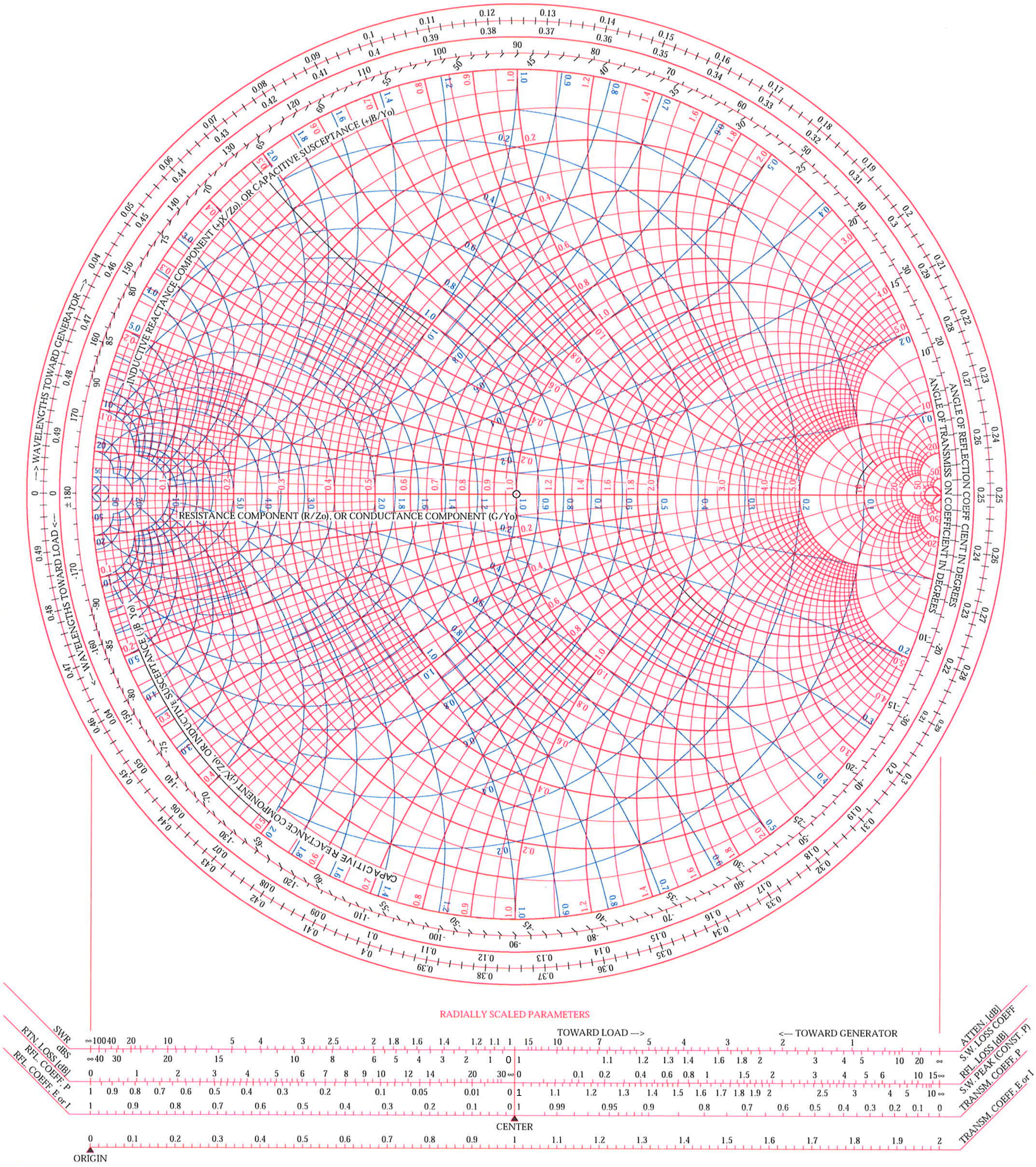
- the reflection coefficient, (¼point)
- the (voltage) standing wave ratio, (¼ point)
- the return loss (in dB), (¼ point)
- the reflection loss (in dB) (¼ point)

for a reference impedance of Z_0 = 50 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.)

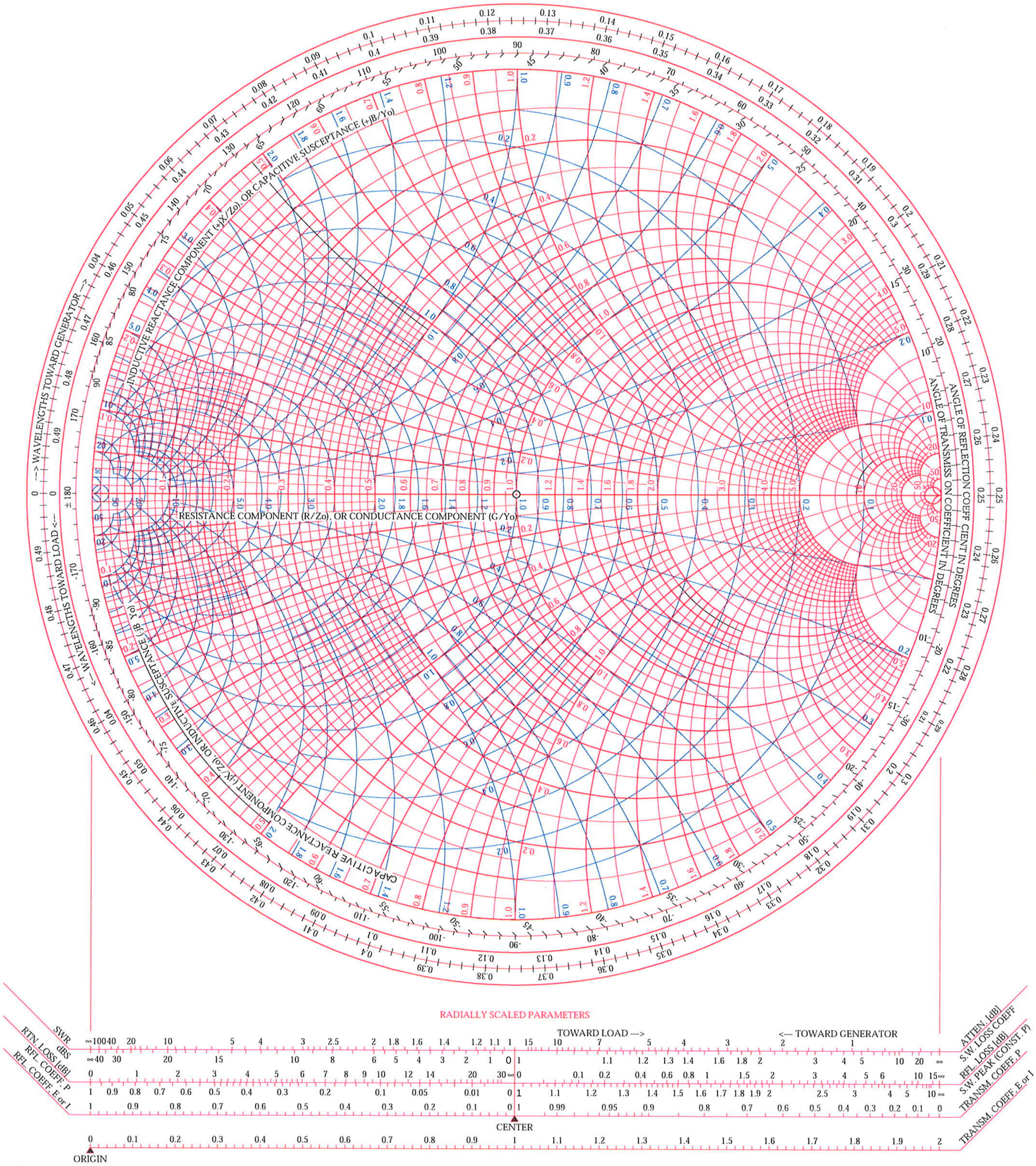
ii. With help of the Smith chart, sketch a lossless matching network, and determine the component values to adapt to a 50 Ω source impedance of the RF generator.

- 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)

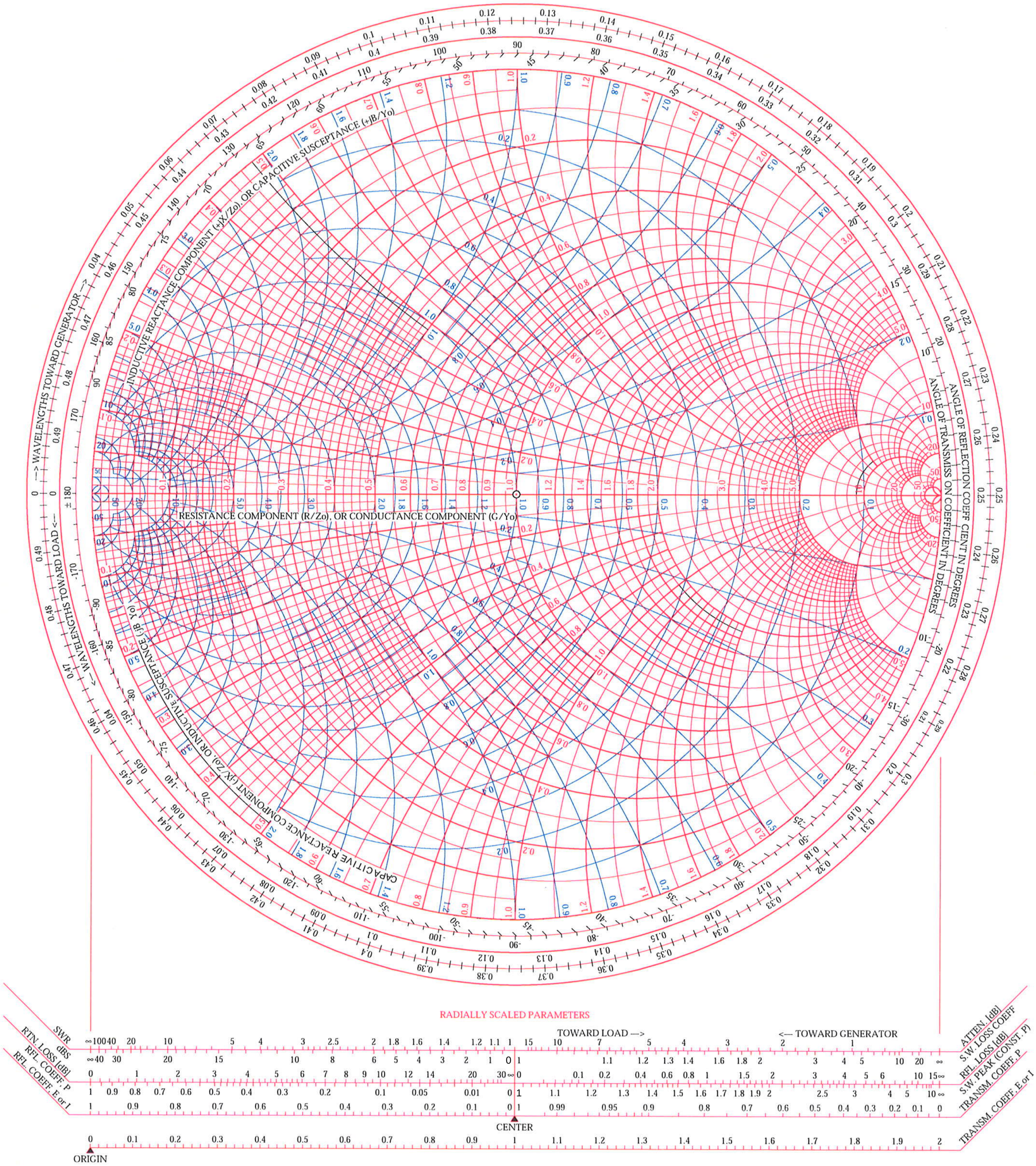
NORMALIZED IMPEDANCE AND ADMITTANCE COORDINATES



NORMALIZED IMPEDANCE AND ADMITTANCE COORDINATES



NORMALIZED IMPEDANCE AND ADMITTANCE COORDINATES



4. S-Parameters (2 points)

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

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

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

component	... dB directional coupler	transmission line, length = λ/...	... 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)

1. 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)
   - o identical
   - o higher
   - o lower
2. TEM stands for (½ point)
   - o Transient Electro-Magnetics
   - o Transverse Electro-Magnetic mode
   - o Turbo Electric Motor
3. For a cylindrical ("pillbox") cavity, the eigen-frequencies are independent of the cavity height *h* dimension: (½ point)
   - o False, for any eigen-mode the resonance frequency depends on height *h* and radius *a*
   - o True only for the fundamental mode
   - o True only for TM_{010} and TM_{110} modes
4. 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)
   - o increased due to
   - o reduced due to
   - o independent of

   the transit time factor.

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