Context. This mini–project consolidates your skill with the Smith chart for *lossless* transmission lines, including walking on the chart, reading reflection metrics, and designing single–stub shunt tuners. You will present both chart-based constructions and analytical checks, and validate numerically in MATLAB/Python.

Learning outcomes

By the end you should be able to:

- Normalize impedances/admittances and place them on the Smith chart (impedance and admittance views).
- Compute and interpret Γ, VSWR, return loss, and input impedance along a lossless line.
- Move on the chart *towards generator* / *towards load* and track phase rotations.
- Design *short-circuited* single–stub tuners in shunt (two valid solutions).
- Estimate matching bandwidth when physical lengths are fixed and frequency varies.
- Infer a possible unknown load from slotted–line (SWR and minima position) measurements.

Given & notation

Assume a *lossless* line:

$$Z_0 = 50\,\Omega, \qquad f_0 = 3\,\text{GHz}, \qquad \lambda_0 = 0.1\,\text{m}, \qquad \beta_0 = \frac{2\pi}{\lambda_0}.$$

Load: $\boxed{Z_\text{L} = 30 - j\,40\ \Omega}$.

Project tasks (produce all intermediate steps)

P1. Load placement and basic metrics.

(a) Normalize $z_\text{L} = Z_\text{L}/Z_0$, **mark the point** on the Smith chart (impedance view). Compute Γ_L, $|\Gamma_\text{L}|$, $\angle\Gamma_\text{L}$ (in degrees), VSWR, and return loss (dB). *Show working and units.*

(b) Find Z_in at $l = \lambda_0/8$ *towards the generator*:

P2. Single-stub *shunt* match (short–circuited stub).

(a) Convert the line point at distance d from the load to **admittance** view: $y(d)$. By rotating *towards the generator*, find the two locations d_1 and d_2 (in wavelengths at f_0) where $\Re\{y(d)\} = 1$. Record the corresponding susceptances $b_1 = \Im\{y(d_1)\}$ and $b_2 = \Im\{y(d_2)\}$. *Show the two intersections on the $g = 1$ circle.*

(b) For each location d_i, choose a shorted shunt stub with length $l_{s,i}$ such that

$$y_s = -j\cot(2\pi l_{s,i}) = -j\,b_i \quad \Rightarrow \quad y_{\text{tot}} = 1 + j0.$$

Report principal solutions $0 < l_{s,i} < \frac{1}{2}\lambda$ and note periodicity (equivalent $l_{s,i} \pm \frac{n}{2}\lambda$).

(c) Convert d_i and $l_{s,i}$ to millimetres at f_0 using $\lambda_0 = 100\,\text{mm}$. List the **two valid designs** as ordered pairs: $(d_1,\, l_{s,1})$ and $(d_2,\, l_{s,2})$ in both wavelengths and millimetres.

P3. Bandwidth estimate (RL$\geq$ 10 dB). Treat the *physical* distances found at f_0 as fixed in space:

$$d_i^{(\text{mm})} = \text{const}, \qquad l_{s,i}^{(\text{mm})} = \text{const}.$$

Sweep frequency f about f_0. For each f, convert those physical lengths to electrical lengths, recompute the input reflection coefficient $\Gamma_{\text{in}}(f)$ of the matched network, and plot $|\Gamma_{\text{in}}(f)|$.

- Report the contiguous frequency range(s) around f_0 where $|\Gamma_{\text{in}}| \leq 0.316$ (i.e. return loss $\geq 10\,\text{dB}$).
- Quote the **fractional bandwidth** (FBW) in % relative to f_0: $\text{FBW} = 100 \times (f_{\text{high}} - f_{\text{low}})/f_0$.
- Include the MATLAB/Python plot (label axes and units).

P4. Concept: Series vs shunt stubs (brief note). Using the Smith chart, explain how a *series* shorted stub design differs:

- Series elements move along *constant–resistance* circles on the *impedance* chart; shunt elements move along *constant–conductance* circles on the *admittance* chart.
- Comment on layout: when and why shunt implementations are typically preferred on RF PCBs/microstrip over series stubs.

P5. Measurement: Inferring a possible load from slotted-line data. A slotted line shows SWR = 3 and the *first* voltage minimum occurs at distance $\ell_{\min} = \lambda/12$ from the load (towards the generator). Using the Smith chart:

(a) Determine $|\Gamma| = \frac{S-1}{S+1}$ and the phase of Γ consistent with the given $\ell_{\min}$, noting the 2π ambiguity.

(b) Give one consistent normalized load z_{L} and the corresponding Z_{L} for $Z_0 = 50\,\Omega$. Clearly state the phase choice you adopted.

(c) Numerically verify the results.

What to submit (single ZIP)

- **Report (PDF)**: clean Smith chart constructions (annotated), all intermediate values with units, and the bandwidth plot.
- **Code (MATLAB/Python)**: a runnable script or live script that reproduces all computed numbers and the $|\Gamma_{\text{in}}(f)|$ plot.

Grading rubric

Item	Marks
P1 Load placement & metrics (correctness, units, clarity)	15
P2 Two shunt–stub designs (chart steps, d, l_s in λ and mm)	35
P3 Bandwidth sweep (method, plot quality, FBW % computation)	30
P4 Series vs shunt (concise, technically accurate comparison)	10
P5 Slotted–line inference (consistent solution, reasoning)	10
Total	**100**

Constraints & expectations

- **Clarity:** annotate all Smith chart readings.
- **Units:** report both wavelength fractions and millimetres at f_0.
- **Verification:** every chart result must be checked by an analytical formula and computation.
- **Assume lossless** lines and stubs unless explicitly stated.
- **Original work:** quote external tools if used (eg: ChatGPT)

Academic integrity

Discuss concepts freely, but your report, figures, and code must be your own. Cite any external tools or charts used.