SMITH/85 - SMITH CHARTS ON THE TI-85 CALCULATOR

VERSION 1.1 -- Provisional

C O N T E N T S

I INTRODUCTION

1.1 Purpose of the Software

SMITH/85 is a program designed to perform basic emulation of a Smith chart. It can be used for both design and evaluation purposes. The program operates in both admittance and impedance parameters, and the operator can freely switch between the two. Only lossless lines are modelled by the software, as is typical for the design and evaluation of matching networks. The user should have basic familiarity with the Smith chart in order to fully utilize this program.

---------- WARNING WARNING WARNING ----------

The author assumes no responsibility for the results obtained using this software. The end user should use prudent engineering design practices, which include, but are not limited to: Using other software to generate alternate data sets; performing calculations by hand; using a graphical solution; and constructing a physical unit.

1.2 Memory Requirements

SMITH/85 requires about 5K of free RAM for its data and code. This version of the program does not preserve any data between sessions; however, certain variables are left intact when the program ends that could be used by other TI-85 applications. These are detailed in section 5.3.

1.3 Notation Conventions

Items appearing within brackets are TI-85 keystrokes. Some of these keys are menu keys, such as [MAIN], while others are fixed-function keys on the keyboard.

Quote marks " " surround references to fields on the LCD display. For example, the field marked "VSWR" indicates the computed voltage standing-wave ratio.

II HARDWARE REQUIREMENTS - LOADING THE SOFTWARE

2.1 TI-Link

SMITH/85 is supplied on a floppy diskette suitable for either an IBM personal computer or an Apple Macintosh. In order to load SMITH/85 into your calculator, you must have the TI-GRAPH LINK kit and software installed on your computer.

To load SMITH/85 into your calculator, follow the instructions that came with TI-GRAPH LINK. The filename on the disk is SMITH, and the name will be the same when it loads into the calculator.

2.2 Software Conflicts

Some users will receive an error message when starting SMITH/85 such as "Illegal Data Type." These error messages are caused by SMITH/85 attempting to use a variable that has been defined differently in another program.

To resolve the error, delete the variable involved by going to the TI-85 MEMORY menu by typing [2nd] [MEM].

III GETTING STARTED: WORKING A SAMPLE PROBLEM

3.1 Starting SMITH

To start the program, you may do any of the following:

- Type "SMITH" and press [ENTER] at the home screen.
- Press [PRGM] and select SMITH from the menu of items; then press [ENTER].
- Call SMITH from another TI-85 program.

Each time SMITH/85 executes, it will display the title and copyright message. It will then prompt for the characteristic impedance of the line being analyzed.

TIP: SMITH/85 can deal in either absolute or normalized impedances. To use normalized impedances (the type used with a real Smith chart), enter a characteristic impedance of 1 Ohm at the starting prompt.

SMITH/85 is menu-driven software. To move around inside the program, press the function key (F1 - F5) that corresponds to the selection desired.

3.2 Display Features

Once SMITH has been started, the main display will appear. It looks like this (assuming that a characteristic impedance of 50 Ohms was selected):

```
Z0   = 50
ZR   = 50
Bl   = 0.0000
Zin  = (50.0<0.0)
       (50.0,0.0)
tr   = 0.00
VSWR = 1.00  :1
```

Also, below this display, the MAIN MENU appears:

```
| ZRChg | BLChg | Walk  | Oper | Quit |
 -------------------------------------
```

The lines on the display show:

* Z0: The selected characteristic impedance

* ZR: The selected or computed load impedance. This can be a complex number; it will be displayed in rectangular form if complex.

* Bl: The number of electrical degrees from the load on the line.

* Zin: The input impedance of the line at position Bl. It is always given in both polar and rectangular forms.

TIP: The program starts in IMPEDANCE mode. You can tell when the calculator is in this mode; just look to see if the display announces "Zin."

* Yin: The input admittance of the line. You won't see this unless the program is instructed to go into admittance mode (by menu command).

* tr : The reflectance coefficient of the load. This can be a complex number; it will be expressed in polar notation if so.

* VSWR: The voltage standing-wave ratio on the line (the ratio of maximum to minimum line voltage).

TIP: Since the program starts with ZR=Z0, the starting VSWR is always 1:1.

3.3 Impedance and Admittance Modes

Depending on what is being done, it is often convenient to express a quantity as an impedance or an admittance. SMITH/85 supports both modes, and always starts in impedance mode.

Switching back and forth between these modes changes the way the data is displayed, but does not affect the data unless other operations are selected in that mode.

To switch modes, first press [Oper] at the MAIN MENU:

```
| ZRChg | BLChg | Walk  | Oper | Quit |
 -------------------------------------
```

This will move to the OPERATIONS menu, where [Y<>Z] would be selected:

```
| MovM  | Y<>Z  | Next  | Shunt| Back |
 -------------------------------------
```

TIP: Press [BACK] at any menu to stop an operation.

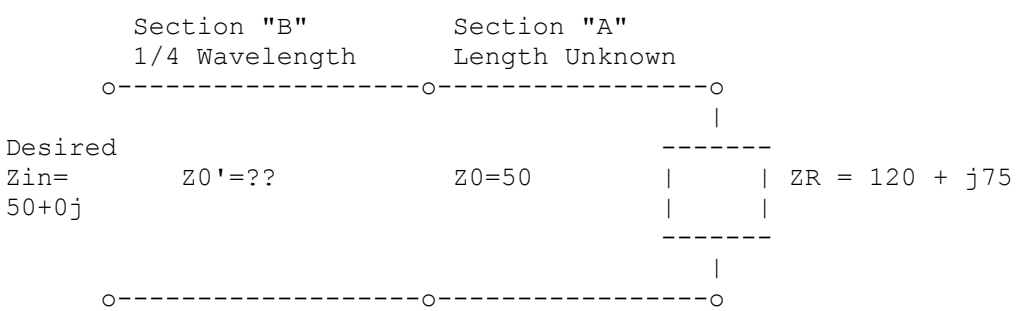
Example: The impedance display reads (50.0,0.0) in rectangular. Pressing [Oper][Y<>Z] results in the admittance mode display of:

```
Yin(S) = (.020<0.000)
         (.020,0.000)
```

The data is not altered. Press [Oper][Y<>Z] again to return to impedance mode.

3.4 Designing a 1/4 Wave Matching Transformer (Load Impedance Complex)

The following problem setup is assumed in the discussion:



A 1/4 wavelength transformer works well when the load impedance is purely real. When the impedance is complex, a "trick" is used. A length of transmission line continuously transforms the impedance to an infinite number of values, depending on its length. There will always be two pure "real" values every 180 degrees on the line. The problem, of course, is to find where the value is "real" and what that value will be. To solve this problem:

1. Start SMITH/85, and set Z0=50.

2. Press [ZR Chg], and enter the load, 120 + j75.

TIP: To enter complex impedances into the TI-85, type in as follows:

(real, imag)

For example, when the calculator prompts:

New Value for ZR?
?

You type:

(120 , 75) [ENTER]

3. To find out where the SWR circle intersects the real axis, use the MKREAL command. It's located on the MovM menu. To get there, press:

[Oper] --- Go to OPERATIONS menu
[MovM] --- Go to the MOVE/MAGNITUDE menu
[MkRea] --- Use the MKREAL (Make Real) command.

TIP: The MKREAL command can be used to find out the two points on the SWR circle where the input impedance or admittance is purely real. It works in all modes.

In response to the [MkRea] key, the calculator responds:

Please Choose Angle
and Resultant Zin:

[1] Zin = (173.28<0.0)
Angle= 11.6

[2] Zin = (14.4<0.0)
Angle= 101.6

| [1] | [2] | | |Abort |

For this example, choose [1]. Note that since two angles give a pure Zin, the calculator gives you a choice.

4. The calculator returns back to the MAIN DISPLAY and menu, displaying a Zin of 173.3 Ohms resistive at a distance of 11.58545 degrees from the load.

This means that the unknown length of cable "A" in this example should be 11.585 electrical degrees.

TIP: When constructing matching networks, be sure to measure the velocity factor of the medium being used. Velocity factor varies from cable to cable, and cable can be defective.

5. Exit SMITH/85 and compute the impedance of the 1/4 wave matching section:

$$Z0' = (ZR*Zin)^{1/2} = (173.3 * 50)^{1/2} = 93.08 \text{ Ohms}$$

TIP: SMITH/85 has no "canned" formulas for matching networks. However, it CAN quite readily verify the solution just obtained:

1. Repeat steps 1-4 above; the display should show a Zin of 173.3 Ohms resistive at 11.58545 degrees from the load.

2. Hook in the 1/4 wave section of 93.08 Ohm cable and determine the final input impedance:

Press [Oper] to go to the OPERATIONS menu
Press [Next] to go to a new section of cable. SMITH/85 prompts:

```
What is the Z0 of
the next section of
line?
?
```

Type in 93.08 [ENTER], the new characteristic impedance. The program returns to the main display and reports that the VSWR in the matching section will be 1.86 : 1.

3. The new line is 1/4 wavelength long, so press the [BlChg] key. The program prompts:

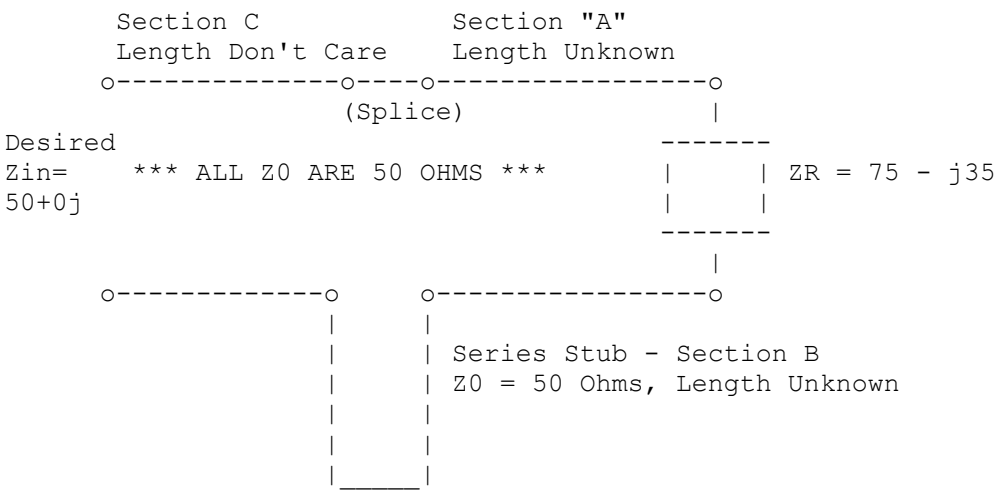
```
New distance Bl from
Load -- Electrical
Degrees?
?
```

Type in 90 [ENTER] which represents a 1/4 wavelength.

4. The calculator returns to the main display mode, and reports that the input impedance is exactly 50 + 0j Ohms, verifying the design effort.

3.5 Matching Impedance With a Series Stub

The following problem setup is assumed in the discussion:



The series stub is an unusual solution to matching; it works just like a parallel stub, except that impedances are used for the calculation, since series impedances are additive. In actual application, a true current-balun should be used between this network and the generator, since it can tend to cause current imbalance on the line (the stub's capacitance to ground asymmetrically affects the line, causing the imbalance). There are two unknowns in this problem, the lengths of section "A" and "B" lines.

The solution method is quite straightforward. The impedance looking into section A will be a complex number. By moving around the SWR circle, we can find a point where the REAL portion of its input impedance is equal to the final desired input impedance. At this point, there will be some leftover reactance; so the stub will be used as an inductor or capacitor to cancel the remaining reactance. The result will be a purely-resistive input impedance.

The steps in solution using SMITH/85 are as follows:

1. Start the program and choose Z0=50 Ohms.

2. Enter the load impedance by pressing [ZR Chg].

3. Find the point on the line where the REAL portion of input impedance is exactly 50 Ohms:

a) Press [Oper] -- go to OPERATIONS menu
   Press [MovM] -- go to MOVE/MAGNITUDE menu
   Press [RlMag] -- To find the point. SMITH/85 prompts:

```
Force real part of
impedance to? Must
be between:
        99.5548921997
and
        25.1117744669
?
```

Type 50 [ENTER]

TIP: The range of impedances depends on the radius of the SWR circle, which is determined by the characteristic impedance of the line, and the load impedance.

4. The MAIN display reappears; note that Bl, the distance from the load, is now 125.2653 degrees. Also note that the input impedance at this point is 50 + j35.1 Ohms.

5. The stub needs to have an impedance of -j35.1 Ohms. (In some applications, an actual capacitor could be used instead of the stub). To compute the length of the stub, press:

```
[Oper]  -- Go to the OPERATIONS menu.
[MovM]  -- Go to the MOVE/MAGNITUDE menu.
[Conj]  -- To compute a conjugate match element.
```

SMITH/85 will report:

```
Stub Z=-35.1   j
Zin   = (50.0, 0.0)

Stub Len = 144.9   Degrees
```

TIP: The CONJ (Conjugate) command computes a SERIES conjugate impedance in impedance mode, and a PARALLEL conjugate impedance in admittance mode.

IMPORTANT: The CONJ command does NOT change any data. It only "suggests" a shorted stub impedance and length to use. When [Back] is pressed, the program is returned to its previous state (the input impedance will still read 50+j35).

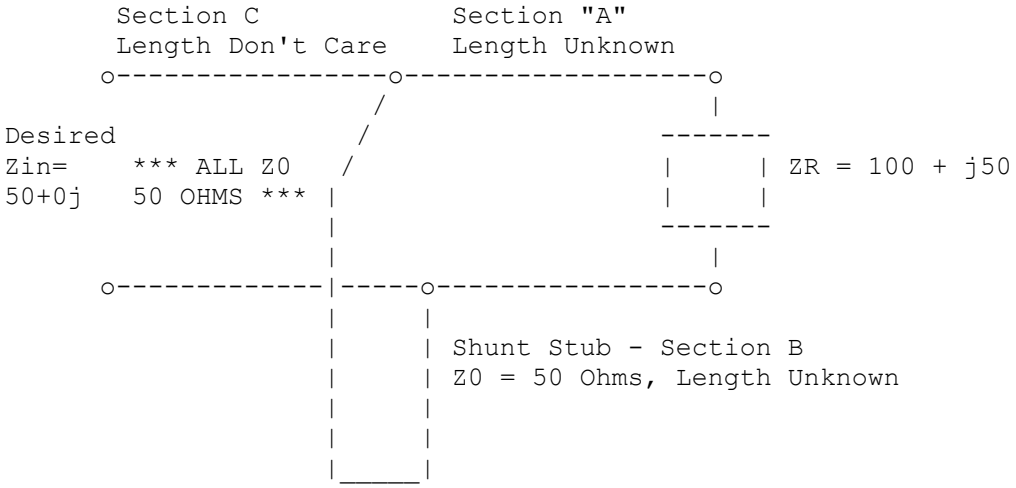
NOTE: If the CONJ command finds no reactive component, an error message will be issued:

Error! Cannot perform
transformation.

There MUST be an reactance (or susceptance) present to perform a conjugate match!

3.6 Matching Impedance With a Shunt Stub

The following problem setup is assumed in the discussion:



When working with shunt elements, it is more convenient to work in admittance units. We can freely jump back and forth between admittance and impedance as needed.

TIP: The load is always entered as an impedance, regardless of the operating mode.

The single-stub match has the advantage of balancing the capacitive parasitic load on the transmission line, but is harder to calculate because of the conversion to admittance. However, it's quite straightforward in SMITH/85. The steps in solution are as follows:

1. Start the program and press [ZR Chg] to enter the load impedance.

2. Press [Oper] [Y<>Z] to switch to admittance mode. The screen should report the load at 0 degrees to have an admittance of .020+j.020 Siemens.

3. Since we want to match the input to 50 Ohms, we need to find the point where the real part of input admittance is 1/50 Siemen. (The imaginary part will be cancelled by the stub susceptance). To do this:

```
Press [Oper] [MovM]  -- To get to the MOVE/MAGNITUDE menu
      [RlMag]        -- To calculate the intercept for the REAL portion of
                        magnitude. SMITH/85 responds:

Force real part of
admittance to? Must
be between:
                 .008
and
                 .052

?

Type 1/50 [ENTER]
```

TIP: You can enter simple math expressions in response to any input prompt in SMITH/85.

NOTE: As with impedance transformation, admittance transformation is limited by the radius of the SWR circle.

4. The MAIN screen reappears with a report of Bl=71.5651 degrees; that is the electrical length of section A. The input admittance at this point is .02 + .02j, which is not purely resistive.

5. Press [Oper] [MovM] [Conj] to compute the matching stub. The program should report:

```
Stub Z=50.0 j
Zin = (50.0, -8.0e-13)

Stub Len=45.0 Degrees.
```

NOTE: This section of the program does not truncate the remaining Zin imaginary portion, thus the display of "-8.0e-13" appears instead of zero.

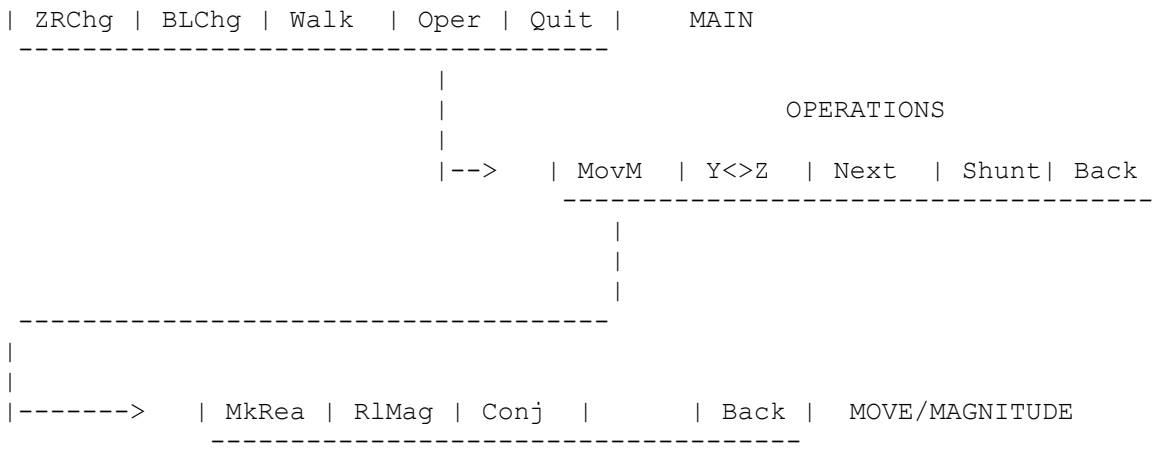
IMPORTANT: The CONJ command does NOT change any data. It only "suggests" a shorted stub impedance and length to use. When [Back] is pressed, the program is returned to its previous state.

IV FUNCTION SUMMARY

4.1 Menu Structure Reference

The structure below lists all the major functions available in SMITH/85. It might be helpful in locating named functions.

The listed structures correspond to the programmable function keys on the calculator; the starting menu is always MAIN. Pressing [Back] at any menu restores control to the MAIN menu.

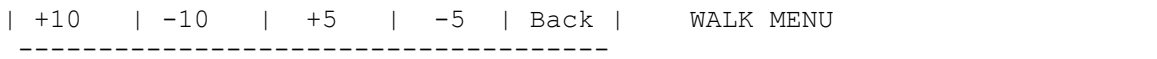


4.2 Main Menu Functions

4.2.1 ZRChg: This function allows the user to modify the load impedance. Regardless of the calculator mode (admittance or impedance), the load is always entered as an impedance.

4.2.2 BlChg: Allows direct entry of a new angle. This angle always represents the number of electrical degrees from the load. 360 degrees is one wavelength.

4.2.3 Walk: This enters WALK mode, where the user can move around the SWR circle by pressing a function key:



Each key in WALK mode corresponds to a number of electrical degrees of movement. This feature is useful to sensitivity testing; for example, the impedance can be monitored as a section of line is lengthened or shortened.

4.3 Operations Menu Functions

4.3.1 Y<>Z: This command switches SMITH/85 between admittance and impedance modes. Data is unaffected by Y-Z mode switches, however, certain operations have a different connotation in each mode.

4.3.2 Next: Allows a change in characteristic impedance. This command causes the impedance at the current line position to become the new load impedance for the next section of line, and it forces the electrical position Bl to zero degrees.

4.3.3 Shunt: Places a shunt impedance or admittance (menu choice) in parallel with the current line position impedance. Doing a shunt operation places the resultant of the shunt into the load impedance, and sets the electrical position to zero degrees. The characteristic impedance remains unchanged.

4.4 Move/Magnitude Menu Functions

4.4.1 MkRea: This command finds the two positions on the line where the input impedance (admittance) will be purely real. It operates identically in both impedance and admittance modes. The electrical position is updated to the user's choice of position. Graphically, this corresponds to the two intersections of the SWR circle and horizontal (real) axis of a Smith chart.

Note: [MkRea] won't have any effect on a "flat" line (SWR < 1.01 : 1).

4.4.2 RlMag: This function finds the closest intersection of the SWR circle and the corresponding real-axis circle. The electrical position on the line is updated to hold this position. If this position is not acceptable, the opposite position (using the complementary angle with respect to 180 degrees) can be entered; the real component will have an identical magnitude, with an opposing reactance or susceptance component.

For example, if Z0=50 Ohms, ZR=120 Ohms, and SMITH/85 is in impedance mode, then pressing:

[Oper] [MovM] [RlMag]

Responding with 75 Ohms will cause the calculator to report an electrical position of 20.7956 degrees, and a Zin of 75 - 49.4 j. Another solution exists at (180-20.9795 degrees) or 159.2044 degrees, with a Zin of 75 + 49.4 j.

In admittance mode, RLMAG has a similar action, but instead forces the real portion of the input admittance to the real value specified. The closest solution is again chosen, with another existing at the 180's complement angle.

The angular answers in admittance mode and impedance mode are normally different, because a different parameter is being adjusted for each mode.

4.4.3 Conj : This option computes a conjugate matching stub. The stub is assumed to be shorted on one end, and of the same characteristic impedance as the line being analyzed.

In impedance mode, the stub is computed as if it will be in SERIES with the line; in admittance mode, the stub is computed as a PARALLEL member.

The stub impedance and length in electrical degrees is given, but no further action is taken; the program data remains unchanged when the [Back] key is pressed.

For a series stub, the impedance is computed from the current Zin:

Zin = R + jX

Zs = -jX

For a shunt stub, the computation is performed using the current input admittance Yin:

Yin = G + jB

Ys = -jB

Zs = 1/Ys = 1/(-jB)

V. Program Limitations

5.1 Error Trapping

There is NO error trapping in SMITH/85 except that provided at the user menus. The TI-85 does not provide a mechanism for interception of errors, and any error will halt the execution of the program.

5.2 Accuracy

For a SWR of less than 10:1, SMITH/85 will generally provide results good to 10 decimal places or better. Degradation of accuracy does occur when input angles are odd multiples of 90 degrees. Internally, SMITH/85 "dodges" 90 degree angles by adding a small offset to the angle (.001 degree). Therefore, an angle entered EXACTLY at 90 degrees numerically is evaluated as 90.001 degrees, even though the display doesn't indicate so.

In the main display screen, fractional units less than 1E-5 are rounded to zero to increase readability.

5.3 Variable Usage

The following variables remain intact after exiting SMITH/85. They can be used in other applications. This version of SMITH/85 is not reentrant, so modifying these variables in other programs has no effect on the application (all data is erased when SMITH/85 is restarted.)

Variable Name	Type	Contents
Z0	Real	Line Characteristic Impedance
ZR	Real or Complex	Load Impedance
D	Real	Electrical distance from load
Z	Complex	Current input impedance
Y	Complex	Current input admittance
YM	Real	Mode flag. 0=impedance mode; 1=admittance mode.
OD	Complex	Temporary register. May hold intermediate angle from RlMag operator.
ST	Real	Menu State Register. Holds last menu state code.