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# A Comprehensive Computational Design for Microstrip Passive and Active Linear Circuits

El-Sayed A. El-Badawy
Said H. Ibrahim

ABSTRACT

*This paper presents a user-oriented comprehensive computational program for designing linear active and passive microstrip circuits such as amplifiers, oscillators, mixers, lowpass filters, and cuoplers. The substrate parameters and the characteristic impedance of the microstrip lines are given to the program as a common statement. Examples for the design of a 3 GHz high gain amplifier, 2.6-GHz oscillators, ring coupler operated at 3 GHz, and maximally-flat lowpass filter operated at 2 GHz with 0.75 GHz cutoff frequency are conducted. The introduced program is compared to other available ones.*

*Keywords: Computational Microstrip Design, Microwave Circuits, Computer Aided Design for Microwave Circuit.*

## INTRODUCTION

Since the mid-1917s, a number of computer programs for microwave circuit design had become commercially available. Some well-known microwave computer-aided engineering software package are SUPER COMPACT (from Compact Software, Inc, 2000), TOUCHSTONE (from EEsof, Inc. 1997), and others. All of these programs have certain advantages and some disadvantages.

In this paper we introduce a new version, HHSS2, of our previous computational program, El-Motaafy et al. (1995). In the comparison with the previous version HHSS2 has the following additional features:

1. It performs two-section branch line couplers.
2. It takes into consideration full discontinuities of microstrip lines.
3. It performs complete design of integrated circuits such as mocrostrip receiver with amplifiers, oscillator, mixer, and lowpass filter.
4. It modofies the format of the output files to suit the particular application.
5. It cover with application.
6. It can be used in case of changing the transistor unconditional stability to potensial unstability and vice versa, either by connecting a cascaded resistor to the transistor terminals.

## GENERAL DESIGN METHODOLOGY OF THE SOFTWARE

1. Depending on the type of the circuit (active or passive) and the internal parameters of the specified circuit, the software displays all the required parameters that can be specified by the user.

2. The substrate parameters of the microstrip H, r, and T are given as common parameters. If the user needs to change these parameters, the software can interact with him/her to enter the new substrate parameters.
3. The software can interact with the user for some selection and assumptions inside the specified circuit such as the number of sections in lowpass filter, or branch coupler, and the bandwidth of the Wilkinson hybrid.
4. After the entry of all parameters required by the user for the specified circuit design, the software performs a complete analytical design with appropriate lengths and width of the microstrip lines of the designed circuit.
5. The software introduced an optimum selestion of circuit elements to fulfill some requirements. These requirements include: a) unconditional stability, b) potential unstability, c) simultaneous conjugate match, d) changing the transistor stability, e) feedback circuit parameters tomaximize $S_{11}$, f) optimum termination for the output circuit to get the maximum output power, and g) optimum selection of [s] parameters (with the optimum feedback stubs at different frequencies or cascaded resistors) to achieve the transistor changes from unconditionalstability to potential unstability and vise versa.

## PROGRAM DESCRIPTION

The current developed program, HHSS2, is used for the design of linear active and passive circuits using microstrips techniques. Appendix I illustrates the main architecture of the software.

### DESIGN OF MICROWAVE AMPLIFIERS

The program performs a complete analytical design of microstrip amplifiers, (Ibrahim 2000; Gonzalez 1997). The [S] parameters of the used transistor and the operating frequency are given to the program while the substrate parameters (relative permittivity $\varepsilon_r$, dielectric thickness (H), conductor thickness (T), and $Z_0$ are considered as a common statement. The program performs the stability of the used transistor (Bodaway 1967). For potential unstable transistor, the user can call a subroutine, called RCAS, to cascade a resistor at the output of the transistor. According to the optimum selection of the value of the cascaded resistor, the transistor will be unconditional stable and the simultaneous conjugate match can be achieved (El-Motaafy et al. 1995, 1990). The program can perform a complete analytical design of input and output matching circuits without using the Smith chart. Using the subroutines MATCH1 and MATCH2, the matching circuits can be performed using stub line of given $Z_0$ with different lengths or λg/8 (3λg/8) stub lines with different values of $Z_0$ (Encelbrecht 1965; Ha 1981). The user can select the type of stub (open/short, single/balanced) used for the design of the matching circuits. The final lengths of the matching circuits are given in mm, radians, or as normalized lengths using the subroutine FLEN.

DESIGN OF MICROWAVE OSCILLATORS.

Transistor oscillators can be designed using either bipolar or GaAs FET devices (Stassiades et al. 1992; Holdzman & Roberston 1992). Using the [S] parameters of the active element, the design of the microwavw oscillator is a follows; 1) Check of the transistor stability. For unconditional stable transistor, the feedback circuit (open/short-single/balanced stub at the emitter/ source terminal) is designed to get the potential unstability (Gentitle 1987). In addition, the feedback circuit can be used to maximize the value of $S_{11}$ at the given $f_0$. Subroutines STABLE and FB are used for stability considerations and feedback circuit design, respectively 2) Analytical design of the input termination circuit (open/short stub at the base/gate) to get maximum reflection coefficient at the transistor output; 3) Calculation of the transistor small-signal output impedance; 4) Analytical design of the output matching circuit so that the load impedance is related to the transistor small-signal output impedance. 4) Analytical design of the output matching circuit so that the load impedance is related to the transistor small-signal output impedance by the relations $R_l = R_{out}/3$, and $X_l = - X_{out}$ (Dobrowolski 1991). Subroutines XX and XX1 are used for the design of the output matching circuit.

DESIGN OF MICROWAVE MIXERS

The program is suitable for diode and FET mixers (Maas 1986). Subroutine SELM is used to select a diode mixer (Hewlett Packard Appl. Notes 995 and 963) or a FET mixer. For a diode mixer, subroutine MIXER1 is used for diode mixer circuit design by calculating the forward and backward impedance and then the hyperbolic mean impedance, while subroutine MIXER2 is used for diode mixer circuit design by calcuting the input impedance of the diode for the given equivalent circuit. For Fet mixer citcuit design, subroutine SGM is used for single-gate FET mixer circuit design. The design of a FET mixer is performed either by the lumped FET model or by the [S] parameters of the FET. Subroutine FETME is used for input impedance calculation from the FET lumped model, while subroutine FETMS is used for input impedance calculation from the given [S] parameters. Subroutine XX is used for matching circuit design for both diode and FET mixers.

DESIGN OF MICROWAVE COUPLERS

The program is used for the design of several types of microwave hybrid couplers (Hewlett Packard Appl. Note 963) such as branch-line couplers with different number of sections (N), ring couplers, Wilkinson couplers, Lange couplers, and coupled line-couplers.

*Design of coupled-line couplers*

A subroutine CLINE is used for the design of the structure of coupled-line couplers for different values of the coupling factors C ≥ 3 (Garg & Bahl 1979). The calculation of the optimum values of strip width (W), strip separation (S), and coupler length (L) is started by initializing the program by the initial values of W and S, then calculating the corresponding values of even and odd mode impedances ($Z_{oe}$, $Z_{oo}$) from the capacitive mode equivalent circuit. $\varepsilon_{eff}$ and the electrical length of even and odd modes

($\Theta_e$,$\Theta_o$)are calculated for a given value L. The average value of the electrical length is checked to equal 90° with a specified tolerace. Getting the optimum value of the coupler electrical length, the value of $Z_x$ is compared with $Z_o$ with a specified tolerance by changing the values W and S.

*Design of branch-line couplers*

A subroutine BRANCH is used for the design of one-section rectangular/ circular branch-line cuoplers with C ≥ 3 dB and also for the design of two-section rectangular branch-line cuoplers (Fusco 1987; Collin 1992). The program calcuted the impedances of shunt and series arms and the corresponding $\varepsilon_{eff}$, $\lambda_g$, widths, and lengths for given $f_o$ and C.

*Design of ring cuoplers*

A subroutine RING is used for the design of the structure of the rate-race (ring) coupler. The program calculates the impedances of the lines forming the coupler and the corresponding widths, $\varepsilon_{eff}$, $\lambda_g$, and lengths for given $f_o$ and C (Fusco 1987; Collin 1992).

*Design of Wilkinson couplers*

A subroutine WILK is used for the design of differrent structures of Wilkinson couplers. The program calculates the values if resistor and $Z_o$ of the lines forming the structure with the corresponding $\varepsilon_{eff}$, $\lambda_g$, and lengths (Fusco 1987; Collin 1992).

*Design of Lange couplers*

The basic equation for the Lange coupler circuit design is (Al-Anwar 1999; Osmani 1981):

$$C = \frac{(N-1)(1-(Z_{oo}/Z_{oe})^2)}{(N-1)(1+(Z_{oo}/Z_{oe})^2)+2(Z_{oo}/Z_{oe})}$$

where: C : the coupling coefficient
N : even number (usually equal 2 or 4)
$Z_{oo}$ : odd mode impedance of the coupler line
$Z_{oe}$ : odd mode impedance of the coupler line

A subroutine LANGE is used for the design of the Lange couplers (Lange 1969) for diffferent values of the number of the strips M and C. The program calculates the even and odd mode W/H ratios, S, W, $\varepsilon_{eff}$, $Z_{oe}$, $Z_{oo}$, and L. The program uses the equations outlined in (Ou 1975).

## DESIGN OF LOWPASS FILTERS

The program uses the lowpass prototype filter C (Fusco 1987; Collin 1992) for the design of a lowpass filter. A subroutine LPF is used for the design of this lowpass filter. The program takes into considerations of the effect of the step discontinuities and the equivalent end-effect length. Either maximally flat or Chebyshev lowpass prototype filters are used in the design of the lowpass filter. The program calculates both lumped and distributed structures of the lowpass filter for given N, cutoff frequency ($f_c$), $f_o$ and $Z_o$ of shunt capacitances and series inductances. The program calculates the attenuation at $f_o$.

EQUIVALENT [S] PARAMETERS FOR A TRANSISTOR CONNECTED WITH A SERIES FEEDBACK STUB

A subroutine TRFB is used for the calculation of the equivalent [S] parameters of a transistor connected with a selected feedback stub at different frequincies. The proram deals with single or balanced open/short stubs. This subroutine is used for transistor stability change from unconditional stability to potential unstability.

EQUIVALENT [S] PARAMETERS FOR A TRANSISTOR CONNECTED WITH A CASCADED RESISTOR

A subroutine TRRCA is used for the calculation of the equivalent [S] parameters of a transistor connected with a selected cascaded resistor at different frequencies. This subroutine is used for the transistor stability change from potential unstability to unconditional stability.

DESIGN OF A HIGH GAIN 3-GHZ AMPLIFIER

Table 1 shows the input parameters and the output parameters (results) of the 3-GHz amplifier circuit design.

TABLE 1. Input and Output parameters of a 3-GHz microstrip amplifier circuit design

| Input Parameters | Output Parameters |
|---|---|
| The substrate/e parameters with 50-Ω normalized impedance are:<br>$\varepsilon_r$=2.33, H=0.7874 mm, T=0.005 mm<br>HXTR 6101 bipolar transistor with [S] parameters at 3 GHz are<br>$S_1$ = 0.57 ∠ 173°<br>$S_{21}$ = 2.2 ∠ 48°<br>$S_{12}$ = 0.043 ∠ 25°<br>$S_{22}$ = 0.77 ∠ 58° | Transistor stability considerations:<br>Δ=0.393 ∠ 140.5o, K=1.25 (the transistor is unconditional stable)<br>Input stability circle: $R_s$ (radius of input stability circle) = 0.5573, and Cs (center of input stability circle) = 1.65 ∠ 173.52° (outside is stable)<br>Output stability circle:<br>$R_L$ (radius of output stability circle)= 0.21, and $C_L$ (center of output stability circle) = 1.26 ∠ 62.64° (outside is stable).<br>Complex conjugate match at the input port : $\Gamma_s$ (source reflection coefficient) = 0.776 ∠ 174.5°, and $Z_s$ = 0.126-j0.04712Ω.<br>Complex conjugate match at the output port : $\Gamma_L$ (load reflection coefficient) = 0.878 ∠ 62.64°, and $Z_L$ = 0.236-j 1.26 Ω. |

Table 2 shows the length and widths of the input and output matching circuits of the designed amplifier.

TABLE 2. Lengths and widths of input and output matching circuits of the 3-GHz microstrip amplifier

| Length and widths of microstrip lines | Input matching circuit | Output matching circuit |
|---|---|---|
| Width of microstrip lines | 2.408 mm | 2.408mm |
| Length of series lines | 3.145 mm | 14.82 mm |
| Length of open circuit balanced stub, or | 10.337 mm | 12.486 mm |
| Length of short circuit single stub | 13.1883 mm | 15.193 mm |

Figure 1 gives the $S_{21}$ (dB), and $S_{22}$ (dB) versus frequency in GHz. Figure 2 shows the schematic diagram of the disigned 3-GHz high gain amplifier.

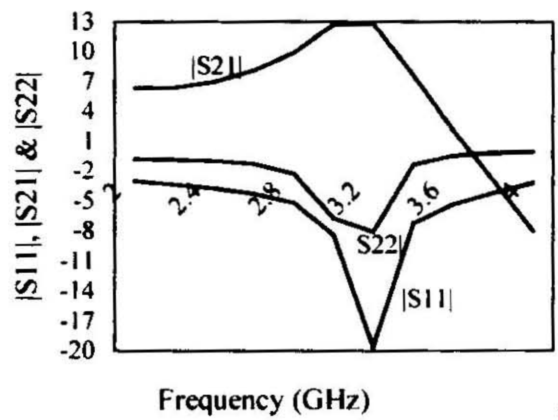



FIGURE 1. $|S_{21}|$, $|S_{11}|$ and $|S_{22}|$ in (dB) versus frequency for the 3-GHz amplifier.

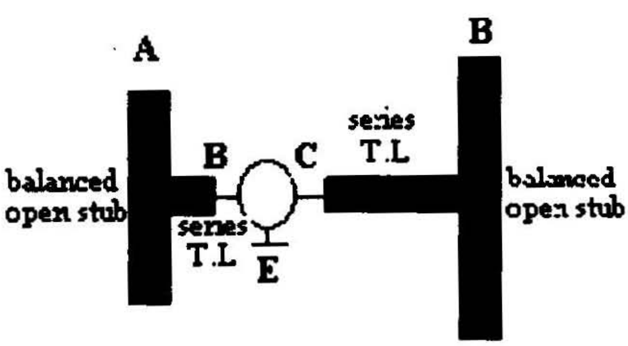



FIGURE 2. Schematic diagram of 3-GHz high gain amplifier.
(A) Input matching circuit using open/balanced stub,
(B) Output-matching circuit using open/balanced stub.

## DESIGN OF 2.6-GHZ OSCILLATOR

Table 3 shows the input parameters and output parameters (results) of the 2.6-GHz oscillator circuit design.

TABLE 3. Input and Output parameters of the 2.6-GHz microstrip oscillator circuit design

| Input parameters | Output parameters |
|---|---|
| The subtrate parameters with 50 Ω normalized impedance are: $\varepsilon_r = 2.33$, H = 0.7874 mm, and T = 0.005 mm. HXTR 4101 bipolar transistor with [S] parameters at 2.6 GHz are:<br><br>$S_{11}$ = 00.9817 ∠ 132.106°<br>$S_{21}$ = 1.96511 ∠ -9.43°<br>$S_{12}$ = 0.065 ∠ 11.599°, and<br>$S_{22}$ = 1.10323 ∠ -62.131°. | Transistor stability considerations: Δ = 0.98 ∠ 74.64°, and K = 0.82 (the transistor is potential unstable)<br>The terminating circuit designed: the terminating circuit is designed to get maximum reflection coefficient at the transistor output. The selected elements of the terminating circuit are an open circuit stub at the emitter terminal and a short circuit shunt stun at the base terminal.<br>Design of output matching circuit: The impedance and the corresponding reflection coefficient at the output of the terminating circuit are $Z_L$ = 10.23-15.8 Ω and $\Gamma_L$ = 0.68725 ∠ 143.63°. |

Table 4 shows the length and width of the terminating and the matching circuits of a 2.6 GHz microstrip oscillator. Figure 3 shows the final schematic of the designed oscillator.

TABLE 4. Length and width of the terminating circuit and the matching circuit of a 2.6-GHz microstrip oscillator

| Terminating circuit | Matching circuit |
|---|---|
| Length of emitter open circuit shunt stub = 11.94 mm<br>Length of base short circuit shunt stub = 3.645 mm | Width of microstrip lines = 2.23 mm<br>Length of series line = 9.496 mm<br>Length of open circuit single (balanced) shunt stub = 14.2285 (9.94) mm |

## DESIGN OF A RING COUPLER

Table 5 shows the input parameters and output parameters (results) of the circuit design of a ring coupler operated at 3.33 GHz.

Figure 4 shows $|S_{21}|$, $|S_{31}|$, and $|S_{41}|$ versus frequency in GHz for a ring coupler operated at 3.33 GHz Figure 5 shows the configuration of the ring coupler.

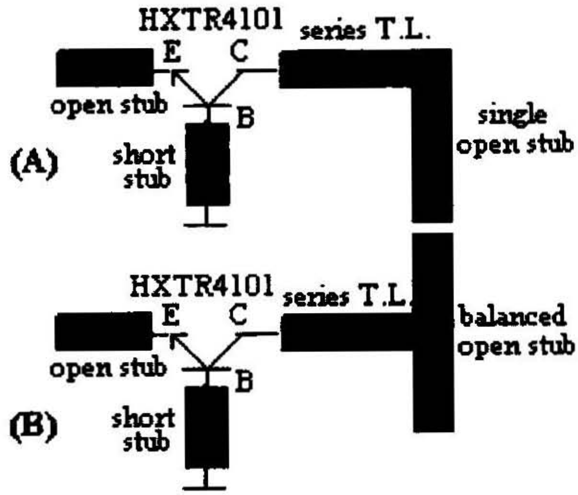



FIGURE 3. Schematic diagram of the final microstrip oscillator

TABLE 5. Input and output parameters of the 3.33-GHz microstrip ring coupler circuit design

| Input parameters | Output parameters |
|---|---|
| The substrate parameters with 50 Ω normalized impedance are: $\varepsilon_r$ = 2.2, H = 0.7874 mm and T = 0.005 mm. The operating frequency $f_o$ = 3.33 GHz, and the coupling factor C = 3 dB | Total length of circular line 100 mm, $\lambda_g$ for circular line = 66.96 mm. Width of circular line = 1.36 mm, Length of $\lambda_g/4$ for circular line = 16.74 mm Length of 3 $\lambda_g/4$ for circular line = 50.22 mm Impedance of circular line = 70.79 Ω Width of 50-Ω line = 1.37 mm |

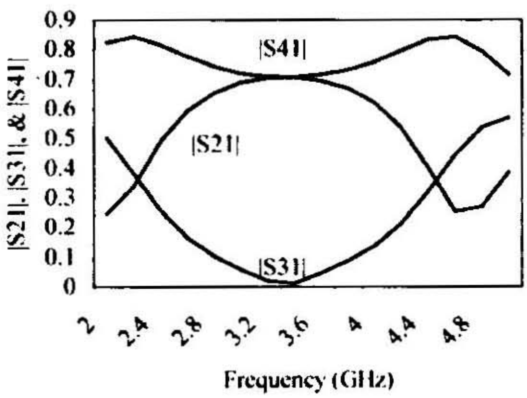



FIGURE 4. $|S_{21}|$, $|S_{31}|$ and $|S_{41}|$ versus frequency for a ring coupler operated at 3.33 GHz.

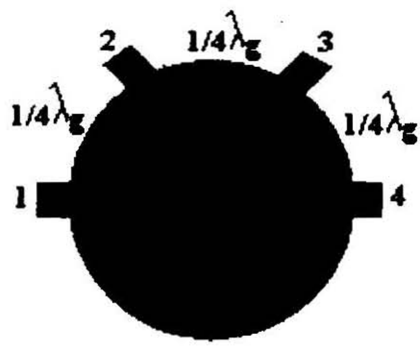



FIGURE 5. Configuration of the ring coupler

DESIGN OF A LANGE COUPLER

Table 6 shows the input parameters and output parameters (results) of the circuit design of a Lange coupler operated at 3.3 GHz.

TABLE 6. Input and Output parameters of the 3.3 GHz microstrip Lange coupler circuit design

| Input parameters | Output parameters |
|---|---|
| The substrate parameters with 50 Ω normalized impedanced are: $\varepsilon_r = 2.2$, H = 0.7874 mm, and T = 0.005 mm. The operating frequency $f_o$ = 3.3 GHz, The coupling factor C = 3 dB, The number of strips M = 4. | $Z_{oe}$ = 176.408 Ω, $Z_{oo}$ = 52.5384 Ω, Even-mode W/H ratio = 1.1589 Odd-mode W/H ratio = 7.293 W (strip width) = 0.41353 mm S (strip separation) = 0.0047989 mm L = 17.36 mm |

Figure 6 shows $|S_{21}|$, $|S_{31}|$ and $|S_{41}|$ versus frequency in GHz for a Lange coupler operated at 3.3 GHz. Figure 7 shows the configuration of the Lange coupler.

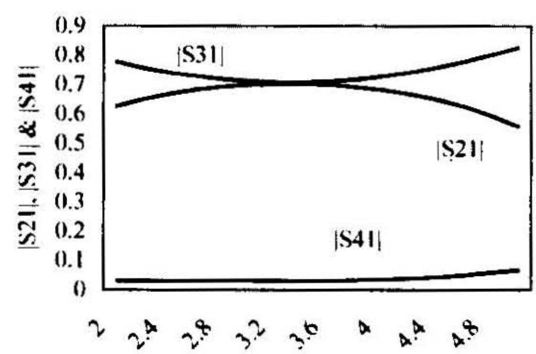



FIGURE 6. $|S_{21}|$, $|S_{31}|$ and $|S_{41}|$ versus frequency for a Lange coupler operated at 3.3 GHz.


FIGURE 7. Configuration of the Lange coupler: (1) Input port, (2) Coupled port, (3) Directed port, and (4) Isolated port

DESIGN OF RECTANGULAR BRANCH LINE COUPLERRS:

*Input:* $\varepsilon_r$ = 2.23, H = 0.7874 mm, T = 0.0005, $Z_o$ = 50 Ω, $f_o$ = 3 $GH_z$, C = 3 dB.
*Results:* Tables 7 and 8 illustrate the results for one-section and two-section rectangular branch line couples.

TABLE 7. One-section rectangular branch line coupler

| | Series lines | Branch lines |
|---|---|---|
| Impedance | 35.3133 Ω | 50 Ω |
| Length | 17.5847 mm | 17.857 mm |
| Width | 3.8089 mm | 2.3282 mm |
| $\varepsilon_{eff}$ | 2.044 | 1.982 |

TABLE 8. Two-section rectangular branch line coupler

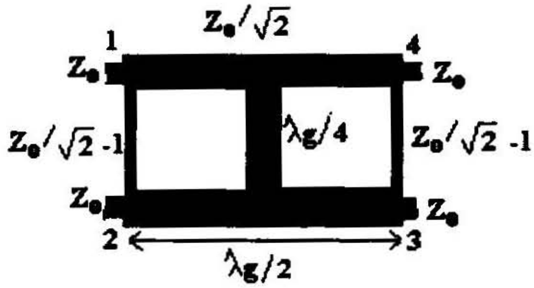
| | Series lines | Branch (inside) lines | Branch (outside) lines |
|---|---|---|---|
| Impedance | 35.3 W | 35.3 W | 120.7 W |
| Length | 17.585 mm | 17.585 mm | 18.723 mm |
| Width | 3.803 mm | 3.803 mm | 0.413 mm |
| $e_{eff}$ | 2.022 | 2.044 | 1.813 |

Figure 8 shows the configuration of one-section and two-section rectangular branch line couplers.

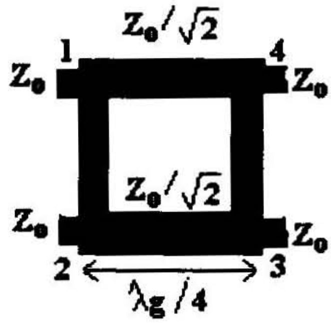
Figure 9 shows $|S_{11}|$ and $|S_{41}|$ for one-section and two-section rectangular branch line couplers. It is seen that the two-section rectangular branch line coupler has a higher bandwidth than the one-section rectangular branch line coupler.

Table 9 shows the input parameters and output parameters (results) of the circuit design of a lowpass filter has a cutoff frequency $f_c$,=0.75 GHz and an operating frequency $f_0$, = 2GHz

Figure 10 shows $|S_{11}|$ and $|S_{21}|$ verrsus the frequency for the designed lowpass filter. Figure 11 shows the distributed and lumped one-section maximally flat lowpass filter.




(a)




(b)

FIGURE 8. The configuration of a) two-section rectangular branch line coupler, b) one-section rectangular branch line coupler (1 input port, (2) isolated port, (3) directed port, and (4) coupled port

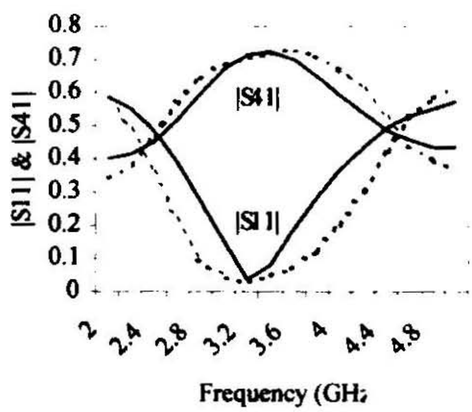



FIGURE 9. $|S_{11}|$ and $|S_{41}|$ for one-section (solid-lines) and two-section (dashed-lines) rectangular branch line coupler

TABLE 9. Input and output parameters of the 0.75 cutoff frequency lowpass filter

| Input parameters | Output parameters (results) |
|---|---|
| The substrate parameters with 50 Ω normalized impedance are: $\varepsilon_r = 2.2$ H = 0.7874 mm, and T = 0.005 mm. The operating frequency $f_o$ = 2 GHz, The cut-off frequency $f_c$ = 0.75 GHz, series conductance = 90 Ω. The characteristic impedance of the shunt capacitance = 20 Ω. One section maximally flat lowpass filter is considred. | Length and width of the inductive microstrip line are 23.52 mm and 0.8321 mm, respectively. Length and width of the capacitive microstrip line are 29.94 mm and The lumped inductance and capacitance of the designed LPF are $0.4579 \times 10^{-12}$H, and $0.7132 \times 10^{-11}$ F, respectively. |

## CURRENT PROGRAM VERSUS OTHER AVAILABLE PROGRAMS

To the best of our knowledge, the available microstrip design programs perform design of microstrip circuits with lengths and widths in a non

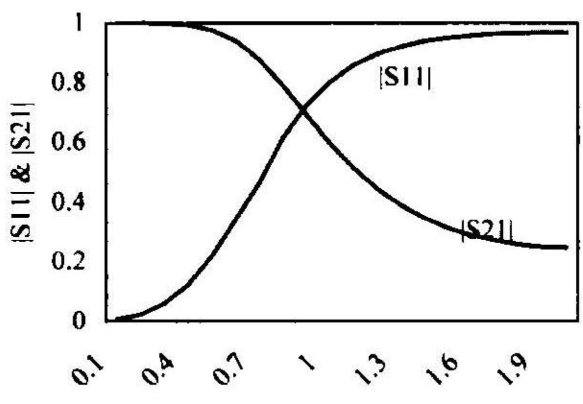



FIGURE 10. $|S_{11}|$ and $|S_{21}|$ versus the frequency for the designed lowpass filter

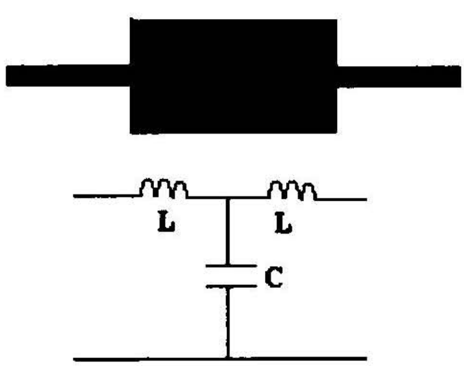



FIGURE 11. Schematic of the designed distributed lowpass filter and the corresponding lumped circuit.

suitable format, such as applying the lengths in radians or electrical lengths but not in the actual lengths that are usually needed for manufacturing or analyzing the circuit. In addition, some of these programs are so expensive, others do not consider full microstrip discontinuities and do not cover a wide range of microstrip circuit design applications.

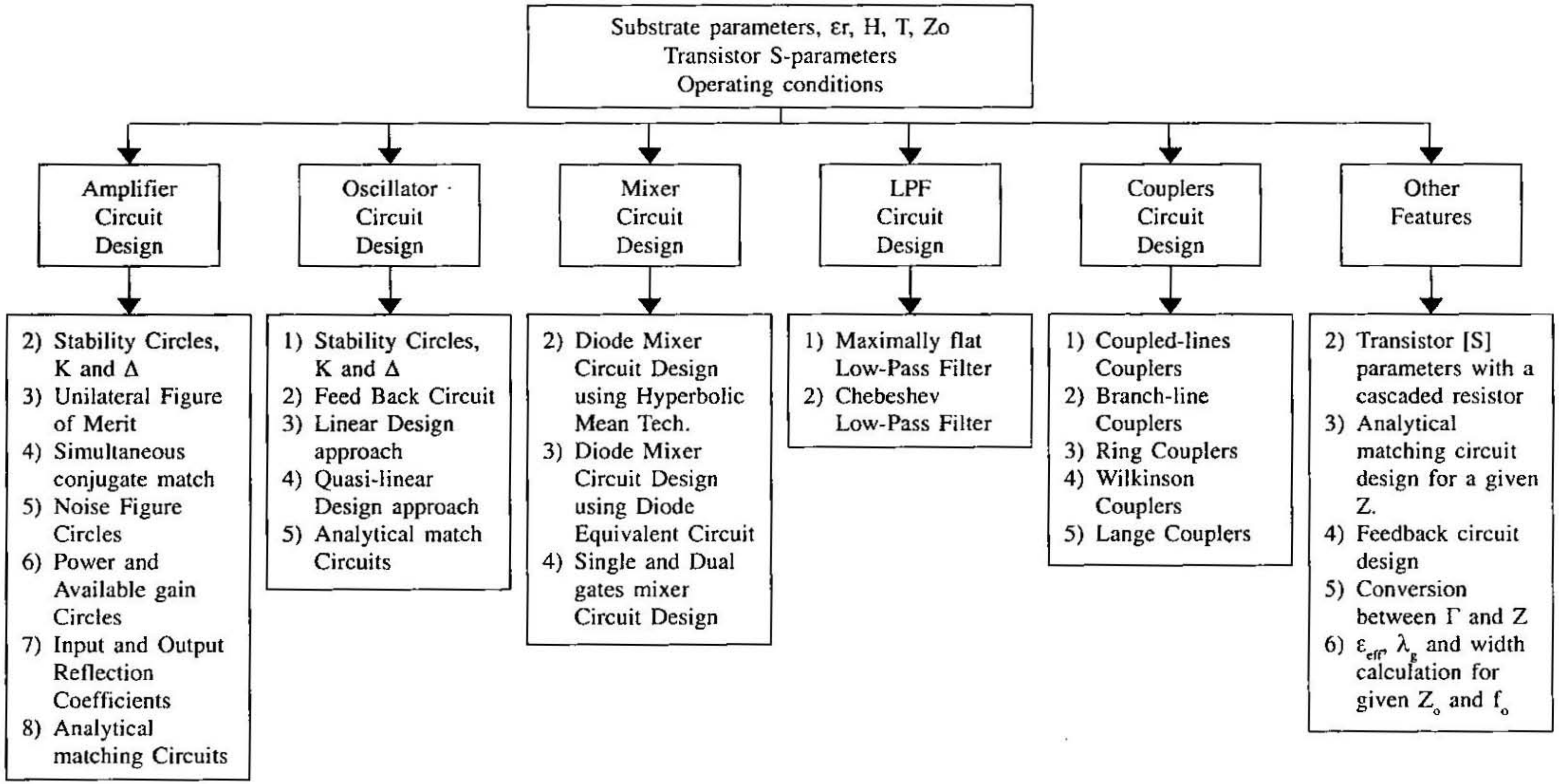
Compared to these programs, our HHSS2-program enjoys the following advantages:

1. It covers a wide range of applications in the design of passive and active linear microstrip circuits.
2. It considers the microstrip discontinuities.
3. It can be used to perform a complete design of microstrip devices such as a complete mixer design with hybrid couplers, matching circuit, and IF filters.
4. It can be used to perform complete design of a microstrip system such as a receiver that cantains local oscillator, RF amplifier, and signal mixer and a transmitter that contains a power combiner besides RF oscillator and amplifiers.
5. The program performs design of $\lambda_g/8$-and $3\lambda_g/8$- matching circuits with different microstrip widths. or 50-$\Omega$ microstrip lines of different lengths as upon the user choice.
6. It presents the microstrip lengths in different format such as radian, normalized lengths or actual lengths or actual lengths that can be used for many circuit analysis packages such as C/NL2 (Artech House 1994), MCAP, modified MCAP, etc.
7. The program is an easy DOS-based user-oriented program with a 150-Kbytes memory size, and thus can be used in XT, or AT PC computers.
8. The program can be attached with a grapher through the output text file to draw the circuit configiration.
9. The output data are formatted and stored in an output file for each application.
10. The program can be modified for used in the design of nonlinear microwave circuits. It can also be modified to draw the circuit configuration for each application. These two modifications will be the subject of a future publication.

## CONCLUSIONS

This paper illustrates the general description of a user-oriented program called HHSS2 for microstrip circuit design. The program is used for passive microwave circuit design such as directional couplers (especially circular/ rectangular branch-line couplers) and maximally flat or Chebyshev lowpass filters. The program is used also for the design of linear microwave active circuits such as amplifiers, oscillators, and mixer. The program can also be used for stability change from unconditional stability to potential unstability and vise versa by connecting a series feedback stub with a certain length or connecting a cascaded resistor to the transistor terminals. The matching circuit obtained by the program is accurately calculated without using Smith chart either by using stub lines of given $Z_o$ with different lengths or lg/8 (3lg/8) stub lines with different characteristic impedance.

APPENDIX 1. The main architecture of the software



APPENDIX 2: A Sample of an Output Data File Data.DAT

The sample illustrates the output data file for the matching circuit design. It is seen that the length of the microstrip lines are given in actual lengths, normalized lengths, and in radians. In addition, the stub lengths are given in actual lengths, normalized lengths, radians, and as equivalent susceptances. It is also demonstrated that the software can perform analytical matching circuit design with 50-(microstrip lines with different lengths or with (g/8, 3 (g/8 lengths with different widths.

ANALYTICAL MATCHING CIRCUIT DESIGN

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ALL LENGTHS ARE IN mm

MATCHING CIRCUIT CESIGN USING 50 OHM LINES WITH DIFFERENT LENGHTS ******

GAMMASMAG = .2915E+00 GAMMASMAG = .4227E+02

ZS(normal.) = .1400E+01 .6000E+00

YS(normal) = .6034E+00 -.2586E+00

ZO = .5000E+02 LAMG = .7144E+02 WIDTH = .2302E+01 EFF = 1.982238

LENGTH OF SERIES LINE (for short stub) = 6.416701

LENGTH OF SERIES LINE (for open stub) = .2320E+02 EFF = 1.982238

LENGTH OF SHORT CIRCUIT BALANC STUB = 14.496100

LENGTH OF OPEN CIRCUIT BALANC STUB = 3.362906

LENGTH OF SHORT CIRCUIT SINGLE STUB = 11.636100

LENGTH OF OPEN CIRCUIT SINGLE STUB = 6.222911

NORMAL LENGTH OF SERIES LINE (for short stub) = 8.982442E-02

NORMAL LENGTH OF SERIES LINE (for open stub) = 2.927487E-01

NORMAL LENGTH OF SHORT CIRCUIT BALANC STUB = 2.029242E-01

NORMAL LENGTH OF OPEN CIRCUIT BALANC STUB = 4.707576E-01

NORMAL LENGTH OF SHORT CIRCUIT SINGLE STUB = 1.628883E-01

NORMAL LENGTH OF OPEN CIRCUIT SINGLE STUB = 8.711164E-02

RAD LENGTH OF SERIES LINE (for short stub) = 5.643835E-01

RAD LENGTH SERIES LINE (open circuit) = 1.839394

RAD LENGTH OF SHORT CIRCUIT BALANC STUB = 1.275011

RAD LENGTH OF OPEN CIRCUIT BALANC STUB = 2.95785E-01

RAD LENGTH OF SHORT CIRCUIT SINGLE STUB = 1.023458

RAD LENGTH OF OPEN CIRCUIT BALANC STUB = 5.473386E-01

SUSCEP OF SHORT CIRCUIT BALANC STUB = 164.082500

SUSCEP OF OPEN CIRCUIT BALANC STUB = 6.094494E-03

SUSCEP OF SHORT CIRCUIT SINGLE STUB = 82.041270

SUSCEP OF OPEN CIRCUIT STUB = 1.218899E-02

MATCHING CIRCUIT DESIGN USING
(1/8)LAMG OR (3/8) LAMGA STUB

SERIES T.L: ZO = 6437E+02 LAMG = 7232E+02 WID = .1546E+01

LENGTH = .1808+02

SHUNT STUB: LENGTH OF SHORT CIRCUIT SHUNT STUB = 9.462488 OR

Length OF OPEN CIRCUIT SHUNT STUB = 28.387460

FOR SINGLE STUB: ZO = 193.333300 WID = 7.804558E-02

FOR BALANCE STUB: ZO = 386.666600 WID = 1.379758E-03

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El-Sayed A. El-Badawy
Department of Electrical Engineering
Faculty of Engineering, Alexandria University
Alexandria 21544, Egypt

Saia H. Ibrahim
Computer Science Department
Faculty of Computer and Information
Mansuora University
Mansuora, Egypt