Exam in Microwave Engineering (MCC121)

Friday, December 20, 2013

MCC121

Exam in **Microwave Engineering**

Friday, December 20, 2013, 1400 - 18:00, "H-salar"

Teachers: Jan Stake phone: 031 -772 1836
Mark Whale phone: 031 -772 5653

During the exam, teacher will visit around 1430 and 1600.

Examiner: Prof. Jan Stake. Terahertz and millimetre wave lab., Department of microtechnology and nanoscience (MC2), Chalmers University of Technology.

The inspection of the results can be done in my office (D615), MC2-building, Friday, January 17th, 13:00-14:30. The final results will be sent to registrar office on January 20th, 2013.

This is an open book exam. The following is allowed:

- *Calculator (approved by Chalmers)*
- *"Microwave Engineering" by Pozar*
- *Mathematics handbook (Beta)*
- *Smith charts*

To pass this written examination, you need at least 24p out of 60p. Final grade of the course will also include results from assignment 1. That is: 3 (≥28p), 4 (≥42p) and 5 (≥56p).

Teamwork is not permitted on this examination. The university academic integrity policy will be strictly enforced. Failure to comply with the academic integrity policy will result in a zero for this examination.

Make sure you have understood the question before you go ahead. Write shortly but make sure your way of thinking is clearly described. It is imperative to clearly explain how the results have been obtained. Solve the problem as far as you can – constructive, creative and valuable approaches are also rewarded. Assume realistic numbers/parameters when needed if data is missing in order to solve the problem.

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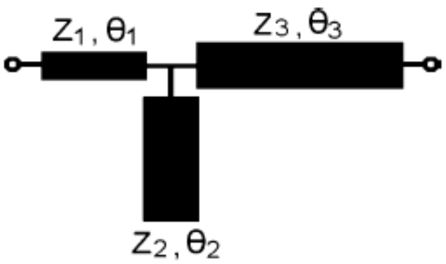
Problem 1

As described in the appended paper, a possible route to reduce the outer dimensions of a Branch-Line Coupler is to replace the quarter wavelength sections with the T-shaped shown below. Prove and derive design equations for the special case when $Z_1=Z_3$ and $\theta_1=\theta_3$. What is the total length of the equivalent circuit, if we chose $Z_1=1.7Z_0$, where Z_0 is the characteristic impedance of the original quarter wave section.



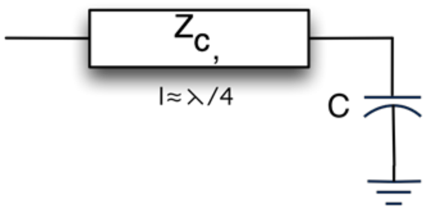
Equivalent T-shaped structure of quarter-wavelength transmission line.

From: Liao, S.-S, et al. (2005). A novel compact-size branch-line coupler. *Microwave and Wireless Components Letters, IEEE*, *15*(9), 588–590. http://dx.doi.org/10.1109/LMWC.2005.855378

(10p)

Problem 2

An open transmission line with $\alpha=\beta$, is equivalent to a series resonant circuit for a frequency when $l\approx\lambda/4$. However, due to stray fields at the end of the line, which give rise to an equivalent capacitance C, the resonant frequency is shifted. Determine the exact length, l, for resonance. Explain also the outcome of the analytical solution in a Smith Chart.



(10p)

Problem 3

A detector diode exhibits a rather high small signal impedance of ca $R_L = 150$ ohm at 10GHz. Design a binomial 3-section transformer, using microstrip transmission lines, to match the diode load impedance to 50 ohm. What is the bandwidth of the signal, which can be received and detected by the diode? Theory of small reflections may be applied. Use a 0.5 mm thick alumina substrate ($\varepsilon_r=9$).

(10p)

Problem 4

The first three resonant modes of an air filled rectangular cavity are 6.7 GHz, 12.6 GHz, and 13.0 GHz. Presuming the standard dimension rules for such a cavity ($b<a<d$), calculate the dimensions of the cavity.

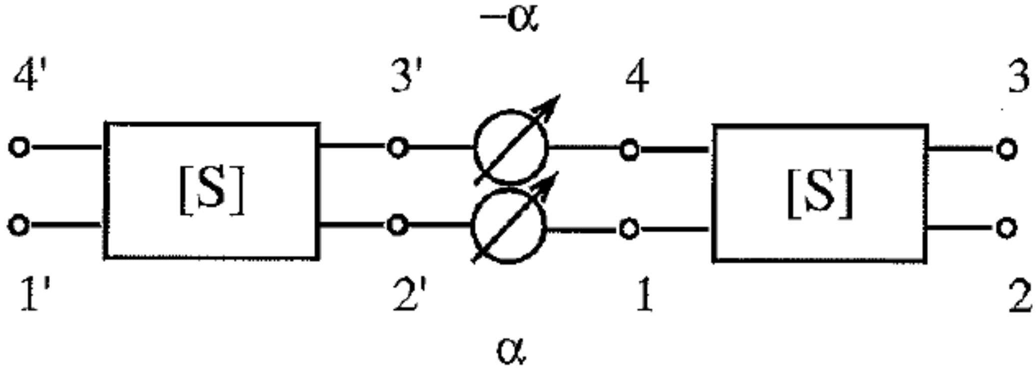
(10p)

Problem 5

Two variable length 50-ohm lines are connected between two 3dB-couplers, with the scattering matrix:

$$[S] = \begin{bmatrix} 0 & C & jC & 0 \\ C & 0 & 0 & jC \\ jC & 0 & 0 & C \\ 0 & jC & C & 0 \end{bmatrix} \text{ where } C = \frac{1}{\sqrt{2}}$$

The electrical length can be adjusted between $-\alpha$ and α degrees, see figure below. Calculate the signals at port 2 and 3 if port 1 is excited with the signal $1\angle 0°$. The system impedance is 50 ohm. Describe the function of the circuit.



(10p)

Problem 6

An air filled rectangular WR-10 waveguide is connected to a 5cm long WR-10 waveguide filled with a dielectric material (ε_r=1.5), which is terminated in a matched load. The load is absorbing 1 Watt, determine the maximum electrical field strength inside the air filled waveguide. Assume lossless case, 94GHz signal and principal wave propagation. WR-10 inside dimensions are 2.54 mm x 1.57 mm.

(10p)

Good Luck! / JS

Enclosures:

1) Smith Charts
2) Liao, S.-S., Sun, P.-T., Chin, N.-C., & Peng, J.-T. (2005). A novel compact-size branch-line coupler. *Microwave and Wireless Components Letters, IEEE, 15*(9), 588–590. doi:10.1109/LMWC.2005.855378

A Novel Compact-Size Branch-Line Coupler

Shry-Sann Liao, *Member, IEEE*, Pou-Tou Sun, Nien-Chung Chin, and Jen-Tee Peng

***Abstract*—A novel compact-size branch-line coupler without any implementation of lumped-elements, bonding wires, and via holes is proposed. In this study, the size of the proposed coupler occupied only 45% of the conventional branch-line coupler at 2.4 GHz. The performances of the circuit can be competed with the conventional coupler. The element sizes of this coupler can be realized easily by using simply standard printed-circuit-board etching processes. It is very useful for applications in the wireless communication systems.**

***Index Terms*—Branch-line coupler, compact-size, T-shaped structure.**

I. Introduction

RECENTLY, wireless communication systems usually require smaller device size in order to meet circuit miniaturization and cost reduction. Thus, size reduction is becoming the major design consideration for the practical applications. However, a branch-line coupler is a very useful component in microwave integrated circuits (MICs). The conventional branch-line coupler is composed of four sections; each section is the quarter-wavelength transmission line. At the lower frequency of the microwave band, the size of a conventional branch-line coupler is too large for practical use. On the other hand, such size is also too large for monolith microwave integrated circuits (MMICs) applications, because a large dimension results in high chip cost.

Several design techniques have been reported to reduce the coupler size. The combinations of short high- impedance transmission lines and shunt lumped capacitors had been considered [1]–[4]. In those cases, metal-insulator-metal capacitors are needed for the MMICs. It will increase the cost and the complexity of fabrication. The lumped-element approach [5]–[10], results in significant size reduction and more suitable in MMIC application, needs precise inductor models based on careful measurements.

Reference [11] suggested that a branch-line coupler is realized in microstrip-line one layer of metal without additional lumped elements, via holes, and bonding wires. The compact-size is achieved by considering artificial transmission lines which consists of microstrip-lines periodically loaded with open shunt stubs. Unfortunately, the size of this coupler is about 63% of a conventional design only. However, the use of unoccupied area of coupler interiors reveals the overlap problems, which is constraining the size reduction process.

Manuscript received March 29, 2005; revised May 13, 2005. This work was supported by the National Science Council of Taiwan under Project NSC 93-2213-E-035-025. The review of this letter was arranged by Associate Editor J.-G. Ma.

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Digital Object Identifier 10.1109/LMWC.2005.855378

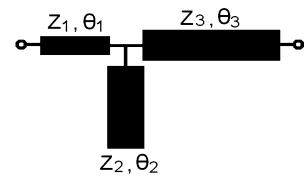


Fig. 1. Equivalent T-shaped structure of quarter-wavelength transmission line.

Therefore, we concentrate on establishing the design descriptions of a novel compact-size branch-line coupler in Section II of this study first. Then, we use them to realize the reduced-size coupler in Section III. These couplers without any lumped-elements, bonding wires, and via holes can be fabricated easily on the FR4 substrate. And they occupy small circuit space at 2.4 GHz and reveal the good performances comparable with the conventional branch-line coupler. Good agreements between the measured and simulated results are observed.

II. Design Descriptions

The traditional design method of the branch-line coupler is based on the normal-mode analysis and using the even-mode and odd-mode analysis techniques. The reason for that is the symmetrical structure is considered. Moreover, a reduced-line with length less than quarter- wavelength has lower inductance and capacitance. One compensated the inductance drop by increasing the characteristic impedance of the line and compensated the capacitance by adding shunt lumped capacitors C [1]. The capacitor C can be replaced by the open-end stub line [1], [11].

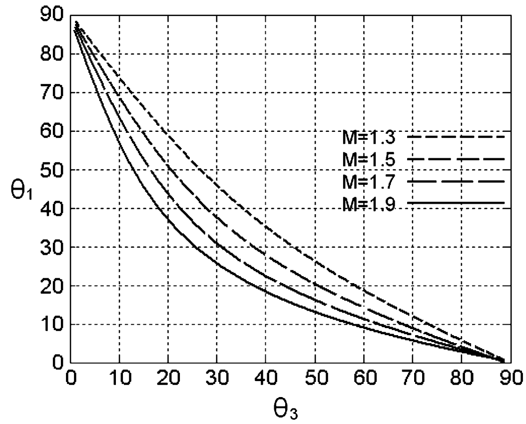
The generally equivalent T-shape structure of reduce-line is shown in Fig. 1. Z_1, Z_2, Z_3, θ_1, θ_2, and θ_3 represent the characteristic impedances and the electrical lengths of the reduced-line, respectively. We notice that is not necessary to posit θ_2 in the middle of the reduced line, nor equating Z_1 to Z_3. Henceforth, the conventional symmetry structure is no longer a necessity. The relations among them can be estimated by the ABCD matrices. The design equations are

$$\tan\theta_1 \tan\theta_3 = \frac{N}{M^2} \tag{1}$$

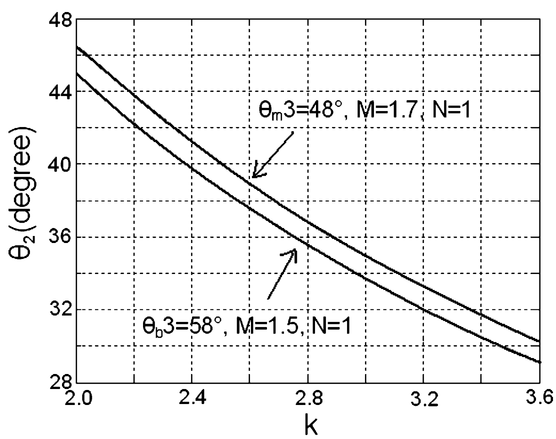
$$\tan\theta_2 = \frac{M^2 - N^2}{KN} \tan\theta_3 \tag{2}$$

with $K = Z_1/Z_2$, $M = Z_1/Z_0$, $N = Z_1/Z_3$.

Equations (1) and (2) decide θ_1, θ_2 and θ_3 under the conditions of K, M, and N have been known. For simplicity, $Z_1 = Z_3$ is assumed. The electrical length θ_1 is plotted against the electrical length θ_3 for different values of M, as shown in Fig. 2(a). It appears that the total electrical length of the reduced line $\theta = \theta_1 + \theta_3$ decreases as M increases. Moreover, the locations of



(a)



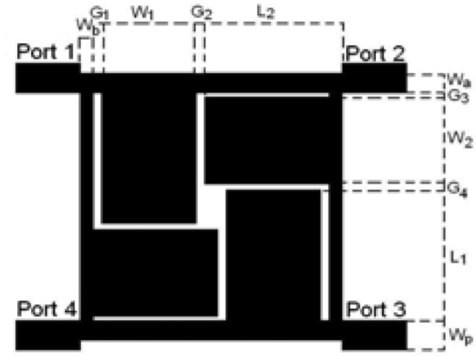
(b)

Fig. 2. Designed curves (a) θ_1 versus θ_3 if M is known and (b) θ_2 versus K if θ_3 and M are known.

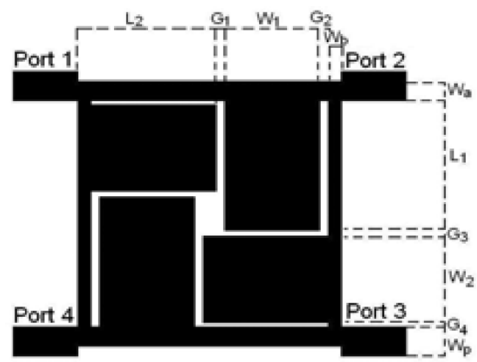
all the open-end stub lines are constrained within the interior of the branch-line coupler under our considerations, then the value of θ_2 is possible between $\theta/2$ and θ. To avoid the overlap, the locations of the open-end stub line are placed as close as possible to the ends of the reduced-line. However, θ_1 and θ_3 are switched each other once M is known, while (2) stays unchanged under the case of $\mathrm{N} = 1$. This result hints the possibility of existence of a second solution, i.e. type II. Also θ_2 and Z_2 are calculated when θ_3, M, and N are known. Fig. 2(b) shows the designed curve of θ_2 and Z_2, if θ_3 and M are known under the case of $\mathrm{N} = 1$.

III. Design and Implement of Compact-Size Couplers

The size of a conventional branch-line coupler is easily reduced by using the method described above. The FR4 substrate with $\varepsilon_\gamma = 4.7$, $\tan\delta = 0.022$, thickness $=$ 0.8 mm, and metal thickness $=$ 0.02 mm has been used for simulations and implementation. All simulations are accomplished by the full-wave Sonnet ***em*** simulator. The characteristic impedance of the conventional branch-line coupler are 35 Ω and 50 Ω, respectively. To minimize the effects of conductor loss, radiation loss, and prevention of spurious modes, the width of the microstrip line is limited and, i.e., limiting the range of characteristic impedances that can be realized.



(a)



(b)

Fig. 3. Compact-size branch-line coupler: (a) type I and (b) type II $\mathrm{G}_1 = \mathrm{G}_2 = \mathrm{G}_3 = \mathrm{G}_4 = 0.4$ mm, $\mathrm{W}_\mathrm{b} = 0.6$ mm, $\mathrm{W}_\mathrm{a} = 1.0$ mm, $\mathrm{W}_\mathrm{p} = 1.4$ mm, $\mathrm{W}_1 = \mathrm{W}_2 = 4.4$ mm, $\mathrm{L}_1 = 6.6$ mm, $\mathrm{L}_2 = 5.8$ mm.

The parameters of the reduced main-lines, are first selected as $\mathrm{M} = 1.7$, with $\theta_{\mathrm{m1}} = 17^\circ$, then $\theta_{\mathrm{m3}} = 48^\circ$ are determined in Fig. 2(a). Substituting all these data into (2), and assuming $\mathrm{K} = 2.6$, then $\theta_{\mathrm{m2}} = 39^\circ$ is obtained. Similarly, the parameters of the reduced branch-line are found by the same steps. I.e. $\mathrm{M} = 1.5$, $\theta_{\mathrm{b1}} = 16^\circ$, $\theta_{\mathrm{b3}} = 58^\circ$, $\mathrm{K} = 3.3$, and $\theta_{\mathrm{b2}} = 31^\circ$. Due to the layout of the enclosed circuits, selection of the line impedances, ports match, and the fabricated tolerances, the slight adjust is necessary in the last step. The final circuit after adjusting is shown in Fig. 3(a). A second type of branch-line coupler, namely type II, with equal size and parameters must exist, as shown in Fig. 3(b). And their simulated and measured results are shown in Fig. 4(a)–(d), respectively. From the results of simulation and measurement of direct and coupling power, the high losses by metal structure and the radiation loss didn't reveal a significant influence of the performance in the interesting frequency range. The dimension of the circuits was reduced by more than 55% comparing with the conventional branch-line coupler. The further size reduction is possible by using another skills based on the idea of this study. It will be reported in another letter.

IV. Conclusion

A novel reduced-size branch-line coupler operating at 2.4 GHz consists of all distributed components without bonding wires and via holes, is presented in this study. The simple design formula is discussed under the condition of the ideally lossless situation. The size of the prototype couplers

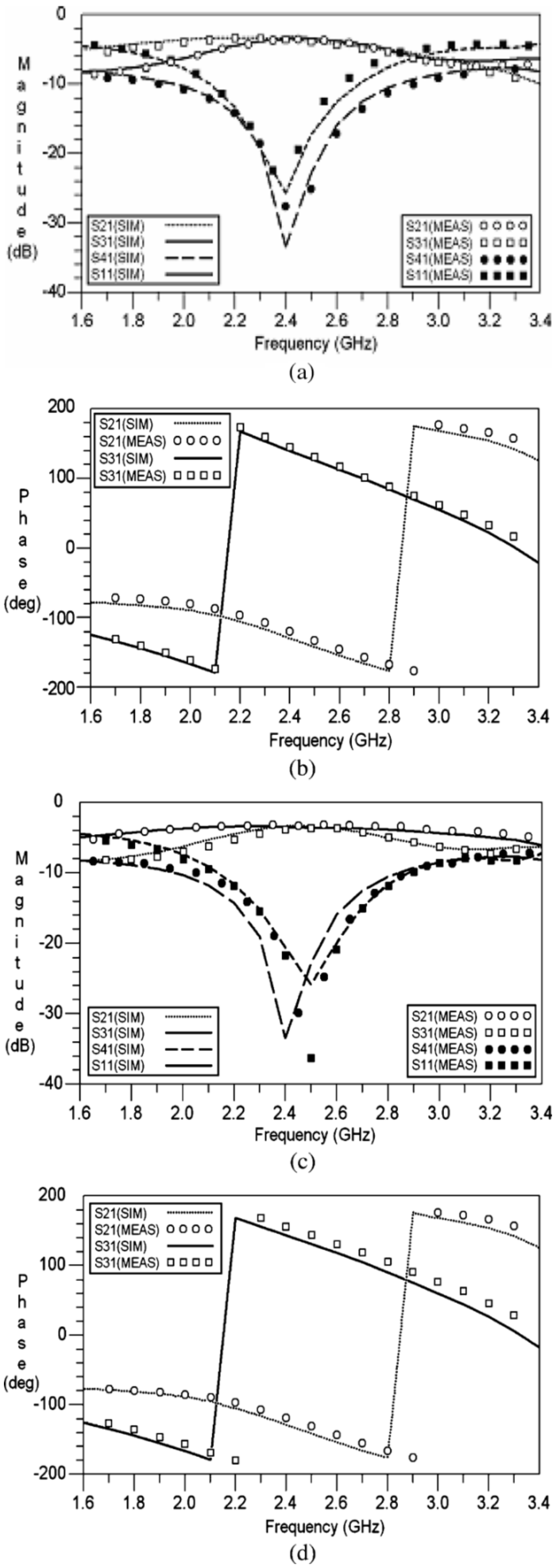


Fig. 4. Simulated and measured results: (a) S-parameters (type I), (b) phase response (type I), (c) S-parameters (type II), and (d) phase response (type II).

compared with the conventional designs was reduced about 55%. The element sizes of this coupler are realized easily by using standard printed-circuit-board etching processes. It is suitable for MICs and MMICs applications.

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NAME	TITLE	DWG. NO.
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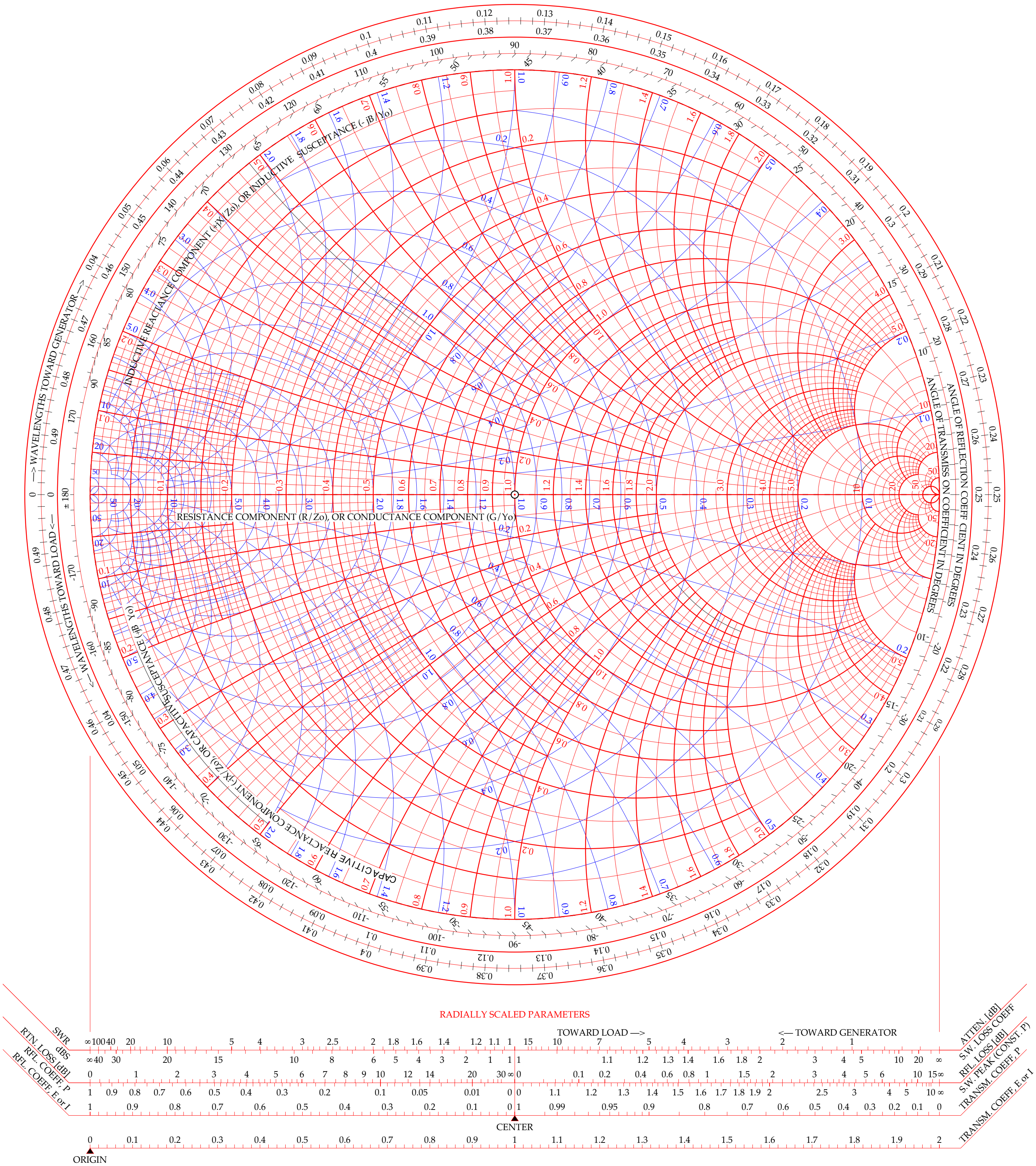
SMITH CHART FORM ZY-01-N	COLOR BY J. COLVIN, UNIVERSITY OF FLORIDA, 1997	

NORMALIZED IMPEDANCE AND ADMITTANCE COORDINATES



The Complete Smith Chart

Black Magic Design