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A COLPITTS OSCILLATOR DESIGN TECHNIQUE USING S-PARAMETERS

BY

TIMOTHY K. JOHNSON  
B.E.E., Auburn University, 1983

RESEARCH REPORT

Submitted in partial fulfillment of the requirements  
for the degree of Master of Science in Engineering  
in the Graduate Studies Program of the  
College of Engineering  
University of Central Florida  
Orlando, Florida

Fall Term  
1986



## ABSTRACT

This research report describes a method for designing a Colpitts oscillator using S-parameters. The oscillator components are grouped into three functional blocks: 1) an unstable active network (which includes the transistor, feedback capacitor, and input resistor); 2) an output matching network (which includes the inductor, tuning capacitor, and load); and, 3) an input matching network (which consists of the remaining tank capacitor). This configuration not only satisfies the standard Colpitts oscillator topology, but allows the use of three simple criteria (based on the network S-parameters) to predict oscillation. A computer program was developed to calculate specific tank component values based on these criteria. An example oscillator (at 100 MHz) was built to verify the procedure.



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## CHAPTER I

### INTRODUCTION

Of the various types of feedback oscillators used at radio frequencies, perhaps the most popular is the Colpitts oscillator. It has certain advantages over the Hartley oscillator (Sentz and Bartkowiak, 1968), in that with two capacitors and a single inductor in its tank circuit (as opposed to one capacitor and two inductors for the Hartley) mutual inductance within the tank is not a problem; furthermore, in some cases circuit size may be smaller for the Colpitts oscillator (an important consideration at high frequencies).

#### Description of Colpitts Oscillator Topology

The standard Colpitts oscillator implementation, including a parallel tuning capacitor, is shown in Figure 1. The tuned tank, or resonating portion of the circuit, consists of two tapped capacitors in parallel with an inductor. These elements are dominant in determining the frequency of oscillation. Two capacitors are used (instead



of one) so that a voltage divider can be used to feed a portion of the output signal back into the input. This positive feedback provides the drive necessary to sustain oscillations. Analysis of this circuit is almost always accomplished using a small-signal transistor model, such as hybrid-pi (or a modification thereof), and tuned-tank network equations (Hayward, 1982). This technique relies on estimates of transistor input and output impedances, since they may have an appreciable effect on the frequency of oscillation. This analysis can be complicated and, at best, very approximate (Krauss, et al., 1980).

#### General Criteria for Oscillation

Many different sets of general criteria for oscillation have been developed over the years, each set having its own particular usefulness. The use of S-parameters to describe circuit behavior at UHF and microwave frequencies is practically essential, but it can also be most helpful in the VHF range. These parameters describe circuit response in terms of incident, transmitted and reflected waves. Using S-parameters, an oscillating system can be described very simply as an unstable active network with input and output matching networks (see Figure 2). The specific criteria for oscillation corresponding to the diagram in Figure 2 are given by Vendelin as:



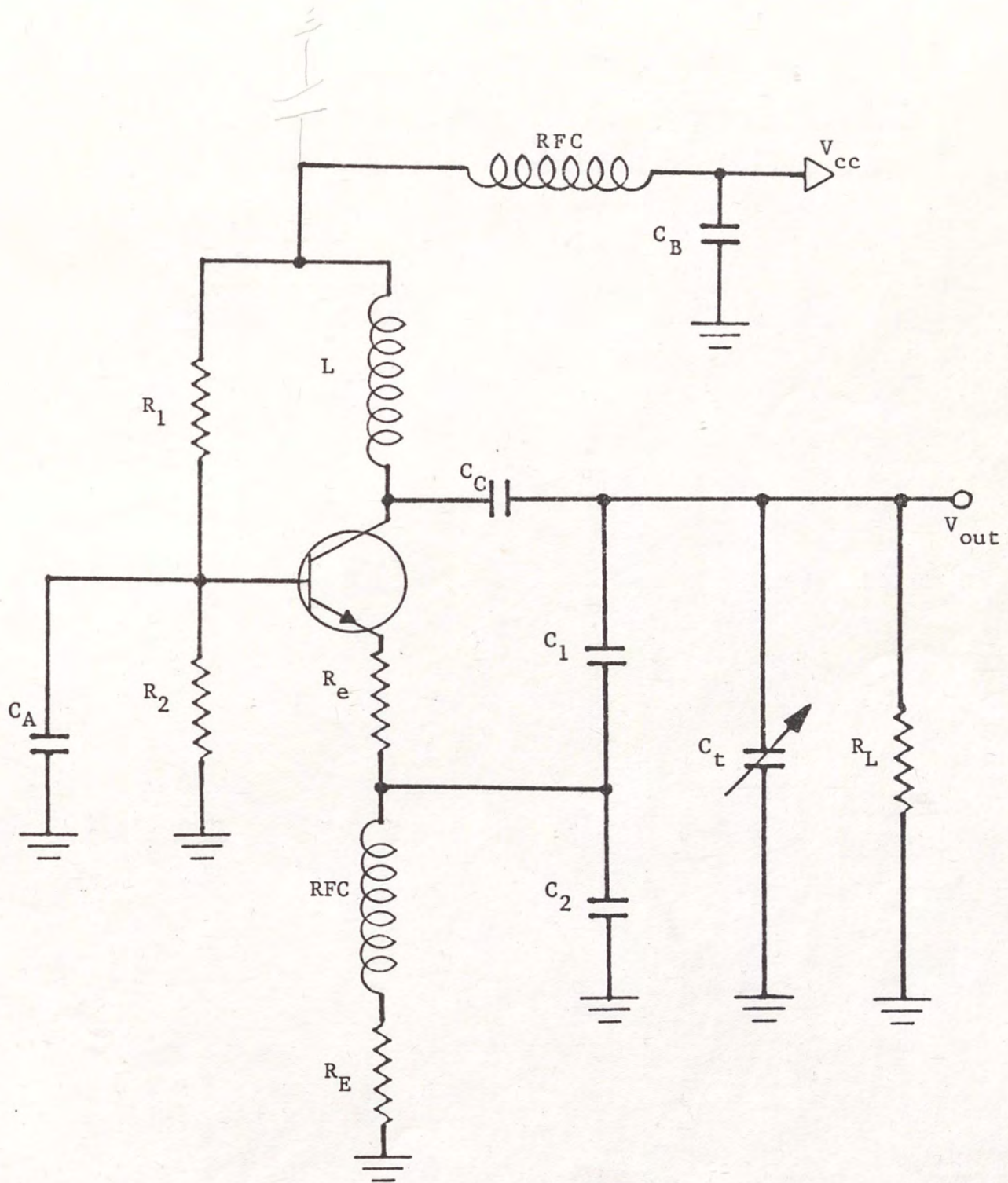


Figure 1. Colpitts Oscillator .



$$1) k < 1 \quad (1)$$

$$2) S_{11}' \Gamma_G = 1 \quad (2)$$

$$3) S_{22}' \Gamma_L = 1 \quad (3)$$

where  $k$  (the stability factor) is given by:

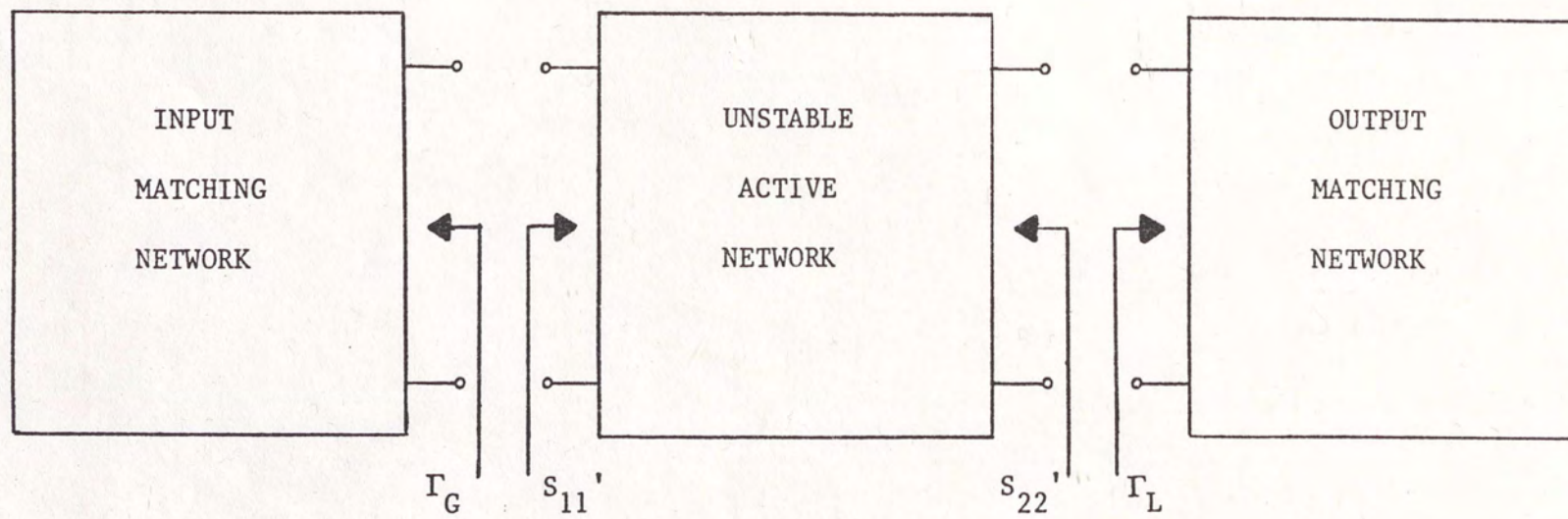
$$k = \frac{1 - |S_{11}|^2 - |S_{22}|^2 + |S_{11}S_{22} - S_{12}S_{21}|^2}{2 |S_{12}| |S_{21}|} \quad (4)$$

and

$$S_{11}' = S_{11} + \frac{S_{12}S_{21}\Gamma_L}{1 - S_{22}\Gamma_L} \quad (5)$$

$$S_{22}' = S_{22} + \frac{S_{12}S_{21}\Gamma_G}{1 - S_{11}\Gamma_G} \quad (6)$$

It can also be shown (Vendelin, 1982) that conditions 2) and 3) are redundant in that if one is satisfied, the other is automatically satisfied.



5

Figure 2. General Oscillator Block Diagram.



CHAPTER II

DESIGN PROCEDURE

In order to use the basic S-parameter criteria for oscillation, the Colpitts oscillator topology shown in Fig. 1 must be made to conform to the configuration illustrated in Figure 2. Such a layout of the AC equivalent circuit is shown in Figure 3.

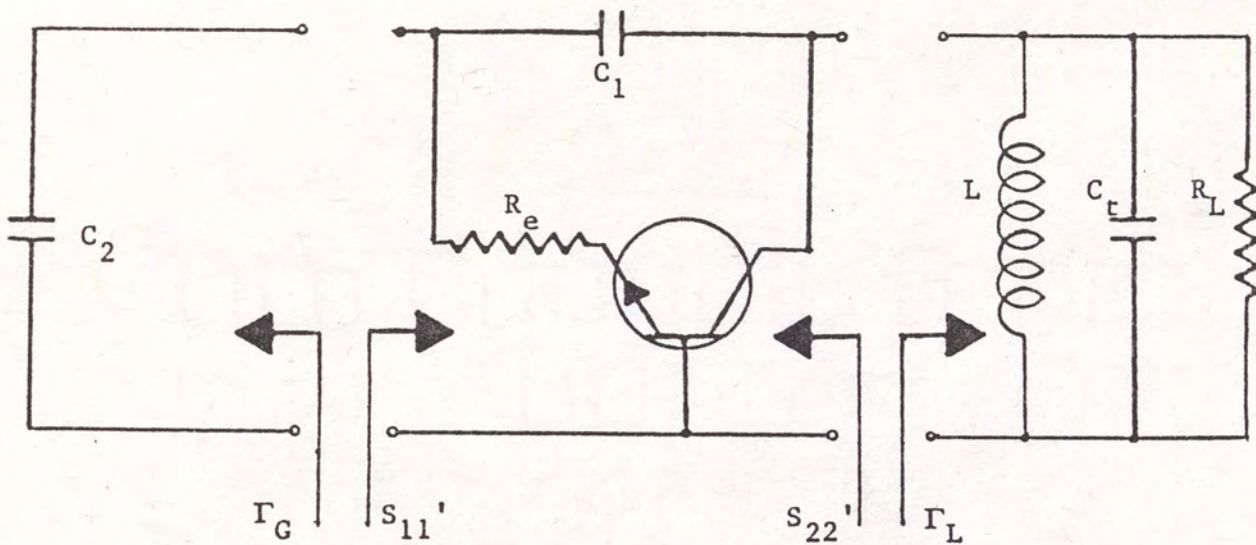


Figure 3. Colpitts Oscillator Block Diagram.

Thus, the combination of the transistor, feedback capacitor ( $C_1$ ), and input resistor ( $R_e$ ), becomes the unstable active network. The parallel circuit containing the inductor ( $L$ ), tuning capacitor ( $C_t$ ), and load resistor ( $R_L$ ) is considered to be the output matching circuit. Finally, the second tank capacitor ( $C_2$ ) will be thought of as the input matching element. Using this arrangement, the requirements for oscillation will be satisfied in the following way:

- 1) The overall S-parameters of the unstable active network will be determined from the Common Emitter transistor S-parameters and the values of  $C_1$  and  $R_e$ .

- 2) For a given load and nominal value of  $C_t$ , an inductor will be selected such that the input match can be accomplished with a single capacitor. (This condition is necessary to satisfy the Colpitts topology.)

- 3) The appropriate resonating capacitor  $C_2$  will be chosen.



Determination of Active Network S-Parameters

Transistor S-parameters are normally supplied by the manufacturer in the CE configuration. In order to combine with these the effects of the input resistor and feedback capacitor to obtain overall S-parameters for the active network shown in Figure 4, several parameter conversions must be performed.

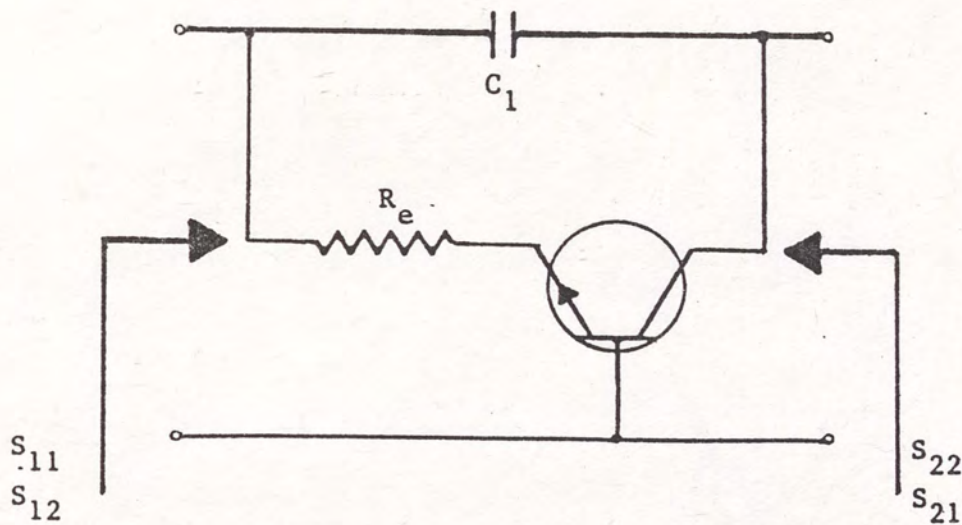


Figure 4. Unstable Active Network.

The CE S-parameters must be changed to CE h-parameters and then to CB h-parameters. These standard transformations (as well as the others mentioned in this paper) can be found in Appendix A. The circuit can now be depicted as in Figure 5:

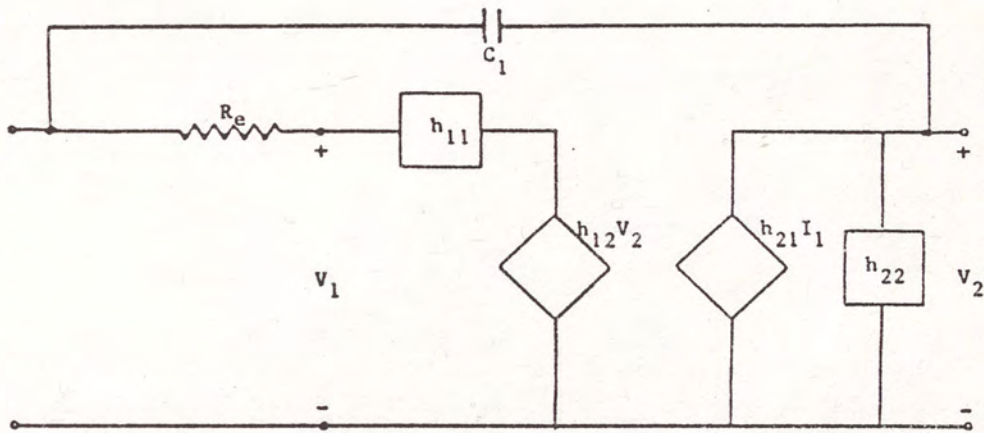


Figure 5. Active Network (h-parameter representation).

If  $R_e$  is combined with  $h_{11}$  and the result is transformed to the  $y$ -parameters (Van Valkenburg, 1974), the arrangement of Figure 6 is obtained, where:

$$Y_{11} = (h_{11} + R_e)^{-1} \quad (7)$$

$$Y_{12} = -h_{12}/(h_{11} + R_e) \quad (8)$$

$$Y_{21} = h_{21}/(h_{11} + R_e) \quad (9)$$

$$Y_{22} = \frac{(h_{11} + R_e)(h_{22}) - h_{12}h_{21}}{(h_{11} + R_e)} \quad (10)$$



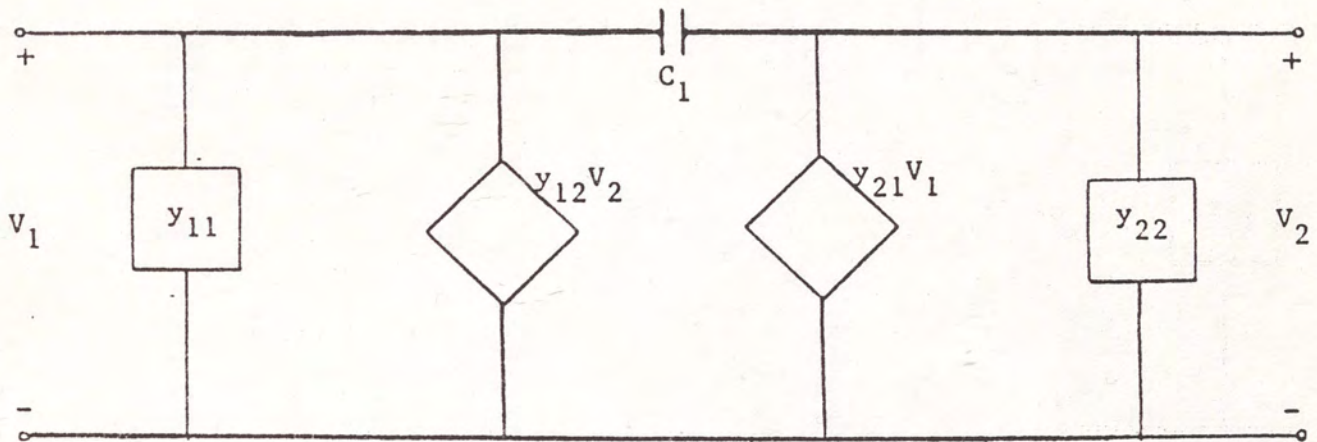


Figure 6. Active Network (y-parameter representation).

Next, the real and imaginary parts of  $y_{11}$  and  $y_{22}$  are separated:

$$Y_{11} = g_{11} + j b_{11} \quad (11)$$

$$Y_{22} = g_{22} + j b_{22} \quad (12)$$

This facilitates the regrouping of the elements of Figure 6 into two parallel networks as shown in Figure 7. The y-parameters of the parallel networks can be combined to give overall y-parameters for the active network (Van Valkenburg, 1974).

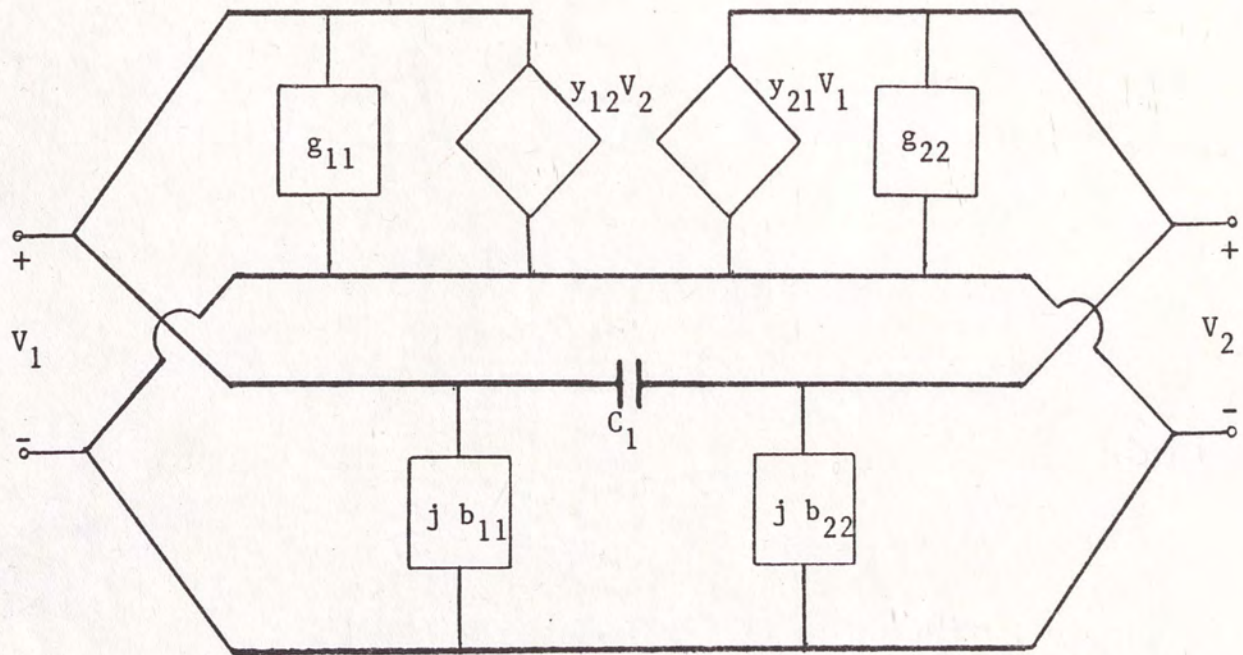


Figure 7. Active Network (parallel network representation).



The y-parameters of the Pi (lower) network are given by:

$$Y_{11} = j (b_{11} + \omega C_1) \quad (13)$$

$$Y_{22} = j (b_{22} + \omega C_1) \quad (14)$$

$$Y_{12} = Y_{21} = -j\omega C_1 \quad (15)$$

Thus, the y-parameters of the active network are:

$$Y_{11t} = g_{11} + j (b_{11} + \omega C_1) \quad (16)$$

$$Y_{12t} = Y_{12} - j\omega C_1 \quad (17)$$

$$Y_{21t} = Y_{21} - j\omega C_1 \quad (18)$$

$$Y_{22t} = g_{22} + j (b_{22} + \omega C_1) \quad (19)$$

These y-parameters may now be converted directly to the S-parameters of the active network (see Appendix A).

#### Determination of Output Network

Once the S-parameters have been determined it can be confirmed that  $k < 1$ . (This should not be a problem in that  $C_1$  is providing positive feedback within the network.) The next step is to determine the inductor value that will allow the resonating of the input with a single capacitor ( $C_2$ ). In other words, an inductor must be chosen such that:



$$S_{11}' = 1.00 \angle \theta$$

where  $0^\circ < \theta < 180^\circ$

This restriction is necessary since for a single capacitor:

$$\Gamma_G = 1.00 \angle \phi$$

where  $-180^\circ < \phi < 0^\circ$

A tuning capacitor is usually placed in parallel with the load and the inductor; its effects must also be considered (see Figure 8).

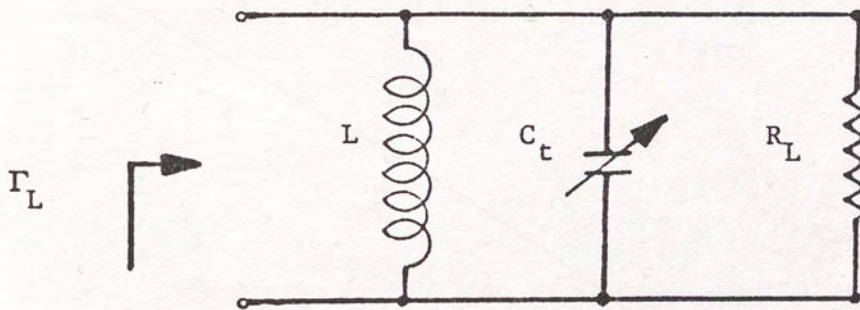


Figure 8. Output Network.



Thus, given the active network S-parameters, and nominal values for  $C_t$  and  $R_L$ , an acceptable value for  $L$  must be found such that  $|S_{11}'| = 1$ . Since a computer will be used, the most straight-forward method of accomplishing this is by trial-and-error.

The total network impedance is:

$$Z_L = R_L + j X_{\text{eff}} \quad (20)$$

$$\text{where } X_{\text{eff}} = [\omega C_t - (1/\omega L)]^{-1} \quad (21)$$

For the purposes of iteration, this parallel reactance can be treated as the reactance of a single inductor,  $L_{\text{eff}}$ . The computer begins with a low value for  $L_{\text{eff}}$  (1 nH) and determines  $|S_{11}'|$ , using Equation (5). It continues to perform this calculation (each time increasing the value of  $L_{\text{eff}}$  by 1 nH) until a value for  $L_{\text{eff}}$  is found that results in  $|S_{11}'| = 1$ . For each value of  $L_{\text{eff}}$  tried, a corresponding value for the actual inductor,  $L$ , is calculated (for the given nominal value of  $C_t$ ). For certain combinations of  $R_e$ ,  $C_1$ ,  $R_L$ , and  $C_t$  with a particular transistor, it is possible that no reasonable value for  $L$  exists that will result in  $|S_{11}'| = 1$ . For this reason a maximum allowable value of  $L$  should be input to prevent unnecessary iterations.



Determination of Input Network

All that remains to complete the design is the proper selection of  $C_2$ . The necessary value of  $\Gamma_G$  has been fixed in the previous determination of  $S_{11}'$  since:

$$\Gamma_G = (S_{11}')^{-1} \quad (2)$$

Therefore,  $C_2$  is determined from:

$$Z_G = Z_0 \frac{1 + \Gamma_G}{1 - \Gamma_G} \quad (22)$$

$$\text{where } Z_G = (j\omega C_2)^{-1} \quad (23)$$

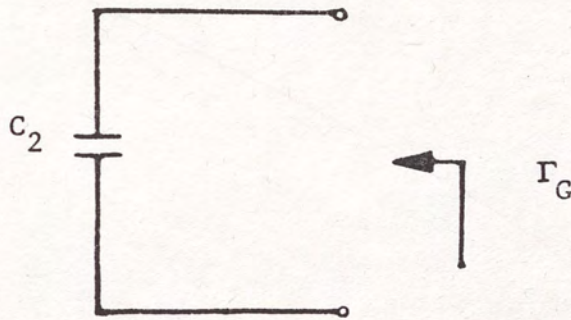


Figure 9. Input Network.



Although an inductor was selected to give  $|S_{11}'| = 1$ , a further restriction is required to ensure that the input match can be achieved with a capacitor (rather than an inductor). As stated previously, for a capacitor:

$$\Gamma_G = 1.00 \angle \phi$$

where  $-180^\circ < \phi < 0^\circ$

Thus, if the angle of  $\Gamma_G$  is:

$$0^\circ < \phi < 180^\circ$$

the input cannot resonate with a single capacitor and the Colpitts topology cannot be satisfied.

#### Description of Computer Program

A program to perform the calculations described in this chapter was written in FORTRAN on the IBM-PC. A listing is given in Appendix B. The program requires the following inputs:



## Transistor S-Parameters (CE)

 $R_L$  $R_e$  $C_1$  $C_t$ 

Frequency

Maximum allowable value for L

The program first determines the overall S-parameters of the active network (transistor,  $C_1$ , and  $R_e$ ) and calculates  $k$ . At that point,  $R_e$  and  $C_1$  can be modified or the program can proceed to determine values for L and  $C_2$ . If no acceptable values exist, the output so states. A flow chart for the program is given in Figure 10.



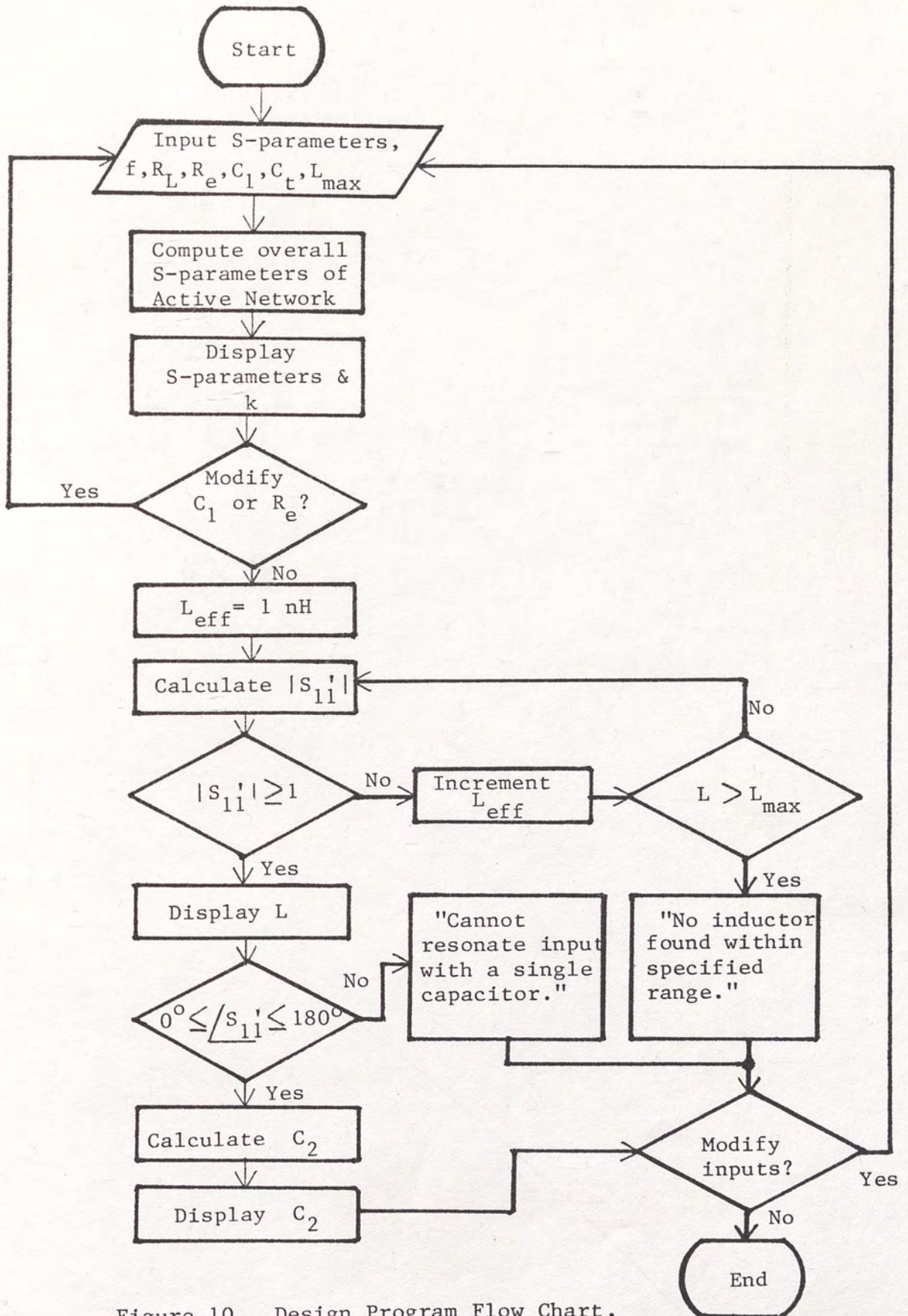


Figure 10. Design Program Flow Chart.



## CHAPTER 3

### DESIGN EXAMPLE

To confirm the validity of the design technique described in Chapter II, a 100 MHz Colpitts Oscillator was built and tested. The transistor used was the HP HXTR-3101. The CE S-Parameters supplied by the manufacturer (with biasing conditions  $I_C = 10$  mA and  $V_{ce} = 10$  V) are:

$$\begin{aligned}S_{11} &= 0.708 \angle -50^\circ \\S_{12} &= 0.015 \angle 60^\circ \\S_{21} &= 24.547 \angle 149^\circ \\S_{22} &= 0.912 \angle -20^\circ\end{aligned}$$

To confirm these values, the S-Parameters were measured in the laboratory using the same biasing conditions. The results were:

$$\begin{aligned}S_{11} &= 0.724 \angle -14^\circ \\S_{12} &= 0.0002 \angle 75^\circ \\S_{21} &= 21.380 \angle 154^\circ \\S_{22} &= 0.933 \angle -10^\circ\end{aligned}$$



which agreed well with those supplied by the manufacturer.

### Design of Biasing Circuit

The DC equivalent circuit is shown in Figure 11.

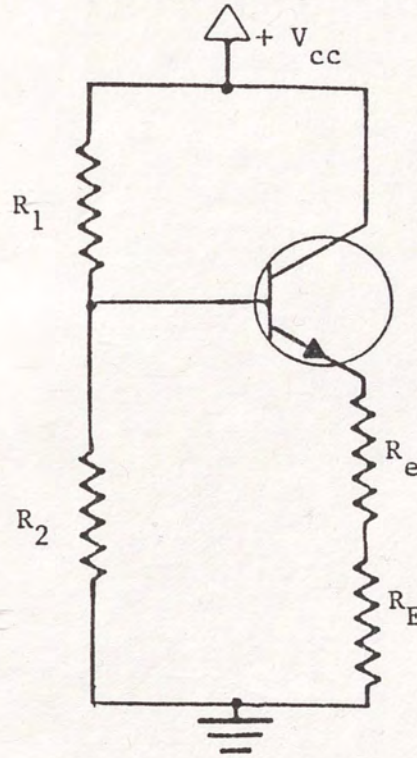


Figure 11. DC Equivalent Circuit.

To satisfy the biasing conditions mentioned in the previous section, the following standard values were chosen:

$$R_1 = 4.7 \text{ K}\Omega$$

$$R_2 = 5.6 \text{ K}\Omega$$

$$R_e = 100 \text{ }\Omega$$

$$R_E = 1 \text{ K}\Omega$$

$$V_{cc} = 21 \text{ V}$$



The value of  $R_e$ , which is a rather insignificant part of the DC circuit, plays a very important role in the AC circuit, in that it is used to linearize the input resistance of the active network and to limit the amount of positive feedback (Sentz and Bartkowiak, 1968).

### Design of Tank Circuit

In order to make the design of this example oscillator as general as possible, a single resistor was used as the load. It can represent the input impedance of an output buffer stage, or it can simply be matched to whatever network it is driving (Vendelin, 1982). It should be noted here that oscillation becomes less likely as the load resistance decreases; a low parallel resistance tends to drastically lower the  $Q$  of the tank (Krauss, et al., 1980).

The computer program was used to determine the tank element values. In addition to the value for  $R_e$  mentioned above, the following were selected for input to the program:

$$C_1 = 15 \text{ pF}$$

$$R_L = 4.7\text{K}\Omega \quad \text{to} \quad 600 \Omega$$

$$C_t = 15 \text{ pF}$$



The results of the program were:

$$S_{11} = 0.299 \angle -52.6^\circ$$

$$S_{12} = 0.541 \angle 57.4^\circ$$

$$S_{21} = 0.756 \angle 11.4^\circ$$

$$S_{22} = 0.847 \angle -33.0^\circ$$

$$k = 0.75$$

$$L = 83 \text{ to } 100 \text{ nH}$$

The program was run several times, varying the load resistance value from  $4.7\text{K}\Omega$  down to  $600\ \Omega$ . This was to allow for the various resistances which are in fact parallel to the load resistor, effectively reducing its value. The primary parallel resistance comes from the equivalent parallel resistance of the coil.

An inductor with a value in the range shown above was wound and its impedance measured on the S-Parameter test set (see Figure 13). The inductor had a relatively low Q, given by:

$$Q_s = X_s/R_s = 13.7 \quad (24)$$

where  $X_s$  is the equivalent series reactance and  $R_s$  is the equivalent series resistance. If the series equivalent



circuit values are changed to parallel equivalent circuit values, the parallel equivalent resistance is given by:

$$R_{pe} = (1 + Q_s)^2 = 886 \Omega \quad (25)$$

where  $R_{pe}$  is in parallel with the load resistor. (It should be noted that for  $Q_s > 10$ , the values for  $L_s$  and  $L_{pe}$  are essentially the same.) Thus, the actual effective load resistance of the output network (Krauss, et al., 1980) is:

$$R_{eff} = R_{pe} || R_L = 745 \Omega \quad (26)$$

Using this value as the load resistor, the program yields:

$$L = 93 \text{ nH}$$

$$C_2 = 82 \text{ pF}$$

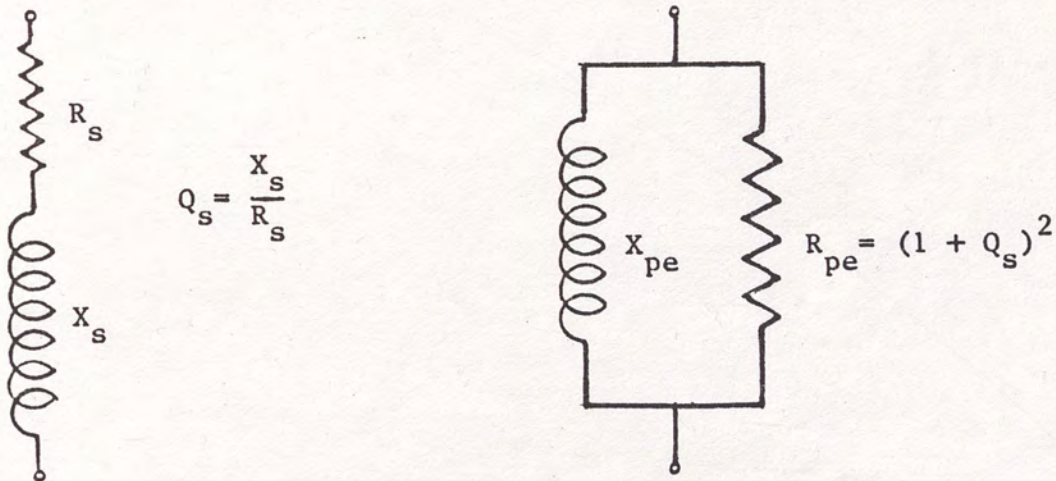


Figure 12. Series and Parallel Models for a Real Inductor.



FULL SCALE 1.0000  
 PHASE REF 0.0deg  
 REF POSN 0.0deg

MARKER 100 000 000.000Hz  
 Z RE (S11) 82.226E-3  
 Z IM (S11) 1.1265

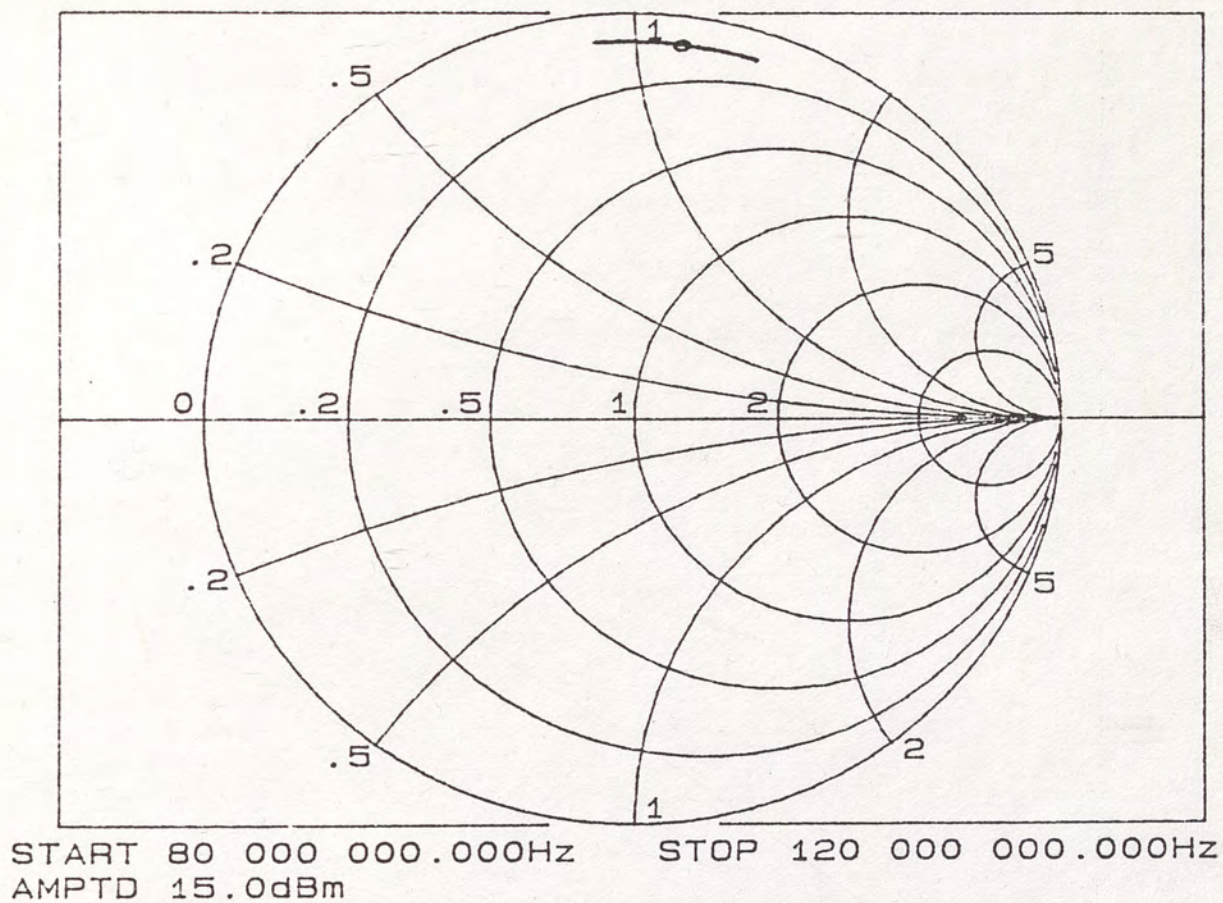


Figure 13. Impedance of a Real Inductor at 100 MHz.



### Final Circuit Implementation

The final circuit was built on two-sided copper-clad board, one side being used as a ground plane. In addition to the components previously mentioned, additional components were used. The power supply was decoupled using a parallel capacitor and series RF choke. The bypass capacitors were realized by two parallel capacitors (to lower effective series inductance of the bypass capacitors and thus reduce the chance of spurious high frequency oscillations). The size of the board was made as small as possible (2 in. x 2 in.) to minimize stray capacitances; leads were made as short as possible to lower inductances (DeMaw, 1982). Variable capacitors were used in the tank circuit to facilitate adjustments and fine tuning. A complete circuit diagram is shown in Figure 14.

### Matching Network

In order to measure the output at 100 MHz on standard 50 Ohm test equipment, a matching network was implemented. The  $4.7\text{K}\Omega$  output resistor was matched to a standard RF characteristic impedance of 50 Ohms using a tunable T-network as shown in Figure 15.



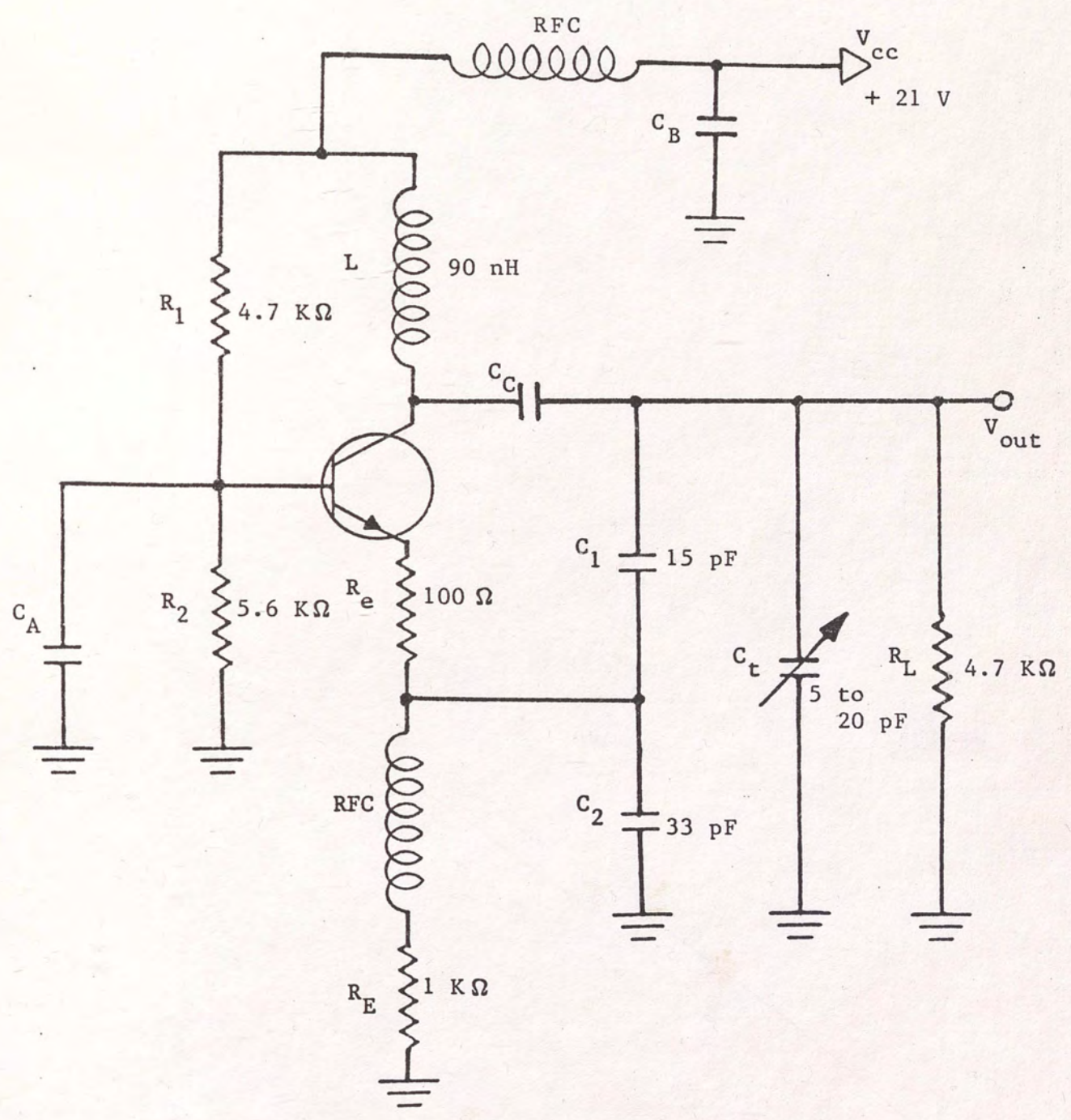


Figure 14. 100 MHz Colpitts Oscillator.



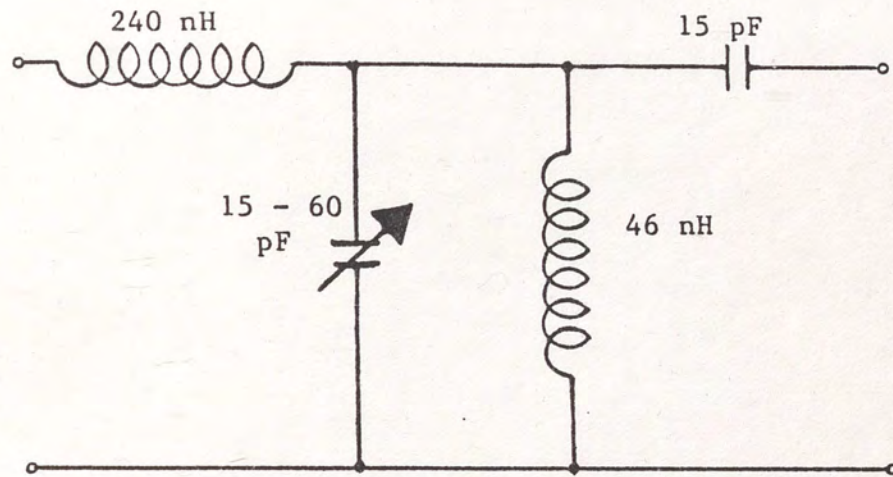


Figure 15. Matching Network .

The nominal values were selected using the Smith Chart, and the circuit was fine tuned using the S-parameter test set to guarantee a good match at 100 MHz. The addition of this parallel network to the load network results in yet another change in  $R_{\text{eff}}$ :

$$R_{\text{eff}} = R_L || R_{\text{pe}} || R_{\text{match}} \quad (27)$$

where  $R_{\text{match}}$  is the  $50 \Omega$  impedance as seen through the matching network. With  $R_{\text{match}} = 4.7 \text{K} \Omega$ :



$$R_{\text{eff}} = 643 \Omega$$

$$L = 97 \text{ nH}$$

$$C_2 = 55 \text{ pF}$$

### Circuit Testing

The actual circuit values which resulted in oscillation at the desired frequency are given below:

$$R_L = 4.7 \text{ K}\Omega$$

$$R_e = 100 \Omega$$

$$C_t = 17 \text{ pF}$$

$$C_1 = 15 \text{ pF}$$

$$C_2 = 33 \text{ pF}$$

$$L = 90 \text{ nH}$$

The output was connected through the matching network to the oscilloscope. The resulting time domain waveform can be seen in Figure 17. The peak-to-peak voltage is 1.6 V, corresponding to a power being delivered to a  $50 \Omega$  load of:

$$P_{\text{ac}} = \frac{V_{\text{rms}}^2}{R_o} = 6.4 \text{ mW} = 8.1 \text{ dBm} \quad (28)$$

Recalling the DC power required by the transistor at the given biasing conditions



$$P_{DC} = V_{ce} I_c = (10 \text{ V})(.01 \text{ A}) = 100 \text{ mW} \quad (29)$$

it is noted that the oscillator efficiency is

$$\text{Eff.} = \frac{P_{ac}}{P_{DC}} = \frac{6.4}{100} = 6.4\% \quad (30)$$

It has been shown (Krauss, et al., 1980) that the maximum theoretical efficiency for this oscillator configuration is 25%. Figure 16 illustrates the testing set-up.

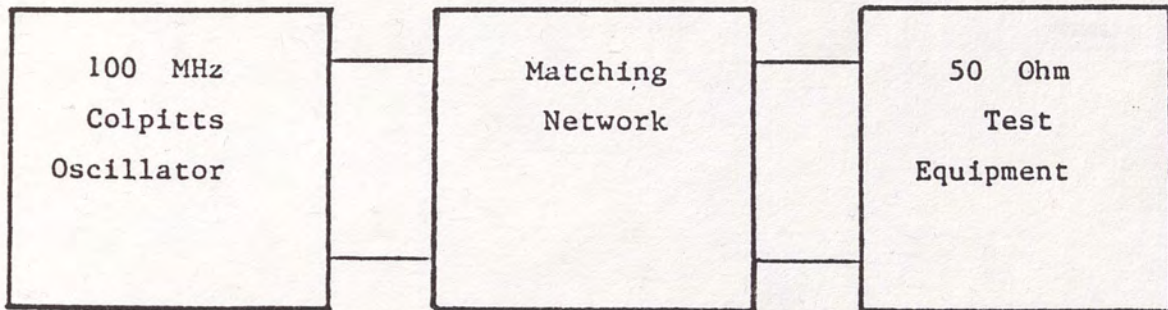


Figure 16. Circuit Testing Arrangement.



The frequency domain characteristics were measured on the spectrum analyzer. Figure 18 illustrates the 6 dBm signal at 100 MHz and Figure 19, using 200 kHz per division, illustrates the phase noise. Harmonics went virtually undetected on the test equipment, since the matching network also effectively serves as a bandpass filter (Bowick, 1982). The maximum tuning range afforded by adjusting  $C_t$  was about 1 MHz.

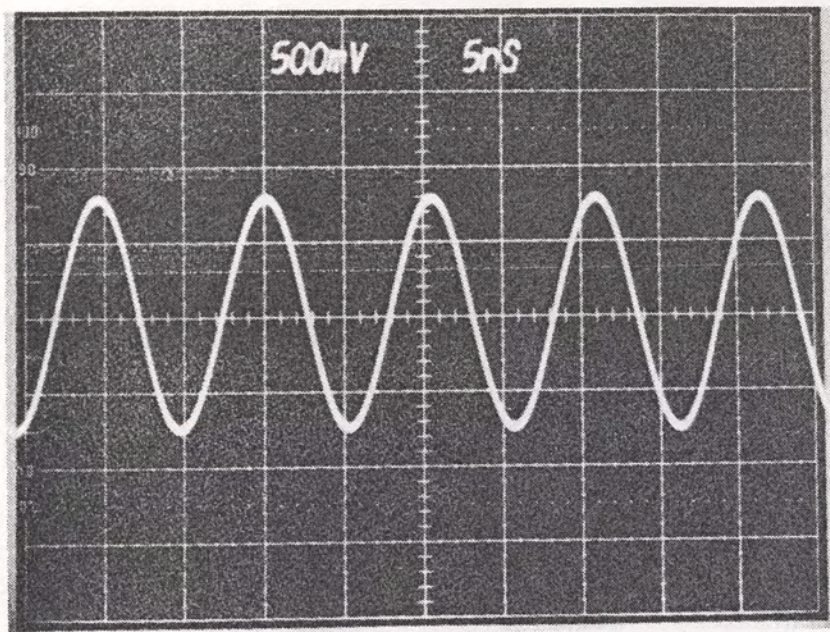


Figure 17. Time Domain Output.



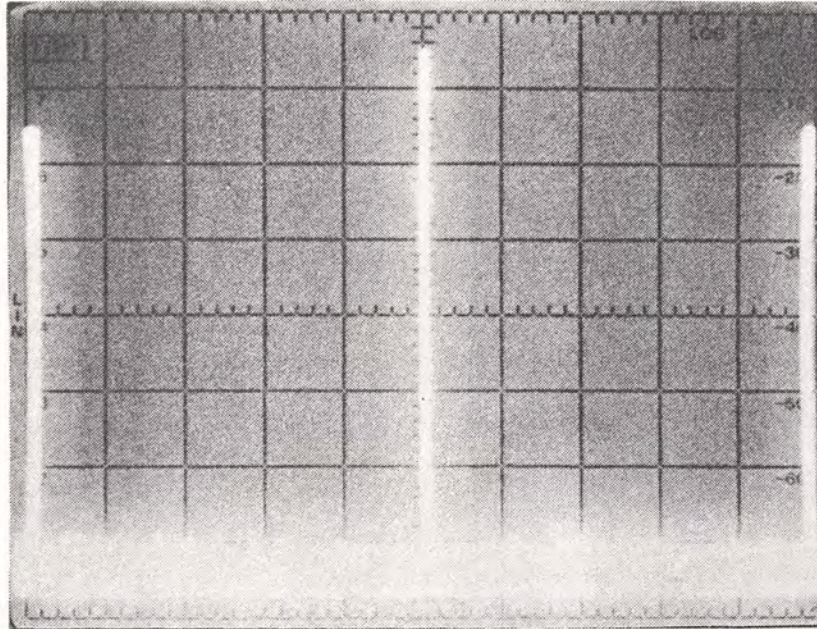


Figure 18. Frequency Domain Output (20 MHz per division).

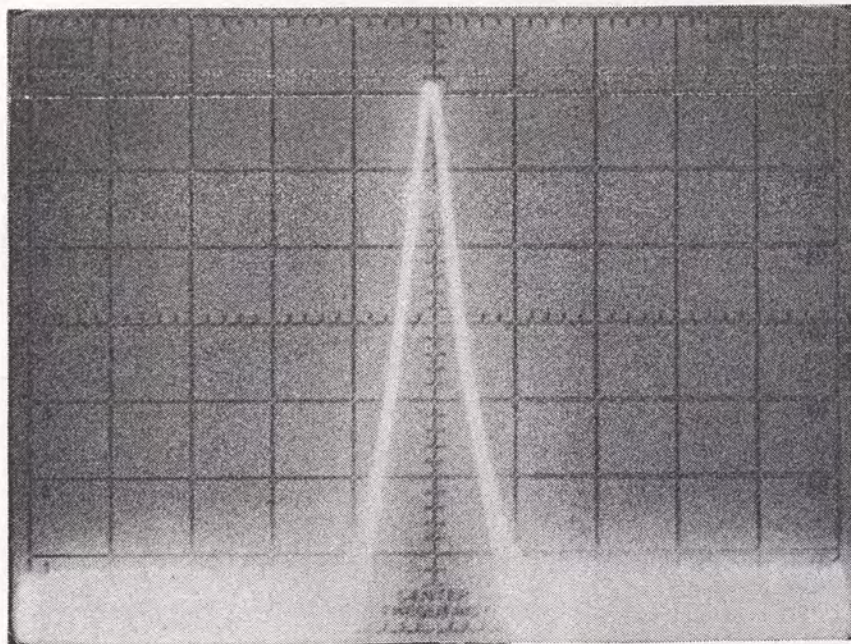


Figure 19. Frequency Domain Output (200 KHz per division).



## CHAPTER IV

### RESULTS AND CONCLUSIONS

The performance of the oscillator described in the previous chapter was very close to that predicted by the design program. The most significant discrepancy arose in the value of  $C_2$ , which differed from the predicted value by 40%. Upon further investigation using the program, it was found that a somewhat lower value for  $R_L$  (  $580 \Omega$  ) resulted in the measured value of  $C_2$  ( 33 pF), although this also raised the required value for L to 104 nH.

Several terms have been neglected in the analysis presented in this paper; no one term by itself is very significant, yet combined they may effect the results substantially. Specifically, consideration should be given to the resistance of the tank capacitors as well as the reactance of the load resistor. The effects of these alone could easily have caused the difference between the predicted and actual values (Bowick, 1982).



It should be noted in conclusion that a feedback system is not necessarily required for all VHF oscillators. At higher frequencies, feedback within the transistor itself can make it unstable (particularly in the CB configuration) without an external positive feedback path. The first part of the design program can be used to assist in oscillator design using topologies with no feedback simply by entering  $R_e = C_1 = 0$ . The program then computes the standard CB S-parameters and the stability factor,  $k$ . If  $k < 1$ , no feedback is required, and a simple oscillator may be designed using the CB S-parameters along with the general criteria mentioned in Chapter I.



APPENDIX A

NETWORK PARAMETER TRANSFORMATIONS



## I. S-parameters (CE) to h-parameters (CE) (Vendelin, 1982)

$$h_{11} = \frac{(1 + S_{11})(1 + S_{22}) - S_{12}S_{21}}{(1 - S_{11})(1 + S_{22}) + S_{12}S_{21}}$$

$$h_{12} = \frac{2S_{12}}{(1 - S_{11})(1 + S_{22}) + S_{12}S_{21}}$$

$$h_{21} = \frac{-2S_{21}}{(1 - S_{11})(1 + S_{22}) + S_{12}S_{21}}$$

$$h_{22} = \frac{(1 - S_{22})(1 - S_{11}) - S_{12}S_{21}}{(1 - S_{11})(1 + S_{22}) + S_{12}S_{21}}$$

## II. h-parameters (CE) to h-parameters (CB) (Casasent, 1973)

$$h_{11cb} = \frac{h_{11ce}}{(h_{21ce} + 1)}$$

$$h_{12cb} = h_{11cb}h_{22cb}(h_{21ce} + 1) - h_{12ce}$$

$$h_{21cb} = \frac{-h_{21ce}}{(h_{21ce} + 1)}$$

$$h_{22cb} = \frac{h_{22ce}}{(h_{21ce} + 1)}$$



III. h-parameters to y-parameters (Van Valkenburg, 1974.)

$$Y_{11} = \frac{1}{h_{11}}$$

$$Y_{12} = \frac{-h_{12}}{h_{11}}$$

$$Y_{21} = \frac{h_{21}}{h_{11}}$$

$$Y_{22} = \frac{h_{11}h_{22} - h_{12}h_{21}}{h_{11}}$$

IV. y-parameters to S-parameters (Vendelin, 1982)

$$S_{11} = \frac{(1 - Y_{11})(1 + Y_{22}) + Y_{12}Y_{21}}{(1 + Y_{11})(1 + Y_{22}) + Y_{12}Y_{21}}$$

$$S_{12} = \frac{-2Y_{12}}{(1 + Y_{11})(1 + Y_{22}) - Y_{12}Y_{21}}$$

$$S_{21} = \frac{-2Y_{21}}{(1 + Y_{11})(1 + Y_{22}) - Y_{12}Y_{21}}$$

$$S_{22} = \frac{(1 + Y_{11})(1 - Y_{22}) + Y_{12}Y_{21}}{(1 + Y_{11})(1 + Y_{22}) - Y_{12}Y_{21}}$$

NOTE: All two-port parameter transformations are normalized to  $Z_0 = 1$ .



APPENDIX B

LISTING OF DESIGN PROGRAM



```

COMPLEX S11,S12,S21,S22
COMPLEX HE11,HE12,HE21,HE22
COMPLEX HB11,HB12,HB21,HB22
COMPLEX YT11,YT12,YT21,YT22
COMPLEX YO11,YO12,YO21,YO22
COMPLEX SO11,SO12,SO21,SO22
COMPLEX DENH,DENS,DENY,DELTH
COMPLEX YC,ZL,Z0,GAML
COMPLEX XL,ZLOAD,SPRIM,SPRIG
COMPLEX GAMG,ZG
REAL MAG,K,LMAX,LEFF

```

```
PI=3.1415926
```

```
WRITE(*,*) ' ENTER MAG(NON-DB) AND PHASE(DEG) OF CE S-PARAMS'
```

```
WRITE(*,*) ' INPUT S11 MAG AND PHASE'
```

```
READ(*,*)S11M,S11D
```

```
WRITE(*,*) ' INPUT S12 MAG AND PHASE'
```

```
READ(*,*)S12M,S12D
```

```
WRITE(*,*) ' INPUT S21 MAG AND PHASE'
```

```
READ(*,*)S21M,S21D
```

```
WRITE(*,*) ' INPUT S22 MAG AND PHASE'
```

```
READ(*,*)S22M,S22D
```

```
WRITE(*,*) 'INPUT FREQ (IN MHz)'
```

```
READ(*,*)FREQ
```

```
1 WRITE(*,*) 'INPUT MAXIMUM ALLOWABLE VALUE FOR L (IN nH)'
```

```
READ(*,*)LMAX
```

```
WRITE(*,*) 'INPUT NOMINAL VALUE FOR TUNING CAPACITOR (IN pF)'
```

```
READ(*,*)CT
```

```
WRITE(*,*) 'INPUT LOAD RESISTANCE (IN Ohms)'
```

```
READ(*,*)RL
```

```
2 WRITE(*,*) 'INPUT Re (IN Ohms)'
```

```
READ(*,*)RE
```

```
WRITE(*,*) 'INPUT C1 (IN pF)'
```

```
READ(*,*)C1
```

```
S11P=S11D*PI/180.
```

```
S12P=S12D*PI/180.
```

```
S21P=S21D*PI/180.
```

```
S22P=S22D*PI/180.
```

```
C CALCULATE CE S-PARAMETERS IN STANDARD FORM (TRANSISTOR ONLY)
```

```
S11=S11M*CMPLX(COS(S11P),SIN(S11P))
```

```
S12=S12M*CMPLX(COS(S12P),SIN(S12P))
```



```
S21=S21M*CMPLX(COS(S21P),SIN(S21P))
S22=S22M*CMPLX(COS(S22P),SIN(S22P))
```

```
C TRANSFORM TO CE H-PARAMETERS (TRANSISTOR ONLY)
```

```
DENS=(1.0-S11)*(1.0+S22)+(S12*S21)
HE11=((1.0+S11)*(1.0+S22)-(S12*S21))/DENS
HE12=(2.0*S12)/DENS
HE21=(-2.0*S21)/DENS
HE22=((1.0-S11)*(1.0-S22)-(S12*S21))/DENS
```

```
C TRANSFORM TO CB H-PARAMETERS (TRANSISTOR ONLY)
```

```
DENH=HE21+1.0
HB11=HE11/DENH
HB21=-HE21/DENH
HB22=HE22/DENH
HB12=HB11*HB22*DENH-HE12
```

```
C TRANSFORM TO CB Y-PARAMETERS (TRANSISTOR AND RE)
```

```
RN=RE/50.0
DELTH=(HB11+RN)*(HB22)-(HB12*HB21)
YT11=1./(HB11+RN)
YT12=-HB12/(HB11+RN)
YT21=HB21/(HB11+RN)
YT22=DELTH/(HB11+RN)
```

```
C CALCULATE Y-PARAMETERS ASSOCIATED WITH C1 & RE AND COMBINE
C WITH Y-PARAMETERS OF CB TRANSISTOR
```

```
G11=REAL(YT11)
B11=AIMAG(YT11)
G22=REAL(YT22)
B22=AIMAG(YT22)
Y=2.0*PI*FREQ*C1*(50.0E-06)
YC=CMPLX(0.0,Y)
```

```
YD11=CMPLX(G11,B11+Y)
YD12=YT12-YC
YD21=YT21-YC
YD22=CMPLX(G22,B22+Y)
```

```
C CONVERT OVERALL Y-PARAMETERS TO OVERALL CB S-PARAMETERS
```

```
DENY=(1.0+YD11)*(1.0+YD22)-(YD12*YD21)
S011=((1.0-YD11)*(1.0+YD22)+(YD12*YD21))/((1.0+YD11)*(1.0+YD22)+
‡ (YD12*YD21))
S012=(-2.0*YD12)/DENY
```



```

SO21=(-2.0*Y021)/DENY
SO22=((1.0+Y011)*(1.0-Y022)+(Y012*Y021))/DENY

```

```

WRITE(*,*)' '
WRITE(*,*)' '
WRITE(*,*)' Re= ',RE,' Ohms'
WRITE(*,*)' '

```

```

CALL STABILITY(S011,S012,S021,S022,K)
WRITE(*,*)' C1= ',C1,' pF'
WRITE(*,*)' '
WRITE(*,*)' K= ',K
WRITE(*,*)' '

```

```

CALL CTMAP(S011,S011M,S011D)
CALL CTMAP(S012,S012M,S012D)
CALL CTMAP(S021,S021M,S021D)
CALL CTMAP(S022,S022M,S022D)

```

```

WRITE(*,*)' OVERALL S-PARAMETERS (INCLUDING RE & C1)'
WRITE(*,*)' ', 'MAG', ' ', ' DEG'
WRITE(*,*)' S11= ',S011M,S011D
WRITE(*,*)' S12= ',S012M,S012D
WRITE(*,*)' S21= ',S021M,S021D
WRITE(*,*)' S22= ',S022M,S022D
WRITE(*,*)' TRY ANOTHER C1 OR RE? (YES=1,NO=2)'
READ(*,*)B
IF (B.EQ.1.0) GOTO 2

```

```

C DETERMINE A VALUE FOR L THAT WILL ALLOW A SINGLE CAPACITOR
C TO RESONATE THE INPUT

```

```

L=0.0
LEFF=1.0
ZO=(50.0,0.0)
3 XX=2.0*PI*FREQ*LEFF*(1.0E-03)
XL=CMPLX(0.0,XX)
ZLOAD=CMPLX(RL,0.0)

```

```

ZL=(ZLOAD*XL)/(ZLOAD+XL)

```

```

GAML=(ZL-ZO)/(ZL+ZO)

```

```

SPRIM=S011+((S012*S021*GAML)/(1.0-(S022*GAML)))
S=CABS(SPRIM)
IF (S.GE.1.0) GOTO 4
YEFF=1.0/XX
YCT=2.0*PI*FREQ*CT*(1.0E-06)
YIND=YEFF+YCT

```



```

ZIND=1.0/YIND
L=ZIND/(2.0*PI*FREQ*(1.0E-03))
IF (L.GT.LMAX) GOTO 44
LEFF=LEFF+1.0
GOTO 3

44 WRITE(*,*) 'NO INDUCTOR FOUND WITHIN SPECIFIED RANGE'
   GOTO 40

45 WRITE(*,*) 'CANNOT RESONATE INPUT WITH A CAPACITOR'
   GOTO 40

4  WRITE(*,*) '
   WRITE(*,*) '
   WRITE(*,*) '
   WRITE(*,*) ' WITH RL= ',RL,' Ohms'
   WRITE(*,*) '      Re= ',RE,' Ohms'
   WRITE(*,*) '      C1= ',C1,' pF'
   WRITE(*,*) '      Ct= ',CT,' pF'
   WRITE(*,*) '      K= ',K

CALL CTMAP(SPRIM,SPRM,SPRD)
WRITE(*,*) '
WRITE(*,*) 'IN ORDER TO RESONATE INPUT AND OUTPUT'
WRITE(*,*) '
WRITE(*,*) ' L= ',L,' nH'
WRITE(*,*) '
WRITE(*,*) '
CALL CTMAP(GAML,GAMM,GAMD)
WRITE(*,*) 'GAMMA OF LOAD= ',GAMM,' AT ',GAMD,' DEG.'
WRITE(*,*) '
WRITE(*,*) 'S11 PRIME= ',SPRM,' AT ',SPRD,' DEG.'

C  DETERMINE A VALUE FOR C2 THAT WILL RESONATE THE INPUT

DEG=ATAN2(AIMAG(SPRIM),REAL(SPRIM))*180.0/PI
GDEG=-DEG
IF (GDEG.GT.0.0) GOTO 45
GAMGP=GDEG*PI/180.0
GAMG=CMPLX(COS(GAMGP),SIN(GAMGP))
ZG=Z0*((1.0+GAMG)/(1.0-GAMG))
XC=CABS(ZG)
C2=1.0/(2.0*PI*FREQ*XC*(1.0E-06))
WRITE(*,*) ' C2= ',C2,' pF'
WRITE(*,*) '
CALL CTMAP(GAMG,GAIM,GAID)
WRITE(*,*) 'GAMMA OF INPUT= ',GAIM,' AT ',GAID,' DEG.'
WRITE(*,*) '
SPRIG=S022+((S012*S021*GAMG)/(1.0-(S011*GAMG)))
CALL CTMAP(SPRIG,SPGM,SPGD)
WRITE(*,*) 'S22 PRIME= ',SPGM,' AT ',SPGD,' DEG.'
WRITE(*,*) '

```



```

40  WRITE(*,*) 'TRY ANOTHER RE, RL OR C1? (YES=1,NO=2)'
    READ(*,*)A
    IF (A.EQ.1.0) GOTO 1

```

```

STOP

```

```

END

```

```

C    THIS SUBROUTINE CONVERTS A COMPLEX NUMBER INTO MAGNITUDE
C    AND DEGREES

```

```

SUBROUTINE CTMAP(COMP,MAG,DEG)

```

```

COMPLEX COMP
REAL MAG

```

```

PI=3.1415926
XXR=REAL(COMP)
YYI=AIMAG(COMP)
MAG=SQRT(XXR**2+YYI**2)
DEG=ATAN2(AIMAG(COMP) , REAL(COMP))*180.0/PI

```

```

RETURN
END

```

```

C    THIS SUBROUTINE CALCULATES THE STABILITY FACTOR, K

```

```

SUBROUTINE STABILITY(S011,S012,S021,S022,K)

```

```

COMPLEX S011,S012,S021,S022
REAL K

```

```

B=CABS(S011)
C=CABS(S022)
D=CABS(S011*S022-S012*S021)
K=(1.0-B**2-C**2+D**2)/(2.0*CABS(S012)
&   *CABS(S021))

```

```

RETURN
END

```



APPENDIX C

EXAMPLE RUN OF DESIGN PROGRAM



```

A:\>
A:\>
A:\>
A:\>tkj
  ENTER MAG(NON-DB) AND PHASE(DEG) OF CE S-PARAMS
  INPUT S11 MAG AND PHASE
0.724,-14.
  INPUT S12 MAG AND PHASE
0.0002,75.
  INPUT S21 MAG AND PHASE
21.38,154.
  INPUT S22 MAG AND PHASE
0.933,-10.
  INPUT FREQ (IN MHz)
100.
  INPUT MAXIMUM ALLOWABLE VALUE FOR L (IN nH)
120.
  INPUT NOMINAL VALUE FOR TUNING CAPACITOR (IN pF)
15.
  INPUT LOAD RESISTANCE (IN Ohms)
650.
  INPUT Re (IN Ohms)
100.
  INPUT C1 (IN pF)
15.

```

Re= 100.0000000 Ohms

C1= 15.0000000 pF

k= 7.476355E-001

OVERALL S-PARAMETERS (INCLUDING RE & C1)

	MAG	DEG
S11=	2.989655E-001	-52.6134100
S12=	5.409708E-001	57.3501700
S21=	7.564967E-001	11.4056300
S22=	8.468690E-001	-33.0495300

TRY ANOTHER C1 OR RE? (YES=1,NO=2)



2

WITH RL= 650.0000000 Ohms  
 Re= 100.0000000 Ohms  
 C1= 15.0000000 pF  
 Ct= 15.0000000 pF  
 K= 7.476355E-001

IN ORDER TO RESONATE INPUT AND OUTPUT

L= 97 nH

GAMMA OF LOAD= 8.716151E-001 AT 38.5130300 DEG.

S11 PRIME= 1.0027850 AT 120.5401000 DEG.

C2= 55.7379500 pF

GAMMA OF INPUT= 1.0000000 AT -120.5401000 DEG.

S22 PRIME= 1.1479440 AT -38.5225600 DEG.

TRY ANOTHER RE, RL OR C1? (YES=1,NO=2)

2



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