Exploring RF

Edited by ***David Newkirk, WJ1Z*** *• Electronic Publications Editor*

ARRL Radio Designer Versus Oscillators, Part 2

In the previous Exploring RF,[1] we learned that *ARRL Radio Designer*[2] can indicate the possibility of instability—instability that may well result in oscillation rather than dependable amplification—in electronic circuits intended to be stable. Even though sustained, stable oscillation is a large-signal, nonlinear phenomenon,[3] *ARD* can indicate the possibility or likelihood of oscillation because oscillation begins under *small*-signal conditions. The return-loss (MS_{11}) and stability factor (K) analyses we used in last column's oscillating-preamp modeling or circuits are just the ticket for circuits we intend to be stable.

This month, we bring *ARD* to bear on predicting useful things about oscillators—circuits we *want* to oscillate. As is true of circuits we intend will be stable, if we know what conditions to look for in an oscillator, we can use *ARD* to confirm or even enhance those conditions. Instead of using last column's MS_{11} and K approach, we'll evaluate a circuit's tendency to oscillate in terms of *negative resistance*.

Another Oscillator Model

In the previous Exploring RF, I characterized an oscillator as consisting of an amplifier, a resonator (filter) and positive feedback. It's also possible to view an oscillator as a resonator and a negative-resistance generator (Figure 1). At start-up in this model, the resonator and oscillator reactances must be equal in value and opposite in sign. In a 1994 *QEX* article,[4] Ulrich L. Rohde, KA2WEU, showed how *ARRL Radio Designer* can be used in evaluating an oscillator's performance in terms of this negative-resistance-generator model:

"Figure 2A shows a simple oscillator circuit. This 800-MHz oscillator uses a Siemens BFQ74 bipolar transistor. Looking at this circuit from the standpoint of the negative-resistance generator of Figure 1, we analyze the net resistance of the resonator (5 nH) and the oscillator circuit. The resistance should be 0 or slightly negative.[5] We most easily view this by breaking the circuit at the ground connection of the coil and treating that point and ground as the terminals of a 1-port circuit, so we can investigate its impedance. The circuit model is shown in Figure 2B.

"We want to select a bias current that is as small as possible, without reducing it to the point where the oscillator output power is too small to give a useful ultimate signal-to-noise ratio. In this case, we selected a bias emitter current of 10 mA. Now we have to find the appropriate feedback network, consisting of C1 and C2. Varying these capacitance values will vary the feedback and thus the loading of the resonator by the oscillator circuit. Finding the point at which the net resistance of the modeled circuit is just negative enough gives us the proper feedback; at this point, the loading is the least that will sustain oscillation, and the loaded Q is therefore the highest available with the selected bias.

"Table 1 shows the circuit netlist used with *ARRL Radio Designer* to simulate the circuit of Figure 2B, and Figure 3 shows the port resistance (RZ_{11}) and reactance (IZ_{11}) calculated by the simulation. The traces labeled 1 correspond to values of C1 and C2 of 5 pF. Traces 2 are with C1 and C2 at 10 pF, and traces 3 are at

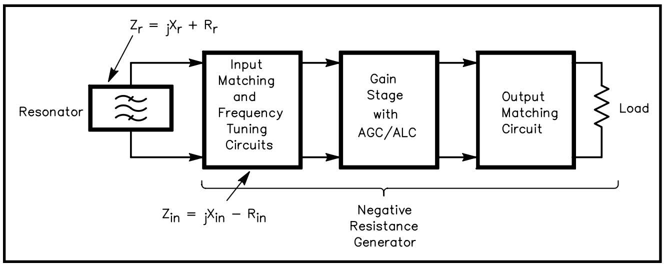

Figure 1—An oscillator viewed as a resonator and a negative-resistance generator. At start-up, the resonator and oscillator reactances must be equal in value and opposite in sign, while the sum of the resonator and oscillator resistances must be less than 0. For sustained oscillation, the sum of the resistances must not become positive.

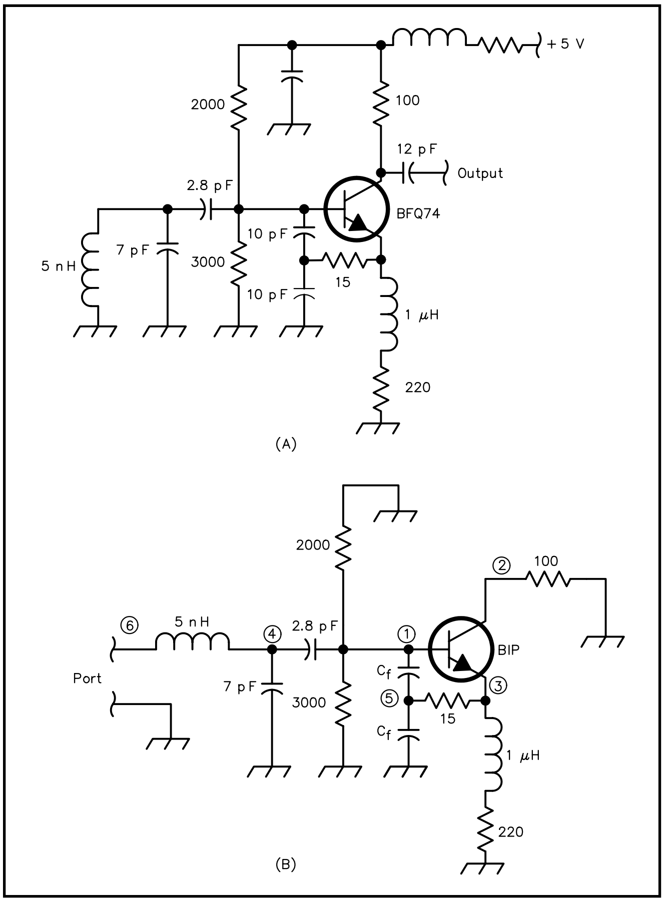

Figure 2—Even though *ARRL Radio Designer* is a small-signal linear simulator, and the active device in an oscillator (A, a simple 800-MHz circuit) operates in a large-signal, *non*linear way, *ARD* can help us determine component values that make oscillation likely, and how close to the edge of *non*oscillation an oscillator circuit may be. B shows the same circuit redrawn for *ARRL Radio Designer* modeling. The model treats the circuit as a one-port device so we can investigate the impedance seen looking into the oscillator's ungrounded resonator (coil) and common. If the resistive part of this impedance is zero or negative, the circuit will likely oscillate.

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[1] Notes appear on page 80.

Table 1
An Oscillator as a Negative Resistance Generator

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* SIEMENS BFQ74 BJT: Analysis of an NPN bipolar
* model.
* Bias network is set for Ie=10 mA.
*************************************************
Cf:10pF        ; Feedback network
IE:10mA        ; Emitter current
FT:6000e6      ; Device ft in Hz
Rd:(26mV/IE)
Cte:(1/(2*PI*FT*Rd))
*************************************************
BLK
   BIP 1 2 3 A=0.98 RB1=4 CE=Cte RE=Rd
* Feedback network
   CAP 1  11 C=Cf
   CAP 11 0  C=Cf
   RES 3  11 R=15
* Emitter feedback network
  SRL 3 0 R=220 L=1UH
* Tank Circuit
  CAP 1  4  C=2.8PF
  IND 4  31 L=5NH F=800MHZ Q1=120
  CAP 4  0  C=7PF
* Collector decoupling
  CAP 2  0 C=1NF
  RES 2  0 R=100
* DC bias network
  RES 1  0 R=2000
  RES 1  0 R=3000
  OSC:1POR 31
END
FREQ
  STEP 500MHZ 1000MHZ 10MHZ
  STEP 700MHZ 850MHZ 2MHZ
END
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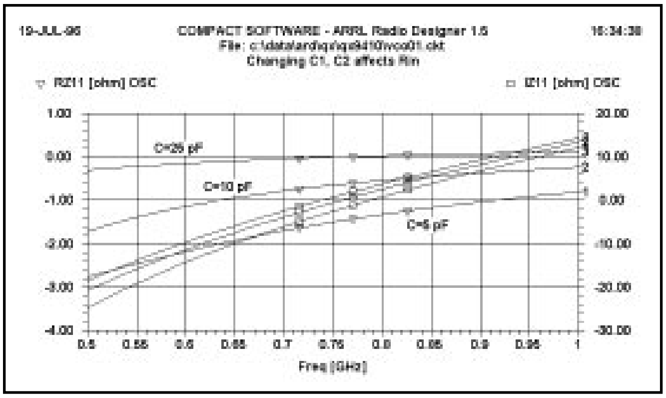

Figure 3—This *ARRL Radio Designer* analysis shows the resistive (RZ_{11}) and reactive (IZ_{11}) parts of the impedance seen across Figure 2B's **Port** terminals for three values of feedback capacitors C1 and C2. (For trace 1, C = 5 pF; trace 2, 10 pF; trace 3, 25 pF.) RZ_{11} values of and below zero indicate that oscillation is likely.

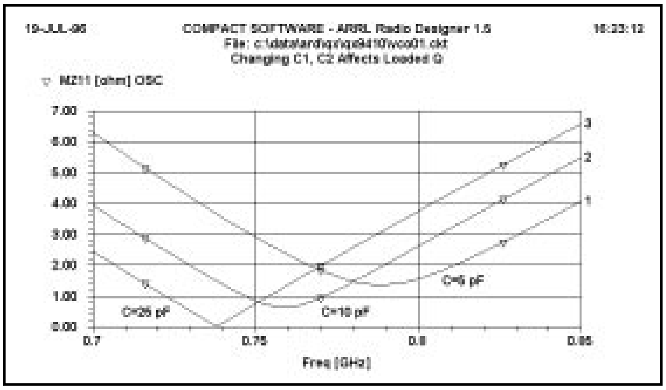

Figure 4—Graphing the magnitude (MZ_{11}) of the impedances plotted in Figure 3 reflects a dramatic Q reduction as the feedback capacitors are decreased in value. (For trace 1, C = 5 pF; trace 2, 10 pF; trace 3, 25 pF.) The more rounded the trace corner, the lower the Q.

25 pF. What we are looking for here is the resistance at resonance, where the reactance the zero. For trace 3, this occurs at about 735 MHz. Here, the resistance is almost exactly zero. This allows no room for component tolerances or for adjusting the frequency upward, either of which may inhibit oscillation. Trace 2 shows a better result. At resonance, about 760 MHz, the resistance is negative, and it stays negative up through about 1 GHz. Small variations in component values, or adjusting the frequency upward, should not keep the circuit from oscillating. Trace 1 might seem to be even better because the resistance is more negative, but now we are loading the resonator—and lowering the loaded Q—more than we need to. This is shown in Figure 4, which shows the magnitude of the impedance for the same three cases.

"Even though the resistive part of the impedance is negative, we can use the magnitude of the impedance to determine the loaded Q. From Figure 4 we can find the impedance at resonance, then find the 3-dB points on the curve, by multiplying the resonant impedance by 1.414. The loaded Q is then the resonance frequency divided by the 3-dB bandwidth. (This is more easily found by outputting the data of Figure 4 in tabular form.) It's obvious from the graph that the Q of trace 1 is lower than that of trace 2. For low phase noise, therefore, trace 2 is a better choice. Setting C1 and C2 to 10 pF results in certain oscillation and good phase noise."

ARRL Radio Designer Versus Oscillators: Conclusion

Whether we want it to oscillate or not, a small-signal, linear circuit on the brink of oscillation exhibits traits that *ARRL Radio Designer* can model and report. If our goal is an unconditionally stable amplifier, *ARD* can help us achieve it through stability factor (K) and return-loss (MS_{11}) analysis, with the amplifier modeled as a two-port network. If our goal is a better oscillator, *ARD* can help us achieve it by directly indicating the presence of negative resistance, and indirectly indicating resonator Q, when we model the oscillator as a one-port network and investigate the impedance of its resonator.

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Notes

[1] David Newkirk, WJ1Z, "*ARRL Radio Designer* versus Oscillators," Part 1, *QST*, Jul 1996, pp 68-69.

[2] Available from ARRL for $150 plus shipping as publication no. 4882. Contact HQ Publications Sales: voice, 860-594-0250; fax, 860-594-0303; or e-mail, **pubsales@arrl.org**.

[3] To put it very sketchily, large-signal operation occurs when the signal level handled by a circuit is high enough to cause a dc shift in the *operating point* of the circuit's active device(s). See Section 1.4, Large-Signal Operation of the Bipolar Transistor, in Wes Hayward, W7ZOI, *Introduction to Radio Frequency Design* (ARRL order no. 4920).

[4] Ulrich L. Rohde, KA2WEU, "Designing Low-Phase-Noise Oscillators," *QEX*, Oct 1994, pp 3-12.

[5] Ulrich L. Rohde, KA2WEU, *Digital PLL Frequency Synthesizers—Theory and Design*, (Englewood Cliffs, NJ: Prentice-Hall, Inc, 1983), section 4-1, "Oscillator Design," (Out of print.)