Resources for Understanding Oscillators

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There have been dozens of books and thousands of papers and articles about oscillators. This is a list of those that I have found most helpful, along with a tool suggestion.

Analysis Tools

Linear Technology LTspice/SwitcherCAD III is the most useful circuit analysis tool I have found. It is fast, convenient, and free! It runs under MSWindows 9X and later and under Linux (using WINE). **http://www.linear.com/software/** Be sure to get the latest version as it gets better every month or so. Since March 2003 it has a "Save Plot Settings" command which makes evaluating circuit changes much easier.
Beware the example oscillator circuits. They all have lossless (infinite Q) resonant circuits and a voltage-clipping diode added to limit amplitude. Add a resistor in series with the inductor and get rid of the diode.

Oscillator References on the Internet

http://www.corningfc.com/library.htm
Tutorials and Technical Notes

http://www.corningfc.com/downloads.htm#vig
John R. Vig Tutorial:
Quartz Crystal Resonators and Oscillators (ver 8.4.3)

http://www.ieee-uffc.org/
IEEE Ultrasonics, Ferroelectrics, and Frequency Control Society home page

http://www.ieee-uffc.org/index.asp?page=freqcontrol/fc_history.html&Part=5#top
History of Frequency Control and Modern Timekeeping

http://www.ieee-uffc.org/index.asp?page=freqcontrol/fc_reference.html&part=5
Links to Review Papers and Tutorials

http://www.ieee-uffc.org/index.asp?page=archive2/index.htm&Part=2
UFFC Digital Archive contains all the publications from 1954 to present.
Only members can download the actual papers, but anyone can use the index.
Members can also buy the complete 1954-2000 archive on 24 CDROMs for $60, a great deal!

http://www.boulder.nist.gov/timefreq/general/publications.htm

1831 time and frequency publications authored by NIST personnel over a period of nearly a century, from 1914 to the present
Oscillator circuits, phase noise measurement, frequency and time dissemination, etc.

http://www.blaenffos.org/
VHF Crystal Oscillator Presentation
Martlesham Microwave Roundtable, November 2002, Chris Bartram GW4DGU
An excellent explanation why the usual Butler overtone crystal oscillator circuit is suboptimum and of a better circuit.

The following are recent papers on phase noise:

http://www.chic.caltech.edu/Publications/phase_tutor.pdf
T. H. Lee and A. Hajimiri, "Phase Noise in Oscillators, A Tutorial," Invited Paper, IEEE Journal of Solid-State Circuits, vol. 34, no. 3, pp. 326-336, March 2000.

http://www.chic.caltech.edu/Publications/general_full.PDF
A. Hajimiri and T. H. Lee, "A General Theory of Phase Noise in Electrical Oscillators," IEEE Journal of Solid-State Circuits, vol. 33, no. 2, pp. 179-194, Feb. 1998.

http://www.chic.caltech.edu/Publications/ISSCC_noise_shift.pdf
R. Aparicio and A. Hajimiri, "A CMOS Differential Noise-Shifting Colpitts VCO," in Proc. of IEEE International Solid-State Circuits Conference, pp. 288-289, Feb. 2002.

http://www.chic.caltech.edu/Publications/CMOS_LC.PDF
A. Hajimiri and T. H. Lee, "Design Issues in CMOS Differential LC Oscillators," IEEE Journal of Solid-State Circuits, vol. 34, no. 5, pp. 717-724, May 1999.

http://www.icims.csl.uiuc.edu/~amehrotr/publications/pdfs/tcas.pdf
Phase Noise in Oscillators: A Unifying Theory and Numerical Methods for Characterization, Alper Demir, Amit Mehrotra and Jaijeet Roychowdhury, IEEE Transactions on Circuits and Systems I: Fundamental Theory and Applications, vol. 47, no. 5, pp. 655-674, May 2000.

Annotated Bibliography for Oscillators.

F. E. Terman, *Radio Engineers' Handbook* (New York: McGraw-Hill, 1943).
A number of key concepts, well explained:
Parallel Resonance with Tapped Circuits, p 148, later generalized by Clarke-Hess.
Oscillator Circuits, Colpitts, Hartley, etc., p. 480
Intermittent Operation, (squegging) p. 483
Circuit Elements, Coils with Air Cores, p. 73 ff
Transmission Lines as Resonant Circuits, p. 191 ff

W. A. Edson, *Vacuum-Tube Oscillators* (New York: John Wiley & Sons, 1953).
A superb summary of the state of the art at that time. Sections on resonators and their components and on the difficulties of temperature compensation are still timely.

K. T. Clarke & D. T. Hess, *Communication Circuits: Analysis and Design* (Reading, MA: Addison-Wesley, 1971)[out of print in 1992]. Reprinted by Krieger Publishing Company; (February 1, 1994) **ISBN:** 0894648632
The single most important reference on the building blocks for communications circuits, not just oscillators.
The section on parallel resonant "transformerlike" networks unifies the analysis of Colpitts, Hartley, Clapp, etc., forms of resonant circuits in oscillators.
The sections on the JFET, BJT and differential BJT show how to simply predict their fundamental frequency output current when operated as limiters (as in most oscillators).

L. Howson, "Designing the VFO," *QST*, Dec 1955.
The best explanation I have found in the Amateur Radio literature, but predates transistors.

E. O. Seiler, "A Low-C Electron-Coupled Oscillator," *QST*, Nov 1941.
Describes the circuit that D. Stockton, *ARRL Handbook*, 1995+, p. 14.14, mistakenly calls "the original Colpitts circuit ... now often referred to as the parallel-tuned Colpitts..."

J. K. Clapp, "An Inductance-Capacity Oscillator of Unusual Frequency Stability," *Proc. IRE*, Mar 1948.
Introduces the Clapp or series-tuned Colpitts oscillator circuit. The circuit was independently developed by G. G. Gouriet at the B.B.C. in England in 1938 but not published until after the war.

J. K. Clapp, "Frequency Stable LC Oscillators," *Proc. IRE*, Aug 1954.
Shows that Gouriet-Clapp, Seiler, and Vackar oscillators have equivalent frequency stability given equal resonator Q. They differ only in how much the amplitude of oscillation changes when they are tuned. The three circuits are useful over frequency ranges of 1.2, 1.8, and 2.5 to one, respectively.

R. Cassey, "The Clapp Oscillator -- and How!," *QST*, Feb 1953.
Explains the Clapp circuit and how to mount the tuned circuit remotely from the tube without much degrading the Q.

G. D. Hanchett, "The Field-Effect Transistor as a Stable V.F.O. Element," *QST*, Dec 1966.
Introduces the dual-gate MOSFET as active element and, since the MOSFET lacks the built-in grid-cathode diode of the vacuum tube, he adds a silicon diode. The diode is connected from gate to ground, not from gate to source; there is no explanation of the choice.

G. D. Hanchett, "Insulated-Gate Field-Effect Transistors in Oscillator Circuits," presented at Western Electronic Show and Convention, San Francisco, CA, August 22-25, 1967, published by RCA, Somerville, NJ as Pub. No. ST-3520
Discusses the single-gate MOSFET in various oscillator circuits. He compares source-resistor bias with bias from a gate resistor and silicon biasing diode, concluding that the diode bias provides better amplitude stability vs. supply voltage.

H. Woods, "The Vackar VFO Circuit," in "Technical Correspondence," *QST*, Nov 1955.

Refers to the Clapp 1954 paper and suggests that a triode oscillator with separate buffer stage is better than a pentode electron-coupled single-tube circuit.

G. Grammar, "Technical Topics -- A High-Stability Oscillator Circuit," *QST*, May 1948.
The first mention in *QST* of the Clapp oscillator circuit.

J. M. Shulman, "An Ultrastable Keyed V.F.O.," *QST* Oct 1957.
Suggests variation of Clapp circuit with tuning capacitor isolated from ground and tapped across part of the inductor.

W. B. Bernard, "Let's Increase V.F.O. Stability," *QST*, Oct 1957.
Suggests using grounded-cathode triode with separate buffer instead of the electron-coupled pentode circuit. Also suggests using the Seiler or Colpitts circuit with the largest available value of tuning variable capacitor instead of the Clapp circuit with a low value of tuning capacitor.

J. Vackar, "LC Oscillators and their frequency stability," *Tesla Tech. Reports*, Czechoslovakia, Dec 1949.
He discusses mechanical design of tuning circuits, presents general analysis of oscillator circuits and their sensitivity to changes of internal capacities of valves (vacuum tubes). He reviews existing circuits, including Gouriet-Clapp, Seiler, and Lampkin, comparing their amplitude dependence on frequency and hence useful tuning range. He describes in detail the design process for circuit we commonly refer to as the Vackar oscillator, which has greater tuning range. He then goes on to describe a slight variation with still greater tuning range. This last circuit, which I have never seen elsewhere, he describes as a compromise between the first-mentioned Vackar circuit and that due to Seiler.