Continuation of oscillators and synthesizers

The discussion last time was intended as an introduction, to bring students to realize some of the factors to consider in oscillator design or selection. In this period let's attempt to include a few more details.
Oftentimes a radio receiver (or transmitter) is designed so that only one of the system oscillators is tunable while the others are fixed. Many types of sources are available for LO and carrier frequency applications. However, many factors need to be considered in selecting sources for a particular application.
Some important questions:

1) What is the frequency needed? Dictates something about expected level of performance and how the oscillator will be designed.

2) How much bandwidth is to be covered?

3) If the frequency is to be tuned, how accurately does it need to be tuned?
4) What is the sweep or frequency change time that is available?

5) How much drift is acceptable?

6) What is the acceptable level of phase noise?

7) What is the necessary power efficiency?

8) What specifications in terms of power output and flatness across the band are needed?
9) Is it necessary to maintain continuous phase during tuning or are phase discontinuities permitted?

10) Are there strict load-pull requirements?

11) What levels and locations of spurious responses are acceptable?

12) How much does the quality of the power supply affect the output?
13) Of course cost, weight and size should be considered.

Basic types of oscillators

1) Free running VCOs
   a) LC or patch (Low) resonator
   b) dielectric stabilized cavity stabilized (Mod.)

2) Fixed oscillators
   a) ceramic or SAW resonators (High) (Q)
   b) quartz crystal (Higher) (Q)
   c) atomic standard (Highest) (Q)
3) Synthesizers
   a) Direct analog
   b) Direct digital
   c) PLL
      i) digital
      ii) analog
      iii) combined digital and analog
      \( \div N, M/N, \) fractional \( N \), multiloop.

   For high-performance systems free-running VCOs are used only as part of a
synthesizer circuit. Free-running VCOs have fairly poor drift characteristics and rather high phase noise. Fig. 7.28 (pg. 363) of the text compares phase noise levels for several types of oscillators. Fig. 7.22 (pg. 348) indicates mechanisms responsible for the phase noise along with stability (drift) characteristics.
To minimize the phase noise, do the following:

1. Maximize the unloaded Q of the resonator.
   (Fig. 7.25 pg. 356 illustrates the effect of loaded Q of the resonator).

2. Maximize the reactive energy by means of a high RF voltage across the resonator, and obtain a low LC ratio.
3. Avoid saturation at all cost, and try to have either limiting or AGC without degradation of Q. Isolate the tuned circuit from the limiter or AGC circuit.

4. Choose an active device with the lowest available NF. Also, the NF improves as the ratio between source impedance and equivalent noise resistance increases.
5. Phase perturbation can be minimized by using high-impedance devices such as FETs where the $\frac{S}{N}$ of the signal voltage relative to the equivalent noise voltage can be made very high.

6. Choose an active device with low flicker noise can be reduced by rf feedback, e.g., an unbypassed emitter resistor of 10-30Ω.
7. The energy should be coupled loosely from the resonator rather than from another portion of the active device.

Consider some classical types of oscillator circuits.

Bypass capacitor

Colpitts oscillator

Ratio of $C_1$ to $C_2$ should be selected to maintain $Q$. 
Bypass capacitor

Hartley oscillator
Ratio of $L_1$ to $L_2$ should be selected to maintain Q.

DC blocking capacitor

XTAL Pierce Crystal

RFC oscillator

$C_1$ and $C_2$ are selected to ensure proper operating point to the XTAL.
The non-XTAL oscillators can be made tunable by placing a varactor in parallel with the capacitor. Consider methods for reducing loading effects on the tuned circuit Q.
Emitter follower buffer amplifier

Bypass capacitors

Differential implementation that includes buffering.
Additional comments on crystal oscillators. The equivalent simplified circuit of a quartz crystal (for a specific response) looks like

\[ \begin{array}{c}
R_1 \\
C_1 \\
L_1 \\
\end{array} \quad \begin{array}{c}
\ \ \ \ \ \ \ \ \ \ \ C_0 \\
\end{array} \]

\( R_1, L, \text{ and } C_1 \) are due to mechanical aspects of the crystal. \( C_0 \) is due to
the electrodes in parallel with the holder capacitance.

Electrical behavior:

Crystal reactance

\[ \text{jX} \]
\[ \text{fs} \]
\[ \text{fr} \]
\[ \text{f} \]

Crystal resistance

\[ \text{fs} \]
\[ \text{fr} \]
\[ \text{fl} \]
\[ \text{f} \]

fs is the frequency where L1 resonates with C1.
fr is the frequency where the crystal looks purely resistive.

fl is the frequency at which the crystal is antiresonant with a capacitive load.

The crystal is generally operated between fr and fl. Generally the crystal is cut to operate with a specific
load; e.g. $C_L \approx 30 \mu F$ is very common. A more complete description of a crystal shows additional resonance. For example,

- Third mechanical overtone
- Fundamental
- Fifth mechanical overtone
- Spurious responses
Some crystals are designed to be operated on third and fifth mechanical overtones. However, caution is required in these modes to ensure that the oscillator doesn't jump to operate on the fundamental mode.

Enough for now about oscillator circuits. Let's discuss frequency
synthesis approaches.

Simple analog approaches

Not usually very desirable.

Fast, but complex and phase discontinuities on switching (unless reference is shared)
In this case $f_1$, $f_2$ and $f_3$ can be varied over limited ranges (or with limited step size). Still more complex than needed but can be fast.

Direct digital synthesis

Becoming very popular, but limited, typically,
to 10s MHz. Of course this depends on number of bits in D/A. Spurious responses can become significant at higher frequencies due to effects of D/A and limited number of bits at higher frequencies.
$\frac{1}{N}$ synthesizers

\[
\text{f}_{\text{out}} = N f_{\text{XTAL}}
\]

$\frac{M}{N}$ synthesizer

\[
\text{f}_{\text{out}} = \frac{N}{M} f_{\text{XTAL}}
\]

High phase noise is a problem for $\frac{M}{N}$. 
fractional- \( N \) synthesizer

This approach allows us to divide by noninteger values.

Idea:

Consider allowing the phase error to increase over part of the PLL cycle, and then we "swallow" a count to bring the
phase error back to 0.

average of phase error (as a result of filtering) is used to control VCO.

This can be achieved by using 2 counters A + B, where the divider ratio is P.
for A counts and P+1 for B counts. A very common circuit element is a dual modulus prescaler. This allows control of the division by a single control line; e.g., 10/11 prescaler.

One problem one needs to watch for is possible
spurious responses.
These may be reduced by appropriate selection of A and B, and/or by use of D/A to incrementally apply the corrections. Effective divider ratio is as follows: If the prescalar divides by N for A output pulses of the VCO and by N+1 for B
pulses of the VCO,
then the equivalent divide ratio is equal to
\[ \frac{(A+B)}{\left[ \frac{A}{N} + \frac{B}{N+1} \right]} \]