Digital RF Control

Martin Konrad

U. S. Particle Accelerator School
Annapolis 2008
Outline

- I-Q modulation/demodulation
  - in hardware
  - in software
- Microphonics compensation
- FPGAs
Motivation

Why *digital* RF control?

- All controllers should be identical
- No offsets, no temperature drift, no noise,...
- Cheaper for accelerators with lots of cavities
- Upgradeable

But

- Finite resolution of ADCs
- Latency
I-Q Demodulation in Hardware
I-Q Modulation/Demodulation in Hardware
I-Q Modulation/Demodulation in Hardware

Diagram showing the process of I-Q modulation and demodulation using hardware components such as the I/Q Modulator, I/Q Demodulator, Amplifier, Low Pass Filter, and FPGA.
I-Q Demodulation in Software

- Baseband: lots of offsets
- Idea: digitize at an intermediate frequency
- Sample signal in-phase and out of phase alternating
e.g. $f_s = 4 \times f_{IF}$
I-Q Demodulation in Software

\[ I = V(0.5), -V(1.5), V(2.5), \ldots \]
\[ Q = V(1), -V(2), V(3), \ldots \]
I-Q Demodulation in Software

Trigonometric functions can be precomputed
## I-Q vs. A-φ control

<table>
<thead>
<tr>
<th>I-Q control</th>
<th>A-φ control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple (two identical controllers)</td>
<td>Different amplification for amplitude and phase possible</td>
</tr>
</tbody>
</table>
Microphonics compensation

\[ E(\omega) = \frac{E_0}{\sqrt{1 + 4Q_L^2 \left( \frac{\omega - \omega_0}{\omega_0} \right)^2}} \]

\[ \varphi(\omega) = \arctan \left( -2Q_L \frac{\omega - \omega_0}{\omega_0} \right) \]

\[ E(\varphi) = \frac{E_0}{\sqrt{1 + \tan^2 \varphi}} = E_0 \cos \varphi \]

⇒ raise power by factor \( \frac{1}{\cos \varphi} \) to compensate for loss in magnitude caused by microphonics
Microphonics compensation

\[ E(\omega) = E_0 \sqrt{1+4Q_l^2 \left( \frac{\omega-\omega_0}{\omega_0} \right)^2} \]

\[ \varphi(\omega) = \arctan \left( -2Q_L \frac{\omega-\omega_0}{\omega_0} \right) \]

\[ E(\varphi) = \frac{E_0}{\sqrt{1 + \tan^2 \varphi}} = E_0 \cos \varphi \]

\( \Rightarrow \) raise power by factor \( \frac{1}{\cos \varphi} \) to compensate for loss in magnitude caused by microphonics.
Microphonics compensation

\[
\begin{pmatrix}
I' \\
Q'
\end{pmatrix} = \left[ \begin{pmatrix}
1 & 0 \\
0 & 1
\end{pmatrix} + p_{\text{err}} k_p \begin{pmatrix}
0 & -1 \\
1 & 0
\end{pmatrix} \right] \begin{pmatrix}
I \\
Q
\end{pmatrix}
\]
Field-Programmable Gate Arrays (FPGAs)

- Programmable logic device
- Consists of logic cells and wires
- Parallel processing is possible ⇒ much faster than Microprocessors/DSPs
- Reprogrammable in circuit

Control Algorithm for Self Excited Loop

\[ I' = k_p \sin \varphi_{\text{sp}} + k_m \sin \varphi_{\text{loop}} \]

\[ Q' = k_p \cos \varphi_{\text{sp}} + k_m \cos \varphi_{\text{loop}} \]

\[ a_{\text{sp}} = A - k_a \]

\[ g_{\text{loop}} = \sin \varphi_{\text{loop}} \cos \varphi_{\text{loop}} \]

\[ m_o = \text{Tuner} \]

June 27, 2008 | IKP TU Darmstadt | Martin Konrad | 14
Thank you for your attention

konrad@ikp.tu-darmstadt.de