A 300-mW Single-Chip NTSC/ PAL Television for Mobile Applications

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Why analog television?

- Isn’t the world going digital?
- Yes, and no! The television world in 2014:

  - 5.5 billion people today have no access to digital TV
  - Analog infrastructure built out worldwide over past 50 years!
Mobility Considerations for Terrestrial TV

- **Small antennas**
  - Maximum size 3-4 inches
  - Broadcast frequencies as low as 47 MHz ($\lambda \sim 6$ meters)

- **Power consumption and size**
  - Conventional solutions on the order of watts
  - Conventional solutions consist of 200+ discretes
  - Input signal bandwidth from 47 to 862 MHz

- **Poor performance (even when stationary!)**
  - Ghosting
  - Loss of synchronization
  - Analog signal sensitivity to noise
Analog TV Signaling (1)

- Baseband CVBS (composite) signal spectrum
Analog TV Signaling (2)

- Baseband-equivalent RF signal spectrum
  - CVBS signal is VSB modulated to RF carrier
  - Audio subcarrier not shown below
Conventional TV Architecture

- Three major components
- Single-conversion or double-conversion tuner translates incoming channel to an intermediate frequency (IF)
- IF demodulator translates VSB IF signal to CVBS baseband
- Video decoder converts baseband analog video into digital component (4:2:2 YCbCr) video
Direct Conversion TV-on-a-Chip

- Single-chip solution combines functions of RF tuner, IF demodulator and video decoder
- True zero-IF solution – center of band placed at DC
- Digital signal processing used to mitigate mobility issues
  - Demonstrated live reception at speeds greater than 430 kph
  - Can filter most short-term fading / multipath effects
Low-Noise Amplifier

- 40-dB gain range
  - 20-dB coarse step
  - 2-dB fine steps
- $A_v = 30$ dB
- Integrated programmable filter embedded within LNA
  - Helps mitigate signal power into mixer input
  - Assists in mixer harmonic rejection
Mixer

- Gilbert-type mixer (Av = 10 dB)
- Generally represents distortion limit of entire tuner
- Output load represents first pole of baseband filter
- M3 – M6: thin-oxide (0.13u) devices – needed for distortion performance

Due to 800 MHz input bandwidth, mixer harmonic rejection and LO generation are two critical design issues!
LO Harmonics in Mixers

- Rectifying action of the LO port results in multiplying the RF input signal with a *square wave*

\[ s_{LO}(t) = \text{sgn} \left[ \cos \omega_c t \right] = \cos \omega_c t - \frac{1}{3} \cos 3\omega_c t + \frac{1}{5} \cos 5\omega_c t \]

- Requires filtering before downconversion or harmonic rejection mixing

- Narrowband systems not affected by this!
Harmonic Rejection Filtering (1)

- For I/Q mixing, the LO signal is effectively

\[
s_{LO}(t) = \text{sgn}[\cos \omega_c t] + j \text{sgn}[\sin \omega_c t] \\
= \cos \omega_c t - \frac{1}{3} \cos 3\omega_c t + \frac{1}{5} \cos 5\omega_c t + j(\sin \omega_c t + \frac{1}{3} \sin 3\omega_c t + \frac{1}{5} \sin 5\omega_c t) \\
= e^{j\omega_c t} - \frac{1}{3} e^{-j3\omega_c t} + \frac{1}{5} e^{j5\omega_c t}
\]

- Must attenuate harmonics at \(-3\omega_{LO}, +5\omega_{LO}, -7\omega_{LO}, +9\omega_{LO}, \) etc.
Harmonic Rejection Filtering (2)

- A complex band-pass filter centered at $+\omega_{LO}$ must attenuate harmonics located at frequency offsets $\pm 4\omega_{LO}$ from $+\omega_{LO}$
  - less stringent attenuation requirements, but requires 4 mixers for downconversion instead of 2

- A real low-pass filter must attenuate harmonics located at frequency offsets $\pm 2\omega_{LO}$ from $+\omega_{LO}$

- Both must be tunable

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Harmonic Rejection Mixing

- The 3\textsuperscript{rd} and 5\textsuperscript{th} LO harmonics may be eliminated by using the following LO waveform (generated by summing the first three waveforms)

- Some filtering is still required to eliminate higher order harmonics as well as residual 3\textsuperscript{rd} and 5\textsuperscript{th} harmonics due to mismatch

\[ \text{LO waveform generated by summing the first three waveforms} \]

\[ \begin{align*}
+1 \\
-1 \\
+\sqrt{2} \\
-\sqrt{2} \\
+1 \\
-1 \\
+(2+\sqrt{2}) \\
+\sqrt{2} \\
-\sqrt{2} \\
-(2+\sqrt{2})
\end{align*} \]

LO Generation

- LO must cover broad frequency range from 48 to 862 MHz
- I/Q LO signals required

<table>
<thead>
<tr>
<th></th>
<th>1724</th>
<th>3448</th>
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<tbody>
<tr>
<td>÷4</td>
<td>431</td>
<td>862</td>
</tr>
<tr>
<td>÷8</td>
<td>215.5</td>
<td>431</td>
</tr>
<tr>
<td>÷16</td>
<td>107.75</td>
<td>215.5</td>
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<tr>
<td>÷32</td>
<td>53.875</td>
<td>107.75</td>
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<tr>
<td>÷64</td>
<td>26.9375</td>
<td>53.875</td>
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</tbody>
</table>

- Minimum divide-by-4 guarantees good I/Q balance
- 67% tuning range
  - requires 2 – 4 separate VCOs to cover entire range
VSB Nyquist Filtering (1)

- NTSC and PAL use vestigial sideband modulation
- Without VSB Nyquist filtering, luma signal is corrupted from spectral overlap
- Ideal VSB filter should have the frequency response below

![Diagram of frequency response](image)

- Traditional approaches rely on the IF SAW filter for VSB Nyquist filtering
  - Physically large
  - Driving SAW input capacitance difficult for low power
Without VSB Nyquist filter, the demodulated signal is incorrect due to spectral overlap at frequencies, $-1.25 \text{ MHz} < f < +1.25 \text{ MHz}$

- VSB Nyquist filter is well-suited to digital implementation
## Performance Summary

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noise Figure</td>
<td>4 dB</td>
<td>700 MHz, max gain</td>
</tr>
<tr>
<td>IIP3</td>
<td>-13 dBm</td>
<td></td>
</tr>
<tr>
<td>IIP2</td>
<td>60 dBm</td>
<td></td>
</tr>
<tr>
<td>Video Sensitivity</td>
<td>-90 dBm</td>
<td>loss of color</td>
</tr>
<tr>
<td>Phase Noise</td>
<td>-90 dBc/Hz @ 10 kHz</td>
<td>700 MHz</td>
</tr>
<tr>
<td></td>
<td>-105 dBc/Hz @ 100 kHz</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-135 dBc/Hz @ 1 MHz</td>
<td></td>
</tr>
<tr>
<td>Harmonic Rejection</td>
<td>&gt; 45 dB</td>
<td></td>
</tr>
<tr>
<td>Image Rejection</td>
<td>&gt; 60 dB</td>
<td>post correction</td>
</tr>
<tr>
<td>Power Consumption</td>
<td>total: 300 mW</td>
<td></td>
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<tr>
<td></td>
<td>2.8V: 250 mW</td>
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</tr>
<tr>
<td></td>
<td>1.2V: 50 mW</td>
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</tbody>
</table>
Chip Micrograph

- 0.13-um 1P8M CMOS
- 5.1 x 3.6 mm²
- 8 x 8 mm² 68-pin QFN package
Conclusion

- A low-power single-chip NTSC/PAL television has been demonstrated
  - Optimized for mobile applications
  - 300 mW power consumption
  - Full band reception (47 to 862 MHz)

- True direct conversion architecture

- For NTSC/PAL reception, harmonic mixing and rejection within the mixer are critical

- Low NF front-end coupled with digital signal processing within decoder achieves unprecedented sensitivity performance
An aside - so what about digital TV?

- Pick four letters and you have a standard....
  - ATSC / ATSC-M/H
  - OpenCable / DOCSIS / DVB-C
  - DVB-S / DVB-S2
  - ISDB-T / ISDB-B / ISDB-S / ISDB-C
  - DVB-T / DVB-T2 / DVB-H
  - DMB-T
  - CMMB / TMMB / DTMB
  - T-DMB / DAB-IP

- Incredibly fragmented by geography
- Most deployments are exceedingly slow!

*From Telegent: Stay tuned!*