TELEGENT SYSTEMS

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

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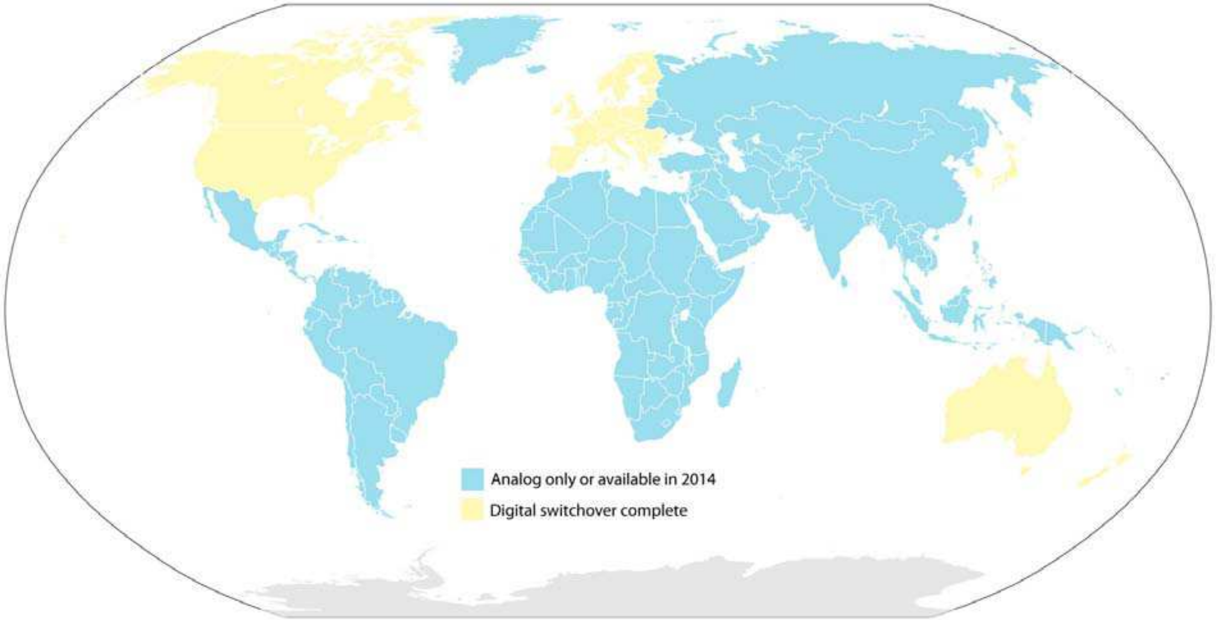
# Why analog television?

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



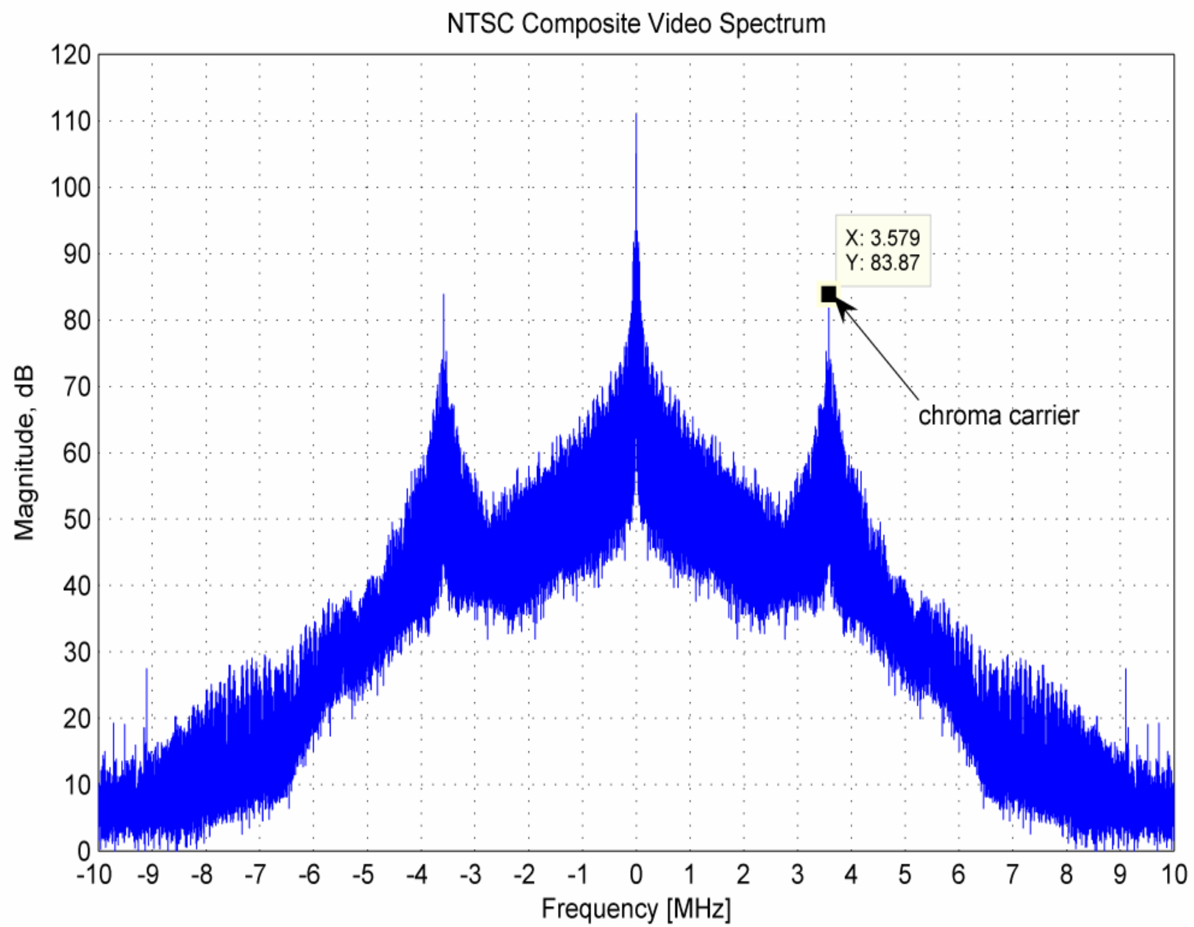

- 5.5 billion people today have no access to digital TV
- Analog infrastructure built out worldwide over past 50 years!

# 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

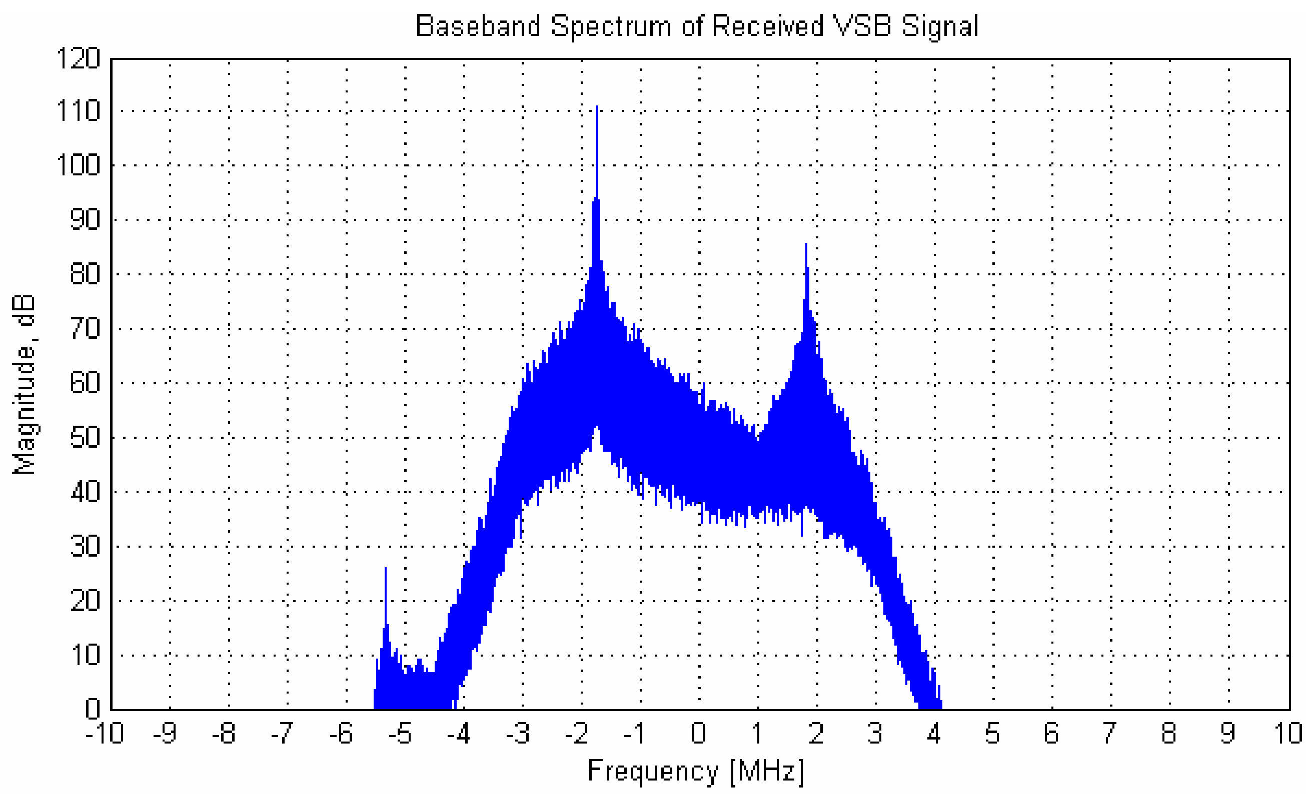
# Analog TV Signaling (1)

- Baseband CVBS (composite) signal spectrum

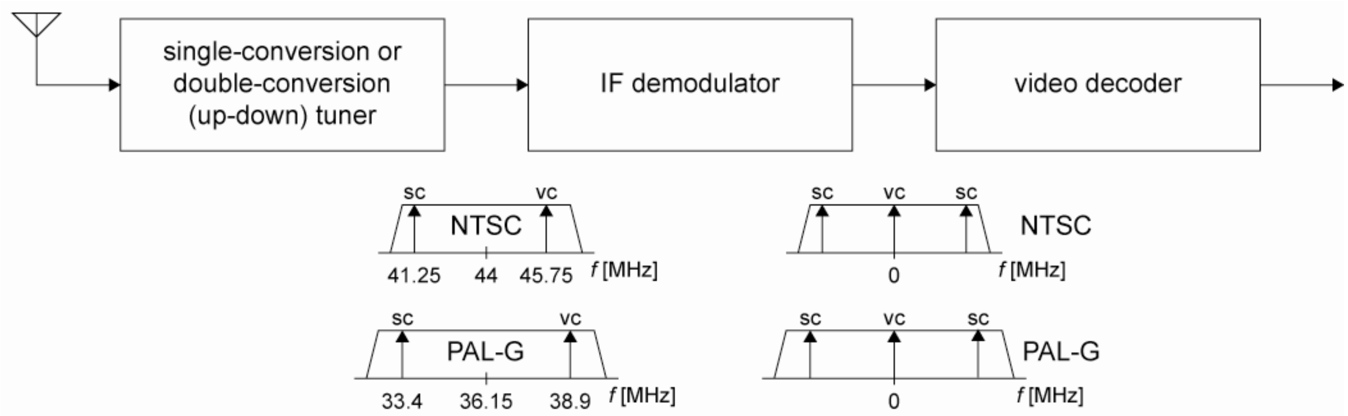


# Analog TV Signaling (2)

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

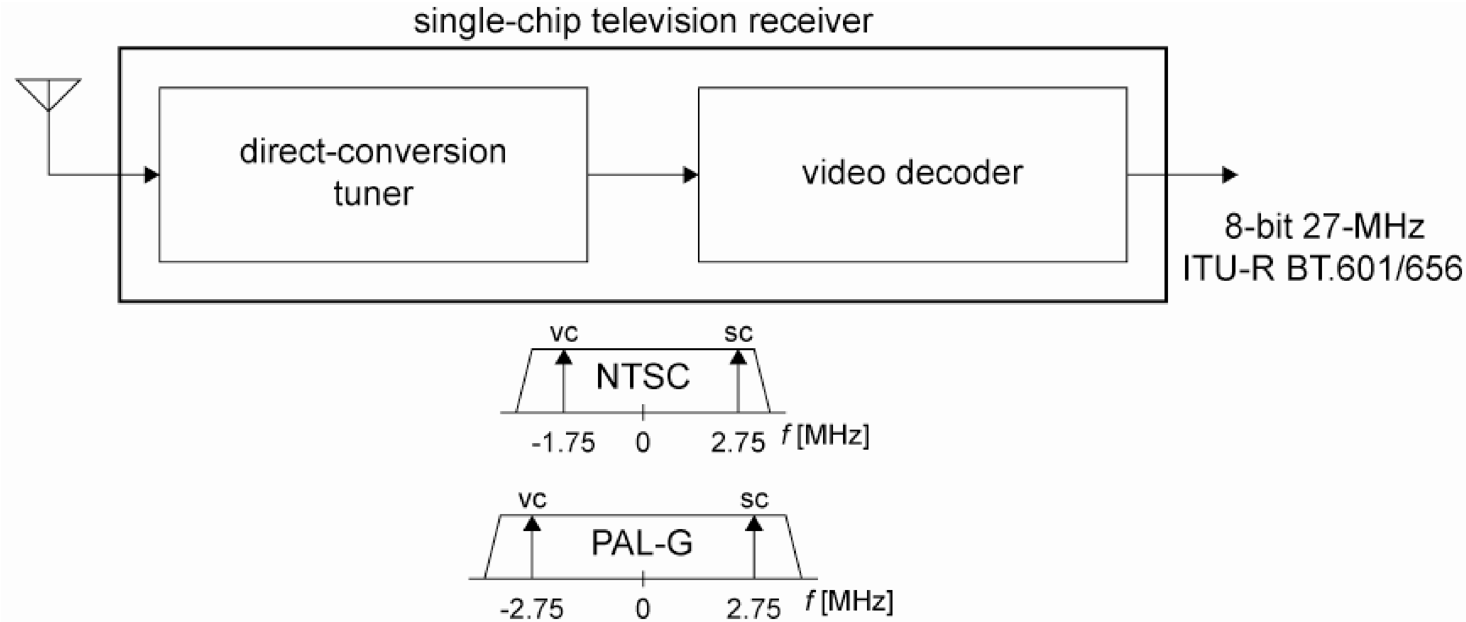


# Conventional TV Architecture



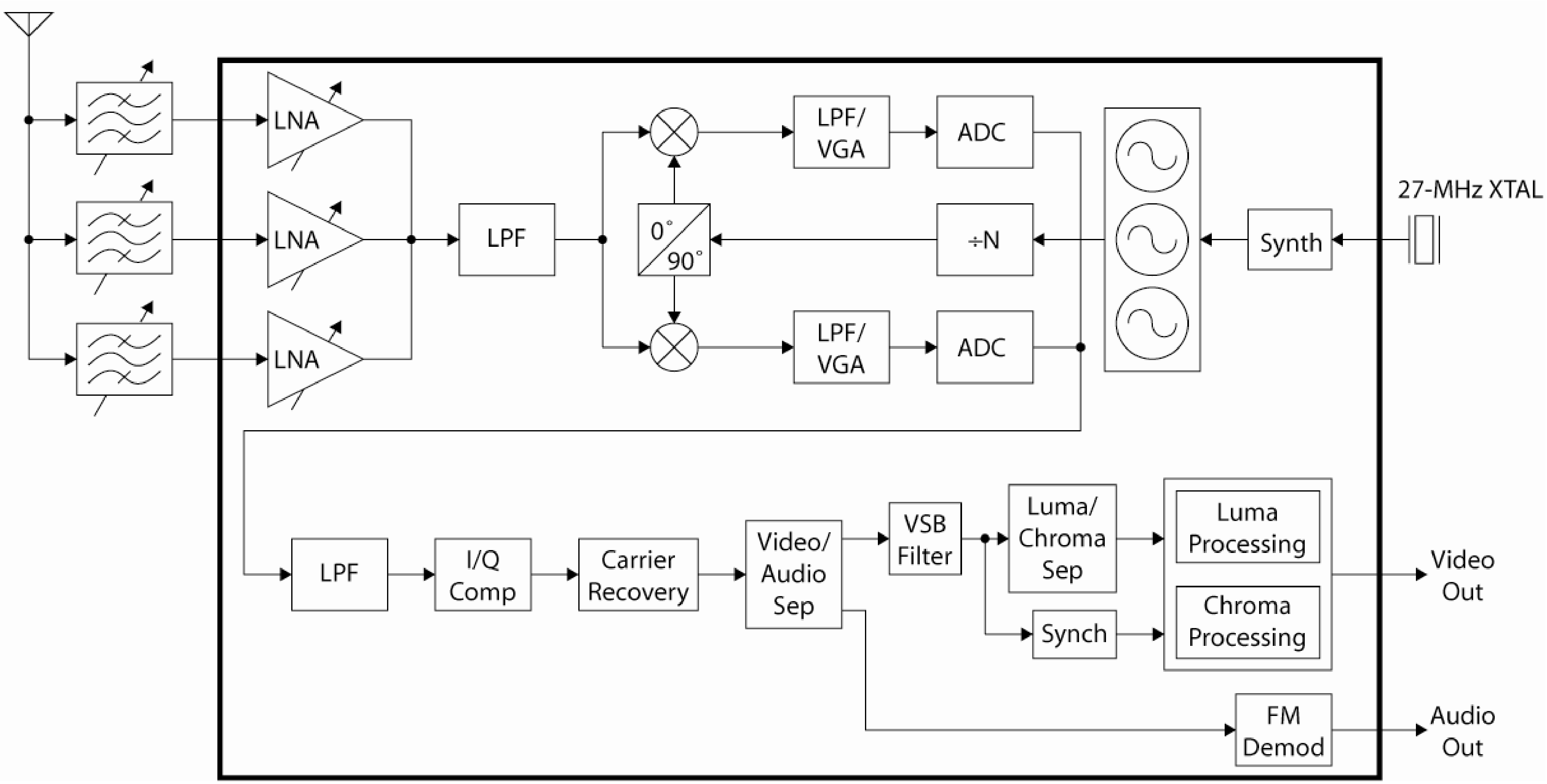

- Three major components
- Single-conversion or double-conversion tuner translates incoming channel to an intermediate frequency (IF)
- IF demodulator translates VSB IF signal to CVBS baseband
- Video decoder converts baseband analog video into digital component (4:2:2 YCbCr) video

# Direct Conversion TV-on-a-Chip

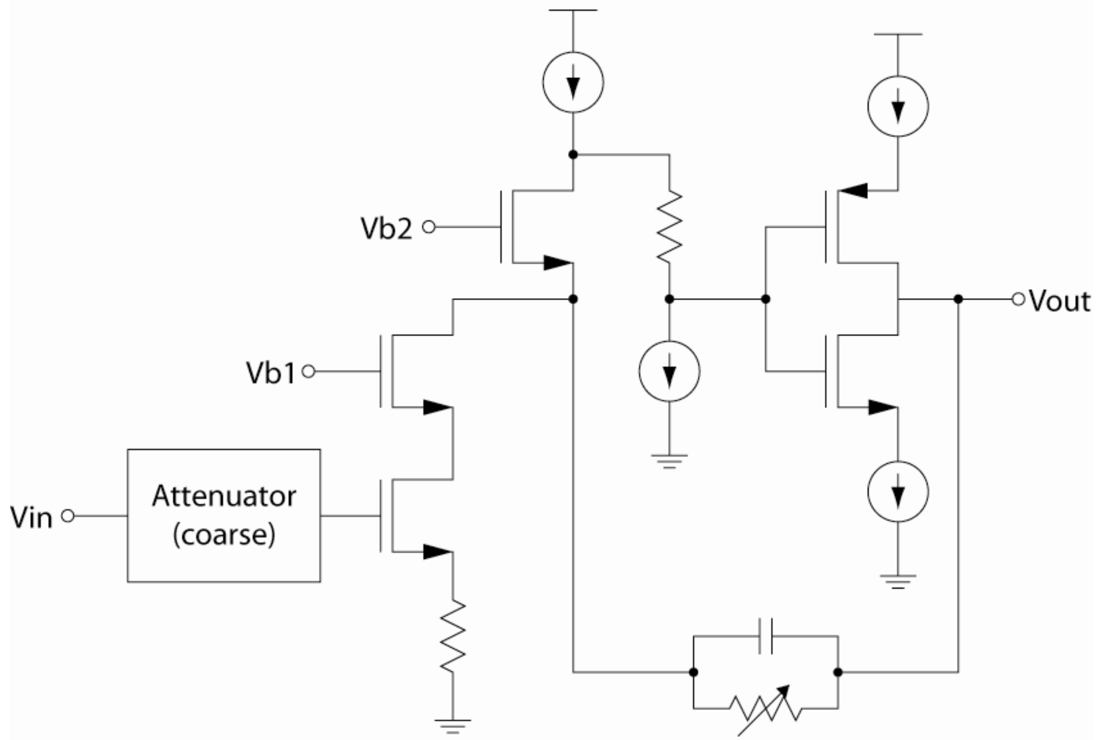



- Single-chip solution combines functions of RF tuner, IF demodulator and video decoder
- True zero-IF solution – center of band placed at DC
- Digital signal processing used to mitigate mobility issues
  - Demonstrated live reception at speeds greater than 430 kph
  - Can filter most short-term fading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

# NTSC/ PAL Receiver Block Diagram

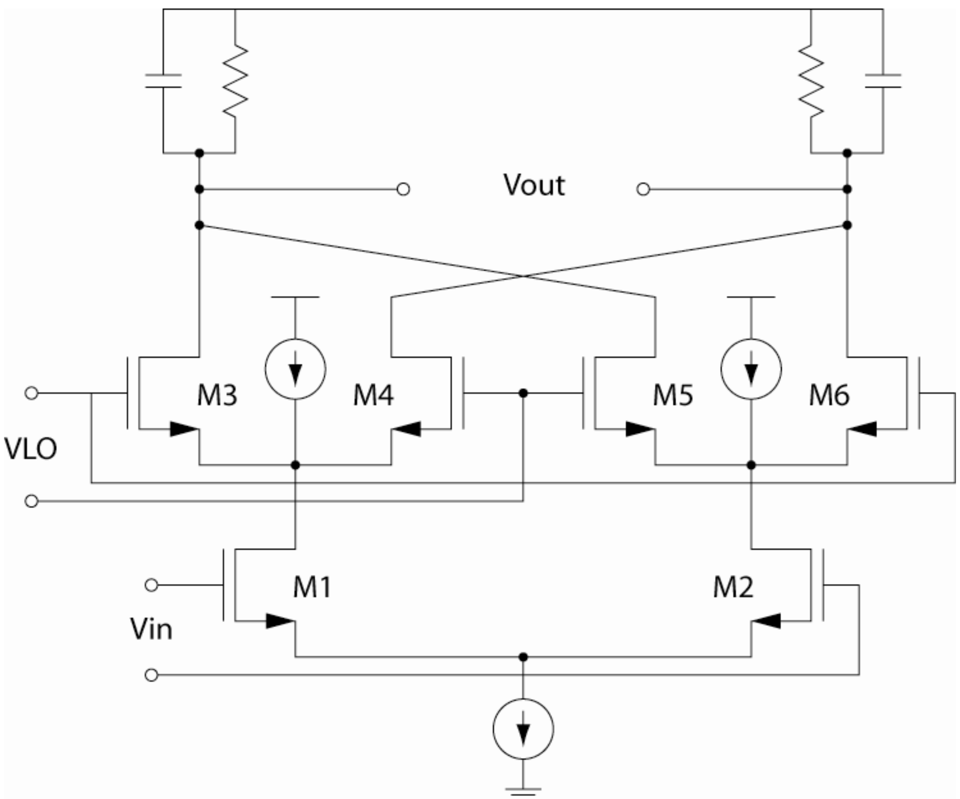


# Low-Noise Amplifier




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

# Mixer

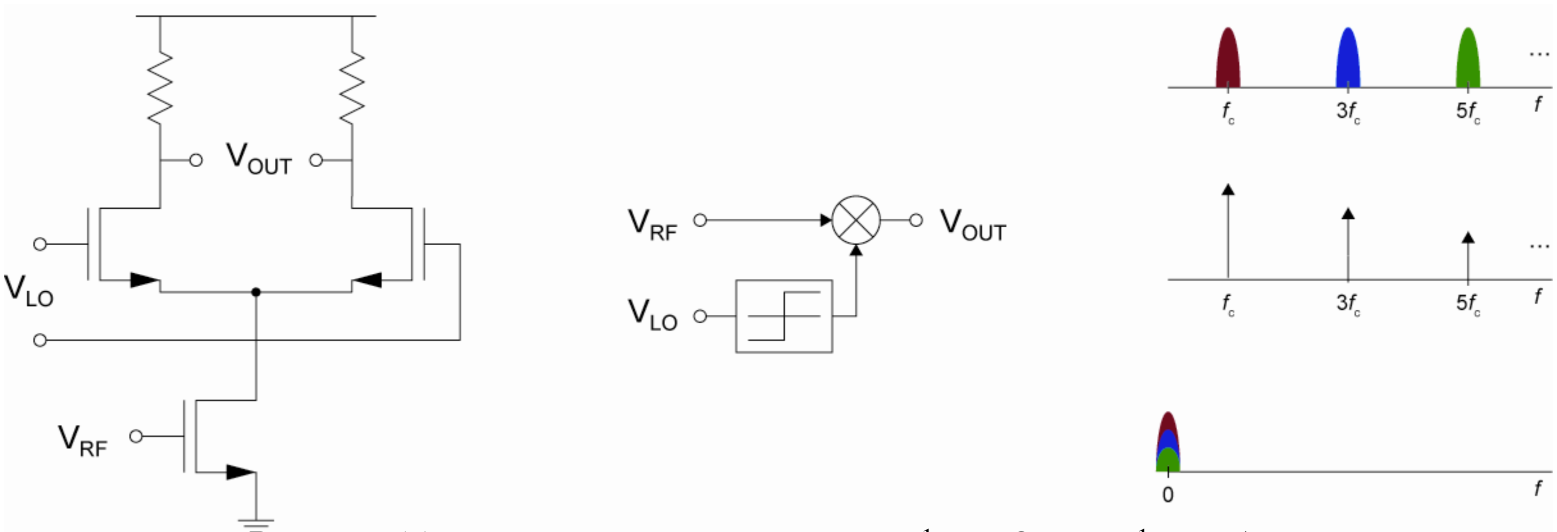



- Gilbert-type mixer (Av = 10 dB)
- Generally represents distortion limit of entire tuner
- Output load represents first pole of baseband filter
- M3 – M6: thin-oxide (0.13u) devices – needed for distortion performance

*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*



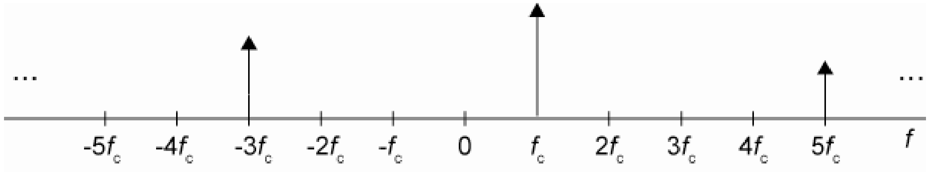

$$s_{LO}(t) = \mathrm{sgn}[\cos\omega_c t] = \cos\omega_c t - \tfrac{1}{3}\cos 3\omega_c t + \tfrac{1}{5}\cos 5\omega_c t$$

- Requires filtering before downconversion or harmonic rejection mixing
- Narrowband systems not affected by this!

# Harmonic Rejection Filtering (1)

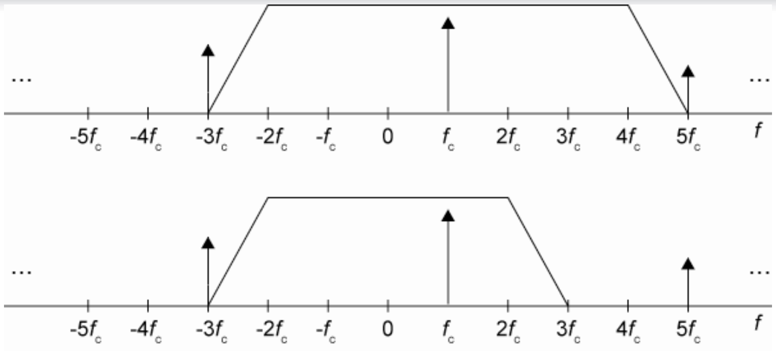
- For I/Q mixing, the LO signal is effectively

$$
\begin{aligned}
s_{LO}(t) &= \mathrm{sgn}[\cos\omega_c t] + j\,\mathrm{sgn}[\sin\omega_c t] \\
&= \cos\omega_c t - \tfrac{1}{3}\cos 3\omega_c t + \tfrac{1}{5}\cos 5\omega_c t + j(\sin\omega_c t + \tfrac{1}{3}\sin 3\omega_c t + \tfrac{1}{5}\sin 5\omega_c t) \\
&= e^{j\omega_c t} - \tfrac{1}{3}e^{-j3\omega_c t} + \tfrac{1}{5}e^{j5\omega_c t}
\end{aligned}
$$




- Must attenuate harmonics at $-3\omega_{LO}$, $+5\omega_{LO}$, $-7\omega_{LO}$, $+9\omega_{LO}$, etc.

# Harmonic Rejection Filtering (2)

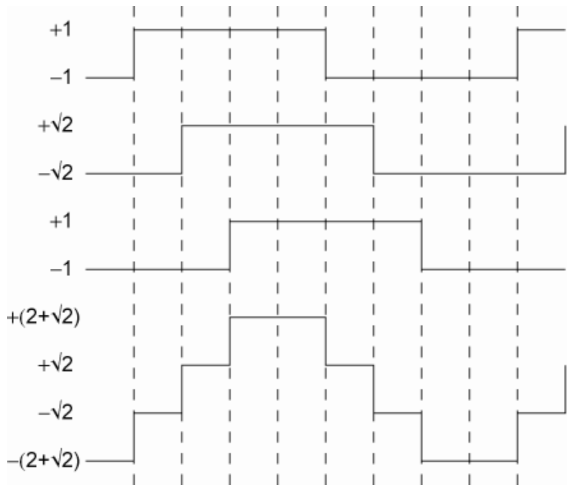



- A complex band-pass filter centered at $+\omega_{LO}$ must attenuate harmonics located at frequency offsets $\pm 4\omega_{LO}$ from $+\omega_{LO}$[1]
  - less stringent attenuation requirements, but requires 4 mixers for downconversion instead of 2
- A real low-pass filter must attenuate harmonics located at frequency offsets $\pm 2\omega_{LO}$ from $+\omega_{LO}$
- Both must be tunable

[1] J. van Sinderen, et al., A 48 – 860MHz digital cable tuner IC with integrated RF and IF selectivity, IEEE ISSCC, vol. XLVI, pp. 444 – 445, February 2003.

# Harmonic Rejection Mixing[1]

- The 3rd and 5th 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 3rd and 5th harmonics due to mismatch

[1] J. A. Weldon, et al., *A 1.75-GHz highly integrated narrow-band CMOS transmitter with harmonic-rejection mixers*, IEEE JSSC, vol. 36, pp. 2003 – 2015, December 2001.

# LO Generation

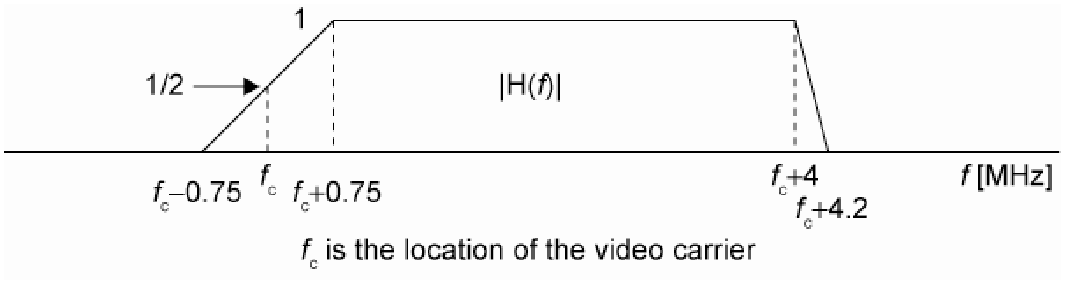
- LO must cover broad frequency range from 48 to 862 MHz
- I/Q LO signals required

| | 1724 | 3448 |
|---|---|---|
| ÷4 | 431 | 862 |
| ÷ 8 | 215.5 | 431 |
| ÷ 16 | 107.75 | 215.5 |
| ÷ 32 | 53.875 | 107.75 |
| ÷ 64 | 26.9375 | 53.875 |

- Minimum divide-by-4 guarantees good I/Q balance
- 67 % tuning range
  - requires 2 – 4 separate VCOs to cover entire range

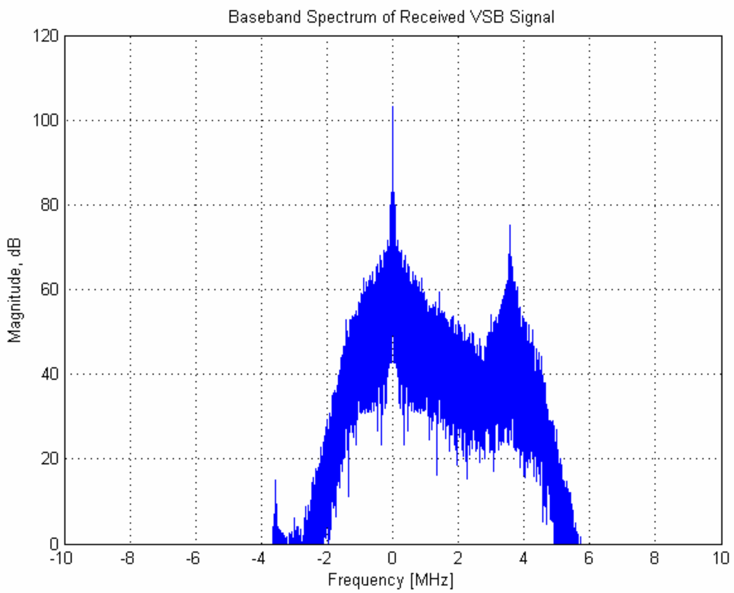
# VSB Nyquist Filtering (1)

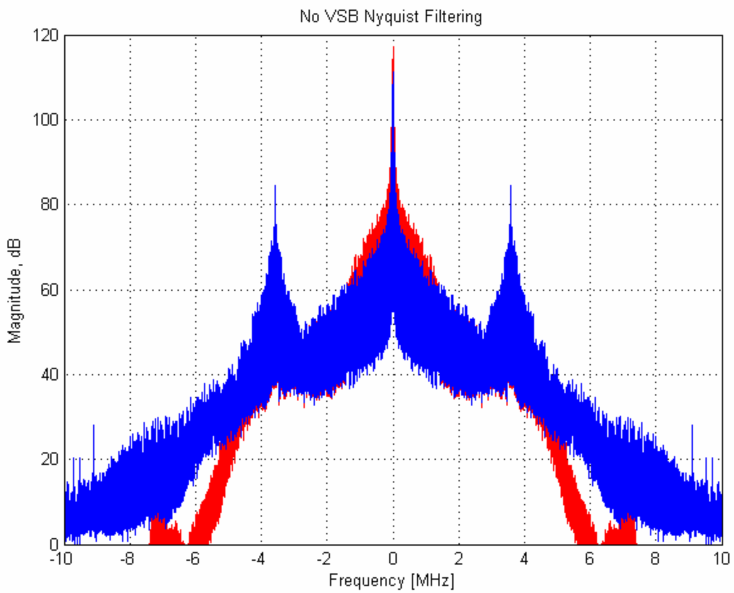
- NTSC and PAL use vestigial sideband modulation
- Without VSB Nyquist filtering, luma signal is corrupted from spectral overlap
- Ideal VSB filter should have the frequency response below




- Traditional approaches rely on the IF SAW filter for VSB Nyquist filtering
  - Physically large
  - Driving SAW input capacitance difficult for low power

# VSB Nyquist Filtering (2)



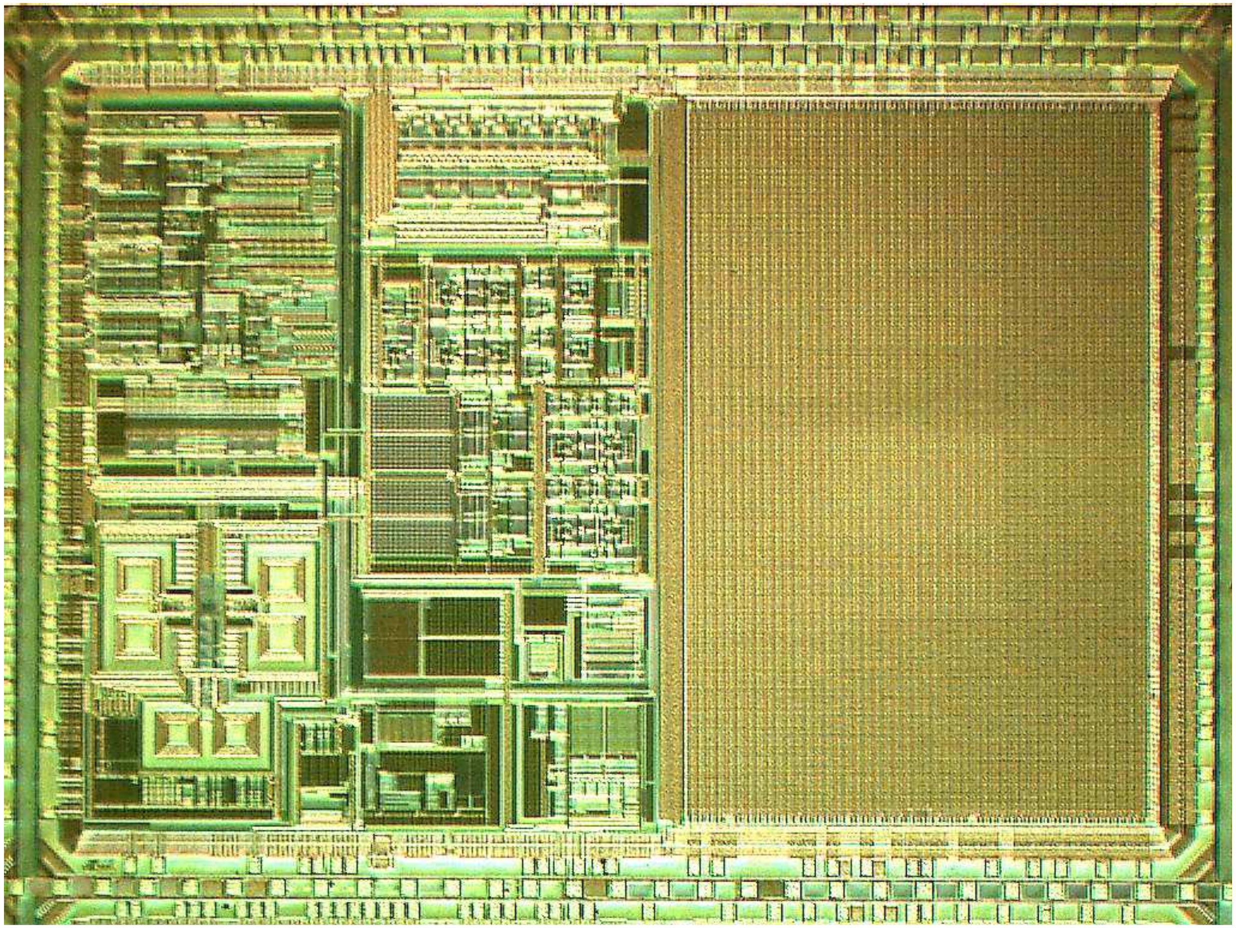




- Without VSB Nyquist filter, the demodulated signal is incorrect due to spectral overlap at frequencies, $-1.25$ MHz $< f < +1.25$ MHz
- VSB Nyquist filter is well-suited to digital implementation

# Performance Summary

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

# Chip Micrograph



- 0.13-um 1P8M CMOS
- 5.1 x 3.6 $mm^2$
- 8 x 8 $mm^2$ 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!***

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