Computing Energy from Complex Envelope

Energy of a passband signal \( s(t) \)

\[
E = \int_{-\infty}^{\infty} |s(t)|^2 dt
\]

\[
= \int_{-\infty}^{\infty} \left( s_c(t) \cdot \cos(2\pi f t) - s_s(t) \cdot \sin(2\pi f t) \right)^2 dt
\]

\[
= \int_{-\infty}^{\infty} s_c^2(t) \cos^2(2\pi f t) + s_s^2(t) \sin^2(2\pi f t) - 2 \cdot s_c(t) \cdot s_s(t) \cdot \cos(2\pi f t) \cdot \sin(2\pi f t) dt
\]

with:

\[
\cos^2 x = \frac{1}{2} + \frac{1}{2} \cos(2x)
\]

\[
\sin^2 x = \frac{1}{2} \left( 1 - \cos(2x) \right)
\]

\[
\sin x \cdot \cos x = \frac{1}{2} \sin(2x)
\]

\[
E = \int_{-\infty}^{\infty} \frac{1}{2} (s_c^2(t) + s_s^2(t)) dt + \frac{1}{2} \int_{-\infty}^{\infty} s_c^2(t) \cdot \cos(4\pi f t) dt
\]

\[
+ \frac{1}{2} \int_{-\infty}^{\infty} (s_s^2(t) + 2 \cdot s_c(t) \cdot s_s(t)) \cdot \sin(4\pi f t) dt
\]

2nd and 3rd integral are (approximately) zero:
- for each cycle (length \( \frac{T}{2} \)) \( s_c(t) \) and \( s_s(t) \) are approximately constant

\[
\Rightarrow \text{over each cycle, integral is approximately zero}
\]

\[
\Rightarrow \text{integral < zero}
\]
\[ E = \frac{1}{2} \int_{-\infty}^{\infty} s_e^2(t) + s_s^2(t) \, dt \]

\[ = \frac{1}{2} \int |s(t)|^2 \, dt \]

where \( s(t) = s_e(t) + j \cdot s_s(t) \) (complex envelope)

**Example:**

What is the energy of \( s_p(t) = I_0 q_3 j(t) \cdot \sin(2\pi ft) \)?

**Ans:** could compile:

\[ E = \int s_p^2(t) \, dt = \int_0^3 \sin^2(2\pi ft) \, dt \ldots \]

**Better:** Complex envelope of \( s_p(t) \):

\[ s(t) = -j \cdot I_0 q_3 j(t) \]

\[ E = \frac{1}{2} \int |s(t)|^2 \, dt = \frac{1}{2} \int_0^3 1 \, dt = \frac{3}{2} \]
Complex Envelope in "real" communica
tions systems

Complex envelope techniques provide the theoretical basis for moving functionality to baseband.

Benefit: Implementation is much easier at baseband—often with digital HW.

In modern transceiver (system with transmitter and receiver):
- Simple, analog RF frontend
- Sophistication at baseband

Example: Options for spectral shaping

\[ m_c(t) \rightarrow \cos(2\pi ft) \rightarrow S_p(t) \rightarrow \text{BPF}\ h_p(t) \rightarrow f(t) \]

\[ m_s(t) \rightarrow \sin(2\pi ft) \rightarrow \text{"Spectral Shaping"} \]

is equivalent to: \( h_p(t) = \Re\{h_b(t) e^{j2\pi ft}\} \)

\[ m_c(t) \rightarrow \text{LPF}\ h_b(t) \rightarrow \cos(2\pi ft) \rightarrow f(t) \]

\[ m_s(t) \rightarrow \text{LPF}\ h_b(t) \rightarrow \sin(2\pi ft) \rightarrow \text{digital} \rightarrow -\sin(2\pi ft) \]
Transceiver Architectures

1.) Direct conversion (Zero IF, homodyne)
- only one conversion stage between baseband and RF

**Transmitter:**
- digital BB samples (I & Q) → Baseband Processing → DAC → Power amp

**Receiver:**
- RF Signal → Band Selection → LNA (low-noise amplifier) → LPF → ADC → Baseband Proc.

Possible challenges with direct conversion:
- Amplifier at RF frequencies
- Carrier leakage (LO signal in RX "leaks" into the receive chain)
- leads to DC offset.
AD9361
High performance, highly integrated RF Agile Transceiver™

ADP7104ARDZ-3.3
High input voltage 500mA LDO

ADP1755ACPZ
Low V_out, 1.2A LDO

ADP190ACBZ
High-side 500mA Load Switch

AD7291BCPZ
12-bit, low power, 8-channel, SAR ADC
FEATURES
RF 2 x 2 transceiver with integrated 12-bit DACs and ADCs
Band: 70 MHz to 6.0 GHz
Supports TDD and FDD operation
Tunable channel bandwidth: <200 kHz to 56 MHz
Dual receivers: 6 differential or 12 single-ended inputs
Superior receiver sensitivity with a noise figure of 2 dB at 800 MHz local oscillator (LO)
RX gain control
Real-time monitor and control signals for manual gain
Independent automatic gain control
Dual transmitters: 4 differential outputs
Highly linear broadband transmitter
TX EVM: ≤-40 dB
TX noise: ≤-157 dBm/Hz noise floor
TX monitor: ≥66 dB dynamic range with 1 dB accuracy
Integrated fractional-N synthesizers
2.4 Hz maximum LO step size
Multichip synchronization
CMOS/LVDS digital interface

APPLICATIONS
Point to point communication systems
Femtocell/picocell/microcell base stations
General-purpose radio systems

GENERAL DESCRIPTION
The AD9361 is a high-performance, highly integrated radio frequency (RF) Agile Transceiver™ designed for use in 3G and 4G base station applications. Its programmability and wideband capability make it ideal for a broad range of transceiver applications. The device combines a RF front end with a flexible mixed-signal baseband section and integrated frequency synthesizers, simplifying design-in by providing a configurable digital interface to a processor. The AD9361 operates in the 70 MHz to 6.0 GHz range, covering most licensed and unlicensed bands. Channel bandwidths from less than 200 kHz to 56 MHz are supported.

The two independent direct conversion receivers have state-of-the-art noise figure and linearity. Each receive (RX) subsystem includes independent automatic gain control (AGC), dc offset correction, quadrature correction, and digital filtering, thereby eliminating the need for these functions in the digital baseband. The AD9361 also has flexible manual gain modes that can be externally controlled. Two high dynamic range ADCs per channel digitize the received I and Q signals and pass them through configurable decimation filters and 128-tap finite impulse response (FIR) filters to produce a 12-bit output signal at the appropriate sample rate.

The transmitters use a direct conversion architecture that achieves high modulation accuracy with ultralow noise. This transmitter design produces a best in class TX EVM of ≤-40 dB, allowing significant system margin for the external PA selection. The on-board transmit (TX) power monitor can be used as a power detector, enabling highly accurate TX power measurements. The fully integrated phase-locked loops (PLLs) provide low power fractional-N frequency synthesis for all receive and transmit channels. Channel isolation, demanded by frequency division duplex (FDD) systems, is integrated into the design. All VCO and loop filter components are integrated.

The core of the AD9361 can be powered directly from a 1.3 V regulator. The IC is controlled via a standard 4-wire serial port and four real-time I/O control pins. Comprehensive power-down modes are included to minimize power consumption during normal use. The AD9361 is packaged in a 10 mm x 10 mm, 144-ball chip scale package ball grid array (CSP_BGA).