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Tech Notes

Miniature Radio Frequency Receivers

A four-channel miniature radio frequency receiver implemented on a single chip detects low-level signals across a wide frequency range in the presence of many interferers.

A dropped cellphone call is a common frustration often caused by a weak signal or a strong interfering signal. Many military applications that aim to detect low-level (e.g., picowatt) radio frequency (RF) signals can also be thwarted by large (e.g., milliwatt) interference signals, such as those emitted by television or radio stations. Multielement RF detection systems, consisting of antennas, receivers, signal processors, and data links, are also constrained by the evolution of military systems to smaller, lighter, less-powered platforms.

In order for small-platform sensors to detect low-level RF signals effectively, they must have high dynamic range, be small and light, consume little power, and scan a wide range of frequencies. The MIT Lincoln Laboratory miniature RF (mini-RF) four-channel receiver accomplishes these feats and is the smallest, least-power-demanding receiver that can detect frequencies over a six-octave range. Furthermore, this tiny system boasts the largest measured spur-free dynamic range (SFDR), which is an indicator of how well a target signal can be distinguished from interference, for an RF receiver of any size.

Lincoln Laboratory Solution

The mini-RF receiver outperforms existing commercial receiver systems by leveraging improvements in commercial silicon germanium (SiGe) semiconductors. The design and manufacturing process of the Lincoln Laboratory mini-RF receiver replaces more costly and low-yielding materials (e.g., indium phosphide or gallium arsenide) with a mass-produced, silicon integrated-circuit process and a low-cost printed circuit board and assembly. The mini-RF receiver does not merely replace a few components with better ones. The entire receiver was designed to be an integrated circuit with novel circuit techniques.

The mini-RF receiver tunes a broad range of frequencies, from 20 MHz to 3600 MHz, and processes 36 MHz of bandwidth. The mini-RF receiver leverages special characteristics of a commercial SiGe semiconductor process and innovative circuit techniques to develop high-SFDR, low-power RF integrated circuits (RFICs).

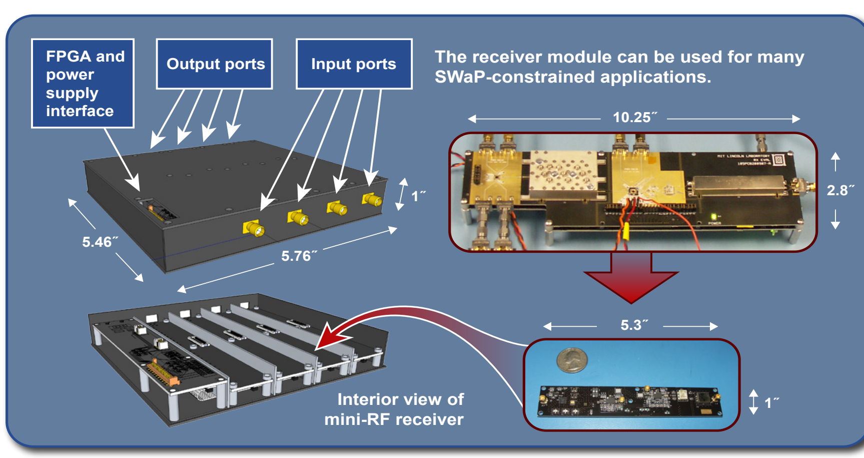

Figure 1. The four-channel mini-RF receiver occupies a single 6U VME card by replacing larger, low-yielding materials with SiGe semiconductors. For comparison, a commercial two-channel RF receiver uses four 6U VME cards.

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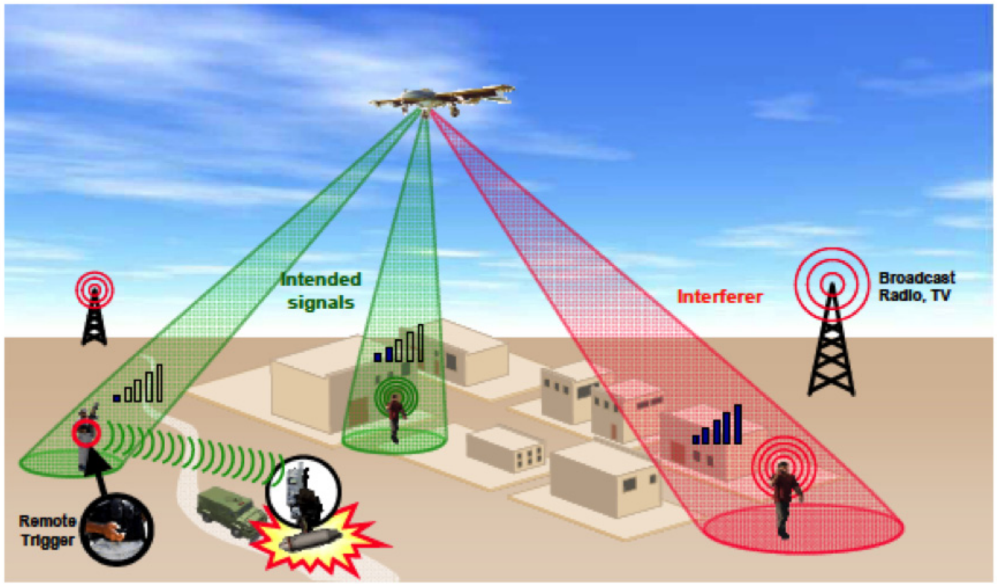

Figure 2. A scenario illustrating the Lincoln Laboratory mini-RF receiver system mounted on an aircraft as well as the sources of desired signals (shown in green) and sources of interfering signals (shown in red).

Interference signals that are very close in frequency to the desired RF input signal produce intermodulation distortions (IMDs) as the signals pass through nonlinear devices in the receiver. Also, IMDs close to the desired RF signal cannot be removed by frequency-selective filtering. For a system requiring a large (e.g., greater than 90 dB) SFDR, the receiver circuits must provide a high linearity with IMDs at least 90 dB below the output signal level.

There are many impediments to achieving such a large SFDR, such as limits on the linearity and dynamic range of the system as well as caps on usable supply voltages and bias currents. To circumvent these roadblocks, the mini-RF receiver employs two novel circuit techniques for the final stages of the second RFIC. A variable gain amplifier (VGA) adjusts the gain depending on the input level and the optimum output drive level required to drive an analog-to-digital converter (ADC). Common methods to adjust the gain (e.g., resistor ladders, multiple transconductance stages in parallel, varying the emitter or source degeneration resistors in series feedback) degrade SFDR. Instead, the mini-RF receiver decouples the linearity and gain variation mechanisms by using an operational amplifier with feedback at the input to linearize with variable degeneration.

A buffer amplifier drives the ADC and requires the highest SFDR in the receiver. In order to avoid the bandwidth limitation of an operational amplifier, a feed-forward path is applied to effectively correct for the nonlinear input. The amplifier consumes a bias current of 60 mA and has a 3 dB bandwidth of 65 GHz, which ensures a minimum propagation delay.

In addition, to help maintain low phase noise and minimal spurs within the broad tuning range and wide instantaneous bandwidth, the mini-RF receiver uses a main phase-locked loop (PLL) with two voltage-controlled oscillators (VCOs). To increase the tuning range, the VCOs operate at a frequency that is 2 to 4 times higher than the PLL frequency. A tunable reference PLL driving the main PLL between 1 and 1.3 GHz allows an improved on-chip VCO performance, eliminating spurs and providing a small frequency-tuning step without introducing a high level of spur within the instantaneous bandwidth.

By using these novel techniques, the Lincoln Laboratory mini-RF receiver achieved an SFDR of nearly 100 dB (relative to the carrier frequency) with a total power dissipation of only 2.5 W per channel—less than one-fifth of the power required by conventional techniques. Specifically, a two-tone test measured third-order IMD tones having a ~96 dB lower amplitude (relative to the carrier frequency) than two fundamental tones at 139.95 MHz and 140 MHz with an output of –13 dB referenced to one milliwatt. Furthermore, a record-low phase noise was measured for a single-chip SiGe frequency synthesizer solution.

Applications

The characteristics of the mini-RF receiver include low power consumption, high performance, and a potentially lower cost. These are RF building blocks and could be implemented in any wireless application that uses a portion of the large bandwidth available. Example military applications include frequency-agile radar, multiple-input multiple-output phased-array radar, and telemetry. Potential commercial applications include broader band wireless local-area networks, signals and electronic intelligence, wireless networking of industries (e.g., hospitals, factories) for monitoring supplies and controlled substances, advanced cellular systems requiring RF communication, and medical screening to detect cellphones, pacemakers, or other electronic devices. These applications would benefit from a lower-power product that more effectively uses the available spectrum. ■

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