Technical Article

LNA Receiver Design for Integrated Automotive Wireless Systems

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Introduction

Demand for in-vehicle infotainment/telematic features is driving the automotive industry to integrate antennas and receiver circuitry for numerous satellite and terrestrial communications. These services include global positioning systems (GPS), cellular, dedicated short range communication (DSRC)/vehicle to everything (V2X), satellite digital audio radio service (SDARS), and more. Connectivity is made possible through high-performance RF electronics packed into compact, cost-sensitive antenna housings, as shown in Figure 1. This integration, along with physical size and cost constraints, presents a variety of RF design challenges.

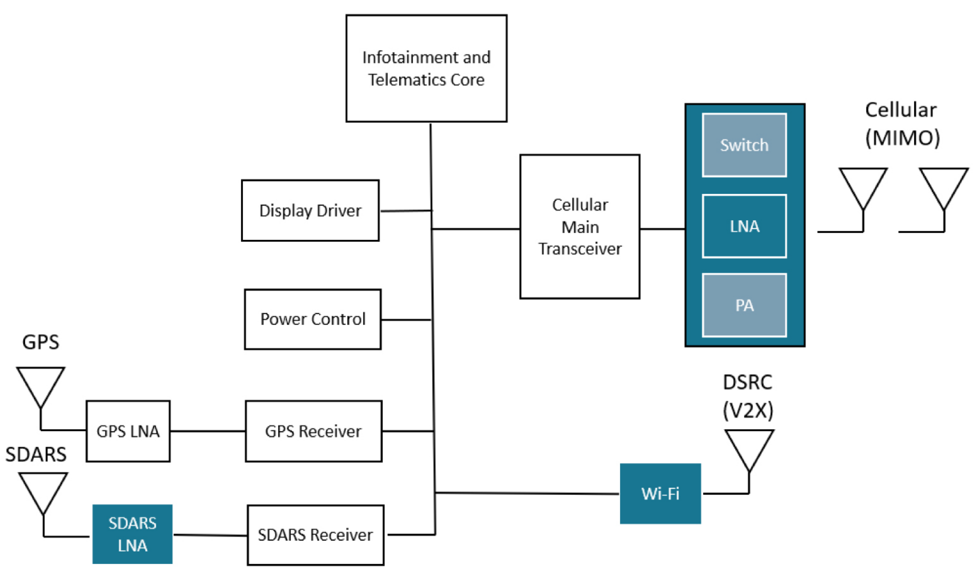

Figure 1 • Antenna and receiver blocks for various wireless services such as cellular, GPS, DSRC, and SDARS.

Interfering signals from out-of-band (OOB) transmissions, coupling, shadowing, and loading from neighboring cellular, V2X, and GPS bands can easily disrupt reception for SDARS receivers. These interferers can emanate from nearby vehicles, or they can be "self-inflicted" due to the proximity of SDARS, GPS, V2X, and cellular aerials within a common radome. As a result, SDARS receivers require highly selective filtering along with the necessary gain and noise performance to meet the system's signal-to-noise ratio (SNR) requirements.

SDARS signals are broadcast from satellites or via repeater stations directly to vehicle-based receivers operating in the S band from 2320 to 2332.5 MHz and 2332.5 to 2345 MHz. The aerial located on the vehicle roof is connected to the receiver through 15 to 20 feet of coaxial cable. A compact low noise amplifier (LNA), located in the small radome, is necessary to overcome this cable loss. Cellular bands in the 2305 to 2320 MHz and 2345 to 2360 MHz range used for the wireless communications service (WCS) are the most disruptive because they neighbor SDARS without any guard band. The filtering in the SDARS receive chain must possess narrow fractional bandwidth (~1%) and steep skirts to reject OOB signals.

Tackling the Design Challenge

Field application engineers from Richardson RFPD, using AWR Design Environment software from Cadence, tackled this design challenge by developing an LNA receiver lineup that covers the SDARS frequency band and meets performance requirements. The LNA architecture is composed of two active LNA stages and two bandpass filters (BPFs), shown in Figure 2. All components meet Automotive Electronic Council (AEC)-Q specifications. Because of the stringent noise requirements, the LNA lineup was developed using discrete components on a printed circuit board (PCB) designed to fit in a very small footprint for automotive rooftop applications.

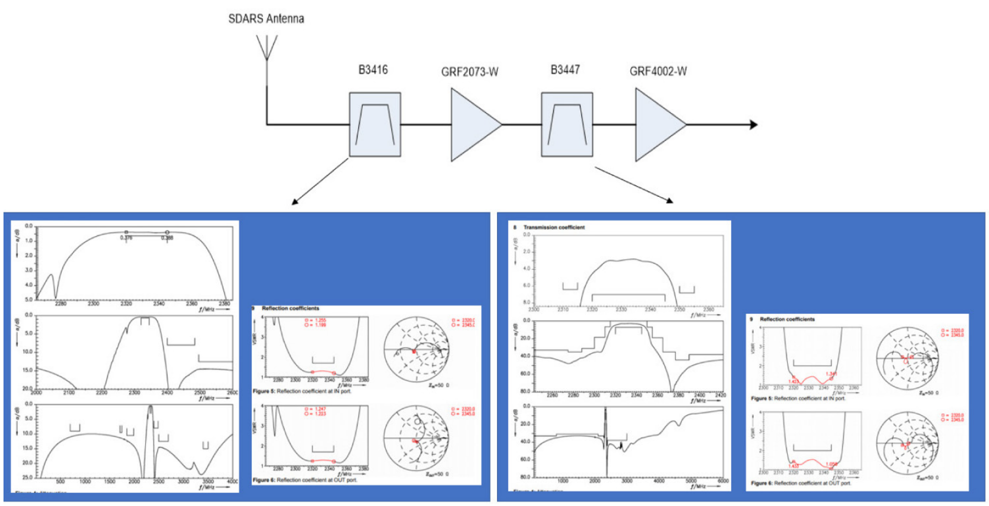

Figure 2 • Two-stage LNA line up with the insertion loss and input impedance of the two narrowband filters.

One of the most critical challenges was to meet the sub-1.0 dB noise figure (NF) for the entire LNA chain, especially since the lineup required placement of a BPF in front of the first LNA stage. Pre-filtering was necessary to protect the LNAs from interference, overloading, and the added noise of signals coupled from nearby cellular antennas. Narrowband receivers typically have a BPF placed before the LNA to guard against this OOB interference. However, the additional insertion loss of a filter placed in front of the LNA will degrade the overall NF, making it more difficult to achieve the noise requirement. To mitigate this impact, Richardson RFPD designers chose Qualcomm RF360 surface acoustic wave (SAW) filter technology for the critical pre-filter. This technology provided extremely low insertion loss (< .5 dB), high selectivity to reject OOB signals, and a small device footprint.

In addition to using low loss, highly selective SAW filters, the designers were able to minimize the in-band noise using a low-noise discrete transistor and pre-matched LNA. Special attention was focused on developing the interstage impedance matching networks to address in-band NF optimization and out-of-band rejection.

The first LNA in the lineup is the Guerrilla RF GRF2073-W, a linear, ultra-low-noise device designed for automotive satellite radio multi-stage LNAs, signal boosters, and 5G applications. At 2332.5 MHz (mid-band), this gallium arsenide (GaAs) enhancement-mode pseudomorphic-high-electron-mobility-transistor (E-pHEMT) has a typical NF of 0.6 dB, gain of 20.5 dB, output P1dB of 19.8 dBm, and an output 3rd order intercept point (OIP3) of 35.0 dBm (bias: 5V/70 mA). The linearity, ultra-low noise, and high gain characteristics made this device an ideal first-stage LNA solution for the multi-stage SDARS LNA design. De-embedded S-parameters and noise data provided by the manufacturer were used in the AWR Microwave Office circuit simulator to develop the matching circuit with the aid of the software's network synthesis and circuit analysis features.

The second LNA in the chain is the Guerrilla RF GRF4002-W, a broadband low-noise gain block. This device is internally matched to 50 ohms at the input and output ports and exhibits broadband NF of 0.85 dB over the SDARS band, 15.0 dB gain, and excellent linearity and return loss from 700 to 3800 MHz. As the second stage LNA, this device delivered an output P1dB with 23.5 dBm with an OIP3 of 36.5 dBm. While the device includes internal matching to 50 ohms, the designers needed to optimize the impedance match between the second stage LNA and the preceding narrowband filter.

Matching networks were required throughout the entire LNA lineup to achieve the required performance. Narrowband front-end SAW filters are typically designed for power matching (maximum power is transferred from the antenna to the input of the SAW filter) to provide a flat passband and low insertion loss, as shown in Figure 3.

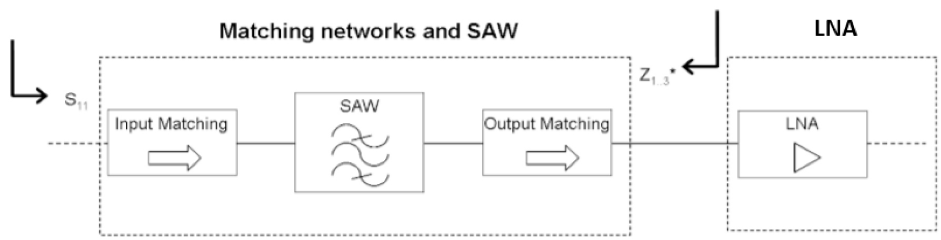

Figure 3 • Input/output matching networks provide the LNA with optimum source impedance for minimal NF and address out-of-band impedance mismatch.

While the far-off selectivity is very good for most SAW filters, the matching topology has a major influence on performance in the reject bands. Meeting the out-of-band rejection requirements, namely the filter frequency response when interfaced with non-50-ohm LNA impedances, was a significant design challenge. The designers focused their attention on obtaining a 50-ohm match between the stages to optimize the overall gain response and minimize the gain ripple.

These challenges were overcome using the Microwave Office network synthesis wizard and iFilter™ integrated filter synthesis wizard, which enabled the designers to explore a greater range of design solutions and quickly optimize the matching networks. Using S-parameter files and noise data provided by the device manufacturers, the designers were able to accurately model the components in the LNA lineup and develop the inter-stage matching circuitry. The network synthesis wizard generated the matching topologies and determined the component values necessary to terminate the BPFs with the required 50 ohms in the critical reject bands, ensuring they would operate properly.

Figure 4 shows the simulated in-band NF (a) and broadband gain (b) for the entire design compared to the measured NF results (c) and in-band gain (d) for the fabricated LNA lineup. The measured results show excellent agreement with the simulation results, excluding losses associated with the test fixture. The fabricated design achieved the target gain, NF, and out-of-band rejection goals. Simulation and optimization played a key role in enabling the designers to meet the aggressive sub 1.0-dB NF requirement.

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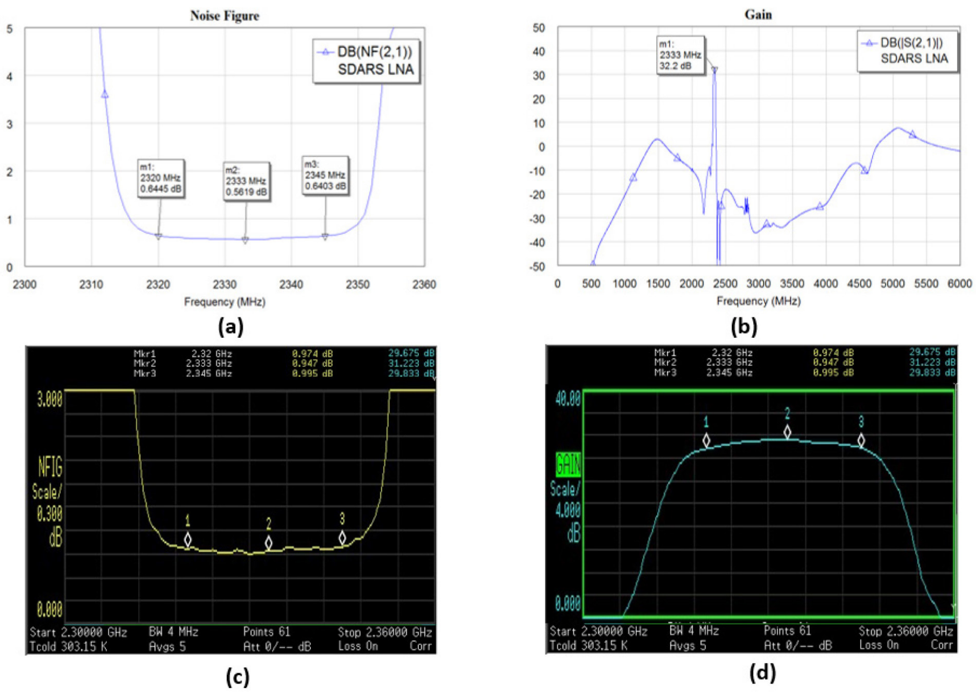

Figure 4 • Simulated and measured gain overlaid on the same graph. (a) simulated in-band NF, (b) broadband gain, (c) measured NF results, and (d) in-band gain. The measured results and the simulation results are very comparable.

Conclusion

Demand for automotive infotainment and telematics services continues to grow, calling for greater integration of antennas and radio front-end electronics housed in the smallest possible footprint and operating in the tightly spaced GPS, cellular, V2X, and SDARS frequency bands. These space, cost, and performance requirements present numerous design challenges that can be overcome using best practice design techniques, the appropriate filter and semiconductor technology, and design software that supports matching network/filter synthesis and RF-aware circuit simulation.

About Richardson RFPD

Richardson RFPD, an Arrow Electronics company, is a global leader in the RF, wireless, IoT and power technologies markets. It brings relationships with many of the industry's top radio frequency and power component suppliers. Whether it's designing components or engineering complete solutions, Richardson RFPD's worldwide design centers and technical sales team provide comprehensive support for customers' go-to-market strategy, from prototype to production. More information is available online at www.richardsonrfpd.com.

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