Single-chip RF front-ends can simplify RF and even power design for set-top boxes. They can also enable distinguishing features in OEM products for volume markets.

By Bart DeCanne

One of the few successes for global standardization in consumer A/V transmission methods is the choice of a single standard by countless broadcasters on all continents for direct broadcast satellite (DBS) TV. Unlike analog or digital terrestrial and cable transmissions that follow a different standard in each world region, the adoption of a single, worldwide satellite standard DVB-S has spurred the digital satellite set-top box (STB) market to grow to more than 60 million receivers, the majority of which are compliant to the DVB-S standard.

Until recently, OEMs were shielded from the details of the satellite RF front-end design by using dedicated ‘metal-canned’ RF modules, which convert the 950 MHz to 2150 MHz L-band input signal—by itself an “IF band” downconverted from a C or Ku band by the low-noise block (LNB) converter inside the receiver dish assembly—to an MPEG-2 transport stream.

The constant pressure on STB makers to reduce system cost, and the availability of more integrated silicon tuners, is enabling OEMs to provide this function on the main board and eliminate the canned RF module. The design of such a front-end is not trivial for a number of reasons: the relatively high RF input frequency; the wide signal bandwidth of a satellite transponder (typically 27 MHz or 36 MHz); the wide range of composite input power (-80 dBm to 0 dBm); and the fact that the LNB and possibly other satellite peripherals (e.g., multiswitch) require a dc power and an ac control feed, which are carried upstream over the same coaxial cable as the received signal.

Furthermore, in this hypercompetitive environment, OEMs are justifiably focusing their design resources on value-added features, such as personal video recorder capability, interactivity, home networking extensions, etc. So OEMs require from their vendors a solution for the RF front-end, which minimizes their research and development investment but allows them to confidently meet required receiver performance standards or a particular pay-TV operator’s certification criteria.

This article aims to outline key performance and functional requirements for the satellite RF front-end. In essence, it provides a checklist the OEM can use to compare satellite RF front-end solutions from different vendors.

Single-chip front-end benefits

Thanks to the common bit stream syntax of an MPEG-2 transport stream (TS) in DVB-compliant satellite, cable, terrestrial and, more recently, portable transmission environments, OEMs have generally favored a common platform approach due to economies of scope and scale. This means the use of a single MPEG decoder/host IC across receivers for different access media. A medium-dependent (cable, terrestrial, satellite, IP) front-end then provides the TS input to the host.

For RF networks, a front-end includes the tuner and demodulator functions. There is significant physical interaction between both AGC, RF tuning and filter bandwidth selection via dedicated analog control signals from demodulator IC to tuner IC. Therefore, the OEM wanting to replace a canned RF module is confronted with board-level signal integrity issues to maintain consistent operation and minimize the impact of external factors (PCB layout and component tolerances) on receiver performance. Clearly, it would be advantageous to integrate the tuner and demodulator into a single IC to avoid the need for these board-level feedback signals.

Implementation loss

For a DVB-S front-end, implementation loss is the single most important specification. This measure quantifies the proximity of actual receiver performance to the theoretical optimum. Implementation loss is expressed as the difference (in dB) between actual required carrier-to-noise (C/N) level and the required C/N of an ideal demodulator to achieve a given allowable output bit error rate (BER) at a specific combination of transmission parameter settings (symbol rate, Viterbi code rate, input power, RF frequency). DVB-S specifies a maximum acceptable implementation loss of 0.8 dB at a BER of 2 x 10^-4, as measured at the output of the Viterbi decoder. This performance is required for any combination of transmission parameter settings. A smaller value is better to minimize receiver desensitization.
It is useful to characterize implementation loss over varying input power levels and RF frequencies. For instance, at higher power levels, a receiver’s intermodulation products can worsen implementation loss; similarly, spurious signals at a particular LO frequency can degrade performance on certain channels.

Figure 1 shows a typical performance curve of required Eb/No vs. input power level, at QEF operation (defined as 2 x 10^-4 BER after Viterbi decoding) for a symbol rate of 22.5 Mbaud at convolutional code rate ¾.

**Additional performance metrics**

Figure 2 shows an example of a satellite receiver sensitivity calculation.

In addition to the demodulator implementation loss, the tuner noise figure (NF) impacts receiver sensitivity. Total input power can vary more than 80 dB due to the presence of many L-band (and possibly UHF) channels and also due to the effects of incidental rain fading and cable losses, especially at the high-end of the RF input range (skin effect).

On the other hand, the satellite environment is relatively benign in terms of selectivity requirements. Unlike terrestrial transmission, all transponders originate from the same location resulting in approximately equal input power levels for adjacent channels at the input of the receiver. Again, unlike terrestrial or cable TV, the varying symbol rate of individual channels (1 Mbaud to 45 Mbaud) and varying signal bandwidth require the receiver to have a matched filter of programmable bandwidth. The potentially high composite power input also requires high linearity (IP2, IP3) in the LNA and mixer to avoid deteriorating receiver performance at high input power levels.

To satisfy these requirements, satellite tuners have been using a zero-IF (ZIF), direct-conversion architecture. Especially in systems with a weak desired signal and strong adjacent channels, the ZIF receiver architecture is advantageous for meeting selectivity and image rejection requirements. This is because the image channel is actually the desired channel and not a potentially much stronger adjacent channel. However, this resilience is less of an advantage in satellite systems due to the fact that channels will be of similar power at the receiver input.
A key disadvantage of a ZIF architecture is the potential feedthrough of the LO signal to the RF channel. This leads to a dc offset after downmixing, which requires the use of larger capacitors between the tuner and demodulator for ac coupling of the ZIF analog I/Q signals.

Furthermore, the LO frequency equals the center frequency of the desired RF channel, a ZIF receiver topology is also particularly sensitive to close-in phase noise of the oscillator. Since the 1/f noise characteristic of CMOS leads to higher close-in phase noise vs. oscillators implemented in bipolar BiCMOS or SiGe processes, the implementation of direct-conversion satellite tuners in CMOS has been difficult to achieve.

Both effects can be avoided with a low-IF (LIF) architecture, which is shown together with the ZIF architecture in Figure 3. In the LIF architecture, the LO frequency is tuned about one channel away from the desired L-band channel. The IF signal is subsequently digitized and converted to baseband by a second digital mixer. By applying a LIF architecture to a wide bandwidth satellite tuner, Silicon Laboratories has integrated both tuner and demodulator into a single CMOS die, rather than reventing to a more expensive system in package (SIP) approach to combine separate BiCMOS tuner and CMOS demodulator die inside a single package.

LNB power and control

In DVB-S systems, the low-noise block (LNB) downconverter at the receiver antenna requires both power (switchable 13 Vdc/18 Vdc) and control signaling (a 22 kHz ac tone burst superimposed on the dc voltage) sent upstream by the RF front-end. While some traditional discrete solutions only support one-way (receiver-to-LNB peripheral) communication, the OEM will prefer an LNB solution, which supports modern two-way communications compliant to the DiSEqC 2.x protocol. For compatibility with older peripherals, simultaneous support for legacy tone/burst and tone/voltage signaling is required, in addition to DiSEqC-compliant messaging.

While existing demodulators integrate the one-way or two-way LNB control signaling, a dedicated IC is required for the LNB power supply regulator. In addition to a generic regulator, an LNB power supply regulator also needs to include robust fail-safe protection for specific overcurrent and short-circuit conditions, which are prevalent during receiver setup, as well as the additional circuitry for insertion of the ac LNB control signals.

As power efficiency becomes more important, particularly in multi-LNB/multituner-type (PVR) STBs, the OEM will favor a power-efficient, switched-mode power supply solution using a boost converter topology rather than a linear regulator-based architecture. A principle schematic for interfacing the satellite receiver with integrated power supply controller to the RF connector is shown in Figure 4 (the superposition of the 22 kHz signal for LNB control is not shown for simplicity). Manufactured in a high-voltage process, the LNB supply IC is, in many cases, not offered by the same vendor as the demodulator IC but does need to interact with it. This leads to additional system integration risk for the OEM, especially because the LNB supply circuit acts on the same line as the RF input signal and could degrade receiver performance.

Clearly, a one-vendor total solution for the complete RF front-end, including LNB power supply regulator and signaling controller, would be desirable.

Environmental factors

Interaction of the receiver with external factors should be minimized. Satellite receivers are particularly susceptible to external electromagnetic signals from GSM or digital enhanced cordless telecommunications (DECT) phones, which operate in a similar frequency range. Susceptibility to mechanical vibrations (microphonics) also has been reported. When evaluating different solutions, the OEM should note whether the VCO tank circuit and the PLL loop filter are integrated in the tuner IC. The need for on-board LC circuits for the VCO tank or RC circuits for the loop-filter indicates that only the VCO is integrated, and not the complete PLL ICs not integrating these peripheral circuits will be more susceptible to external interference and will likely perform worse in EMI testing in general.

To minimize interaction with the LNB, an impedance-matching network on the receiver input should be specified by the tuner vendor and a worst-case specification given for return loss or, equivalently, the voltage standing wave ratio (VSWR). The silicon vendor should provide an example input network with the recommended PCB layout.

Larger chip integration leads to potential heat issues. A thermally enhanced package with exposed heat pad is preferred because of the additional electrical connection when the exposed heat pad is connected to the ground plane.

Last but not least, as consumer environmental standards become more strict, packages should be lead-free and comply to the European reduction of hazardous substances (RoHS) guidelines.

Value-added features

Some would argue that the end customer has little visibility to the features discussed, but there are two specific features with a direct out-of-the-box impact on the customer experience. First, in the interest of giving the user an indication of the quality of his/her receiver dish setup and resulting received signal strength, the box maker implements a “signal quality indicator” based on the corrected error results from the channel decoder. Since DVB-S uses a separate inner (Viterbi) and outer (Reed-Solomon) forward error correction (FEC), this indicator can be made most accurate when the number of corrected/uncorrected errors can be read
from both parts of the channel decoder. Additional test modes could be provided to aid the OEM during characterization testing with specific lab test equipment (such as a pseudorandom bit sequence, or PRBS, test mode).

Second, channel setup should go as fast as possible. This is not a trivial task in the case of a free-to-air (FTA) STB due to the large numbers of parameters that define a DVB-S broadcast and the fact that channel parameters are not known a priori to FTA STBs (as opposed to STBs marketed to receive a specific pay-TV service).

The RF frequency must be swept over a range greater than 1 GHz with two polarizations to scan for all channels. While searching for DVB-S channels during channel scan, the receiver needs to deal with a potentially wide variety of symbol rates (1 Mbaud to 45 Mbaud), a choice of convolutional code rates (1/2, 2/3, 3/4,...), the possibility for spectral inversion, and a possibly significant RF offset (up to several megahertz) due to mixer offset in the LNB.

Especially in Southeast Asia and the Middle East, broadcasters are independently uplinking to parts of the same satellite transponder (shared transponder) using frequency-division multiplexing, a so-called multiple channels per carrier (MCPC) configuration. In this case, each uplinked MPEG-2 TS has a reduced bit rate, resulting in a low channel symbol rate after modulation. Unless the demodulator is equipped with a hardware ‘blind-scan’ accelerator, it is not uncommon for the receiver to take up to an hour, sometimes longer, for a full-band channel scan when such low symbol rate channels are present. On-chip blind-scan can lower this to only a few minutes. Especially for free-to-air applications, some box makers rate a fast blind-scan feature on the demodulator more important than inherent RF performance.

In the mature market of DVB-S, many vendors offer ICs that in some shape or form offer a subset of the required RF front-end functionality discussed. Some system-level issues, key performance criteria and satellite-specific features that an end-equipment maker should take into account were highlighted. For an OEM procuring metal-canned RF modules, with limited engineering resources or experience in RF, this may be a daunting task. However, the continuous pressure to reduce system costs and form factors necessitates his/her adoption of more integrated solutions.

Silicon Laboratories Inc. SiRX product family of RF front-end ICs for DVB-S and DirecTVs’ proprietary DSS satellite transmission standards are the world’s first single-chip implementation of the complete RF satellite front-end, consisting of tuner, demodulator, LNB signaling controller and LNB supply regulator. This solution resolves many of the systems issues designers of satellite front-end systems face today.

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