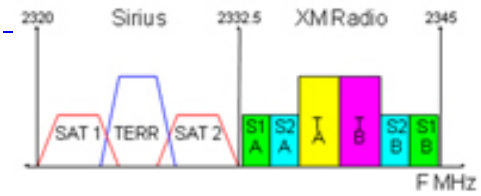
Custom IF SAW Filters for Sirius Satellite Radio Receivers

Problem Solvers - Filters

By Jidong Dai, Ph.D., Mike Ferguson, Frank Perkins RFM, and Bob Dockemeyer, Delphi

Sirius Satellite Radio broadcasting utilizes highly elliptical orbit (HEO) satellites, resulting in superior coverage over North America where the service is targeted. However, even with superior coverage, there are still areas where the satellite signals are blocked, like city centers with many skyscrapers, overpasses, and areas with strong interference signals.



[1]

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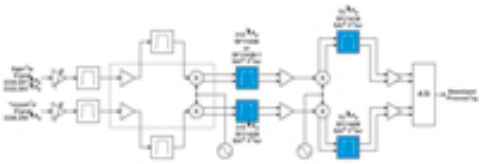
To cover the areas where the satellite signals are blocked, terrestrial stations are deployed to broadcast the same contents as from the satellites. So, the Sirius Satellite Radio broadcasting network is a combination of HEO satellites and a terrestrial station network. The Sirius Satellite Radio Network frequencies are also adjacent to the XM Satellite Radio Network, which include a significantly higher number of terrestrial stations. Figure 1 is an illustration of the RF frequency allocations of Sirius satellite (SAT1, SAT2) and terrestrial (TERR), plus the XM satellite (S1A, S2A, S2B, S1B) and terrestrial (TA, TB) signals.

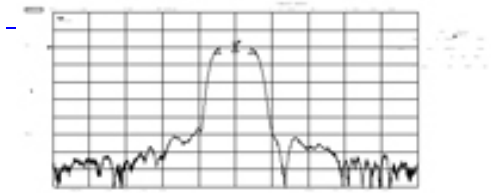
Power Level Differences



[2]

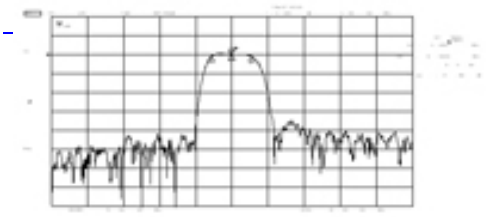
Because the HEO satellites are at a very high altitude, the satellite signals reaching the Sirius radio receivers are relatively weak. The terrestrial signals, on the other hand, can be very strong, especially when a receiver is near a terrestrial station, i.e., there is a dramatic power level difference between satellite and terrestrial signals that the radio receivers have to manage. In addition, the satellite and terrestrial signals use different modulations, COFDM for terrestrial signal and TDM for satellite signals. For these reasons, it is desirable to separate and filter the satellite and terrestrial signals before processing them.

Custom Designed IF Filters



[3]

Since the Sirius SAT1, TERR and SAT2 frequency bands are right next to each other with essentially no guard band, it is impractical to perform channel filtering at RF. It is also difficult to reject the XM TA signal as its frequency is not much higher than the Sirius frequency. Additionally, we observed intermodulation interference in the Sirius band from combination products of two-way radios and other broadcast services. Because of these limitations, earlier generations of Sirius radios used a double-conversion architecture that spread the channel filtering function between the two IF stages. Figure 2 illustrates the block diagram of the analog section of the earlier generation dual-arm configuration of Sirius radios.



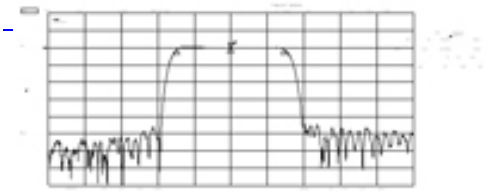
[4]

The four IF filters, highlighted in the block diagram, can only be realized practically

by SAW technology because of their stringent specifications. They are custom designed by RFM for the Sirius radio chipsets and are still in production today. These state-of-the-art IF SAW filters are "brick wall" channel filters with steep roll-off and high rejection, packaged in relatively small (5 x7 mm) surface mount, hermetically sealed ceramic packages with metal lids. Figures 3 through 6 show the performances of these filters.

In combination, these four IF SAW filters provided at least 80 dB rejection to out-of-band signals, enabling the Sirius radio receiver to have satisfactory performance in most conditions. However, in certain extreme conditions, e.g., when very close to the Sirius and XM terrestrial stations, in very dynamic signal condition areas, in areas with mixed intermodulation interferences such as some airports, pager, cellular and TV coverage, etc., the radio still experienced certain short periods of "mutes" that did not meet the stringent requirements posed to Delphi by the automotive OEM manufacturer, who was the leading adopter of Sirius satellite radios at the time.

"Mutes" Can be Eliminated



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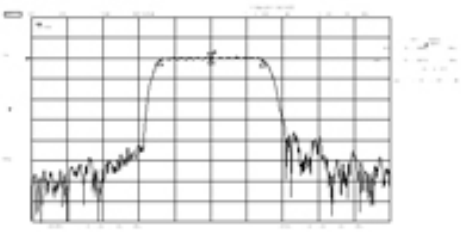
With an extensive investigation including field trials, Delphi engineers concluded that the many "mutes" could be eliminated with improvements that allowed post ADC Sirius three-signal error correction and signal synchronization capability to be increased, helping the following factors:

1. Sirius terrestrial station COFDM self interference, e.g., unneeded Sirius terrestrial signals in the satellite arm that were limiting the satellite ADC dynamic range and reducing the satellite time buffer and dynamic three-stream error correction effectiveness in very dynamic Sirius mobile signal conditions.

2. Satellite frequency interferences, e.g., intermodulation product signals in S band, from UHF, 2-way radios such as government, aviation, cellular, and public band types whose high level spurs are often found in the Sirius band, airport radar spread spectrum bursts, and other adjacent band interferences such as PCS and WCS signals.

3. XM interferences in COFDM, e.g., 3rd, 5th and 7th order products presented to the 2nd mixer and ADC of the Sirius radio.

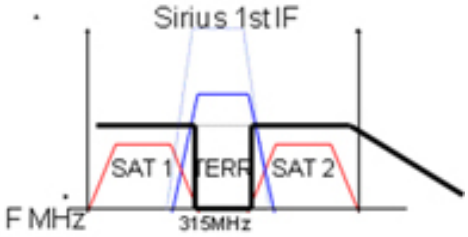


[6]

In order to reduce and shorten the "mutes" to meet automotive OEM requirements, Delphi made numerous design improvements to the Sirius radio receiver, e.g., redistributing system gains including the antenna, adding additional automatic level control, adjusting COFDM gain setting and the AGC threshold set point, etc. However, one key improvement can be attributed to improvements in filtering. It is evident from the block diagram that the most challenging part of the receiver front end is the satellite arm, where wide-band IF filters are used, allowing unwanted terrestrial signals to pass through.

Terrestrial Signal Level

As stated earlier, the terrestrial signal level at a receiver is significantly higher than that of the two satellite signals. These terrestrial signals add unnecessary power into the satellite path, limiting satellite processing dynamic range in both low signal and high signal dynamic signal areas, especially when a car with Sirius radio is driven close to terrestrial stations in dynamic signal conditions, in and out of line of sight with the satellites. This puts extremely high demand on the dynamic range and interference immunity of the receiver to manage synchronization and large power level differences, and proved very challenging to the early generations of the receiver chipsets.



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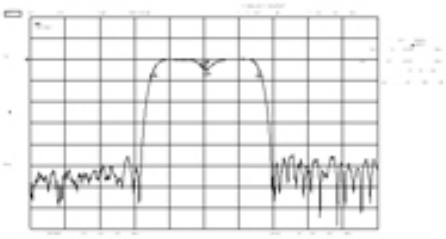
One solution is to put a "notch" in the middle of the satellite path to reject the unwanted terrestrial signal, and the more front end the "notch" can be, the better. Due to the limitation of filtering technologies, it is impractical to put such a notch at RF (the very front end), so the best place to put such a notch is at the first IF, as shown in Figure 7.

Of course, such an ideal notch to completely reject the terrestrial band signal is not possible. However, even a few decibels of rejection in the terrestrial band will go

a long way in helping to alleviate the pressure on the dynamic range of the satellite ADC, and reduce the effects of all the factors listed above that cause the "mutes".

Right before the critical field trial of the Delphi radio for the automotive OEM, RFM made a special wide-band filter that had a "notch" in the middle of the passband, providing several dB of rejection to the terrestrial signals, while passing the signals from the satellites on both sides of the terrestrial band. The performance of this special notch filter is shown Figure 8.

Notch Filter Paves the Way



[8]

After replacing the original wide band first IF SAW filter (SF1143B) with this special notch filter (SF1143B-1), the Delphi Sirius satellite radio passed the critical field test of the automotive OEM with the most stringent requirements, in the most critical city, Detroit. This helped pave the way for automotive OEM adoption of Sirius satellite radios.

Since then, this special one-of-a-kind notch filter, the SF1143B-1, has been used to replace the "normal" wide-band first IF filter, the SF1143B, where more stringent requirements on the radio performance is required. As far as we know, it remains the only such special notch filter manufactured in volume for commercial applications. So far, RFM has delivered about 800,000 of these special notch filters to Delphi for some automotive OEM Sirius radios, including all initial launch generation Sirius radios made by Delphi. As a leading supplier of SAW filters to both Sirius and XM radios, RFM has delivered more than 100 million Sirius and XM SAW filters combined to different Sirius and XM radio manufacturers. As a leading supplier of automotive electronics systems, Delphi has delivered over 25 million receivers for Sirius and XM.

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