Evolution of Low Noise Receiver Design for Ka-Band Satellite Terminals in Hostile Environments

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Low Noise Block Converters (LNBs) are the principal components used in receivers for the frequency translation of incoming signals from a satellite to a modem. With the widespread use of Ka-band satellite terminals in a range of environments, and particularly for SATCOM on the Move (SOTM) and airbourne and maritime applications, the ruggedisation requirements for the hardware have increased. This paper describes the evolution of the LNB from a single module to a split design for SOTM, and discusses some of the issues that have arisen to achieve reliable operation in a range of increasingly hostile environments.

I. Introduction

To achieve reliable operation from a satellite ground terminal, sufficient RF performance is required from the Block Upconverter (BUC) and the Low Noise Block Converters (LNB). The LNB translates the received signal from the satellite to a suitable frequency for a modem. Typically, a military Ka-band satellite operates with a down-link in the 20.2-21.2GHz range. This 1GHz band is translated to L-band, typically 1-2GHz or 950MHz to 1.95GHz, which is applied to the receive port of a satellite modem. The LNB performs a critical function for the receiver of a satellite terminal - to achieve sufficient carrier to noise performance - and is thus required to have a very low noise figure, typically 1.3dB, and high gain, typically 60dB. Additionally the LNB is required to have good image rejection and filtering of the upconverted signals at the same terminal.

The LNB for Ka-band satellite terminals consists of a WR42 waveguide input, followed by a low noise amplifier (LNA), an image reject filter, and frequency conversion to the L-band interface, as shown in the block diagram of Fig.1. A local oscillator (LO) with very low phase noise and high immunity to vibration is used for translating the satellite receive band to the L-band frequencies.

Figure 1. Block diagram of Ka-band LNB.

Apart from the key RF parameters, the LNB is required to provide reliable operation in a wide range of environments and over a wide temperature range. Typical satellite terminals are fixed or transportable outdoor systems with a parabolic dish antenna and with the LNB mounted close to the feed. Some LNBs for Ka-band satellites are used in SATCOM on the Move (SOTM, also known as Communications on the Move - COTM) in land-based, maritime or airbourne platforms. These applications present greater challenges in terms of the operating environment. This paper will describe some of the challenges faced in developing the LNB to operate from a relatively benign, fixed ground-based environment to more demanding moving platforms and hostile environments.

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II. Fixed Ground-based LNBs

Figure 2 shows a photograph with two views of a Ka-Band LNB. The approximate dimensions are 100mm (L) x 65mm (W) x 51mm (H). The LNB has a WR42 waveguide receive port which connects to the antenna feed. The LNB shown also has a single SMA connector for the downconverted L-band output, as well as being used to provide DC bias to power the module, and conducting the reference signal for the on-board local oscillator used for the frequency translation. Most LNBs will be a variation of this, with some having different RF connectors or separate multi-pin connectors for DC and for monitoring. Mounting arrangements also vary, depending on the requirements of the installation. The LNBs shown in Fig.2 have mounting feet for installation on a platform, but in many cases, the low mass (400g typ.) has enabled the LNB to be mounted directly to the waveguide structure of the antenna feed with little or no additional support. The relatively low DC power consumption means that fans are generally not required for the LNB.

Figure 2. Photograph of Ka-band LNB showing front and rear views.

The LNBs are historically made as a sealed unit, to withstand environmental conditions to IP65 or greater.1 2 This has included the use of O-rings for sealing all of the joints, screws and connectors, as well as external painting. A waveguide pressure window has ensured that the waveguide port is also sealed. The LNBs may also be pressurised as a further measure to prevent water ingress. These design factors have ensured that the LNBs have provided many years of reliable operation under the environmental conditions faced in typical outdoor fixed installations.

III. Airbourne LNBs

Airbourne applications for LNBs has resulted in additional requirements to be met. The LNB is required to meet standards from DO-160 for approved operation on airbourne platforms.3 The standard includes environmental conditions, vibration and shock, as well as EMI/EMC and lightning susceptibility. In terms of the environmental specifications, the operating altitude and temperature ranges have increased from those of the standard LNB. The minimum operating temperature has gone from -20°C or -40°C for standard LNBs to -55°C, while the maximum operating temperature has increased from 60°C to over 70°C. This has required careful component selection and some re-design from the standard LNB to ensure that the wider operating and storage temperatures are satisfied.

For the airbourne application, the LNB is also required to operate to altitudes well over 13000m. This has meant that the airbourne LNB is no longer a sealed unit, as for the ground-based models. A breather hole with a moisture patch has been included to allow the air pressure to equalise between the LNB internals and the surrounding space, while still maintaining a barrier to water and dust ingress.

The DO-160 airbourne LNB requirements for lightning susceptibility have required additional protection circuitry to ensure the reliability of the electronics under induced lightning effects. Figure 3 shows a test setup where some direct lightning waveforms with multiple peak pulses of over 1000kV were applied to the chassis of an LNB, with no deleterious effects observed.
IV. SOTM LNBs

For SATCOM on the Move (SOTM) terminals manufactured by EM Solutions, the LNB is no longer a component that is sold separately to a system integrator. The SOTM terminal is the system into which the LNB is integrated. In the system architecture of the SOTM terminal, the function of the LNB was split between the LNA and the low-noise downconverter, which were physically located apart from each other. While this was mainly due to a requirement to provide an RF input to the monopulse tracking technology used in the system, a secondary reason was to reduce the size and weight of the movable antenna feed, on which the LNAs were fixed. Figure 4 shows a photograph of a separate LNA sub-module that was used in a Ka-band SOTM system. The separate LNA performs a critical function in the SOTM terminal, such that the overall system performance is highly dependent on the LNA specifications.

In the standard LNBs previously described, the internal sub-modules are all well protected within the sealed enclosure and isolated from the external environment. With the splitting of the LNB into separate LNA and downconverter sub-modules, the previously used sealed enclosure is no longer present, potentially reducing the environmental protection for the sub-modules. It is to be noted that the SOTM terminal has its own radome which provides the bulk of the protection from the external environment, such as shown in Fig.5.
It was discovered during environmental testing that, if the airconditioned radome was opened in a high humidity environment, some moisture was able to condense on internal surfaces within the system. Following this, the system could exhibit a reduced Carrier to Noise performance for the satellite downlink. After some investigation, it was found that this may have been due to water droplets forming on various surfaces of the system. One of these potential surfaces was within the LNA itself. Further experimentation showed that droplets of moisture in particular parts of the circuit could lead to bias changes and a reduction in gain in the low noise HEMT amplifier. For example, any condensation around one of the DC block capacitors between the HEMT stages may result in a resistance of around 100k-300kΩ, as shown in Fig.6. Instead of blocking the DC between the drain voltage of one stage and the gate voltage of the following stage, the condensation could disrupt the normal bias to the HEMT. Since the gate resistance of the HEMT is very high (hundreds of kΩ), the any moisture could lead to the gate voltage being pulled higher, potentially to 0V or slightly positive. This could result in an increase in the drain current and a reduction in the drain voltage, lowering the RF gain of the amplifier and leading to a reduced Carrier to Noise performance of the satellite receiver.

To reduce the potential for moisture issues in high humidity environments, selected parts of the LNA PCB have been conformally coated, so that the moisture condensation can no longer bridge the conductive surfaces and disrupt the normal operation of the LNA. Improved sealing of the LNA cavity has also been implemented.

Another solution that is being explored to counter moisture effects is to change the RF lineup of the LNA. There are, at present, no packaged MMIC amplifiers available that can meet the low noise figure requirements of the LNA. However, there are a number of MMIC amplifiers that have a relatively low noise figure of around 2 to 2.5dB. These amplifiers are potential candidates for a second-stage amplifier, with the low noise provided by a first stage HEMT. The advantage of this approach is that separate DC block capacitors in the RF path are no longer required, since they are internal to the MMIC amplifier. This means that the RF path should be more resilient in the presence of moisture, since the drain voltage of the first stage can no longer affect the bias of the second stage amplifier. The MMIC amplifiers are also typically sealed separately with a covering lid, which would provide these components with additional protection from moisture.
While the above solutions minimise the potential of moisture to affect the performance, any condensation formed on the RF track could still result in a detuned response, since the dielectric constant of water is about $\varepsilon_r \sim 80$. To ensure that there is no moisture ingress requires a sealed LNA with O-rings or with hermetic sealing.

V. Maritime LNBs

The extension of the SATCOM on the Move (SOTM) terminal to maritime platforms has also required additional environmental protection. The satellite terminal is required to meet various parts of the maritime standards of IEC-60945 and of IEC 60092.\textsuperscript{5,6} The external surfaces, particularly the covering radome, are required to provide a higher level of protection from the more hostile maritime environment. However, to ensure reliable operation in the maritime environment, the LNA and downconverter require sealed enclosures. This means that O-rings are required for the lids, the waveguide and for the connectors. Waveguide windows for the LNA, as well as other waveguide apertures are also required for prevention of moisture and salt spray ingress.

VI. Conclusions

The paper has described the evolution of a ground-based Ka-Band LNB to the harsher environments of SATCOM on the Move (SOTM) terminals. In a stand-alone LNB, a sealed enclosure provides environmental protection for the LNA and downconverter submodules, and has a proven reliability track record over many years of operation in outdoor fixed installations. For airborne LNBs, the more stringent temperature, altitude and other environmental and electrical requirements have entailed some careful re-design from the standard LNB. For the land-based SOTM terminals, some lessons were learned to ensure sufficient sealing and moisture retardation. These have been applied to the even more stringent requirements of maritime SOTM terminals for Ka-band satellite receivers.

References