Technical White Paper

How Innovative Semiconductors for Sensing Payloads in Satellites Help us Better Understand our World

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ABSTRACT

Since the beginning of the space race in the 1950s, scientists have been designing instruments to monitor and measure our planet's environment. In 1958, the first U.S. satellite, Explorer 1, measured the cosmic radiation zones surrounding Earth, which were later named the Van Allen belts after the scientist who designed the experiment. This launch, and the discovery of Van Allen belts helped start the era of satellite monitoring of Earth that continues to today. As technology has advanced, the capabilities of the sensors in satellites has increased dramatically to include measuring weather patterns, the concentration of pollutants, ice pack thickness and crop yields.

This white paper explores different payload instruments used aboard satellites for radar and optical imaging, and how those instruments are constructed using innovative semiconductors.

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Trademarks

1 Sensor Technology in Satellites

The types of sensing payloads (also known as “sensing instruments”) used in satellites for measurement can be broken down into two categories:

- Active sensors generate their own illumination in the form of light or electromagnetic waves, similar to using a flash on a camera. The synthetic aperture radar (SAR) aboard the satellite launched in the joint NASA-Indian Space Research Organization (NISAR) ISRO mission in 2025 is an example of an active sensor.
- Passive sensors sense illumination from other sources, similar to taking a picture outside where the sun is providing the light. An example of a passive sensor is a multispectral imager such as those used on the Sentinel 2 mission from the European Space Agency (ESA).

2 Active Sensing Payloads for Satellites

An SAR is a common type of active sensing payload found in satellites. Like any radar system, SARs emit a pulse or frequency chirp of radio waves from their antenna, which propagates to the target and then is reflected back for receiving by the same antenna. Measuring the time it takes for this journey to occur makes it possible to determine the distance to the target. However, since a satellite flies at an angle to the target on the ground (see Figure 2-1), the amount of reflected energy is determined by the smoothness and angle of the target.

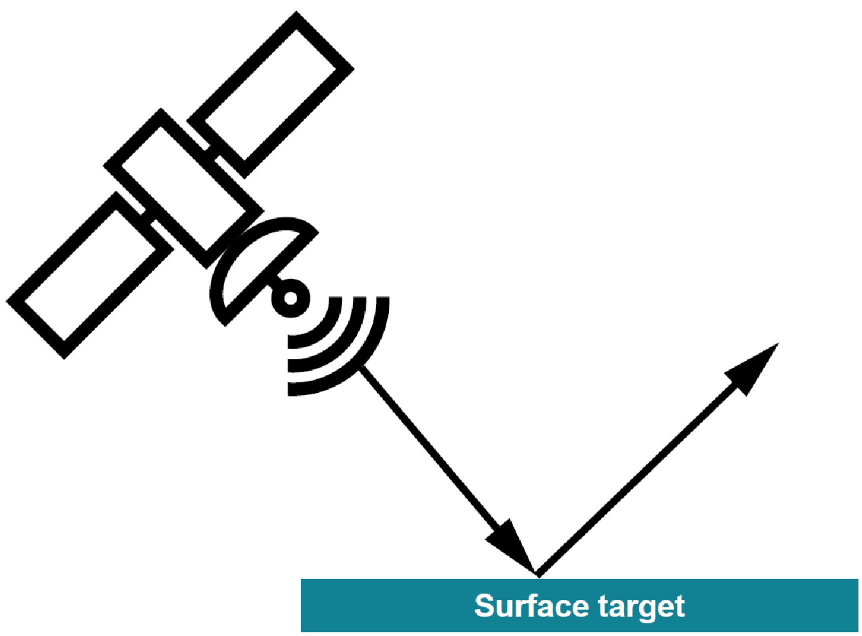

Figure 2-1. Radio Waves Reflecting off a Smooth Surface Target

For example, smooth water reflects all of the radio waves used for radar sensing away from the receiver (i.e. the antenna). The amount of reflected energy is displayed as a gray scale image where white areas indicate high reflection and dark areas indicate low reflection.

Radio waves can also reflect off of multiple objects. For example, first water and then a tree, which is called a double bounce. A double bounce can make a smooth water surface appear bright in an SAR image instead of dark, as the radio waves first reflect off the water’s surface and then the tree, as you can see in Figure 2-2.

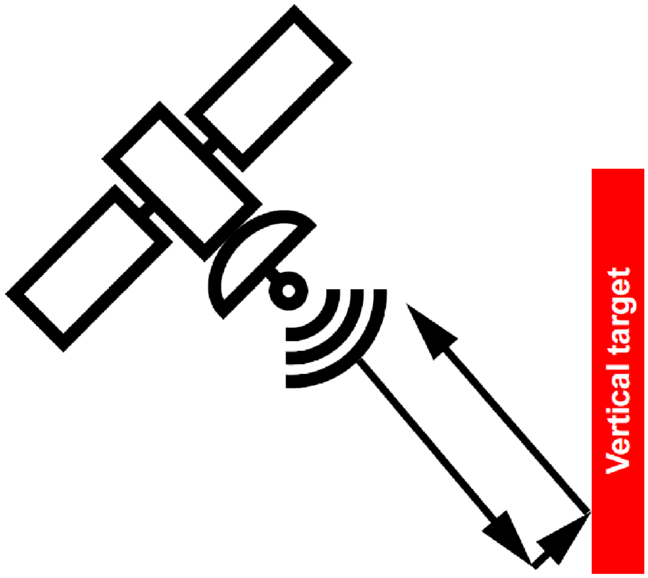

Figure 2-2. Double Bounce of Radio Waves

The frequency of the radar is an important property that significantly affects what it can observe. Radio waves only reflect off of objects that are larger than the wave's wavelength.

The property of radio wave reflection enables a radar to see through clouds and even vegetation on the ground. Very low frequency radars can even penetrate soil to determine moisture levels or features undetectable by optical imaging.

Another feature of the radar is its aperture size. The effective size of the radar is inversely proportional to the spot size of the radar beam as it scans the ground. The spot size is referred to as the azimuth resolution of the radar, which is the ability of a satellite to distinguish between two objects that are close to each other. A bigger radar creates a smaller spot size on the ground and has better azimuth resolution. Unfortunately, it isn't practical to launch very large radars into space given their size and weight. System designers, however, are able to use computer processing to make the radar appear larger than its physical size. This method takes advantage of the fact that the satellite is moving with respect to its target and synthesizes an aperture by using the reflection of multiple overlapping pulses of the radar spot size.

Implementing an SAR instrument in a satellite requires very specialized radio frequency (RF) components. Figure 3 shows a typical block diagram of a radar imaging payload for implementing SAR in a satellite.

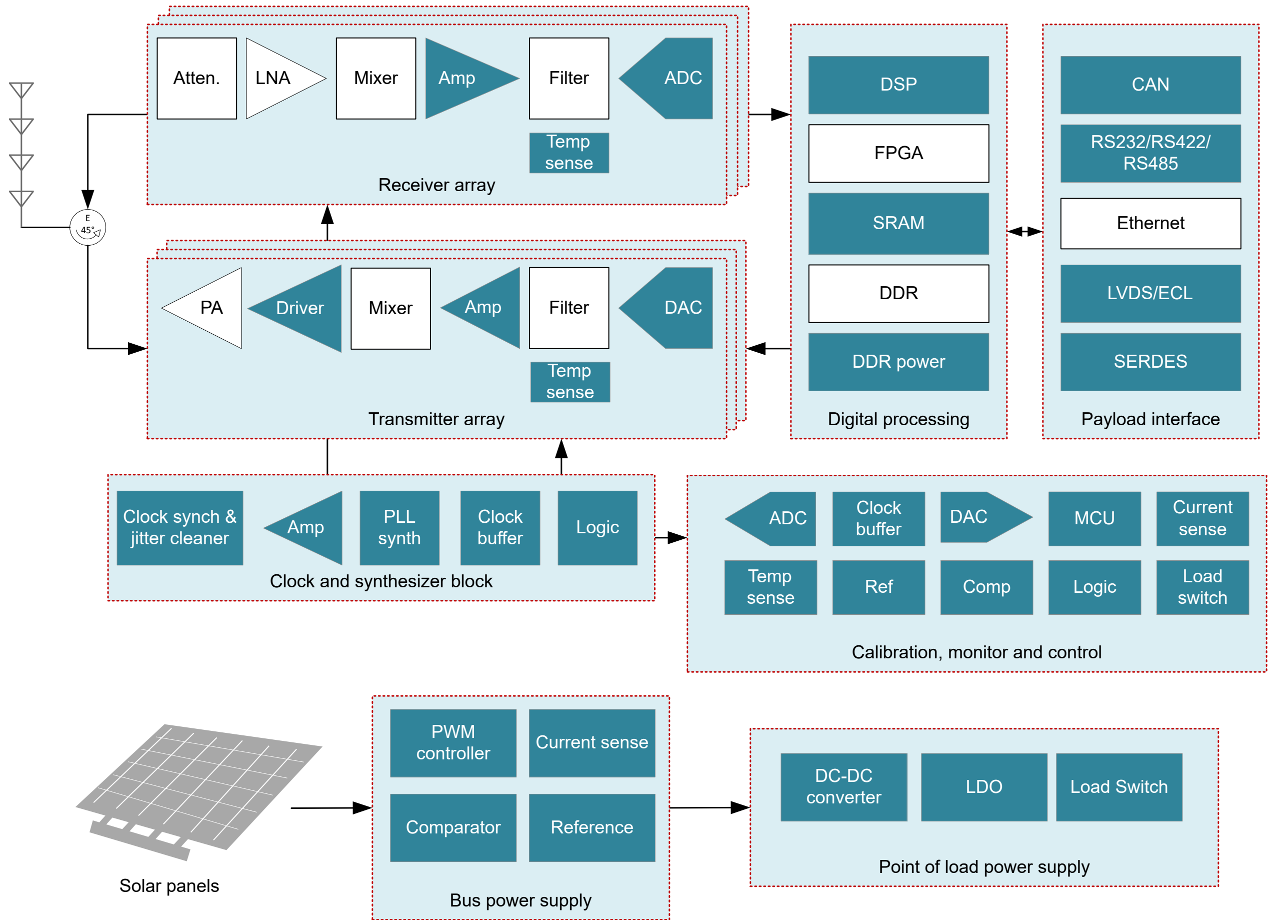

Figure 2-3. Radar Imaging Payload Block Diagram

High-speed data converters in the radar imaging payload can help determine the performance and architecture of the radar. For example, an RF-sampling data converter can directly convert the radar frequency band into digital information for processing. The most important requirements for these data converters are:

- An analog input bandwidth greater than the maximum input frequency.
- A sampling rate greater than twice the instantaneous bandwidth of the radar signal.
- High signal-to-noise ratio and spurious-free dynamic range to meet the system performance needs at the frequency of interest.
- Radiation tolerance to meet the mission needs.

For example, the AFE7950-SP RF-sampling transceiver provides these features:

- 10.6GHz, –3dB analog input bandwidth to support RF sampling from the L-band to X-band.
- Six 3GSPS analog-to-digital converters (ADCs) and four 12GSPS digital-to-analog converters (DACs). A maximum instantaneous bandwidth of 1.2GHz provides for better range resolution and implementation of anti-jamming techniques.
- Noise spectral density better than –155dBc/Hz and third-order intermodulation distortion (IMD3) >76dBc through 5GHz input frequency enable high receiver sensitivity.
- Pin-compatible 100krad/75MeV enable use in low Earth orbit (LEO) to geostationary orbit (LEO).

Another type of active sensor uses a laser as the illumination source, rather than the electromagnetic waves from the radar, but the same principle of using time to measure distance still applies. However, lasers operate at a very high frequency and with a short wavelength, which is unable to penetrate clouds or other objects on the ground and therefore requires clear conditions. Instead of an antenna, a laser system uses a photo diode to receive and measure laser light reflected from the target. Figure 2-4 shows a block diagram of this type of system.

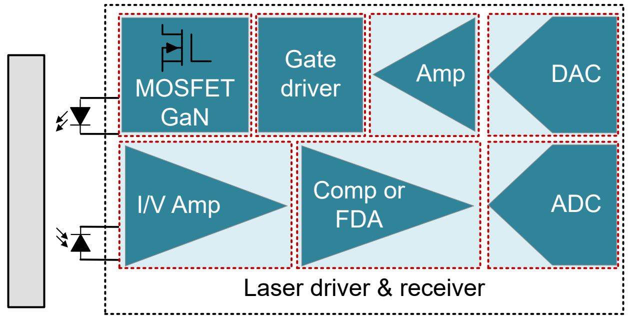

Figure 2-4. Laser Imaging Block Diagram

As Figure 2-4 illustrates, the photodiode sensor array is followed by a transimpedance amplifier to convert its current output to a voltage that the data converter can sample. In this case, the data converter needs to be fast enough to sample the rising edge and wave shape of the reflected pulse of light, which depends on the laser rise time and pulse repetition rate.

3 Passive sensing systems for satellites

The first and most familiar passive sensing system is a camera. Just like the camera in a cellphone, it uses a complementary metal-oxide semiconductor (CMOS) or a charge-coupled device (CCD) to capture photons of light reflected off the target by a light source such as the sun. The photons captured by each pixel of the sensor are converted into digital information through an ADC and processed by the system's processor to form pictures of Earth from space.

With these images, it is possible to look at weather patterns, ice coverage and the impact of natural disasters. However, the quality of the image is determined by the resolution of the sensor (the number of pixels), the dynamic range of the sensor (the number of photons that the pixel can hold), and the accuracy of the conversion of that information into a digital format. Figure 3-1 is a typical block diagram of an optical imaging payload for implementing passive sensing in a satellite.

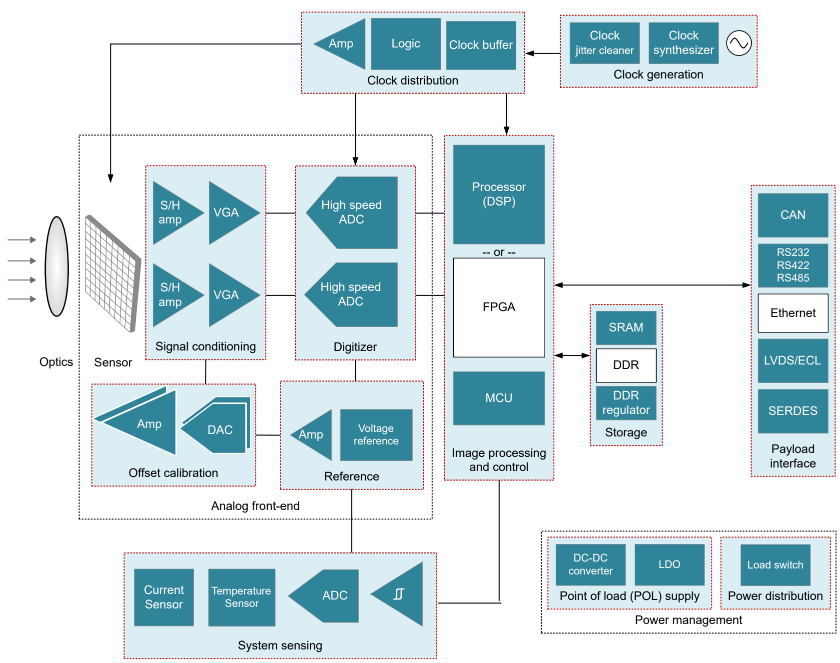

Figure 3-1. Optical imaging payload block diagram for passive sensing systems in satellites.

While some image sensors integrate a data converter, others rely on the performance of external data converters such as the ADC3683-SP, which offer these features:

- Dual-channel, 18-bit resolution at up to 65MSPS enables the maximum image sensor dynamic range extraction.
- A noise spectral density of –160dBFS/Hz provides high signal-to-noise ratio for the clean images.
- <100mW of power consumption to reduce the heat generated from the electronics, which can affect sensor noise.
- 100krad/75MeV (-SP version) and 30krad/43MeV (-SEP version) enable use in any space orbit from LEO to GEO.
- 11mm-by-11mm ceramic quad flat pack (-SP version)

While you are most familiar with visible light, there are many other wavelengths of light not visible to the human eye, such as infrared and ultraviolet.

By looking at pictures from all of the spectrum of light, scientists can measure details such as the amount of pollutants in the atmosphere, the change in crop yields, geological formations, vegetation density and moisture. By exploring how these details change over time, scientists can predict what may have happened in the distant past but also estimate what could happen in the future.

It is possible to measure nonvisible light in three ways:

- Single-band imaging measures one band in the electromagnetic spectrum. For example, an infrared sensor detects infrared radiation to measure temperature changes.
- Multispectral imaging combines the images from multiple bands to sense phenomenon such as vegetation density that isn't visible with a single band. A multispectral sensor measures three or more coarse spectral bands.
- Hyperspectral imaging captures images from very narrow slices of a certain band of light. Hyperspectral sensors can measure hundreds of narrow bands to identify features that cannot be seen with the coarse bands of multispectral imaging.

All of these imaging systems rely on sensor ICs that are sensitive to the specific bands of light being measured. It's possible to use CMOS or CCD sensors for the visible or near-infrared spectrum, but they are not applicable for longer wavelengths of light. Indium gallium arsenide detectors can measure wavelengths from 900nm to 2500nm, making them suitable to see further in the infrared spectrum.

Prisms or gratings placed in front of an image sensor separate light into individual bands. Each pixel of the sensor in the y dimension senses a single band. The resulting two-dimensional image comprises all of the spectral information for each point across the line. It then becomes possible to examine the spectral composition of each individual pixel to look for patterns or characteristics of things like minerals, vegetation or pollution.

A sensor is just one of the components necessary to produce images, however. The output of the sensor must also be conditioned, digitized by a high-speed ADC, and then processed into a viewable format. As in the image sensor described above, the performance of the ADC is vital to the quality of images and must match the dynamic range of the sensor to get the best results. Additionally, it's important to carefully select signal conditioning, clocking and power supplies components in order to not add additional noise to the sensor output or data converter. Low-noise components such as the TPS7H1111-SP RF low-dropout regulator introduces as little noise into the system as possible.

4 Conclusion

All of these sensing techniques provide valuable data to the scientific community to facilitate a better understanding of our planet's past, present and potential future. As the accuracy of satellite sensing payloads and their requisite components (like semiconductors) improves, we will be able to make more detailed measurements and more accurate predictions about the future of our world.