Millimeter Wave Body Scanners Market: Past, Present, and Future

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Abstract

Full body scanners have become an important part of the security and threat detection toolkit around the world. As RF, microwave, and millimeter wave technologies have advanced, full body scanners that utilize this technology have become popular. The overall acceptance of a full body scanning solution depends a lot on its performance, design, and commercial viability. This article discusses how, by making the right technical design and partnership choices, system integrators of these full body scanners can be more confident in offering commercially viable solutions for this fast growing market.

Introduction

We live in a very different world compared to a few decades ago. The changing geopolitical landscape of the global community and heightened threat of global terrorism has increased the need for personal security. The need for security is no longer limited to just critical infrastructure but is more ubiquitous. Governments, security agencies, and businesses across the world are recognizing this new reality and using technology to solve these new security challenges. Full body scanning is one of the commonly used security tools to help overcome these challenges and deter potential threats. This equipment is important and quite commonly used at airports, train stations, and government buildings. They scan people entering or exiting buildings for concealed weapons, explosives, and other prohibited items. While body scanners are almost necessary, they have a few major downsides. Most body scanning solutions today take a long time to scan a person, which causes congestion. Many of them have insufficient resolution to detect modern day threats or are too obtrusive for the daily flow of activities. And, if they meet all the above expectations, they are usually too expensive to commercially deploy in mass quantities.

Advances by Analog Devices in RF, microwave, and millimeter wave technologies are changing this reality. With new semiconductor solutions available, companies can realize next-generation body scanning solutions that define the limit of what's possible. This article discusses the evolution of body scanning technology and solutions available today for development of next-generation body scanners.

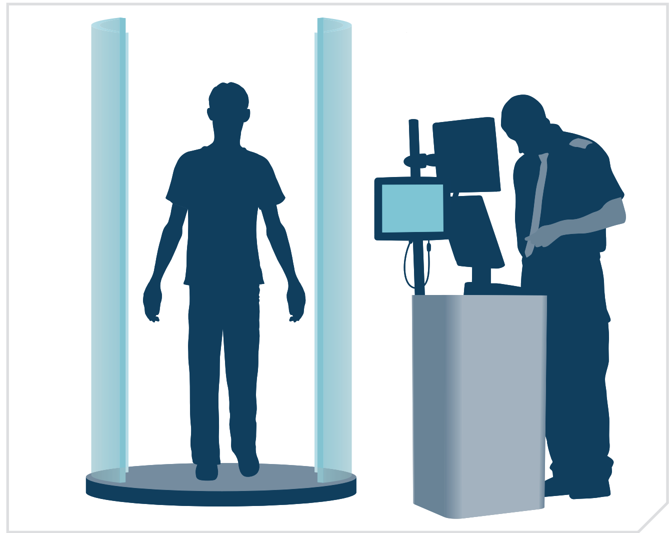

Figure 1. Typical millimeter wave body scanner.

History of Body Scanning Solutions

Long before automated body scanning systems were introduced, people were primarily screened by manual frisking. Of course, as one would expect, this took a long time, overreached individual privacy, and was not always the most accurate way to detect threats. As threats got more sophisticated and technology caught up, manual frisks were replaced by metal detectors. Metal detectors automated the flow of people and allowed them to walk through security gates without stopping. Only when a metal object was detected on the person would he or she be stopped and manually frisked. The assumption was that most, if not all, threats were made out of metal. For that day and age the assumption and the expected level of resolution of metal detectors served well. These fixed metal detectors were further supplemented with portable handheld metal detectors that allowed officers to scan a person more closely without physically touching him or her.

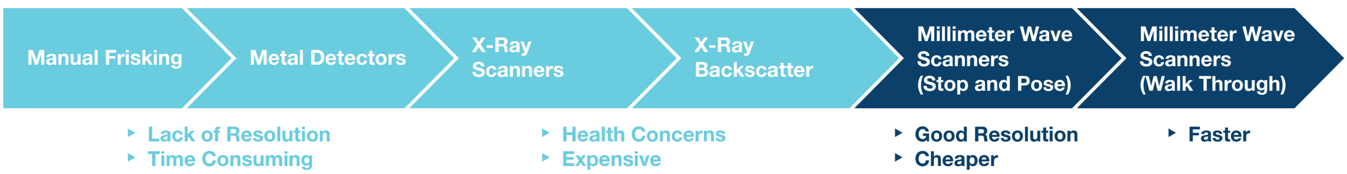

Figure 2. Evolution of body scanning technology for threat detection.

Eventually, as the kinds of concealed objects became more discreet, traditional metal detectors became insufficient. Now with the advent of technologies such as 3D printing, one could create weapons using nonmetallic materials, and so metal detectors are no longer the best detection method. As a result, agencies need more accurate forms of scanning.

That's where X-ray technology became the technology of choice. X-ray scanners are fast and can penetrate through a living body to provide extremely high resolution images of the body and concealed objects. The downside of the technology is that the person under scan was subjected to high intensity radiation, which caused considerable public concern about health and personal privacy. X-rays, due to their inherent penetration characteristics, reveal a lot of information that most people do not feel comfortable sharing and this caused a lot of outrage. The initial versions of these machines required the screening officer to manually judge the image for concealed objects, making personal privacy a major drawback. Further, since these machines use active radiation, regardless of the claims of X-ray companies, many people have major long-term health concerns.

As a result, X-rays were modified to offer X-ray backscatter solutions that do not penetrate through the target but rather reflect from the surface of the target. From a health standpoint they are relatively better, although people continue to have similar health and privacy concerns with this technology. Today, backscatter technology is used in many places worldwide.

In the meantime, RF, microwave, and millimeter wave technologies have advanced. Scanning companies are now utilizing this technology to develop scanners that are fast, provide high resolution scans without overreaching personal privacy, and do not utilize any radiation. These scanners typically operate in 10 GHz to 40 GHz range, and sometimes as high as 60 GHz to 80 GHz range as well. As RF and microwave technologies are becoming more universal, these scanners are becoming cheaper and smaller, thus allowing wide commercial use across various markets. In general, these scanners are safe, reliable, and more privacy friendly than previous options. Millimeter wave scanning is gradually becoming the technology of choice for body scanners of today and tomorrow.

Millimeter Wave Body Scanning Market Overview

Millimeter wave body scanning offers a large market opportunity, not just for security and threat detection but for other commercial applications. As per a Global Industry Analyst, Inc. report published in 2015, the full body scanner market is expected to grow to $1.7 billion by 2021 with a 41.5% CAGR. Based on another report by MarketsandMarkets, the airport body scanning market itself is expected to reach $118 million by 2021, at a CAGR of 8.4%. This does not take into account the large growth opportunity in nonairport and commercial markets.

The use of millimeter wave technology has parallels in industries such as the commercial sector, where lower cost body scanners are being used for security at shopping malls, concert halls, and stadiums. Similarly, in the consumer world, the same technology can be used in retail stores to replace traditional fitting rooms with modern day scanning and fitting systems. Rather than using older, active radiation full body scanning methods, the healthcare industry is also considering millimeter wave for various treatments.

With a worldwide shift from X-ray, backscatter, and metal detector technology to millimeter wave body scanners, the market offers a huge opportunity. To sustain market share, industry leaders in this area need to not just build body scanners, but optimize them for better image resolution and faster performance with improved features such as walk through scans that never require a person to stop.

Overall, the prospects for millimeter wave technology for full body systems across government, commercial, and consumer segments are promising. Analog Devices is already seeing several startups utilizing microwave and millimeter wave solutions to develop next-generation body scanners.

Millimeter Wave Body Scanner—Technical Solution

As shown in Figure 3, at a high level the design of an active millimeter wave body scanner consists of antenna elements, RF subsection (RF, microwave, and millimeter wave together referred to as RF for simplicity), a mixed-signal section, and the digital domain.

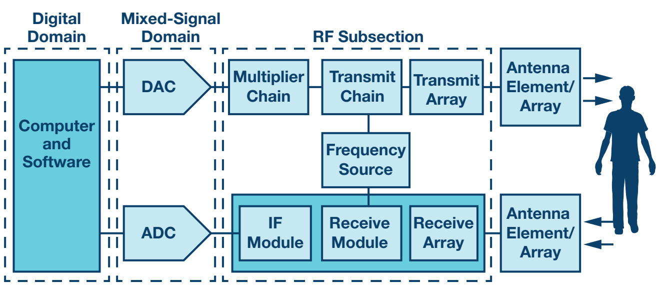

Figure 3. High level millimeter wave body scanner block diagram.

The antenna elements consist of a physical construction with small antenna structures that transmit and receive signals. The RF subsection behind these elements consists of all the high performance semiconductor hardware (chipsets) that carry the transmit signal to the antenna elements and the receive reflected signal from the antennas. The design of the RF subsection is critical to ensure the scanner captures the maximum information about the target in the least amount of time, without losing critical details.

The mixed-signal section contains high speed analog-to-digital converters (ADCs) and digital-to-analog converters (DACs). These ADCs and DACs translate the analog RF information to digital bits that the scanner's computer can process to transmit RF signals.

Finally, the digital section is where much of the software algorithms for image processing, scanning, and threat identification reside. The requirements for the digital section usually drive the requirements (such as the number of channels, frequency, bandwidth required, and sampling rate) for RF and mixed-signal sections. Most companies developing millimeter wave scanners tightly control the digital/software portion and the antenna design of the scanner. This is where they differentiate their scanner's performance by developing proprietary software algorithms and antenna designs that provide the optimum resolution and fastest scan in the smallest footprint.

The RF subsection and mixed-signal domain are critical portions of the overall solution, but the overall design is similar for most scanners. Figure 3 and Figure 5 respectively show the transmit and receive portions for the RF subsection.

As shown, the transmit and receive signal chains are driven by the same frequency source (frequency generation block). The frequency source generates 5 GHz to 10 GHz signal that goes through a multiplier chain where it is amplified and multiplied twice to generate a 20 GHz to 40 GHz signal, in the RF band of operation of the scanner. This 20 GHz to 40 GHz signal then goes through a transmit chain where, depending on the system configuration, the signal may be amplified again and filtered to eliminate any spurs that were added in the preceding stages. Since most scanners operate across a wideband, they require a filter that can filter across that entire frequency range. Traditionally, a single wideband filter is difficult to build or cost ineffective to implement. As a result, manufacturers use a filter bank with multiple narrowband filters that are then combined using switches. These narrowband filters together work as one wideband filter.

Analog Devices can simplify this traditional architecture through the use of tunable filters. By changing a tuning voltage, the filter can continuously be tuned to a desired frequency. ADI's tunable band-pass filters replace multiple filter banks or relax the filter bank requirements when used together in the signal chain.

The filtered transmit signal then goes through a matrix of switches to multiple transmit channels. Depending on each system integrator's performance requirements and antenna design, the signal chain may consist of anywhere from a few dozen to a few hundred transmit and receive channels. The number of channels typically affects the performance and cost of the system. The switch matrix consists of multiple switches that take the transmit signal and distribute it to multiple transmit antenna elements.

Traditionally, this switch matrix, especially at high frequencies of up to 40 GHz, was implemented using PIN diode and GaAs switches in SPDT configurations. With PIN diodes, each switch requires a large amount of external components to control high bias voltages and currents. These peripheral circuits get even more complex as the number of channels increases. Similarly, designs with GaAs counterparts require many switches in order to build a switch tree for high channel count.

Analog Devices has simplified this design with its 40 GHz SP4T SOI (silicon on insulator) switches, such as ADRF5046. Instead of each switch supporting two switching positions, the SP4T allows designers to have up to four switching positions. As an example, for a simple 12-channel system, three SP4T switches can replace up to seven SPDT switches. For systems with a higher channel count, the benefit of SP4T SOI switches is even greater as the system complexity increases exponantially. Besides reducing the number of switch ICs, it is equally important to reduce the number of external components and bias power. ADRF5046 is designed in an SOI process that runs on low supply voltage with negligable levels of bias current and can interface standard CMOS control signals without any need for external components. Figure 4 shows the difference between a switch implementation using the older pin diodes and the new SOI switches.

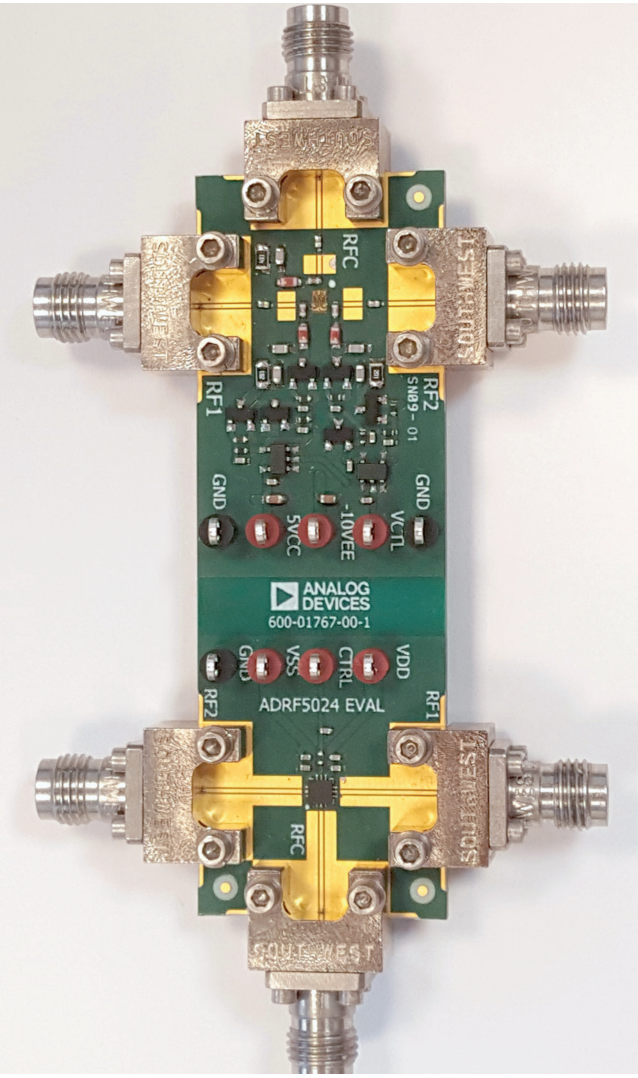

Figure 4. Implementation comparison of pin (top) vs. SOI switch (bottom).

Finally, the transmit signal is emitted out from the transmit antenna elements. Depending on the system architecture, single or multiple transmit antennas may be active at any given time. For most systems, usually one transmit antenna is active at any given time. The system may linearly sweep signals through multiple transmit antennas consecutively, with a very small time interval (on the order of a few μs) between each transmission.

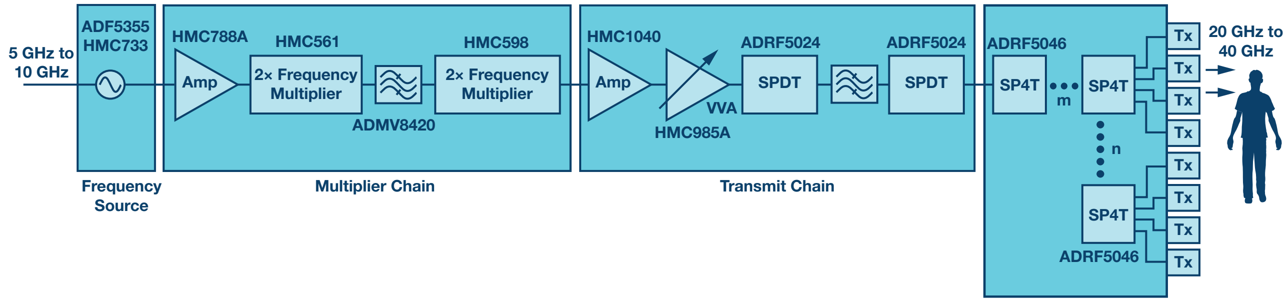

Figure 5. Generic millimeter wave imaging transmit (Tx) signal chain.

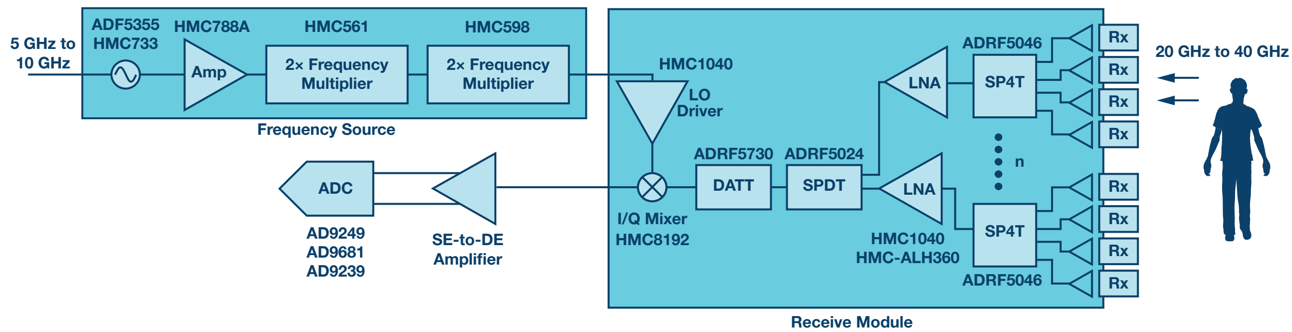

Figure 6. Generic millimeter wave imaging receiver (Rx) signal chain.

On the receive side, multiple receive elements are active at the same time. The receive elements look for a reflected signal from the target. It captures the reflected receive signal through multiple channels and passes it through a low noise amplifier (LNA) at each channel to amplify the signal without inducing added noise. The amplified signal from multiple channels is then consolidated using a switch matrix, similar to the transmit side. A digital attenuator is used for gain adjustment and ADRF5730 in the SOI process will meet fast-switching settling requirements. The received signal then goes through downconversion and further amplification stages. Traditionally, system integrators use superheterodyne architecture to downconvert a high frequency signal down to IF in multiple stages. Although, with the availability of wideband mixers such as HMC8192 (20 GHz to 42 GHz I/Q mixer), integrators can downconvert from as high as 42 GHz down to low IF or baseband in just one stage. This mixing stage is driven off the same frequency source module that drives the transmit stage. The IF of the wideband I/Q mixer is then fed to a single-to-differential amplifier that then connects into a high speed ADC. This high speed ADC digitizes the signal and provides digital input to the computer that runs various software algorithms to detect images.

As shown in previous figures, Analog Devices can provide a complete signal chain solution for millimeter wave body scanners from antennas to bits and back. With a broad portfolio of RF, microwave, and millimeter wave parts, integrators can be assured to find the right part that meets their performance and price expectations. ADI is the only company in the industry that has the portfolio, experience, and technical support to provide a complete bits to antenna solution. This saves manufacturers a great deal of time, money, and effort by not needing to individually select, evaluate, and negotiate the price for each part.

From an RF subsection standpoint, the accuracy (resolution) and the speed of a body scanner largely depends on a few key factors:

- **Frequency range** determines the penetration characteristics and available bandwidth of a scanner. Higher frequency usually means improved penetration and greater available bandwidth. Higher bandwidth translates to better resolution as more data can be transferred about the target in each frequency channel. Higher frequency systems, due to a shorter wavelength, also require smaller antennas. Therefore, for systems with many channels, several high frequency small antennas are used. Unfortunately, due to the complexity of semiconductor design, packaging, and limited integrator expertise in high frequency designs, body scanner designs that rely on very high frequencies (>60 GHz) can be very expensive or complicated to build for mass commercial applications. As a result, the majority of systems today are commonly designed using 10 GHz to 40 GHz frequencies.
- **Number of channels** translates to the amount of collective information that can be carried from multiple different sources about the target. Higher channel count usually provides increased resolution of the target and better spatial diversity of the antennas. Increasing the number of channels requires duplicating the hardware content for each channel, and that can significantly increase the size and cost of the RF subsection. A higher channel count also means that the system would require multiple high speed ADCs, which would mean further increasing the cost of the mixed-signal domain.
- **Dynamic range** of the signal chain drives the sensitivity of the body scanner system. The higher the dynamic range, the better the system's ability to detect small and concealed objects. In order to improve the dynamic range of the system, integrators typically select parts with very good linearity and a low noise figure.

Key Success Factors

The success of a system integrator or manufacturer of a millimeter wave body scanner depends on many factors beyond just the technical performance of the scanning system. In addition to a scanner's ability to detect small, concealed, and dangerous objects accurately, the system needs to operate quickly to allow use in high traffic areas, needs to be cost effective to allow mass deployment, and needs to offer competitive differentiation for business viability. As a result, the success of a body scanner manufacturer depends on the following factors:

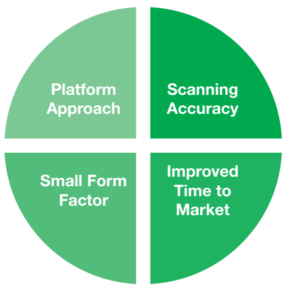

Figure 7. Key success criteria for body scanner manufacturers.

Scanning Accuracy

This is essential for body scanners to clearly distinguish between potentially dangerous and nonsignificant objects. The first generation of millimeter wave scanners was fraught with issues and had a very high false alarm rate. This caused a lot of wasted time, effort, and frustration to reassess the risk through alternate means. Increased resolution and low false alarms are generally conflicting requirements. As the resolution of a scanner increases, the probability for false alarms also increases. As a result, most system integrators work hard to find the right balance of resolution and false alarm rates. From experience, the 10 GHz to 40 GHz range provides this wideband coverage and a broad selection of low noise parts, like the ones from ADI, to provide high dynamic range. The right hardware architecture and selection of parts increases the resolution of the system. System integrators then develop advanced software algorithms to more intelligently interpret this high resolution image to correctly identifying real threats in the first scan.

Improved Time to Market

Millimeter wave body scanning market is expected to grow at a rapid pace, inviting many new entrants, so time to market is key to success and system integrators need to be able to reduce their time to market by using more integrated and modular parts from a few key suppliers. This reduces their need to individually select, evaluate, and implement each discrete part in the signal chain. Instead by using more integrated and wideband parts, companies can spend less time on hardware design and more on software differentiation. Analog Devices is the only company in the industry that offers a full signal chain solution to meet all design needs from dc to 100 GHz. Several millimeter wave system design companies rely on this portfolio to reduce their time to market.

Small Form Factor

For millimeter wave scanners to be widely used, the form factor of these scanners needs to be reduced significantly. For aesthetic reasons or for lack of space, the next generation of scanners will need to be smaller. Also, as the need for resolution increases, next-generation scanners will require many more channels, which will mean more hardware and antennas. In order to increase resolution while offering small form factors, system integrators will need to work closely with semiconductor providers like Analog Devices to develop highly integrated chipsets. Very few companies today have the expertise to develop products up to 100 GHz, offer it in package, and then integrate several functions into the same part. Analog Devices leads the industry in this high frequency integration (for example, an E-band transmit and receive SiP) and multichannel design (for example, a 24 GHz, 4-channel radar solution) that has continued to lead the market with such high frequency, integrated, and packaged parts.

Platform Approach

In order to ensure that millimeter wave scanners are not just a single generation product and can be evolved over time, system integrators need to take a platform design approach. This means integrators should select parts that offer them a path to utilize the same hardware architecture for multiple generations of full body scanning solutions. This way, every time the integrator wants to evolve the solution for improved performance, speed, or cost, they do not need to redesign every component in its signal chain.

They can do this by making the right long-term choices, such as utilizing wideband parts instead of narrowband parts. This way even if the integrator modifies the frequency plan or plans to utilize higher frequency for higher bandwidth, it does not need to find a new part. The same wideband part(s) can serve the needs for the new system.

Similarly, by using the same supplier for multiple parts, the integrators can work with the supplier to integrate multiple functions into a single chip or a single package. Analog Devices offers the industry's broadest portfolio of wideband devices and so offers a unique opportunity to continually evolve a hardware architecture without the need to redesign each time.

Lower Cost Solution

Finally, cost is an important element to ensure business viability of any scanning solution. For full body scanners to be widely usable for commercial applications beyond just airports, system integrators will need to support significantly lower price points. This puts intense pressure on their cost structures. On one hand, they need to increase the number of channels and use wider band and higher frequency parts, which increases the system cost, but on the other hand, the market demands a lower cost structure. As a result, integrators need to look for newer and more creative ways to reduce cost. The following are a few potential ways for integrators to reduce their total system cost and maximize gross margins:

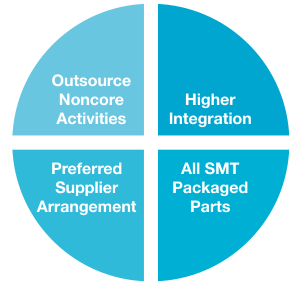

Figure 8. Ways to reduce full body scanner costs.

- **Higher integration:** By utilizing parts that integrate multiple functions into the same part, integrators can significantly reduce the number of components needed to build their signal chain. Fewer components translates to fewer parts to assemble, which means quicker assembly, smaller PCB size, and simpler design to support. In the long run this means lower cost to build and better ability to provide technical support for the scanning system.

- **All packaged parts:** By using all packaged parts, even at high frequencies, integrators will not require special assembly methods to assemble die parts. This eliminates the need for expensive assembly techniques such as chip and wire for die parts, and instead integrators can use simpler SMT package soldering. Very few semiconductor companies have the expertise today to offer high frequency packaged parts. Analog Devices is one of the only companies with proven packaging solution up to 86 GHz. Integrators should carefully select a long-term design partner that offers a range of SMT packaged products.
- **Preferred supplier arrangement:** System integrators should try to reduce the number of suppliers needed to build their overall solution. By doing this integrators can gain greater negotiating (buyer) power while leveraging economies of scale with the same supplier across multiple platforms. As a result, integrators should pick the right industry partners that can offer them the right solutions and future pathway.
- **Outsource noncore activities:** As previously discussed, the core expertise for most system integrators that develop full body scanners is the software algorithm for imagery and detection. The software algorithms drive the detection of small objects with high resolution while reducing false alarm rates. Most of the time, semiconductor hardware requirements are driven by software requirements. As a result, to best maximize each company's core functions and ensure a quicker time to market, system integrators should consider outsourcing the hardware development to companies that possess hardware expertise. This way the integrators can focus on their core functions and let the hardware experts develop the state-of-the-art hardware platform using the latest advances in technology.

With millimeter wave technology becoming more systems and solutions focused, semiconductor companies like Analog Devices offer a unique advantage with their complete signal chain solutions. By outsourcing system design, integrators can focus on their core competence and reduce their costs by eliminating noncore functions while leveraging economies of scale with one supplier.

In summary, microwave and millimeter wave full body scanners are becoming an important part of security and detection systems across the world. By leveraging the latest technological advances, making the right design choices, and establishing the best strategic partnerships, system integrators have an opportunity to differentiate their solutions.

Semiconductor companies such as Analog Devices are deeply committed to enabling the next generation of millimeter wave full body scanners and welcome the opportunity to work with the system integrators to develop a new ecosystem of more accurate, fast, and commercially viable full body scanning systems.

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