White Paper

Advances in S-Band Radar Technology
Reducing overall system cost through higher levels of integration

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I. INTRODUCTION

The S-band has long been an application space servicing both commercial and military radars. Many of the radar systems required very high peak power levels with low to medium pulse widths that were best served by silicon bipolar technology. Silicon Bipolar Junction Transistor (BJT) technology has demonstrated very high power density under pulsed conditions and established ease of use. A true measure of power density must include a very dense die delivering a very high power level in a small package footprint combined with a small matching circuit wrapped around the device. The RF power devices were biased in Class C mode of operation to maximize efficiency at maximum power with little regard for linearity which wasn't a critical factor. The small matching circuits and simple bias circuitry make the BJT devices easy to implement into complex systems [1]. The growing S-band market grew to demand wider bandwidths and higher power levels which were both well served with silicon BJT technology.

In the last few years the trend in radar systems requires longer pulse widths and some measure of linearity. A new technology was required to satisfy these advanced requirements. Although most MOSFET (Metal Oxide Semiconductor Field Effect Transistor) technologies would provide the functionality being sought, the simplest solution is a LDMOS (Laterally Diffused MOSFET) process which is silicon-based and therefore the most cost effective in a price sensitive market. Silicon LDMOS technology has many advantages including higher gain, better ruggedness [2], and is inherently more linear while running in Class AB mode of operation.

Even more recently, the market has demanded not just higher power or wider bandwidth devices, but products that reduce the design time of the complex radar systems. Due to fewer resources and more focus on system level design features, the RF portion of the system is being designed at the semiconductor vendor more and more often. Integrating several power transistors in parallel and matching the module to 50 ohms creates pallets that customers can drop-in to their systems. Combining several pallets together for any power level is straight forward and reduces the design time. Higher levels of integration have been provided by combining more than one stage cascaded together to provide a high gain pallet that offers a complete solution and eases the work load on the busy radar system design engineer.

Leveraging their long history in the S-band and RF expertise, the designers at Integra have developed another product that offers a complete 50 ohm RF power solution in a single package. Miniaturized Power Amplifiers utilizing LDMOS (MPALs) are matched to 50 ohms at the package leads and only need a bias circuit to complete the solution.

II. PRODUCT RELIABILITY

Reliability is a very important factor in many designs and is critical in markets serving commercial and military radar systems as lives are at risk. Other markets served are ISM (Industrial, Scientific and Medical) and military RF jammers which also demand the highest level of reliability. In order to maximize reliability, an all-gold process is utilized in the manufacture of all RF power devices at Integra Technologies. Gold metal is used in the construction of all lines carrying current inside the die and in connecting the die to the peripheral components such as matching capacitors and package leads. No interconnect problems are possible during wirebond assembly as the MOSCAPs and leads are all gold plated.

In these pulsed applications, the RF signal is on for a period of time and then removed from the input for a period of time. During the on-state, the full RF peak power is delivered and the full current flows through the metals of the device and wires generating heat. During the off-state the device and wires have time to cool. The extremes in temperature cause the metal to expand and contract and thus induce stress. The Coefficient of Thermal Expansion defines how much stress is induced during the billions of pulses that these devices will see over their lifetime. While Integra uses gold, many of the traditional LDMOS vendors use aluminum metals either in their die structure or in the wirebonding process. Aluminum is a hold-over from the CMOS fabs where the LDMOS vendors use to fabricate their devices. The CTE of Aluminum is more than 3 times that of gold, causing additional stress on the current carrying metals, even causing the metal wirebonds to sag as noted here [3]. While running wafers in a CMOS fab is less expensive due to the low cost of aluminum, the effect on long term reliability must be considered as others before have been warned 'you get what you pay for.'

Integra also provides ceramic packages with ceramic lids that are optimal in high power applications. Ceramic packages are also capable to be sealed hermetically. Other LDMOS products are provided in plastic packages that are not rated for the level of moisture resistance to protect against harsh environmental conditions.

III. HISTORY

The company's first customer was supplying Air Traffic Control (ATC) radars, per the FAA guidelines, to commercial airports through out the world. In order to provide a first-class solution, they needed a device to provide more than 200W from 2.7-2.9GHz with medium pulse conditions (100us pulse width and 10% duty cycle). The problem was that devices of this nature did not exist at the time as no RF power vendor could provide 200W in a single package under these specifications. Problems such as

these were looked at through some eyes as opportunities. So the original founders of Integra Technologies set out to create such a product and successfully designed a novel dual-cell layout for S-band frequencies [4]. The device demonstrated nearly twice the power than available at the time which was approximately 115W. Figure 1 shows the performance of this RF power transistor including the high gain, nearly 10dB at S-band, and high power of 200W across 200MHz of spectrum developed over ten years ago.

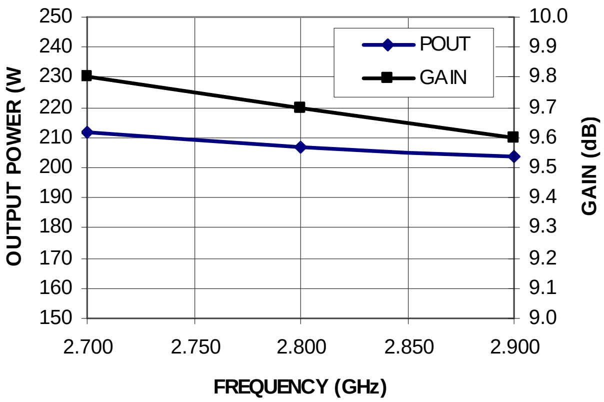

Fig. 1. IB2729S170 Performance: providing over 200W of pulsed power from 2.7 – 2.9 GHz since 1998.

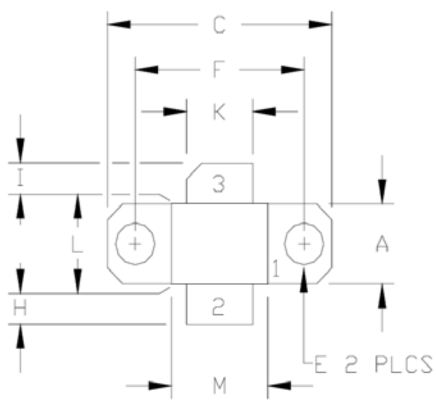

Fig. 2. IB2729S170 Package footprint. Providing 200W of power in 320 mils (Length 'M') by 250 mils (Width 'A') package.

Another unique aspect of this device was that the high power density of the die enabled the package to be much smaller than the high power devices at the time, which is still true today. Figure 2 demonstrates that the length of the package is only 320 mils compared to an industry standard package of the time that was nearly 50% bigger at 500 mils long. Even with the high gain shown in Figure 1 and the small package footprint shown in Figure 2, the device delivered a clean spectrum into a 1.5:1 VSWR load. Exhibiting this high level of stability, the pulse shape has always been considered well behaved by the customer, who still installs this radar system throughout the world today.

Expanding on this first S-band radar product, Integra today possesses more than two dozen products in their S-band portfolio [5] covering a number of frequency bands and a number of power levels in order to deliver a full line-up for a complete solution from a single vendor.

The device is housed in a physically small form factor, but this is valuable only if it translates into actual power density – that is, power per unit width including matching and biasing circuitry. A well designed transistor has low parasitic capacitance which results in higher impedances at the device leads. The higher impedances make it easier to design matching networks. The output impedances for this S-band device are over 2 ohms real with the input impedances over 3.5 ohms real. The resulting matching circuit is simple and small in area. BJT bias circuitry is known for being easy to implement: see Figure 3.

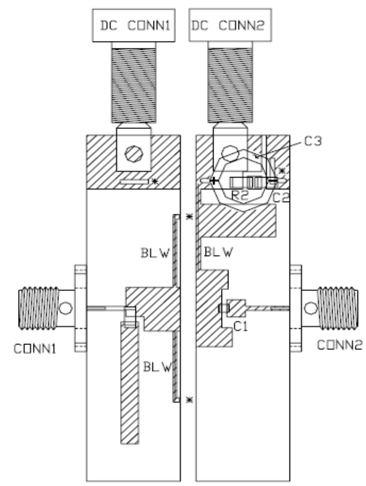

Fig. 3. IB2729S170 Test Fixture footprint. Each half of the TF evaluation board is 0.5" wide constructed on high dielectric laminate.

Part Number	Description	Output Power (W)
IB2856S30	F = 2.856 GHz PW = 12us, DC = 3%	39
IB2856S250		300
IB3000S60	F = 3.000 GHz PW = 12us, DC = 1%	73
IB3000S200		250

Table 1. ISM Product Portfolio

With short pulse width and low duty cycle requirements, the high density BJT technology is ideal for the ISM market. Medical applications at 2.856GHz and 3.0GHz are well served using bipolar technology. These applications require maximum power in the smallest space with no additional circuitry. The simple yet reliable bipolar solution offers the maximum power level in the smallest footprint.

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IV. SHIFT TO LDMOS

Recently, more and more customers have demanded new radar systems to be developed that can not be satisfied with a traditional Class C bipolar transistor line-up solution. The new radar system designs will exhibit state of the art detection and tracking range only accomplished with long pulse widths and higher duty cycles. The longer pulse widths and higher duty cycles input pulse signal conditions require a MOSFET technology. Although compound semiconductor technologies, such as GaN and GaAs, would handle the severe input conditions, a silicon solution, such as LDMOS, is preferred. LDMOS technology, based in silicon, still has price advantages over the competing technologies.

The industry shift to system level solutions based on LDMOS technology offers several advantages. LDMOS devices control the flow of current through the Drain-Source channel by a voltage on a third terminal – the gate. Biased in a Class AB mode of operation, the devices are inherently linear. Increased linearity leads to a higher dynamic range of the input to output power. The bias level can be varied to a highly linear state, Class A, at the expense of efficiency if the system demands such linearity. In radar systems, the devices are typically biased at a light Class AB to more closely resemble the highly efficient Class C designs. Additional efficiency can be achieved by pulsing the gate bias which mimics the Class C operation. Additionally, the technology has a spread geometry compared to bipolar layouts. This spreads the heat generated during normal operation over a larger area. This cooling effect reduces the droop in power across a given pulse, even under extremely long pulse conditions. Another advantage is the increased ruggedness of a LDMOS device which is typically 3:1 VSWR over all phase angles. Integra has developed a 50V LDMOS process that has shown the ability to withstand more than 10:1 VSWR without damage on devices targeted for the L-band market, as first reported at the European Microwave Week in 2008 [6] and now characterized at 20:1 VSWR for all avionics products using this technology [7].

Integra now provides devices that produce more than 150W of output power across both the lower (2.7 – 3.1GHz) and upper (3.1-3.5GHz) S-Band under industry standard radar input signal conditions as seen in Table 2. The real value in using LDMOS at S-band, however, is the long pulse capability that enables new features of the radars including enhanced range and resolution. The spread geometry of LDMOS technology is able to satisfy the long pulse requirement while maintaining high levels of performance in gain and efficiency.

Product Name	Pulse Condition PW/DC	Output Power (W)
ILD2731M30	300us/10%	37
ILD2731M140	300us/10%	160
ILD3135M30	300us/10%	36
ILD3135M120	300us/10%	154

Table 2. LMDOS Product Portfolio

Table 2 shows the ILD3135M120 which is specified to operate with medium pulse width input of 300us pulse width and 10% duty cycle. Figure 4 shows this same device operated under harsh input signal conditions with a pulse width of 4ms and a 40% duty cycle. The data shows the device produces more than 120W across the frequency of operation from 3.1-3.5GHz. It also demonstrates the ability of the technology to accommodate an input signal at near CW levels and still maintain excellent performance.

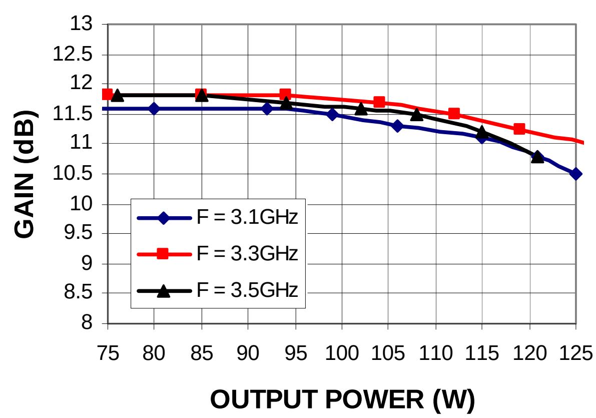

Fig. 4. Performance characteristics of the ILD3135M120 under extremely long pulse conditions. The device was tested with an input signal with pulse width = 4ms and a 40% duty cycle. The device delivers more than 120W P1dB, while providing more than 11dB of gain across the frequency band of operation in the S-Band from 3.1 – 3.5GHz.

Another device was characterized under even more extreme input signal conditions. ILD3135EL20 was tested under an extremely long pulse width of 16ms and a long duty cycle of 50%. The device delivers more than 28W of output power to the load and produces over 10dB of gain. Of course, this device provides adequate performance as a driver stage under standard pulse conditions and at the harshest input signal conditions to satisfy any application including CW type requirements.

V. Higher Levels of Integration

Recently, higher power levels are being achieved through multiple devices in parallel on a pallet. More and more of the RF portion of the entire Power Amplifier design is being shifted to the RF power semiconductor provider allowing more resources to be devoted to higher level system enhancements that offer a larger differentiator to the end user of the radar system. In order to be able to provide this level of integration, the semiconductor vendor has to be able to not only provide high power devices, but must indeed have the expertise to design the RF matching circuits and the capability to manufacture the mechanical assembly in a cost effective manner. Integra is able to provide all three levels of service and offers easy to use 50 ohm pallets.

Depending on the applications pallets can be constructed utilizing either bipolar or LDMOS technology. Some pallets combine two or more discrete devices together for higher levels of power than that achieved with single discrete devices. Figure 5 shows an example of one such module. The module is fabricated on high performance laminate dielectric material with a 10.2 dielectric constant. The high dielectric material achieves impedance transformations in a small area. The small form factor is ideal for avionic applications that go into airborne vehicles where size and, therefore, weight are high on the list of concerns.

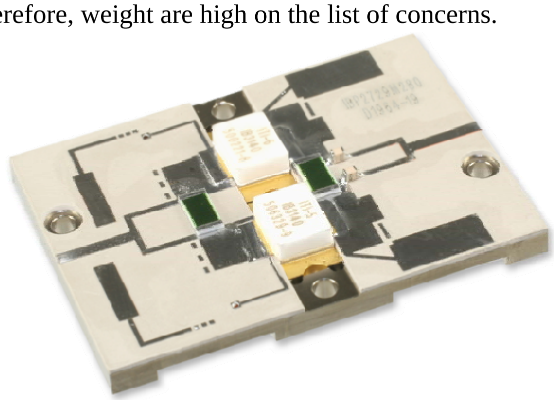

Fig. 5. Picture of a pallet combining two discrete transistors. The IBP2729M280 provides more than 300W of output power from 2700 – 2900MHz.

Another important key to a successful design is the manufacturability. For most designs, normal PCB laminate tolerances are acceptable, however, at high power levels and at such high frequencies the tight tolerances exhibited by the high dielectric laminate material are critical for repeatability performance. The full compliance tested 50 ohm modules enhance the ease of manufacturability by an order of magnitude compared to integrating high power devices onto a PCB.

Multiple stage line-ups in pallet form offer a complete solution. Even higher levels of integration can be achieved by combing several transistors together in a cascade configuration with a pre-driver stage combined with a driver stage combined with several devices in parallel comprising the output stage.

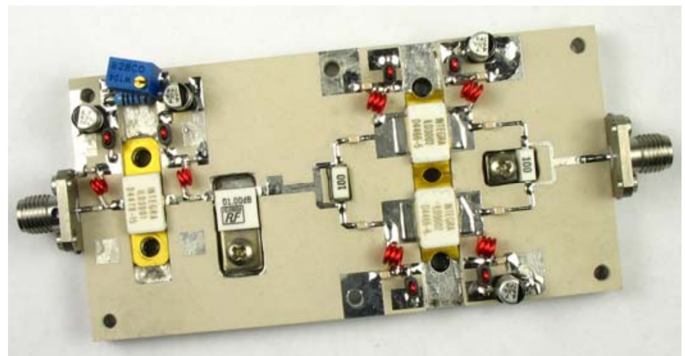

Fig. 6. Example of a multiple stage pallet. The IPAL3002 has two gain stages, produces over 20dB of gain and 50W of output power from 3.1 to 3.5 GHz frequency band.

Integra has demonstrated its technical capability to provide higher levels of integration in the form of 50 ohm modules or multi-stage, multiple combined device pallets that significantly decrease the time to market of complex RF power systems. The pallets are small and easy to work with; and from a manufacturing point of view the fully tested pallets place many of the headaches associated with RF design with the semiconductor vendor.

Table 3: High Power Pallet Portfolio

Product Name	Frequency (MHz)	Output Power (W)	Gain (dB)	Pulse width (us)	Duty Cycle (%)
IBP2729M300	2700 – 2900	>300	7.5	100	10
IBP2731M200	2700 – 3100	>200	8.7	200	10
IBP3134M25	3100 – 3400	>25	9.8	30	10
IBP2934M190	2900 – 3400	>200	7.5	100	10
IBP3134M220	3100 – 3400	>220	9.0	200	10
IBP3135M150	3100 – 3500	>150	7.5	100	10
IBP3135MH200	3100 - 3500	>225	8.5	100	10
IPAL3002	3100 - 3500	>50	22.5	16000	20

VI. HIGHER INTEGRATION THROUGH INNOVATION

Building on a long history of innovation in the S-Band and driving to higher levels of integration that the market demands, Integra has introduced a portfolio of high impedance devices matched inside the package. Matched to 50 ohms at the package leads and covering as much as 500MHz of bandwidth, these devices are self-contained miniaturized power amplifiers (MPAs). Internal to the package, the die is matched using a series of matching networks to achieve the high impedance levels.

The high level of integration almost eliminates all matching network design thus saving space, time and money. Of course, a 50 ohm line and DC bias need to be applied to the device for operation, but no additional matching elements are required. Reducing matching elements allows for better repeatability and higher reliability as there are inherently fewer parts that can vary, shift or fail.

Fig. 7. Example of a miniaturized power amplifier using LDMOS technology. The MPAL3035M30 produces more than 30W of output power from 3.0 – 3.5 GHz. The package flange is 230 mils x 800 mils.

Table 4 displays the product portfolio of the S-band MPALs and Figure 7 shows an example product. Physically small in size and housed in a 230 mil by 800 mil flanged package, the MPALs are perfect for driver applications, reducing size and weight, directly reducing the bottom line, which is always important but critical to success during these price sensitive times.

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Integrating MPAL devices into designs will open up new opportunities such as phase array radar (PAR) applications. PARs combine a very large number of devices in parallel, in some cases more than a 1000 devices, which, in a traditional design including the matching circuitry, is extremely large and prohibitively expensive. The MPAL product line will enable such applications, as it is now feasible to construct a PAR in a much smaller area without sacrificing performance.

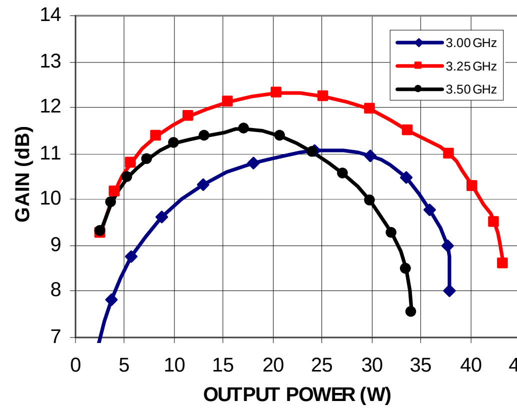

Fig. 8. Example of a miniaturized power amplifier using LDMOS technology. The MPAL3035M30 produces more than 30W of output power from 3.0 – 3.5 GHz. Operating in Class AB with 10mA of quiescent current at VDD = 32V, the devices produce more than 10dB gain and 50% efficiency. Currently characterized at medium pulse width = 300us and duty cycle of 10%, the LDMOS technology is capable of handling full CW input signal conditions.

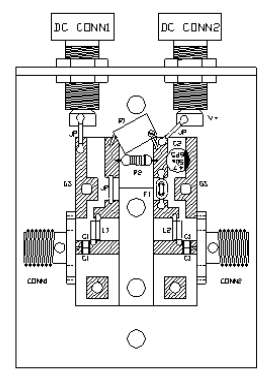

Fig. 9. Example Test Fixture for MPAL devices.

Product Name	Frequency (MHz)	Output Power (W)	Gain (dB)	IRL (dB)	OPF (dB)
MPAL2731M15	2700 – 3100	16	12.1	-12	0.5
MPAL2731M30	2700 – 3100	32	11.5	-12	0.6
MPAL3035M15	3000 – 3500	15	11.8	-14	0.7
MPAL3035M30	3000 – 3500	30	10.6	-14	1.0

Table 4: MPAL Product Portfolio

Fig. 10. Example of a high power miniaturized power amplifier using LDMOS technology. The MPAL2731M100 produces more than 110W of output power from 2.7 – 3.1 GHz.

Even more exciting are the possibilities of offering even higher power level devices that will change the way traditional high power RF line-ups are constructed. Figures 10 and 11 demonstrate an output power level device that produces more than 100W across the lower S-band frequency band. The low cost silicon solution is housed in a 10 mm x 15 mm (0.4"x 0.6") ceramic package with hybrid integrated impedance matching circuitry; this 50 ohm product is the smallest size power amplifier in the industry.

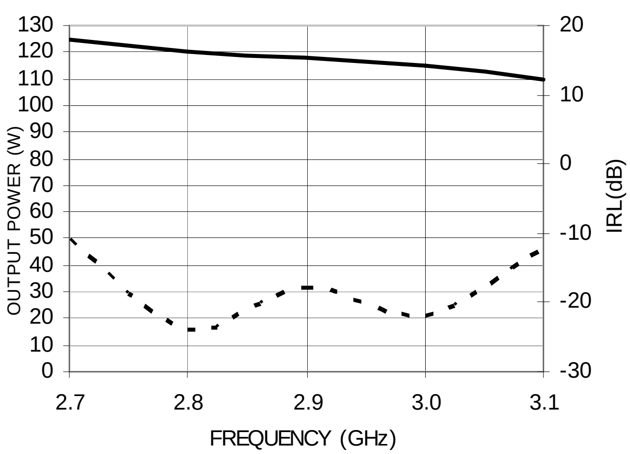

Fig. 11. Performance of the ILD2731M100 device. Biased at 32V with 25mA of quiescent current this Class AB device produces over 100W of output power with a 100us pulse width and 10% duty cycle.

VII. Summary

The advantages of BJT technology serving several markets in the S-band with small, simple, reliable products addressing the radar and ISM bands were examined. As market demands grew and required a new technology, an all-gold LDMOS process with high power ceramic packages was developed satisfying the extreme reliability and temperature swings encountered during pulsed operation.

Responding to higher levels of integration, new solutions were developed, including integrating multiple devices in parallel for higher power than discrete devices alone and cascading multiple devices together for higher gain. Additionally, miniaturized power amplifiers were developed, which will continue to reduce system size, weight and complexity, enabling a host of new applications that are unable to be served using traditional design methodologies.

VIII. Conclusion

Founded as a company that solves customer's problems, Integra Technology continues to listen and respond to the concerns in the marketplace by now shipping LDMOS products that support longer pulse widths and duty cycles including CW. The LDMOS products are designed and optimized for high power pulsed applications with higher ruggedness and an all-gold metal process for maximum reliability.

Possessing a design engineering staff with the RF expertise to design full power amplifier line-ups for all current and future S-band applications, Integra will continue to provide the highest level of service and support in the industry by providing discrete transistors, single or multiple stage pallets and 50 ohm modules using the best silicon technology that caters to the job.

Acknowledgement

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ABOUT INTEGRA TECHNOLOGIES

Integra Technologies is an ISO9001:2000 certified manufacturer of RF/Microwave power transistors, pallets, modules covering HF through C-Band. With our 150 mm (6") silicon wafer fabrication facility, equipped with sub-micron steppers in the 300 square meters Class-100 clean room, we offer Bipolar, VDMOS and LDMOS chip technologies to accommodate various application opportunities. In addition, device assembly and 100% functional testing is performed on-site using fully automated equipment.

Integra excels by providing the highest power, gain and efficiency devices available. Extensive technical support and application specific designs make Integra the preferred choice for your system. Integra's patent protected technology is intended for Broadcast, ISM, Avionics, Radar and other defense applications.

As a niche manufacturer of application specific products, Integra has been the leading supplier for over a decade to all US airport S –Band approach Radar OEMs.

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