Millimeter Wave Sub-Assemblies Enable Next Generation R&D Projects

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For those engaged in R&D of next generation products, incorporating millimeter wave components into broader designs is facilitated by partnering with established industrial experts that have already spent decades in the design, development, and testing of such systems.

Millimeter waves (30-300 GHz), a sub-set of the microwave band, are utilized to deliver pencil-beam thin, high bandwidth, wireless communications at speeds that rival fiber optics without the associated latency issues. For applications where every nanosecond counts, this can be critical.

Millimeter wave technology is also being applied to the next generation of radar systems, buoyed by quantum leaps in digital processing bandwidth and processing speed.

Whether breadboards, sub-assemblies, pre-production modules, or even through to sole source full production, doing so can significantly speed development and lower costs.

This approach is already being employed in high profile projects for the Department of Homeland Security in its current development of advanced phased array radar systems for detection of suicide bombers at stand-off distances and for one of two particle accelerators in the world to transmit course correction high speed signals ahead of speed of light.

Staying Ahead of the Speed of Light

At Brookhaven National Laboratory on Long Island, New York, millimeter waves are being used to deliver critical course correction information to sub-atomic particle beams travelling at 99.995% the speed of light in its Relativistic Heavy Ion Collider (RHIC).

The RHIC is one of two operational particle accelerators in the world. The other, the Large Hadron Collider (LHC) located near Geneva, Switzerland, is the largest ever built and recently made international news with the announcement of the discovery of the elusive Higgs boson on July 4, 2012.

The RHIC uses electromagnetic fields to circulate heavy ions in two well-defined beams travelling in opposite directions in independent beam pipes designed to intersect at four different locations.

The positively charged particles, travelling at a fraction below the speed of light, then collide with each other and the results recorded. Analysis of the byproducts of these collisions is critical to understanding quarks, the particles that make up the neutrons and protons inside the atomic nucleus   and the forces that hold the nucleus together.

The RHIC operates continuously 6 months of each year, detecting and recording approximately 50,000 collisions per second.

To keep the beams focused in the RHIC, Brookhaven National Laboratory utilizes a process known as stochastic cooling to keep the approximately 100 billion particles tightly bunched together, increasing the likelihood and intensity of collisions. The technique is estimated to increase the rate of collisions by 3-5 times.

For this to work, sophisticated electronics sense beam errors and a signal with critical correction information is sent using wireless carrier waves to a point ahead of the beam where more electronics deliver a correction “kicker.”

“The point of stochastic cooling is to significantly increase the productivity of the collider,” says Michael Brennan, a Senior Physicist at Brookhaven National Laboratory charged with electrical engineering associated with construction of the collider.

So, how can carrier waves – in this case millimeter waves – travelling the speed of light, catch up to a beam also moving at the fastest known speed in the universe?

By cheating, says Brennan.

Like an Olympic marathoner that takes shortcuts to shave off a few miles and finish with a faster time, millimeter waves are used to “cut the course” and intersect the travelling atoms. Because the microwaves travel at the speed of light and the link cuts a chord of 1/6 of the collider’s circumference, the feedback signals arrive in time for beam correction.

According to Brennan, stochastic cooling had never been implemented before on an ion collider, including the LHC.

“We weren’t able to build from existing designs or established principles,” explains Brennan. “This project required several years of R&D experimentation to prove the concept was viable before we actually created an operational system.”

In early 2006, Brennan began investigating technologies that could deliver point-to-point communications between the beam sensors and the kickers. Believing in the potential of microwave band transmission, he searched the Internet and followed up with on-site visits to find an industrial partner with the background and product development experience to collaborate on the project.

His search eventually led him to **Renaissance Electronics and Communications** and its subsidiary **HXI**. Since 1991, **REC/HXI** has provided RF, microwave and millimeter wave components, sub-assemblies, integrated assemblies, and sub-systems for military and commercial applications.

The millimeter wave link that **Renaissance Electronics** created for the project was unique, even for them.

Most of the company’s products are designed to meet the needs of the digital age. However, in this case, standard signal processing techniques would consume precious nanoseconds and slow the arrival of the signal to an unviable level. As a result, the communications link had to deliver analog information.

Renaissance Electronics’ engineers were able to convert an existing digital communications link product to analog, at 5-9 GHz, along with other required hardware modifications. The result was a completely customized system in the 70GHz light-licensed millimeter wave band that met the needs of the RHIC, delivered in a matter of months.

The initial tests of the analog link during operation indicated that it more than doubled the luminosity of heavy ion collisions. “It worked flawlessly,” says Brennan, adding that the planned future upgrade of the LHC may include stochastic cooling assisted by millimeter wave wireless.

In opting for a millimeter wave solution, Brennan estimates that Brookhaven National Laboratory saved a significant amount of money over the other alternative – lasers. Due to attenuation caused by atmospheric conditions, a laser-based system would require building a tunnel and sending the laser through an evacuated vacuum tube at great cost.

“The millimeter wave link was very cost effective despite being a custom product,” says Brennan. “It was a huge savings, because any other solution would have cost a million dollars more.”

Millimeter Wave Radar Systems

As early as 1992, **REC/HXI** (then known as the Harmonix Corp.) developed and marketed one of its first millimeter wave products, a 60 GHz hand-held, concealed weapon detector developed for law-enforcement personnel.

The hand-held detector utilized millimeter wave radar to allow law enforcement personnel to scan a suspect for concealed weapons at several meters of stand-off distance prior to “pat-down,” the most dangerous action for a police officer.

Although sophisticated for the time, range resolution was limited and false alarms occurred. Still, the detection rate was high for metal objects hidden under clothing, the cost was low, and police officers liked the product.

Today, these early attempts at detecting weapons concealed under clothing at a distance using millimeter wave technology appear archaic when compared to the next generation systems being created under the guidance and supervision of the Department of Homeland Security.

In 2008, a $12 million grant from the Department of Homeland Security established the ALERT (Awareness and Localization of Explosives Related Threats) Center at Northeastern University, a partnership of academic, industrial and government entities.

As part of its mandate, the ALERT Center is developing advanced phased array radar systems designed to detect a bomb-toting terrorist at a distance of 50 meters or more in large crowds. The technology could be used to spot suicide bombers or terrorists like the Boston Marathon duo that carried improvised pressure cooker devices in backpacks and left them to detonate in crowded areas.

Person-borne improvised explosive devices (IEDs) are often shaped from a variety of metals and concealed under clothing so are extremely difficult to detect. With a typical blast ratio of 50 meters or more, close-up detection methods such as airport-style scanning booths and pat-downs are of limited value, given that detonation would still claim many innocent victims.

The concept currently in development involves multiple radar units that can be pointed in the direction of crowds of people that are approaching a venue, checkpoint, or other area of entry.

The system would scan each individual at a distance of 50 meters or more to identify anyone that appears to be dressed normally, but are concealing IEDs strapped to their chest or limbs.

Fulfilling the need for detection in large gathering areas, such as concerts in the park, parades, political rallies, protests, and sporting events, the equipment is designed to be mounted to a van or truck for wide-ranging field use. Permanently mounted solutions would also be available for high security buildings, checkpoints or border crossings.

“For the suicide bomber problem we need a high performance radar system that can send out very specific types of signals a half a football field away and identify specific features under clothing,” says Carey Rappaport, Distinguished Professor of Electrical and Computer Engineering at Northeastern University.

In early research, the ALERT Center successful demonstrated the viability of millimeter wave radar, coupled with advanced synthetic aperature radar processing techniques.

The next phase required development of a complete radar sensor, one that involved a number of components including multiple millimeter wave transmitters, receivers and antennas.

According to Rappaport, **HXI** developed and provided all the necessary “proof-of-principle” radar modules for the project.

The project has since moved beyond breadboard testing to pre-production hardware expected to be trialed in early 2014.

REC/HXI is delivering minituarized versions of its 70-77 GHz multi-static radar modules. The modules deliver superior RF performance, despite a significant descrease in size compared to the breadboards. The receive module, for example, measures only 2.2 cubic inches (a 65:1 volume reduction compared to breadboard); the transmitter 6.1 cubic inches (24:1 volume reduction) and the larger LO module at 118 cubic inches (7:1 volume reduction).

The modules not only reduce the overall weight of the system, but represent an order-of-magnitude reduction in cost.

Rappaport explains that the completed system would not be able to take high resolution images such as those produced by security scanners at airports due to the distance, nor does it capture a 360 degree field of view.

However, through sophisticated signal processing, the system would be able to collect enough information in the radar signal to delineate an object that doesn't meet the smooth contours and characteristics of skin, for example, is metallic, or otherwise meets the characteristics of person-borne IEDs.

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