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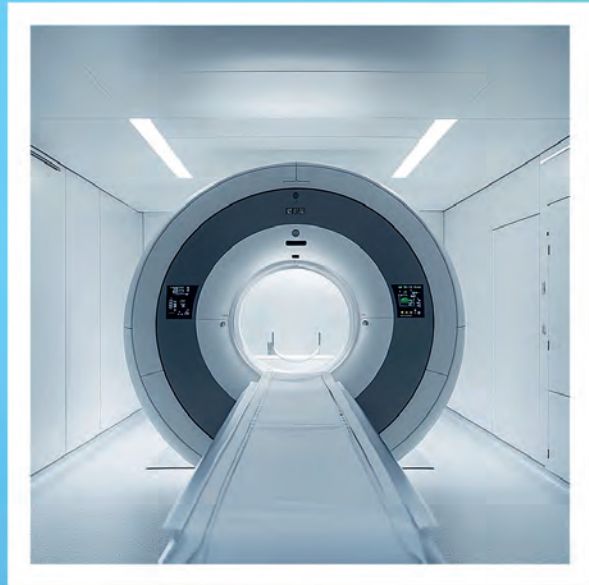
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IN THIS ISSUE:

- Medical electronics
- Power management
- RF and microwave
- Internet of Things

Regular columns:

- Focus: Neoclouds
- Embedded design
- Silicon systems design



DUAGON

Powering up THz systems with injection-locked amplifiers

By Greg Rankin, US-based technology writer

For decades the terahertz (THz) region of the electromagnetic spectrum (roughly 300GHz-3THz) has intrigued researchers with its potential to enable faster wireless communications, ultra-high-resolution spectroscopy and more precise sensing. Yet, despite a solid understanding of the underlying physics, real-world THz systems have remained elusive. A major challenge has been the lack of THz sources capable of delivering both the output power and spectral purity required for practical applications.

That may be starting to change. Researchers at IMRA America have demonstrated a new THz source architecture that overcomes several long-standing limitations. By combining a resonant tunneling diode (RTD), a photomixed dual-wavelength Brillouin laser and a low-loss waveguide circulator, the team achieved gain over 40dB at 260GHz; see their setup in Figure 1.

Just as importantly, these researchers became the first to characterise the residual phase noise of an injection-locked RTD at this frequency, providing

new insight into how high-power, low-noise THz oscillators can be built and scaled.

Although this is only a proof of principle, this architecture shows a clear path to combining power and spectral

purity at terahertz frequencies, which makes practical THz systems possible.

From diode to THz oscillator

As shown in Figure 2, at the heart of the system is the RTD: a well-established

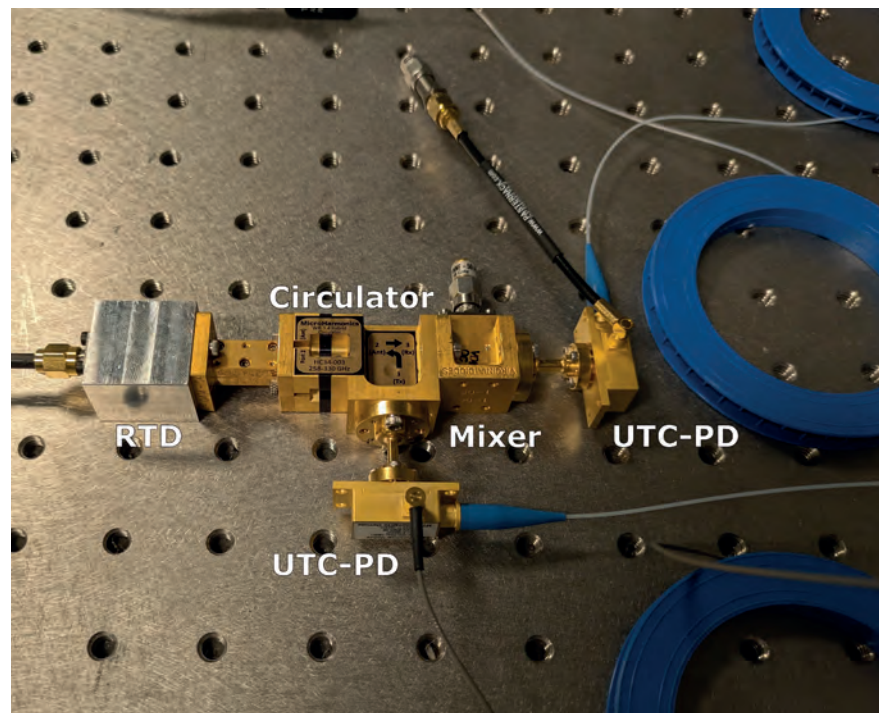


Figure 1: IMRA RTD Setup

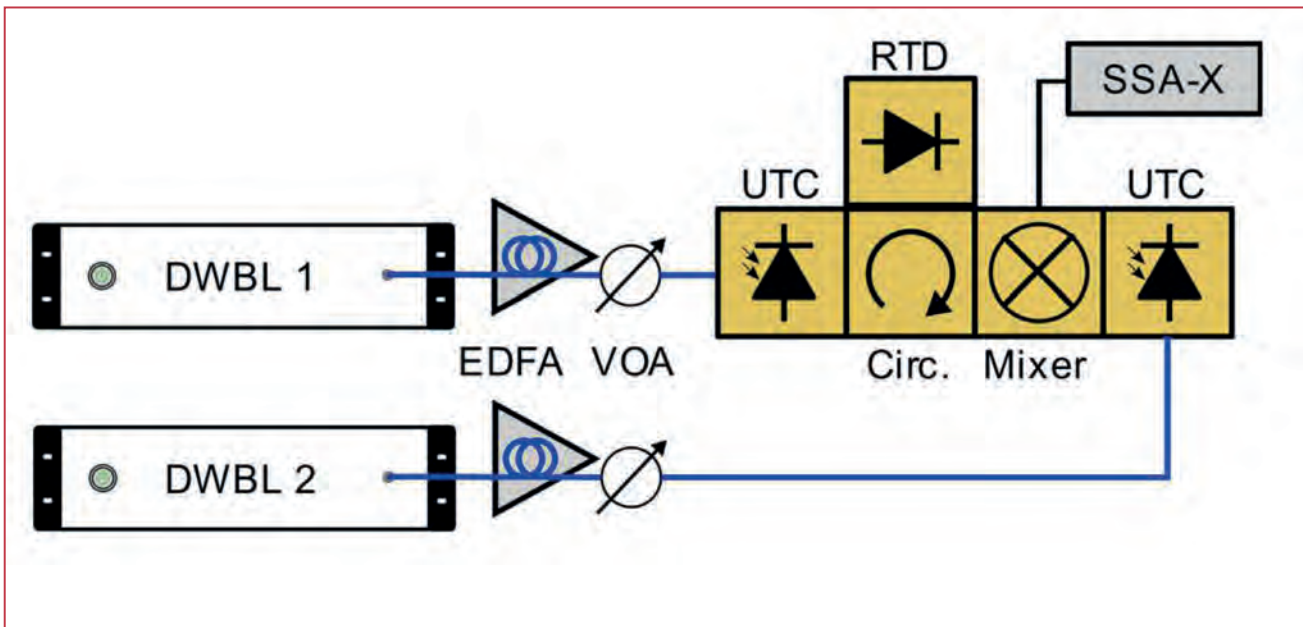


Figure 2: A schematic diagram of RTD injection setup and phase noise measurement

semiconductor device that, when properly biased, can generate radiation in the THz range.

RTDs are like the laser diodes of the terahertz world: They convert electric current directly into high-frequency radiation and, because they're chip-scale, efficient and fabricated with standard semiconductor processes, they're inherently scaleable. They offer advantages in size, efficiency and integration potential. However, historically they have struggled with spectral purity. Their output linewidths, often several megahertz, have limited their use in applications that require narrow frequency resolution. These include rotational spectroscopy, high-precision sensing, or next-generation wireless links where clean carrier signals are critical.

Injection-locked amplifier in waveguide

To overcome the RTD's limitations in spectral purity, the IMRA team turned to a technique known as "injection locking", which enables a lower-purity oscillator to synchronise with a higher-quality reference. In this case, that reference is a dual-wavelength Brillouin laser that's

photomixed to generate a stable THz tone with exceptionally low phase noise.

The study emphasises that the concept of injection locking is not new, but it is the way the IMRA researchers utilised it that makes it novel. Most previous demonstrations relied on quasi-optical free-space setups. Those introduce significant power loss, alignment sensitivity and are hard to scale.

The photomixed signal was injected into the RTD, which re-radiated the same frequency but at significantly higher power, functioning as a THz amplifier. This allowed the IMRA team to combine the low noise of the laser with the high output power of the RTD.

A hybrid THz circulator

What made this system practical wasn't just the injection method, but the physical implementation. The entire signal chain – source, amplifier and diagnostics – was built with waveguide components. That architecture reduced insertion loss, preserved signal integrity and delivered stable, repeatable performance. Just as critically, it enabled clean isolation between components, preventing unwanted reflections that can degrade spectral purity or disrupt the injection

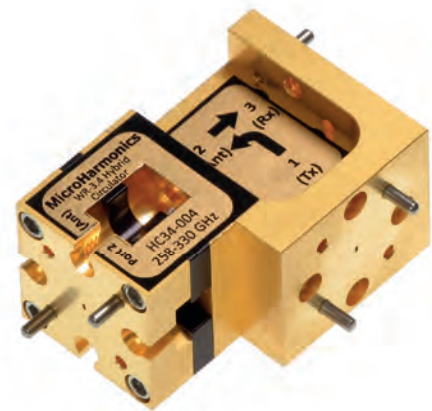


Figure 3: The patent-pending hybrid circulator, HC34 by Micro Harmonics is designed for wideband millimeter wave applications

lock. IMRA was the first to do this in a waveguide. That is because in free-space set-ups, the losses are so high that it makes it nearly impossible to demonstrate amplification. However, with a new THz circulator, IMRA was able to show gain of 40dB, which was unprecedented at such frequencies.

Traditional Y-junction circulators aren't viable at most MMW and sub-THz frequencies primarily due to

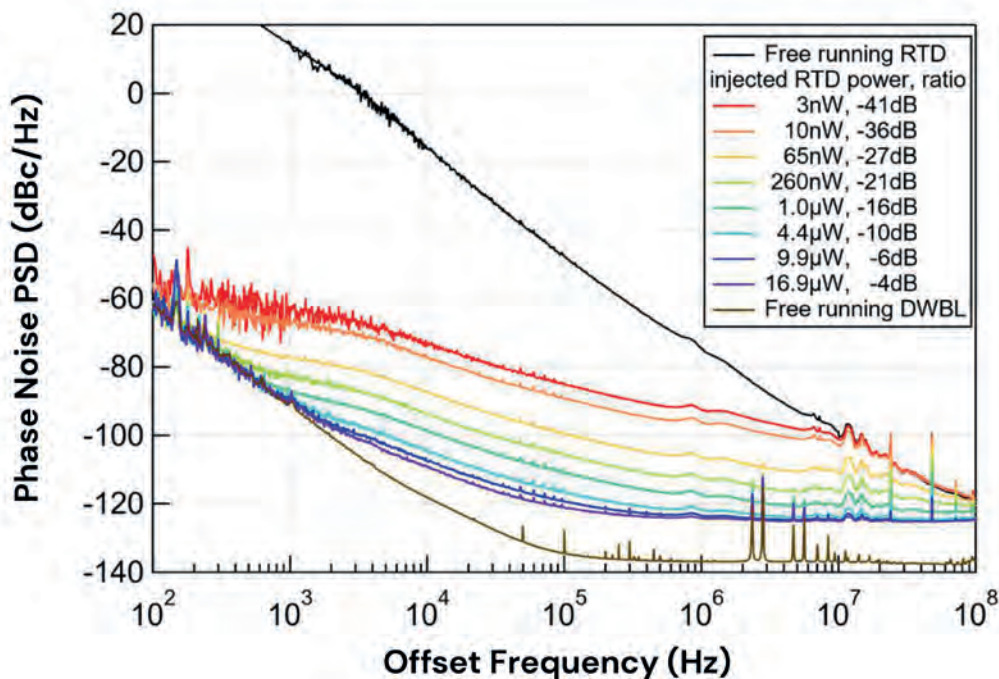


Figure 4: Phase noise power spectral densities (PSD) for the free running RTD (top trace), DWBL (bottom trace) and injected RTD and several injection powers

extremely narrow bandwidths, stringent manufacturing tolerances and material limitations.

The broadband hybrid circulator IMRA applied was developed by Micro Harmonics; see Figure 3. The design combines a Faraday rotator with an orthomode transducer (OMT): both components are inherently broadband and, when properly configured, enable low-loss signal routing across the entire band.

Beyond 260GHz

Although the proof of concept centred on 260GHz, the IMRA team states that the architecture is scalable to 1THz and beyond. Fundamentally, nothing limits the research to 260GHz. The RTD, the photomixed source and the waveguide infrastructure can all support operation well above that frequency. If a 1THz circulator existed today, IMRA could run the same experiment at 1THz.

The RTD itself, fabricated by Rohm Semiconductor, spans a tuning range of 240-260GHz and produces up to 40µW of power in free-running mode. Once injection locked, the team achieved a

spectral linewidth narrowing from 5MHz to below 1Hz, enabling precise control over the frequency output.

This kind of tunability is vital for real-time signal processing and opens up architectures like tracking oscillators, where noisy or drifting signals can be amplified, filtered and stabilised inside the same waveguide loop.

First-ever residual phase noise characterisation

In addition to demonstrating signal amplification, the IMRA team performed the first ever residual phase noise characterisation of an injection-locked RTD at THz frequencies.

The results confirmed key trade-offs between gain and bandwidth; see Figure 4. As injection power increased, the phase noise dropped by up to 90dB at 100Hz offset. But the effective locking range narrowed accordingly. The study quantifies this behaviour using theoretical modelling based on the Adler-type injection locking and the oscillator's quality factor ($Q \approx 165$).

This level of detail enables researchers

to treat the RTD amplifier as a “resonant amplifier”, one that is narrowband but extremely quiet within its range.

Why it matters

Reliable THz sources have applications across a wide range of industries. In wireless communications, they can unlock ultra-high-speed links or reduce congestion via parallel channelisation. In sensing, they're essential for rotational spectroscopy, molecular clocks and narrow linewidth radar.

Until now, the tools to generate these signals, with both high power and low noise, have been lacking. This shows that with the right architecture, researchers can have both.

Looking forward, the IMRA team is exploring ways to push the technology even further via RTD arrays, integrated amplifier designs and extended frequency operation.

As high-frequency systems inch closer to mainstream adoption – especially in the context of 6G, compact atomic clocks, or THz imaging – the ability to produce clean, tunable and powerful THz signals will be essential.

With this work, IMRA has provided a concrete step in that direction. **EW**