The article titled " Enabling Extreme Mobile Broadband and Wireless Fiber " was published on August 15, 2024, in the world's most renowned wireless technology journal, **Microwave Journal**. This article discusses that the future development of technology is driven by two key forces: computing power and the transmission capacity of wireless information. Internationally, two leading companies are at the forefront: Nvidia has enhanced computing power, propelling the advancement of AI, while **Swiftlink** has increased wireless transmission capacity, promoting the LEO integrated 5G/6G and the Internet of Everything (IOE) and Ai.

Microwave Journal

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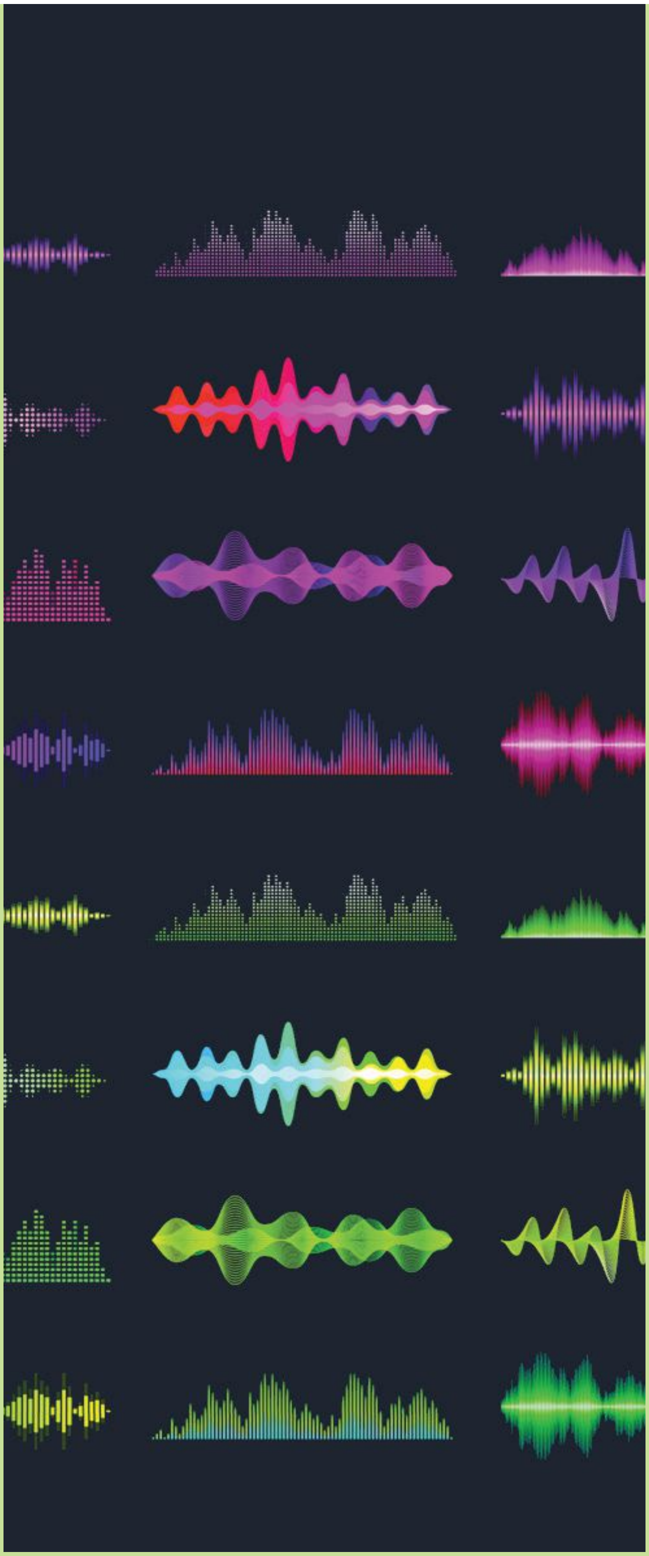

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Enabling Extreme Mobile Broadband and Wireless Fiber

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Over the past several years, companies have been developing technology to enhance data transmission capacity through the advancement of what the 5G vision called "Extreme Mobile Broadband" (EMB). At SwiftLink, this effort has spanned eight years and the result has been advances in chip technology and the development of phased array antenna beamformers. This article describes the efforts that have gone into the EMB beamformer solutions.

These EMB beamformers are designed to support a wide range of frequencies, encompassing all the bands used in low Earth orbit (LEO) satellite communications and the upcoming 5.5G/6G cellular networks. They are compatible with a diverse array of devices and demonstrate the capability to deliver high speed data transmission. With this wideband solution, the concept of the "Internet of Everything" (IoE) is closer to realization. As illustrated in the diagram in ***Figure 1***, there is a benefit to connecting everything through a combination of non-terrestrial and terrestrial network resources. The EMB chip signifies a pivotal step towards the realization of this vision of the IoE and more ubiquitous global connectivity. By facilitating seamless wireless connectivity and integrating fiber-like speeds into wireless infrastructure, users are on the brink of an era where every device connects with unprecedented efficiency and reliability. The dream of a fully wireless world, where every interaction and transaction can occur instantaneously and without physical constraints, is on the horizon.

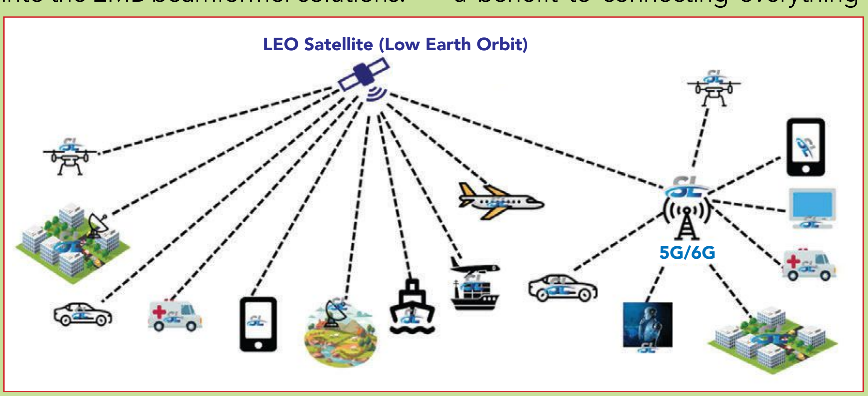


Fig. 1 **Universal network connecting LEO satellites and 5.5G/6G devices.**

These EMB chips operate at mmWave frequencies to provide full compatibility with non-terrestrial LEO communications networks and the emerging 5.5G terrestrial network infrastructure. This combined frequency range of 24 to 44 GHz has 20 GHz of bandwidth at mmWave frequencies. The EMB chiplet solution envisions extending coverage and network interconnectivity to 6G and satellite communications at even more mmWave communication frequency bands.

MMWAVE SOLUTIONS

Every step in the evolution of mobile technology is driven by solving consumer problems. The problem comes first and technologists target these problems by creating innovative solutions. It is the role of the industry to drive down the cost of technology solutions so they are accessible to more consumers. The massive transmission capacity and capabilities bring unprecedented experiences to the consumers and it is these experiences that service providers are looking to monetize. This massive transmission capacity will lead to a great upheaval of communication technologies, providing opportunities such as Tbps peak data rates, Gbps user experience data rates, millisecond latency, centimeter positioning accuracy and millions of connections per square kilometer.

mmWave technology harnesses high frequencies to revolutionize communication. Communications at these higher frequency bands deliver data transmission speeds that are exponentially higher than those of 4G networks. However, to enable interconnectivity for terrestrial networks typically operating below 6 GHz with LEO networks that may operate into Ka-Band, operating with a bandwidth of more than 20 GHz is necessary.

The adoption of mmWave technology represents a significant leap forward in the telecommunications industry, offering a robust solution that meets the burgeoning demand for high speed, high-capacity communication networks. As users transition into the 5.5G era, innovations in the industry must ensure that users and networks are well-equipped to handle the ever-increasing data requirements of a hyper-connected world. It is also worth noting that the upcoming 6G wireless communication networks are looking to incorporate the benefits of mmWave frequencies while also considering the balance with deployment, coverage and capacity issues. THz technology and frequencies, the future of information transmission, are expected to provide even higher data transmission rates than mmWaves, laying the technical foundation for 6G networks. Furthermore, the mmWave/THz bands are envisioned to provide fiber-like bandwidth over a wireless link. The SwiftLink EMB single-chip solution can receive mmWave signals from a phased array antenna feed and then down-convert those signals to IF frequencies that will drive the IF modem. Since these ICs can down-convert mmWave frequencies across the 20 GHz bandwidth from 24 to 44 GHz, using a single device, system providers only need one chip and one antenna array to meet universal deployment requirements in 5.5G/6G and satellite communication networks.

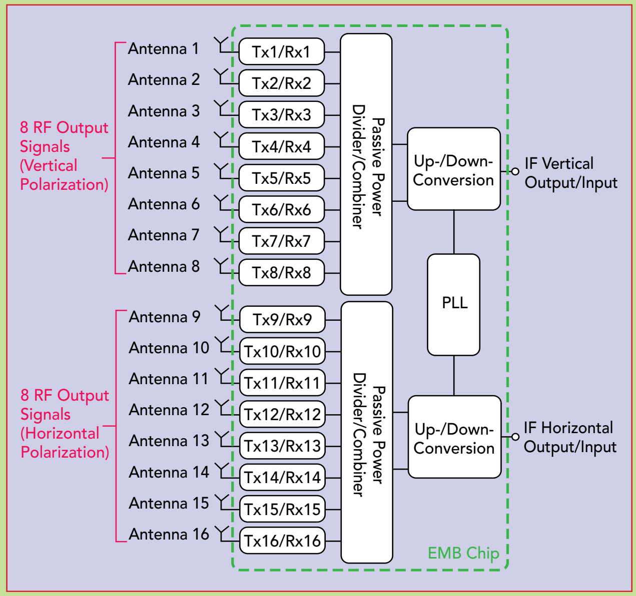


Fig. 2 **Block diagram of EMB beamformer.**

Figure 2 shows a block diagram of the EMB beamformer configured with a 16-element antenna array. Each antenna element connects to a transmit/receive (Tx/Rx) channel. These channels couple to one of two passive power dividers/combiners and they are followed by an up-/down-conversion (UDC) block. In transmit mode, the IF input signal enters the UDC, where the signal is up-converted to RF frequency for transmission in the Tx/Rx channels. The Tx/Rx channels amplify and shift the phase of the RF signals that will be transmitted from the antennas. In receive mode, the antennas collect the RF signals and the Tx/Rx stages amplify and phase shift the signal for IF down-conversion in the UDC.

The EMB chips that realize these functions are fabricated using the GlobalFoundries GF 45RFSOI process, a 45 nm RFSOI CMOS node. This process improves the transistor performance capabilities at mmWave frequencies and it is a mature process with high production wafer yields. This is important because the Tx/Rx channel performance largely dictates the beamformer capability and cost is always a concern. ***Figure 3*** shows a block diagram of the Tx/Rx channel.

As Figure 3 shows, the phased array antenna element feeds the input Tx/Rx switch. In receive mode, the LNA amplifies the mmWave signal received by the antenna. The LNA

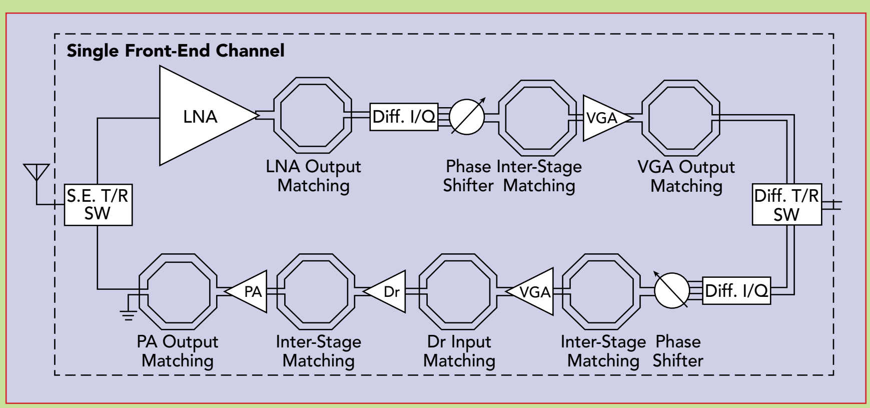


Fig. 3 **EMB beamformer chip Tx/Rx channel block diagram.**

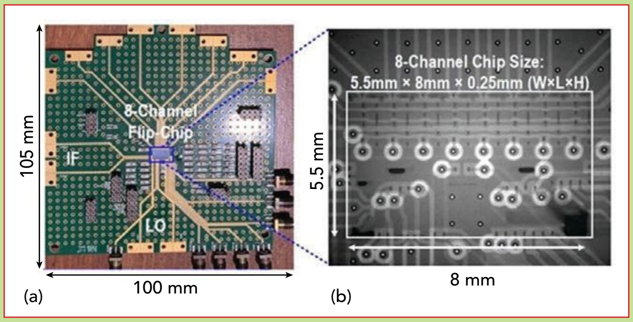


Fig. 4 **(a) 8-channel EMB chip on test board and (b) chip X-ray.**

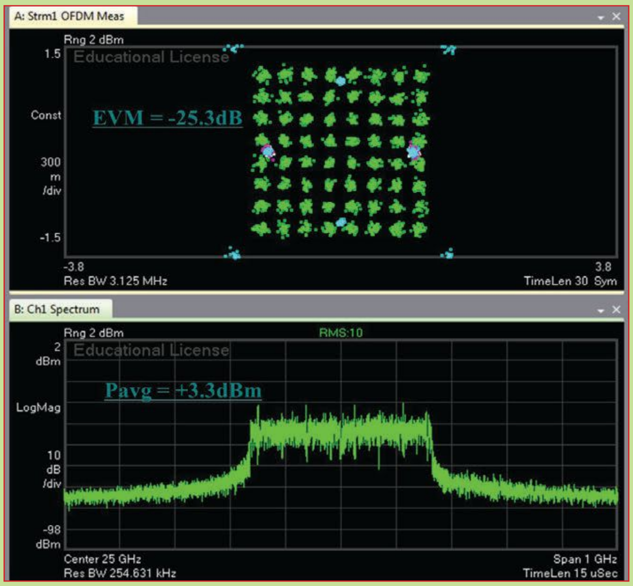


Fig. 5 **EVM results for the EMB Tx/Rx channel at 25 GHz.**

drives a differential I/Q section that feeds a phase shifter. After the signal is phase-shifted, it is amplified by a variable gain amplifier (VGA). Matching for the LNA and VGA is accomplished with on-chip circuit elements. The output matching network of the VGA connects to an output Tx/Rx switch that directs the received signal to the processing circuitry.

In transmit mode, the Tx/Rx switch routes the modulated signal from the processing circuitry to a phase shifter. Since the transmit power is substantially higher than the receive power, the output of the phase shifter will go through several stages of amplification. In the EMB beamformer chip design, this lineup includes a VGA that feeds a driver amplifier (DR) and, finally, a power amplifier (PA). Again, all the amplifiers are matched using on-chip circuit elements. The PA is the final amplification stage to ensure that the transmit signal to the antenna element is at the required levels. For both the receive and transmit signals, the phase shifters are essential to array beam steering, making this a vital function in the beamformer operation. ***Figure 4*** shows the eight-channel EMB chip mounted in a flip-chip configuration on a connectorized 105 × 100 × 5 mm evaluation board in Figure 4a and an X-ray photograph of the 5.5 × 8 × 0.25 mm eight-channel chip in Figure 4b.

TABLE 1

TX/RX PERFORMANCE SUMMARY

	Measurement Frequency (GHz)			
Parameter	25	28	37	40
Tx $OP1_{dB}$ (dBm)	+16.9	+16.5	+16.7	+16.0
Tx PA + SW efficiency at $OP1_{dB}$ (%)	23.1	23.7	24.2	22.0
Tx total DC power draw (mW)	345	304	333	300
Rx conversion gain (dB)	31.8	34.8	33.5	33.6
Rx noise figure (dB)	7.3	5.3	5.9	7.0
Rx $IP1_{dB}$ (highest gain) (dBm)	-24.3	-25.3	-26.7	-26.6
Image rejection ratio (IRR) (dB)	> 30	> 30	> 30	> 30

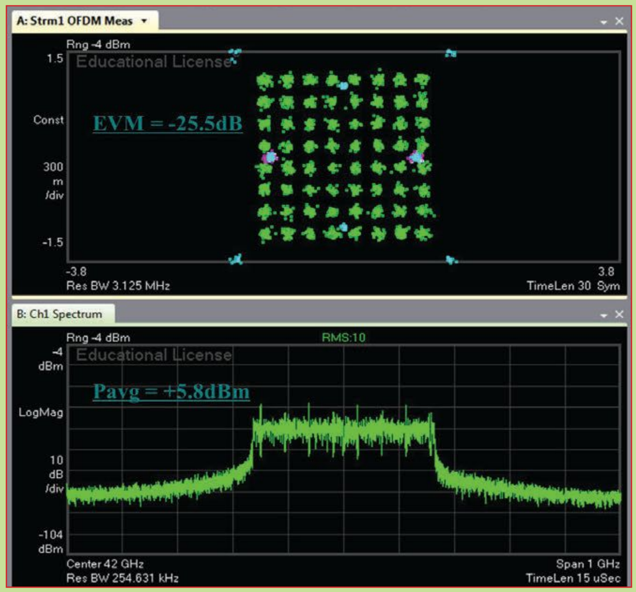
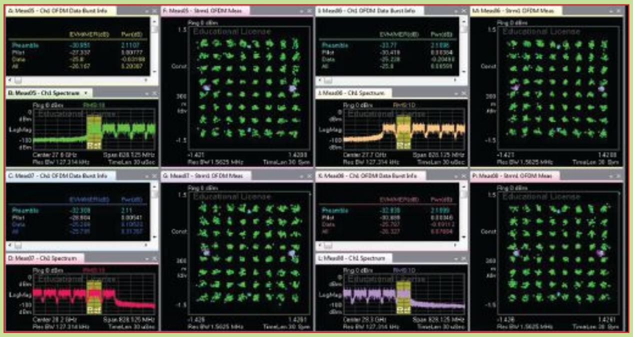


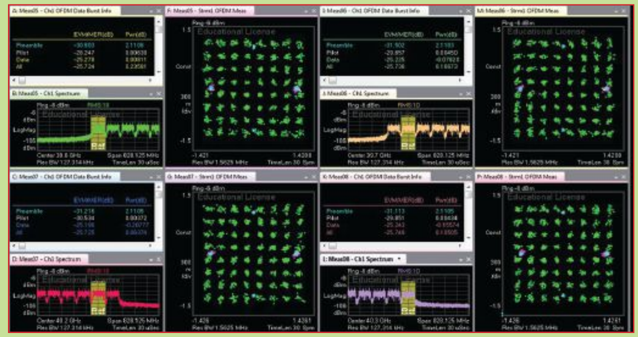
Fig. 6 **EVM results for the EMB Tx/Rx channel at 42 GHz.**

While the architecture is relatively common, what differentiates this development from competitive solutions is the 20 GHz bandwidth over the 24 to 44 GHz frequency range. This result is possible because great care has been taken to ensure that each functional block of the Tx/Rx channel shown in Figure 3 achieves the necessary 20 GHz operation bandwidth at the frequencies of interest. ***Table 1*** shows typical RF measurement results for the Tx/Rx channel.

As Table 1 shows, the transmitter output P_{1dB} is greater than +16 dBm across a broad frequency range. In addition to an output power level, emerging wireless modulation schemes require that the transmit channel deliver a high-fidelity, wideband-modulated output signal while maintaining sufficient average output RF power. ***Figure 5*** shows measurement results for error vector magnitude (EVM) and transmitter output power when transmitting a 400 MHz bandwidth signal with a 64-QAM OFDM modulation scheme at an RF carrier frequency centered around 25 GHz. ***Figure 6*** shows the results from the same set of test conditions for the



▲ Fig. 7 Measured 8-CCA results for the EMB chip at 28 GHz.



▲ Fig. 8 Measured 8-CCA results for the EMB chip at 40 GHz.

64-QAM signal centered at 42 GHz.

Part of the reason that operators are going into the mmWave and THz bands is to increase bandwidth, which translates to higher data rates and capacity. A common technique to get more bandwidth is to aggregate several smaller channels. ***Figure 7*** shows that the EMB chip will support this architecture. The results in Figure 7 show EVM and transmitter output power results when transmitting a 100 MHz bandwidth signal using a 64-QAM OFDM modulation scheme with an eight-component carrier aggregation (8-CCA) at an RF carrier frequency centered at 28 GHz. ***Figure 8*** shows the same measured data set for an RF carrier centered at 40 GHz. In terms of receiver performance, ***Figure 9*** shows measured constellation and spectral results with the concurrent wideband-modulated 64-QAM image signals at various power levels.

The EMB receiver is tested with concurrent wideband-modulated 64-/256-QAM image signals over a range of power levels and frequency spacings. The result is a reduction in EVM on the demodulated desired signal. This is attributable to a diminished SNR and an expanded spectral overlap.[1-2] Despite these conditions, the desired signal exhibits a clear constellation and is successfully demodulated for 6/12 Gbps, 64-QAM signals with EVM results of -32.56 dB and -27.6 dB, respectively. For an 8 Gbps, 256-QAM signal, the EVM is -33.47 dB. These measurements show a decrease from the -35.14 dB, -30.48 dB and -35.1 dB EVM values for 6/12 Gbps, 64-QAM and 8 Gbps 256-QAM signals when only the desired signal is taken into account.[1-2] As shown in Figure 9, when only the desired signal is applied to the receiver input, the result is an 18 Gbps, 64-QAM signal with an EVM value of -26.65 dB.

Systems that support high data transmission rates will enable many exciting applications that will benefit from mmWave and THz frequency bands. For example, metauniverses and the tactile internet can usher in a more immersive and intense user experience, including holographic communication. Users will be able to touch and see friends remotely in real-time as they appear in three dimensions in front of them. The advent of THz bands and mmWave capabilities makes such disruptive experiences possible.

INTEGRATING SATCOM AND THE TERRESTRIAL NETWORK

Satellite communications have been used for decades in maritime and in-flight connectivity applications. Emerging LEO constellations are revolutionizing connectivity opportunities with lower latency and lower transmit power capabilities and requirements. These satcom systems are becoming pivotal for global communication since their large geographic footprints provide options to counter terrestrial network constraints. Satellite networks can function as space-based relay stations for various data types across multiple frequency bands, including Ka- and V-Band. Satcom system architecture includes the space segment (satellites with transponders), the ground segment (Earth stations) and the user segment (end-users with satellite terminals). Technological advancements such as high-throughput satellites and LEO constellations are being developed to meet the demands for increased data rates and enhanced reliability. Like terrestrial communications, satcom systems are venturing into higher frequency mmWave bands and advanced transceiver and antenna technology, along with more sophisticated signal processing techniques to address channel capacity and speed challenges. Currently, these services require a separate user terminal. While the industry is starting to see the emergence of direct-to-satellite mobile connectivity, data rates for these connections are low. Receivers operating at mmWave frequencies with integral beamformers, like those being developed by SwiftLink and others, could enable future mobile phones to link to satellites.

The integration of 5.5G and artificial intelligence (AI)-driven management brightens the future of satcom. These emerging techniques are poised to enhance spectrum utilization and system performance. This will cement the role of satcom as a foundational element of connectivity, supporting applications from emergency response to universal internet access and affirming its leadership in communication technology.

COMPUTING POWER AND INFORMATION CAPACITY WILL REVOLUTIONIZE THE FUTURE

Consumer wants drive data traffic needs and, ultimately, wireless technology. First voice, then data, then the internet and now video. The next application that will drive data traffic and bandwidth demand is AI. AI promises many new applications and capabilities, from real-time language translation to real-time image analysis. Most of AI's capabilities require high performance computing power in specialized AI data centers using AI chips from companies like NVIDIA and specialized AI software. The processing and computing capabilities required for AI are currently beyond the capabilities of mobile phone processors. To provide users with seamless, real-time AI functionality, networks must handle the data and compute needs of AI. This requires the data speeds of optical communication links or enhanced wireless networks enabled by mmWave and THz technologies.

In the digital era, computing power and information transmission capacity are the fundamental forces propelling technological advancement. By heading into mmWave frequency bands, with 20 GHz of bandwidth and doing this on a workhorse RF CMOS process, version 1 of the EMB chip extends the capabilities of traditional 5G bands and enables new ones. These activities adhere

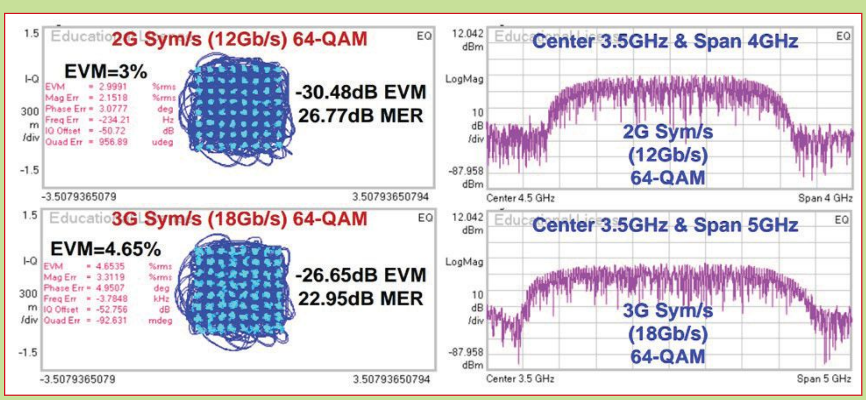


Fig. 9 Measured constellation and spectral data for the EMB chip.

to ITU standards while also pushing boundaries by dramatically increasing the expected transmission speeds up to 18 Gbps. This increase in performance not only enhances wireless data transmission infrastructure capabilities it also has implications for emerging AI applications.

AI processing relies on enormous amounts of data and can benefit from these advancements in transmission capacity. Increasing data transmission capabilities benefit AI processor operations by facilitating a more robust and seamless flow of data. This is essential for training complex neural networks and deploying AI solutions at scale. Improving the wireless pathway to help carry the high data traffic of AI systems will enable real-time analytics and decision-making processes that are crucial for the next generation of AI applications. These technologies and capabilities are set to be the foundation of the architecture of tomorrow's digital landscape. The fusion of wireless high speed data transmission with advanced computing power is set to unlock new horizons in AI development, driving the world to a future where the potential of AI can be fully realized.

The leap in computing power is the outcome of several important innovations: CMOS transistor scaling, the collaborative evolution of the CPU and GPU, the multicore revolution and heterogeneous computing in CPUs and the evolution of GPU for general-purpose computing. Advancements in multicore technology and heterogeneous computing are making CPUs more efficient in processing complex tasks. Initially designed for graphics rendering, GPUs have become vital in general-purpose computing due to their powerful parallel-processing capabilities, playing crucial roles in deep learning and scientific computing.

CMOS transistor scaling has also been significant in the information transmission capacity space, enabling breakthroughs in mmWave and THz technology. Scaling means smaller transistors that can operate at mmWave frequencies, which allows high-power transmission from a phased array antenna. The EMB chip architecture relies on Tx/Rx channels that operate in parallel. Since each Tx/Rx channel drives an individual antenna element, a large phased array beamformer has many parallel paths, which resembles the parallel processing of a modern GPU processor.

CONCLUSION

The industry stands as the vanguard of information capacity innovation. To enable this innovation, mmWave wideband technology is spearheading the continuous advancement of transmission capabilities. These emerging wideband technologies will lay the robust technical foundation for next-generation communication standards, including 5.5G, 6G and satellite communications. They will also pave the way for the seamless integration of terrestrial and non-terrestrial networks to form the backbone of a hyper-connected future. Concurrent revolutions in computing power and information transmission capacity are the twin engines driving the rapid pace of technological evolution.

As we stand on the edge of this new digital era, the advancements spearheaded by these industries are set to redefine our daily experiences. The integration of faster data rate capabilities and AI is poised to catalyze a paradigm shift in how the world interacts with technology. This synergy will unlock a level of digitization that delivers unparalleled convenience and efficiency, revolutionizing personal lives and professional environments. The promise of this technological renaissance is a world where the seamless and intelligent application of digital solutions enhances every aspect of our existence. ■

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