Keywords: mobile backhaul, wireless backhaul, 5G base station, radio frequency, HetNet, small cells, Distributed Antenna System, point-to-point microwave, RF-DAC

APPLICATION NOTE 6545

BACKHAUL ALTERNATIVES FOR 4G/5G HETNET BASE STATIONS PART 2 – PTP MICROWAVE AND BROADBAND SATELLITE SYSTEMS

By: Damian Anzaldo, Principal Member of Technical Staff—Field Applications, Maxim Integrated

Abstract: Seeking mobile backhaul alternatives, Wireless Service Providers (WSP) have adopted a "solution toolbox" to meet backhaul capacity demand in 4G/5G cellular base stations. The WSP solution toolbox includes both wired and wireless transport technologies. For many backhaul deployment scenarios, the Service Providers recognize that wireless transport has significant advantages over wired media alternatives. However, wireless technologies present some unique design challenges. Overcoming these challenges requires specialized RFIC devices that can help shrink equipment size, lower operating power, improve dynamic performance, and extend mean-time-between-failures (MTBF).

Introduction

This application note is Part 2 of two-part series that discusses wireless mobile backhaul systems deployed in 4G and 5G heterogeneous networks (HetNets). The application notes present different equipment categories and emerging equipment segment trends. They also discuss microwave, millimeter wave, and sub-6GHz radio applications in small-cell and macro-cell base stations. The application notes also explore the role of radio frequency (RF) analog integration and high-performance RF building blocks, with a focus on point-to-point microwave systems and broadband satellite systems.

Part 1 of this series takes a look at mobile backhaul market drivers, equipment trends, and the toolbox of different backhaul solutions deployed across cellular radio-access networks. It discusses equipment segmentation and equipment configurations. Part 1 also presents considerations and selection criteria to help guide the backhaul-solution decision process.

Part 2 of the series focuses on point-to-point microwave and broadband satellite systems typically used for wireless backhauling in macro-cell and small-cell base stations. The second part discusses techniques to improve radio-link spectral efficiency and radio lineup scenarios. Part 2 also explores the role of RF analog integration and RF building blocks, along with relevant solutions.

Conventional Point-to-Point, Line-of-Sight Microwave Systems

Conventional point-to-point (PTP), line of sight (LOS) microwave systems operate in the licensed spectrum from C-band to Ka-band. Common operating band frequencies are 6GHz, 11GHz, 18GHz, 23GHz, 26GHz, and 38GHz. These systems require unobstructed LOS. **Figure 1** illustrates a PTP microwave backhaul link connecting a macro-cell base-station tail node to an aggregation node. For small-cell base-station applications, some microwave equipment vendors have demonstrated non-line-of sight (NLOS) operation using conventional LOS microwave bands. This NLOS operation is achieved by leveraging high antenna gain characteristics with operating guidelines for the well-known electromagnetic wave propagation effects of diffraction, reflection, and penetration.

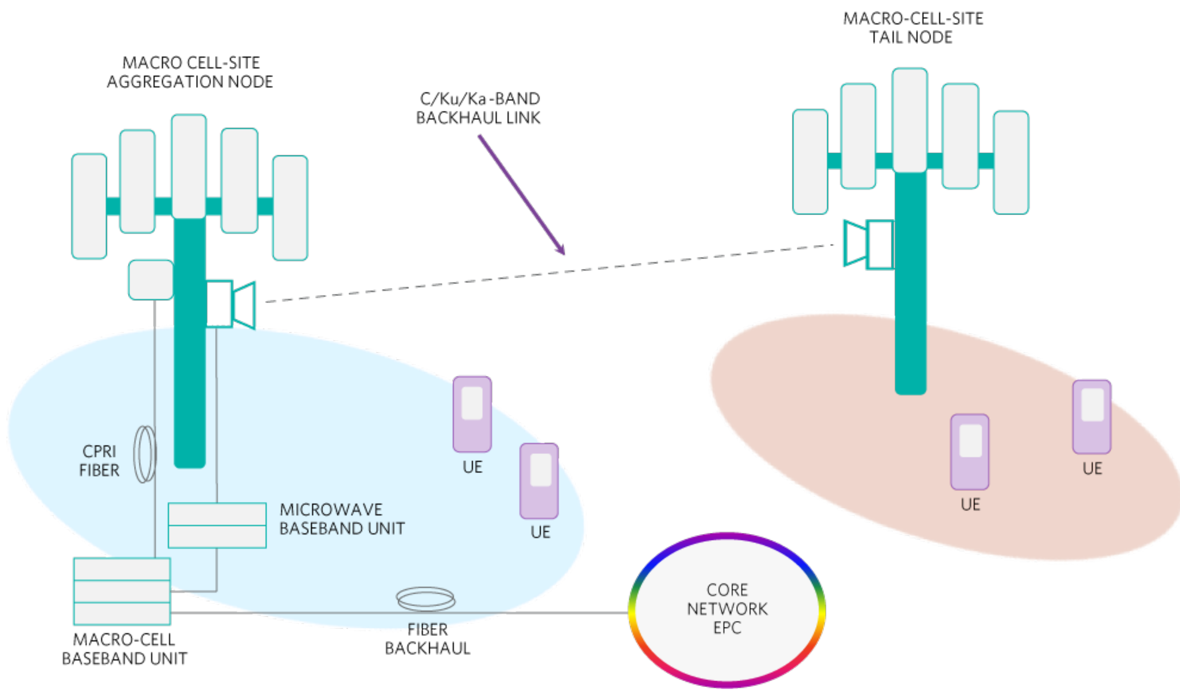


Figure 1. A PTP LOS microwave link uses a tail node and aggregation node. This approach lets remote base stations access the core network.

Common Microwave Backhaul Configurations

The split mount unit (SMU) and full outdoor unit (FODU) represent two of the most common microwave backhaul equipment configurations for macro-cell base-station applications. An SMU configuration comprises two separate boxes: an indoor unit (IDU) and outdoor unit (ODU). The FODU is a single unit that integrates the IDU and ODU functions. The FODU and split-mount ODU are installed at the tower top, where they are exposed to harsh environmental conditions and extreme temperature changes. Given this environmental exposure, all outdoor units must be housed in a hardened enclosure (refer to **Figure 7** in Part 1[MN3]).

SMU Radio

In an SMU system, the IDU transmits and receives two different low-intermediate frequencies (IF1)—one for the transmitter (TX) channel and one for the receiver (RX) channel. IF1 is routed over coaxial cable between the IDU and ODU. The IDU also handles TDM or Ethernet data routing and transport.

At the IDU a common receiver IF1 ranges from 120MHz to 140MHz and a common transmitter IF1 ranges from 310MHz to 350MHz (**Figure 2**). The 350MHz and 140MHz IF, along with DC power, are routed over coaxial cable between the IDU and ODU. At the tower top within the ODU, a second IF (IF2) is synthesized at L-band or S-band, which ranges from 1GHz to 4GHz. IF2 is then upconverted to, or downconverted, from the desired microwave carrier frequency (RF OUT/IN), for example, 26GHz carrier (**Figure 3**).

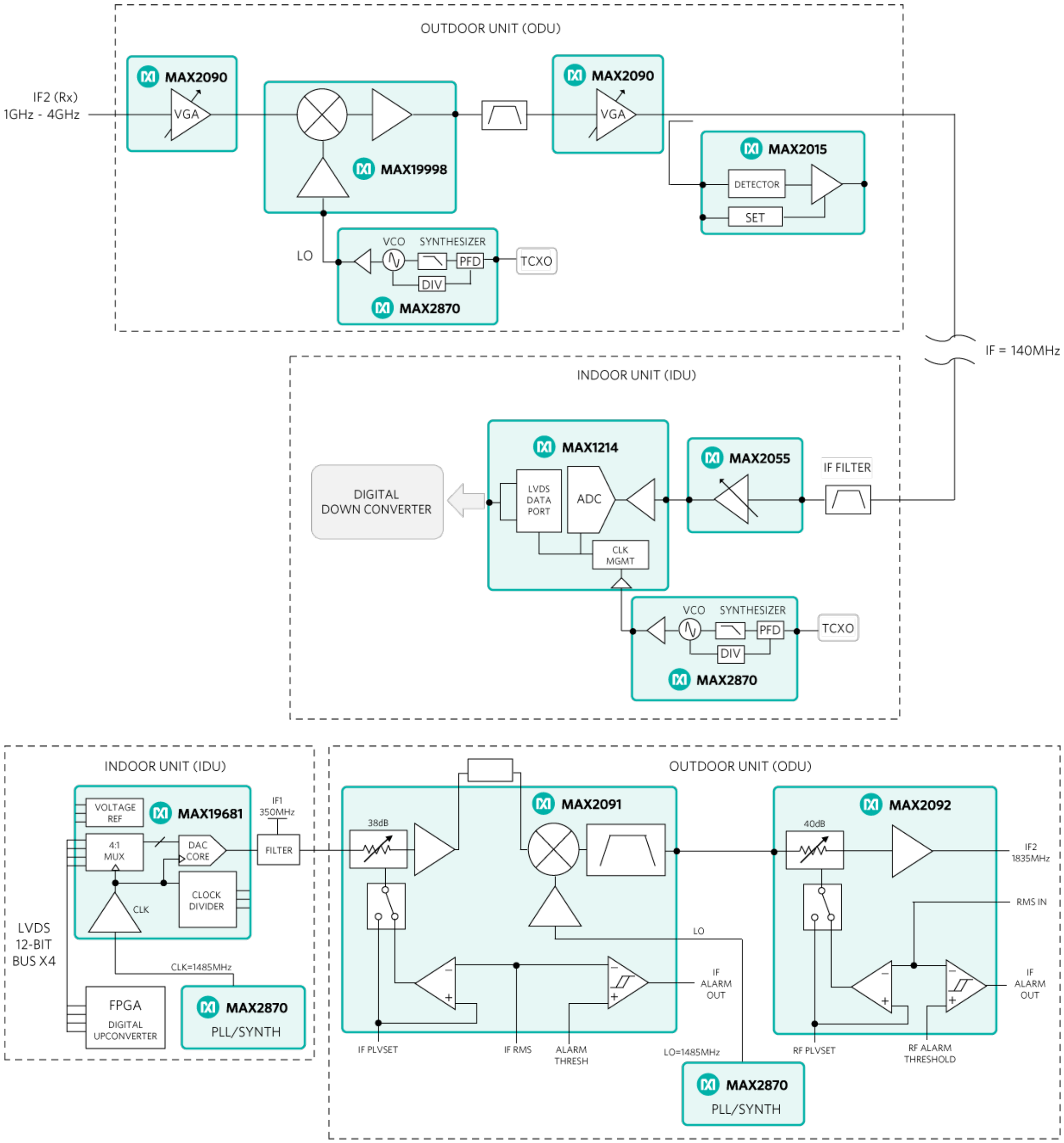


Figure 2. IF signal routing in the schematic of an SMU radio IF section. The IDU/ODU receiver (RX) is shown at the top; the IDU/ODU transmitter (TX) is at the bottom.

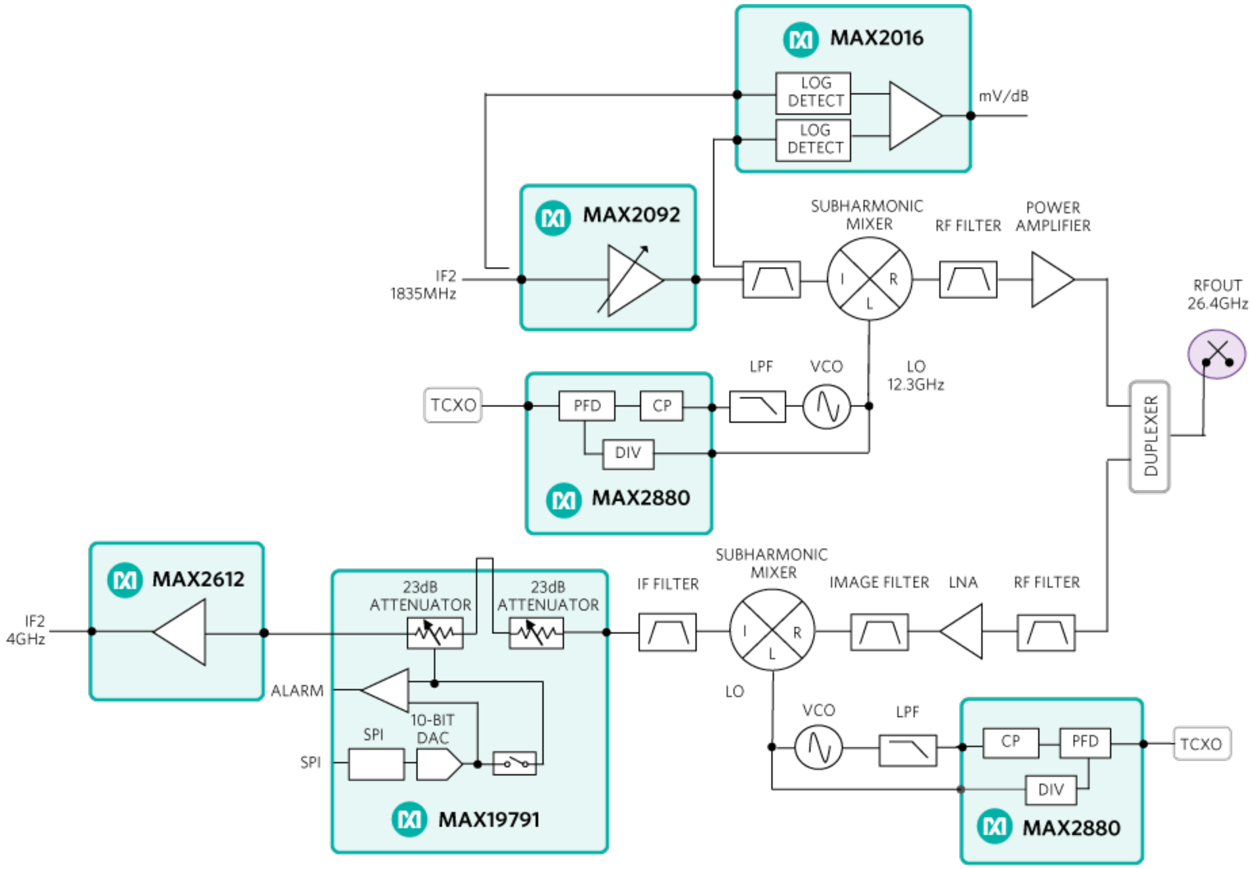


Figure 3. Schematic for the microwave up/down frequency converter section in a split mount ODU.

FODU Radio

In a FODU configuration, the entire radio is located within the outdoor unit. A high-speed serial interface, such as 1000BASE-T with Power over Ethernet (PoE), connects the FODU and baseband unit (refer to Figure 7, Part 1) or microwave router. In some small-cell applications the FODU can interface directly with a small-cell base station through PoE, where the small cell acts as the power source equipment (PSE) and the FODU is the powered device (PD). **Figure 4** shows a typical RF to Bits® radio transceiver front-end.

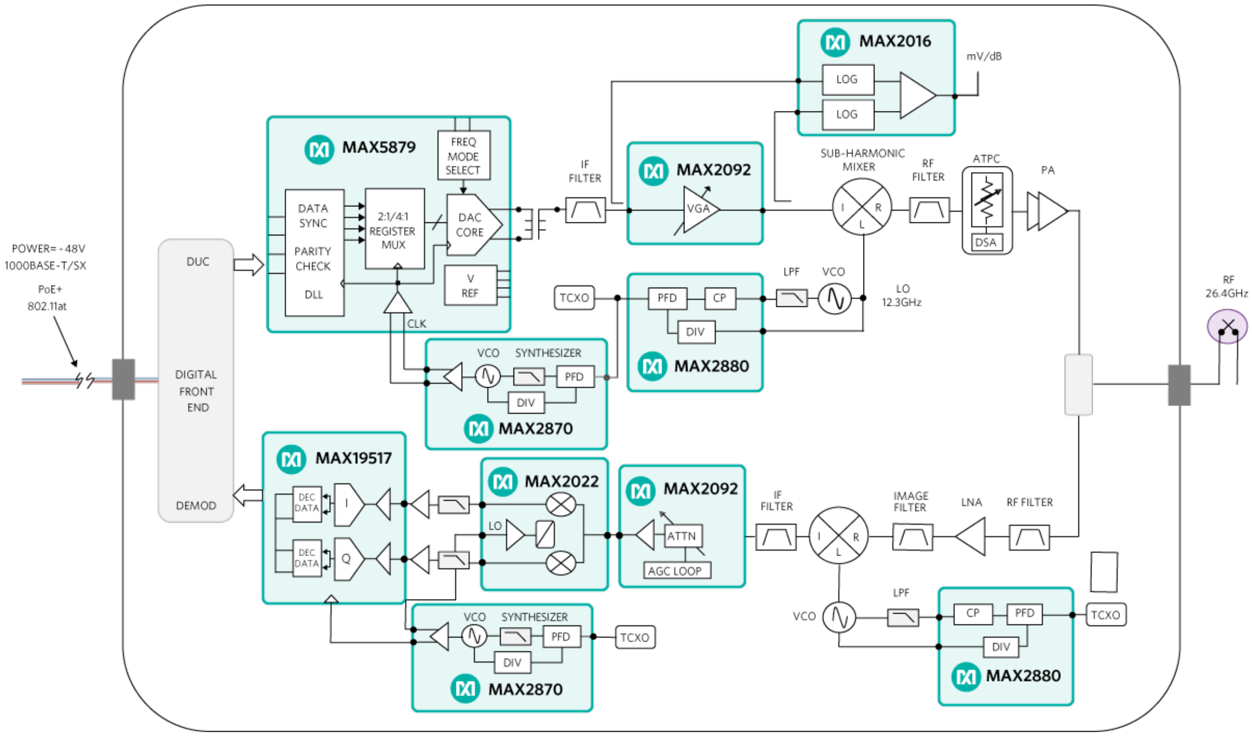


Figure 4. Schematic for a FODU RF to Bits microwave transceiver with PoE+. This radio would be encased in an environmentally hardened enclosure.

The FODU configuration in Figure 4 is basically a bits-to-RF and RF to Bits box that moves digital transport, typically Ethernet, and handles all modulation/demodulation, analog-to-digital/digital-to-analog signal conversion, and up-/down-frequency conversion. The frequency lineup for the FODU is different than the SMU because the FODU has two up-/down-frequency conversion stages (IF1 and RF OUT/IN) and the SMU requires three up-/down-frequency conversion stages (IF1, IF2, and RF OUT/IN).

Generally, in a FODU radio lineup, IF1 can range from 1GHz to 4GHz. IF1 assignment is driven by complexity and the cost of the image-reject filter, based on carrier frequency, channel bandwidth, image separation, and local oscillator (LO) rejection. In a C-band application, for example, the carrier ranges from 6GHz to 8GHz and channel bandwidth can extend to 56MHz. Therefore, IF1 can be as low as 1GHz, allowing a low-Q image filter to achieve the necessary LO and image rejection. In a Ka-band application operating at 32GHz or 38GHz, the IF1 might be set at 4GHz which yields wider image separation to help relax the image-reject filter requirement.

Better Spectral Efficiency Increases Capacity

For service operators, key priorities include optimizing spectrum utilization and achieving the lowest cost-per-bit transmission. Due to telecommunications regulations, a service operator's PTP microwave link is confined to an assigned channel size or channel bandwidth at an agreed licensing fee. An operator can license more RF spectrum to increase capacity, but this comes with additional expense. And in many cases, more RF spectrum might not be available. Ultimately, some advanced communication techniques are needed to achieve capacity gains within the constraint of assigned channel size but without adding additional spectrum licensing cost.

To improve spectral efficiency and increase system throughput without using more radio spectrum, three common techniques are available: adaptive modulation, co-channel dual polarization (CCDP), and spatial multiplexing (SM) (**Figure 5**).

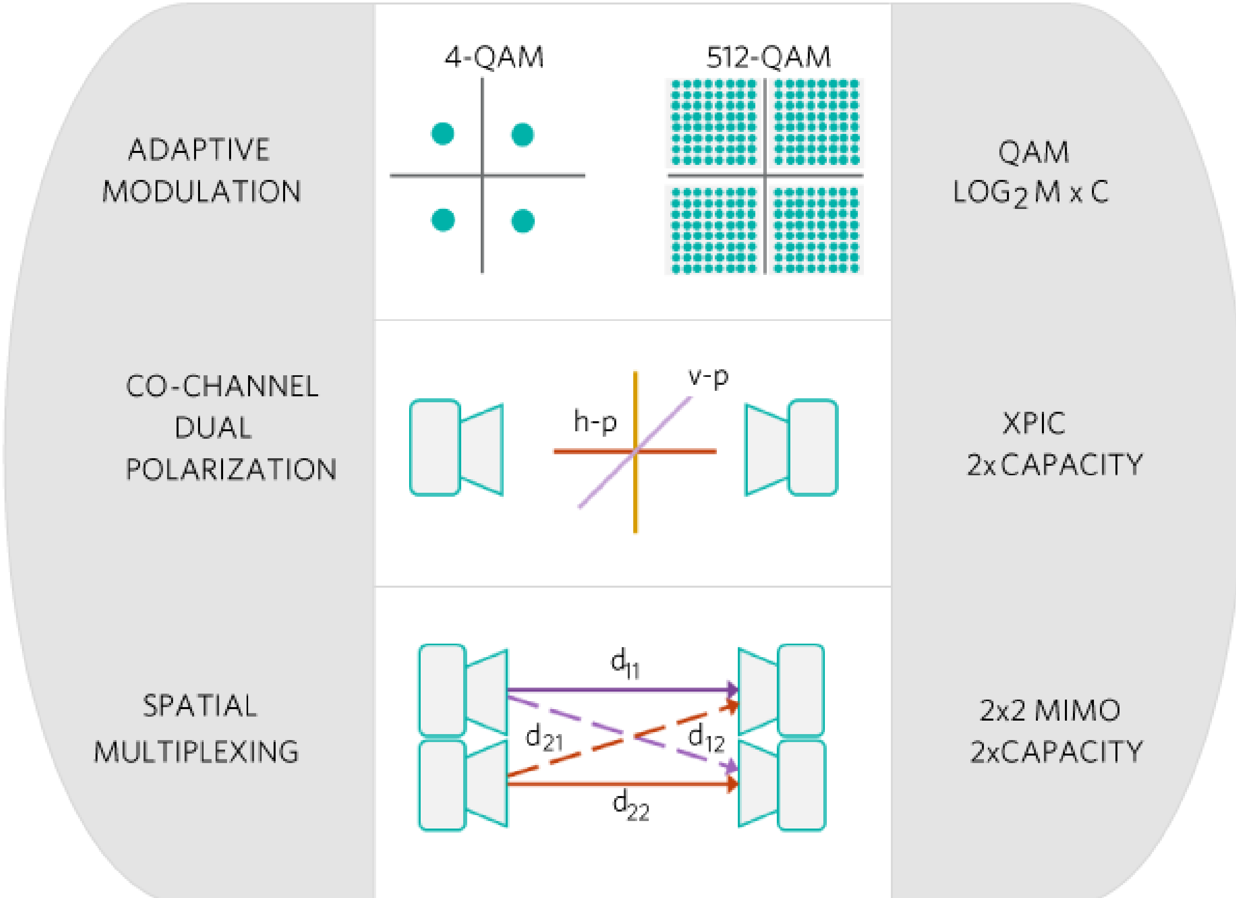


Figure 5. Three advanced digital communication techniques for increasing spectral efficiency.

Adaptive modulation dynamically changes modulation constellation for maximum throughput under varying weather conditions and different link budgets. This approach offers two key advantages: maintaining service quality by ensuring radio link operation under poor conditions and achieving the highest throughput in a bandwidth-limited channel. As presented in Claude E. Shannon's classic theorem, the capacity of a communication channel is defined by signal-to-noise ratio (SNR) and transmitter power.

Adaptive modulation uses Shannon's theorem as a blueprint to optimize spectrum utilization. In clear weather conditions, when radio-link SNR is high, the spectral efficiency and throughput are increased by employing dense QAM constellations such as 256QAM, 1024QAM, or even 4096QAM. In poor weather conditions, as SNR degrades, the modulation can be lowered to 16QAM or QPSK to ensure link operation for high-priority data but at reduced throughput. However, when increasing QAM constellation density, a point of diminishing returns is reached in terms of throughput gained versus added cost, RF transmitter power expended, better RF signal-chain linearity, and higher dynamic range. With each increase in QAM density (e.g., 64QAM, 128QAM, 256QAM), a 3dB to 4dB increase in SNR or transmitter power is needed. At the same time, each increase in QAM density improves the throughput by only approximately 10%. So, in summary, the RF signal-chain performance must be doubled to achieve a 10% incremental gain in throughput. As a result, another method is needed to significantly improve spectral efficiency and achieve higher capacity gains.

CCDP utilizes cross-polarization interference cancellation (XPIC) to double link capacity over the same channel. With CCDP-XPIC, you can simultaneously transmit two separate data streams on the same frequency. Data is transmitted on orthogonal antenna polarizations (vertical and horizontal), and cross-polarization interference is cancelled using digital signal processing.

SM significantly improves spectral efficiency. SM uses multiple-input multiple-output (MIMO) antennas to send multiple data streams over the same RF channel. A 2×2 MIMO link can double capacity. SM with MIMO, used in many wireless applications including LTE access and 802.11n/ac WLAN, relies on multipath interference and exploits spatial propagation paths caused by reflections. There is, however, a minor complication to be aware of. The nature of a LOS microwave link does not exhibit multipath, so a multipath condition is simulated by intentional antenna separation, which creates a pseudo multipath condition.

While combining adaptive modulation with CCDP and MIMO techniques leads to considerable capacity gains, some trade-offs must be considered. A 2×2 MIMO radio requires two transceiver paths (two transmitters and two receivers) with each transceiver dedicated to a single antenna. A CCDP radio requires two transceiver paths, one transceiver dedicated to each antenna polarization. However, adopting 2×2 MIMO with CCDP requires four RF transceiver paths (**Figure 6**). This 4x increase in RF channel density delivers a major benefit: a 4x increase in link throughput without using more RF spectrum. Amortizing this over the equipment life span, the extra cost of additional radio hardware is offset by a significant savings in annual spectrum licensing fees.

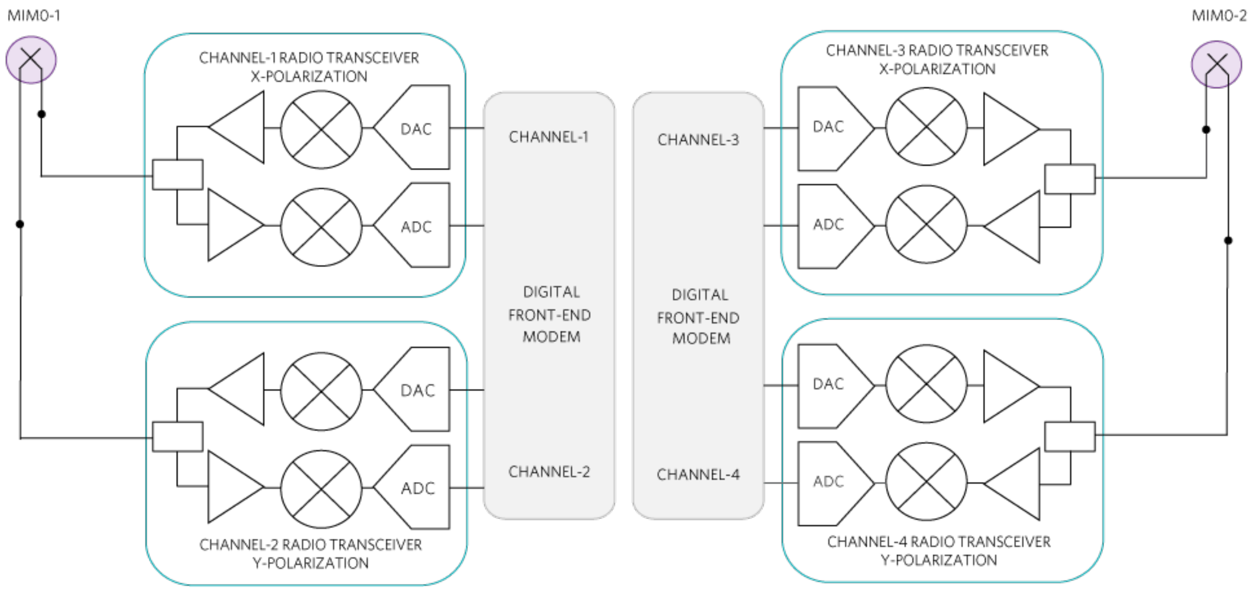


Figure 6. Spatial multiplexing with CCDP increases RF channel density.

Supporting Hot Standby Redundancy

Another advantage of adopting 2×2 MIMO is that it meets the requirement to support hot standby (HSB) redundancy. PTP microwave systems support HSB with basic protection of 1+1 HSB. As such, two radios are used, a primary radio and a backup radio. If the primary radio fails, then the secondary backup radio is switched in. HSB is inherent with 2×2 MIMO radio architectures. The purpose of HSB is to deliver five nines (99.999%) availability over an extended mean time between failures (MTBF) period. In at least some cases, the expected MTBF period can be up to five years. This level of sustained 24/7 protection is needed because of the critical nature of the radio link and the installation location. After all, wireless backhaul equipment can be part of a mission-critical public-safety radio link or located in a macro-cell base-station site supporting many mobile subscribers, at a tower-top location where maintenance must be scheduled, or at a remote hard-to-reach base-station site.

Consider that four radio transceiver channels are required with 2×2 MIMO CCDP 1+1 HSB. Further, as modulation constellations increase from 256QAM to 4096QAM, better radio dynamic performance is needed to achieve the desired bit error rate (BER) and error vector magnitude (EVM) margin. Ultimately, the wireless backhaul evolution increases RF signal-path channel density along with expectations of higher dynamic performance. This means new demands for increased analog integration by RF engineers.

Smaller RF Solutions Driving Need for Analog Integration

The demand for smaller RF solutions that don't sacrifice performance or reliability is driving a need for greater analog integration. Recall the first IF transmitter section above. In a FODU transmitter, the first IF can range between 1GHz to 4GHz. In an SMU transmitter, the first IF ranges from 310MHz to 350MHz. Also consider that adaptive modulation supports constellations from QPSK up to 4096QAM and, depending on the application, channel bandwidth can vary from 3.5MHz to 112MHz. Together, these factors dictate a software-defined radio topology that supports requisite EVM dynamic performance based on a common transmitter architecture platform.

A Versatile RF-DAC Transmitter for a Microwave PTP Platform

Several radio architecture options are available when designing a first IF transmitter stage, including zero-IF, complex-IF, real-IF, and direct-RF. But, what if the microwave PTP transmitter platforms must support high-order modulation, wide bandwidths, software-defined radio capability, low power consumption, and compact size? Now the best architecture is direct-RF conversion using an RF digital-to-analog converter (RF DAC) with direct digital synthesis (DDS). Figure 7 illustrates a direct-RF transmitter using the MAX5879 RF DAC to synthesize an IF of 2GHz.

- The RF-DAC transmitter is beneficial because it can be used in split-mount indoor units to directly synthesize the 350MHz IF. It can also be used in the FODU to directly synthesize up to 2.8GHz IF, where it serves as a common transmitter platform spanning different equipment configurations.
- An RF-DAC transmitter requires fewer discrete devices and occupies considerably less printed circuit board (PCB) area (Figure 7). This space savings is critical for space-constrained MIMO and CCDP radios.
- The DDS-based RF-DAC transmitter architecture eliminates gain-phase errors and achieves perfect carrier suppression with no LO leakage. This is an important advantage for addressing the strict EVM requirements necessary to transmit high-order modulation signals with dense constellations like QAM-2048 at low BER.
- Compared to conventional architectures, an RF-DAC consumes approximately 1W less power per channel. In a FODU radio using 2×2 MIMO with CCDP and powered by POE+, this translates to a 4W power savings, or 15% of the POE+ power budget. Also, lower operating power means less heat dissipation, a critical concern for passively cooled outdoor units subjected to high-temperature extremes approaching 40℃.

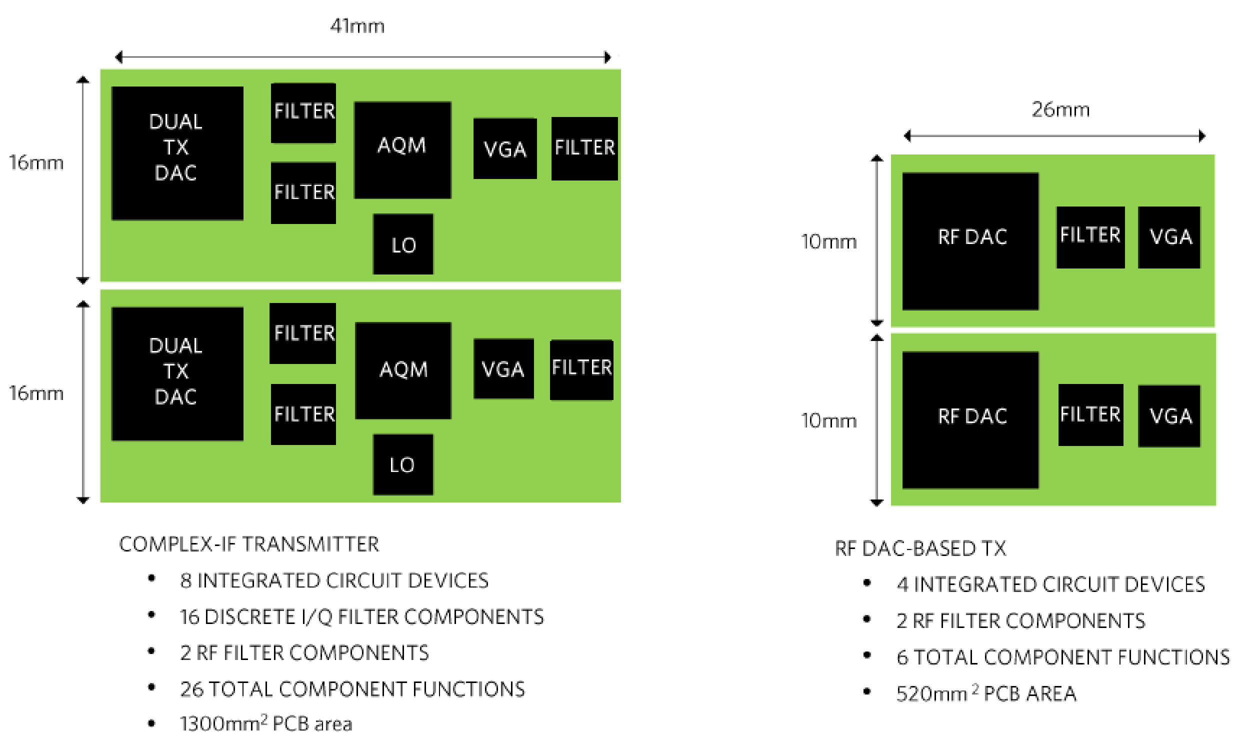


Figure 7. PCB area comparison of a complex-IF versus RF DAC transmitter supporting CCDP or 2×2 MIMO. The RF DAC transmitter (right) significantly reduces PCB area and component count. AQM = analog quadrature modulator; LO = local oscillator (PLL/VCO synthesizer); VGA = variable gain amplifier; I/Q filters = multipole, differential. Diagram not to scale.

Critical RF Building Blocks

Dense RF analog integration is important for shrinking size and lowering component count, but there are still many radio functions that rely on RF building blocks. The IF section and microwave up-/down-frequency conversion sections, as shown in Figure 2, Figure 3, and Figure 4, represent two RX-TX areas that require several key analog functions. Two requisite circuit functions are the phase-locked loop (PLL) frequency synthesizer and the variable gain amplifier (VGA).

PLL Frequency Synthesizer

In the IF section of the RX and TX signal paths, a PLL frequency synthesizer generates the mixer LO and high-speed ADC/DAC conversion clocks ranging from 100MHz to 4GHz. The device commonly used must integrate a VCO and fractional/integer-n PLL, and offer wide frequency coverage. The MAX2870/MAX2871 are a common choice.

In the RF microwave section, a PLL frequency synthesizer is used to generate the high-frequency LO for either a fundamental mixer or subharmonic pumped mixer. The LO frequency can range from 6GHz to 12GHz, depending on the final carrier frequency. A PLL with external VCO like the MAX2880 is typically used.

Both PLL synthesizer applications require excellent phase noise and spurious performance, which directly impacts system capacity. As stated above, a PTP microwave radio can use modulation constellations up to 2048QAM or 4096QAM to achieve high spectral efficiency and deliver high throughput. A PLL synthesizer phase-noise margin and spurious performance that do not significantly degrade EVM are needed to support dense modulation constellations. This preserves the radio link SNR and allows the system to achieve maximum capacity and throughput. **Figure 8** shows the MAX2880 phase-noise performance at fOUT = 12GHz. Over a 20MHz integration bandwidth and setup for integer-n mode, the MAX2880 achieves EVM of -43.6dB. For a 2048QAM radio lineup, this translates to only 0.6dB degradation in EVM with +10dB SNR margin.

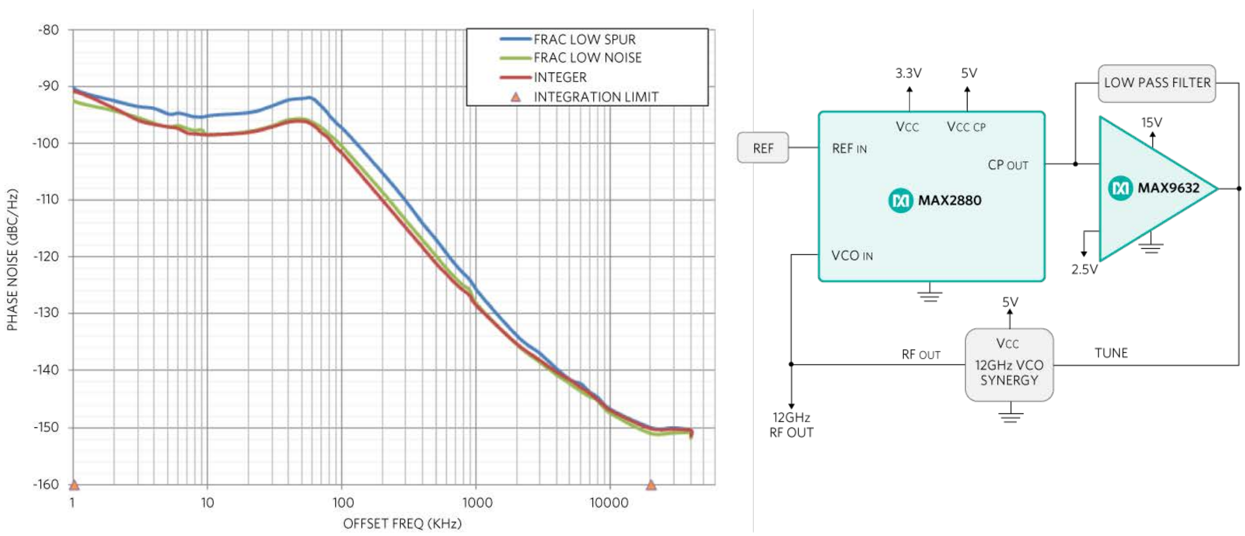


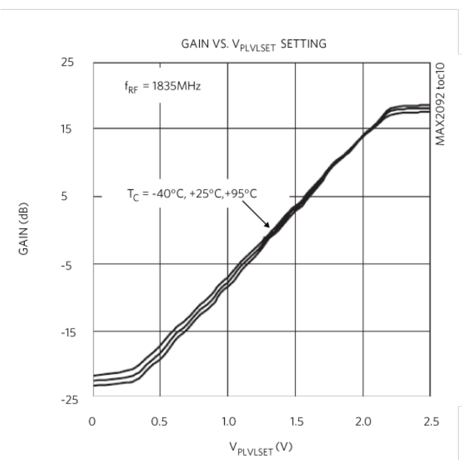
Figure 8. Phase noise is an important PLL-frequency-synthesizer performance metric in LO applications. For simplicity, passive R-C components for filtering, AC-coupling, and impedance matching are excluded at the lowpass filter for the MAX2880.

An important PLL frequency synthesizer feature is independent dual-channel RF outputs that can be set to different power levels and output frequencies. This capability is helpful for generating both the LO and high-speed converter (ADC or DAC) conversion clock from a single device. In an example zero-IF RX architecture with IF = 1.9GHz and 56MHz channel bandwidth, the analog quadrature demodulator LO can be set to 1.9GHz with LO drive level at +2dBm; the high-speed ADC clock is set to 118.7MHz (divide-by-16) at +5dBm. By using a single device like the MAX2871 with independent dual-RF output ports and independent output power levels, you can eliminate an extra synthesizer, LO buffer, and clock buffer. At the system level, you can lower costs and benefit from a smaller occupied PCB area.

Ensuring Proper Signal Level in RX and TX Paths

In PTP microwave radios, automatic transmit power control (ATPC) is a critical function. ATPC is used to increase the transmitter power level during a fade event and, thus, maintain link quality under adverse environmental conditions. The function also lowers interference with adjacent channels. ATPC can be used in conjunction with adaptive modulation to change the transmitter power level based on desired modulation. This presents a method for optimizing power back-off and to dynamically set for individual modulation constellations. ATPC improves link availability by maintaining adequate SNR and conserves energy by reducing average operating power consumption. Guidelines for ATPC are up to 20dB dynamic range in 1dB steps with 100dB/s tracking speed. Typically, transmitter output power tolerance is ±1dB. When used with adaptive modulation, the gain range must cover an additional 8dB to 10dB to compensate for PA back-off under different modulation scenarios from QPSK to 4096QAM.

The VGA is an important component for ATPC operation and throughout the signal-chain lineup, ensuring a proper signal level in the RX and TX paths. In the TX path of an SMU, a VGA is also important to compensate for cable loss and equalization. High linearity overtemperature, wideband performance, and linear-in-dB control with integrated alarm circuits are among the key features of a VGA for ATPC applications. **Figure 9** shows how a wideband VGA uses a proprietary technique to achieve highly linear control-voltage response over the temperature range of -40℃ to +95℃. High linearity over temperature is critical for FODU radios that are subject to wide operating temperature extremes. Note that the device operates at an IF from 700MHz to 2.7GHz. This range enables partial power control at IF and support for full ATPC at RF (i.e., from 6GHz up to 40GHz). Augmenting power control at IF requires another 10dB to 15dB of VGA dynamic range to compensate for impairments in the subsequent RF stages. Impairments include insertion loss, gain variation, and component temperature drift. Also in SMU applications, the VGA might need to provide 6dB cable loss compensation. This is why the example VGA, the MAX2092, has up to 40dB of dynamic range and +18dBm P1dB (i.e., ATPC range = 6dB; modulation back-off = 8dB; impairment compensation = 10dB' cable loss compensation = 6dB; total VGA range = 30dB).



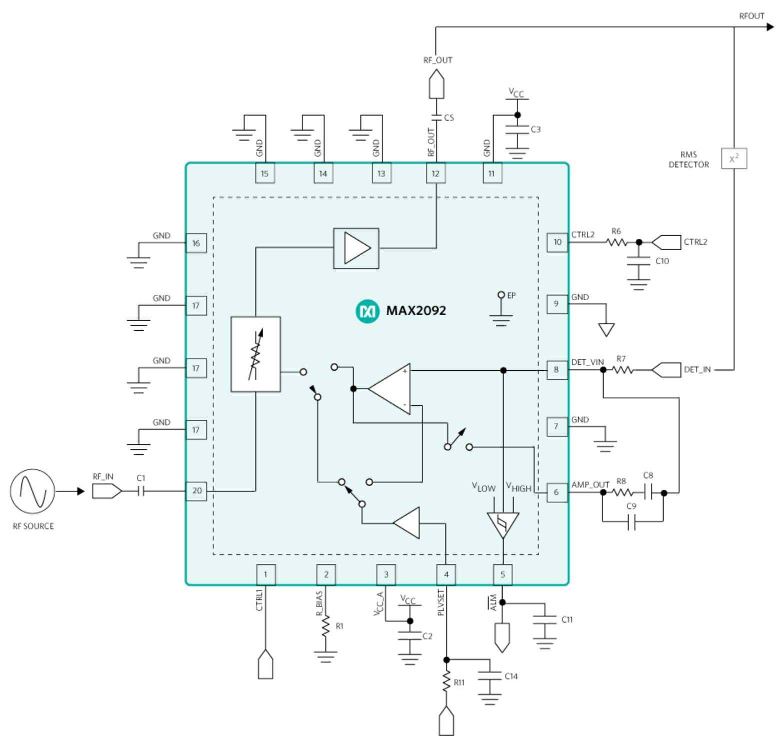


Figure 9. An important VGA feature is high linearity over a wide operating temperature range with precise linear-in-dB level control (shown in the performance curves on the left). A VGA, like the MAX2092, is a common RF building block used for ATPC applications and RX-TX signal leveling.

VSAT Satellite Backhaul

Commercial satellite systems use very small aperture terminals (VSAT) for cost-effective delivery of telephony, broadband access, and video content. VSAT systems are deployed in enterprise-grade private networks, consumer broadband services, and cellular base-station backhaul. In cellular base-station backhaul applications, VSAT systems are ideal for remotely located small-cell sites. **Figure 10** shows a typical VSAT system used in a base-station backhaul application.

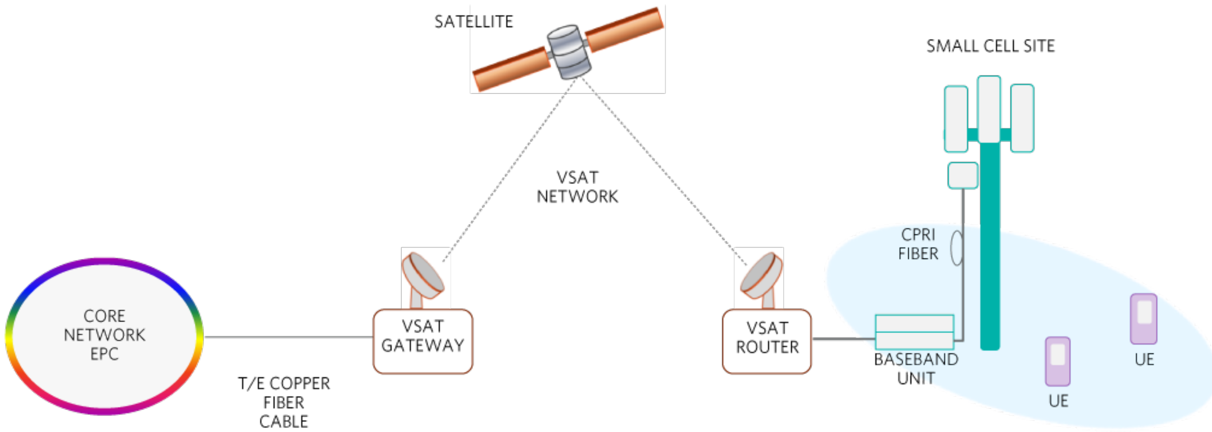


Figure 10. Satellite backhaul with a broadband VSAT system connects a remote small cell base station to the core network.

Router and gateway VSAT terminals are ground-based units with a two-way communication link to C/Ka/Ku-band satellites. The satellites can be in geosynchronous earth orbit (GEO) or medium earth orbit (MEO). The size of ground-based VSAT antennae range from 75cm to 3m. Because they're powered by a finite energy source, orbiting satellites are energy constrained. Because of this, a satellite downlink channel has limited transmitter power. The link is also susceptible to atmospheric loss because geosynchronous satellites orbit at 30km from ground terminals. As a result, the radio link operates with low SNR. To achieve desired data throughput with acceptable BER at low SNR, VSAT systems use wide-channel bandwidths with relatively low-order modulation, such as QPSK, 8PSK or 16APSK.

Conventional satellites occupy 500MHz to 1GHz of spectrum comprising multiple transponders with bandwidth from 27MHz, 36MHz or 54MHz. A new generation of high-throughput satellites (HTS) operates at Ka-band, where more RF spectrum is available. The Ka-band satellites can have up to 120 individual spot beams reaching a capacity of 150Gbps. The HTS Ka-band systems use wide transponder channels with up to 500MHz bandwidth. The ODU and IDU are two main radio elements in a VSAT system. The topology is similar to a microwave point-to-point SMU. Located at the antenna dish, the ODU handles block frequency translation of the C/Ka/Ku-band microwave carrier (6/4GHz, 14/12GHz, 30/20GHz) to an L-band intermediate frequency (IF = 925MHz to 2175MHz). The IDU handles up/down frequency conversion from L-band IF to baseband.

Radio Solutions for VSAT Applications

Figure 11 illustrates a typical ODU microwave up-/down-frequency converter operating at Ku-band. The ODU comprises two blocks: the low-noise block (LNB) receiver and the block upconverter (BUC) transmitter. As in a microwave PTP backhaul radio, fundamental and sub-harmonic pumped mixers are used with PLL frequency synthesizers. The PLL can be replaced with a dielectric resonator oscillator (DRO) in applications where the LNB and BUC operate at fixed frequencies and where frequency drift is not an issue. The DRO exhibits typical frequency drift ranging from ±1 ppm/℃ up to ±4 ppm/℃. For a 10GHz design operating over -10℃ to +45℃ temperature range, this equates to frequency drift of 550kHz to 2.2MHz. This frequency variation over temperature could be a problem in outdoor units that are subjected to wide operating temperature extremes or single-channel-per-carrier systems. Even so, in many VSAT applications, the DRO is a low-cost alternative to a PLL frequency synthesizer.

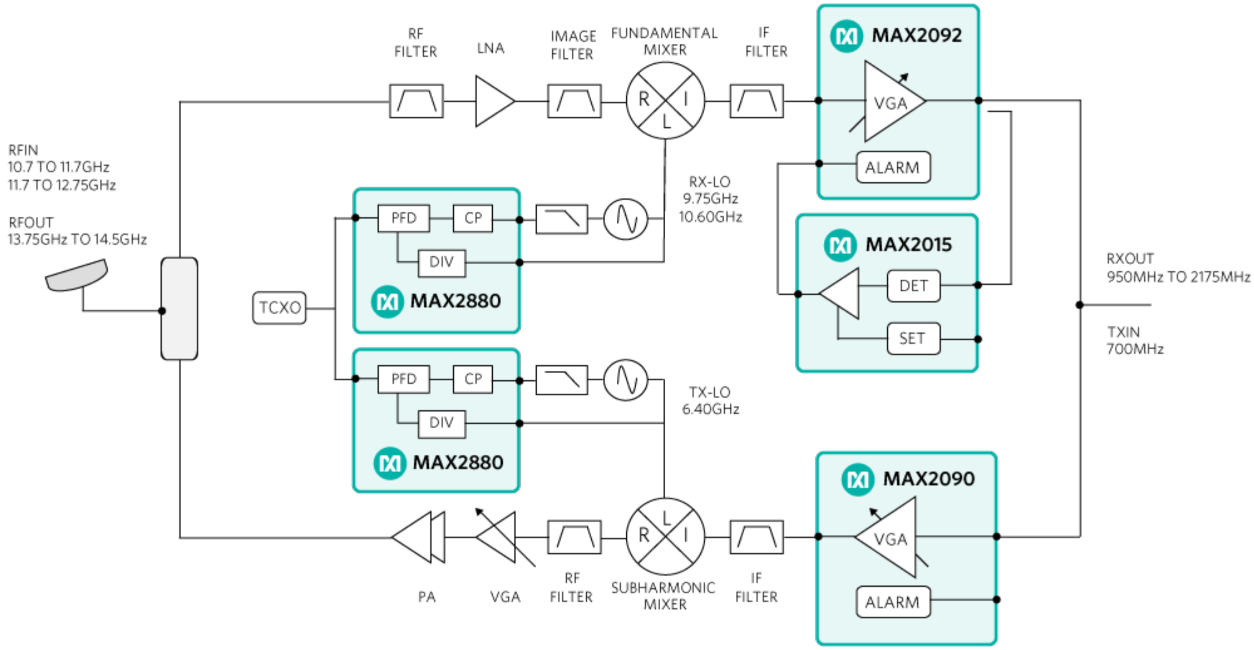


Figure 11. Analog RF building blocks play an important role in VSAT ODU microwave radios. Here the LNB and BUC rely on PLL frequency synthesizers and high-linearity VGAs for stable performance over temperature extremes.

IDU VSAT terminals require wideband frequency coverage and high dynamic range with selective tuning to a desired transponder channel. For broadband VSAT tuners, key features include a high-dynamic-range VGA; a fractional-n synthesizer using multiple VCOs for LO tuning; and baseband I/Q filters with variable bandwidth control. **Figure 12** shows a direct-conversion broadband VSAT tuner.

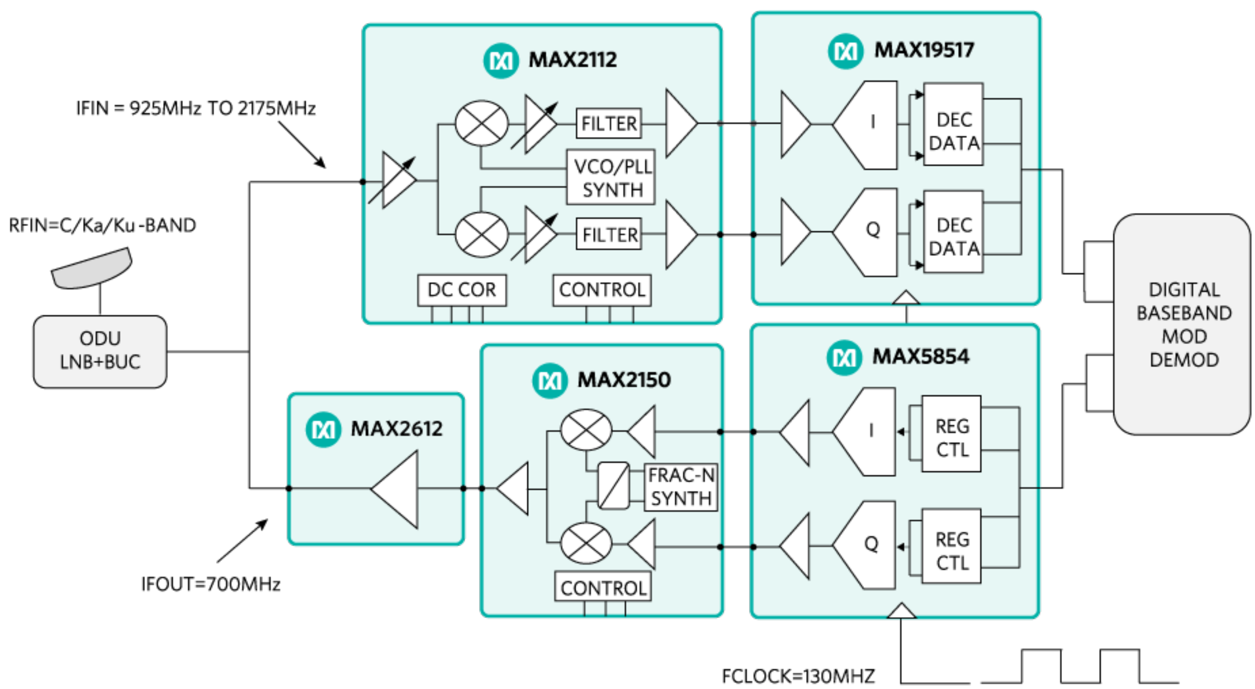


Figure 12. VSAT indoor unit (IDU) based on a direct-conversion transceiver architecture

The broadband tuner has wideband frequency coverage from 925MHz to 2175MHz to support the L-band ODU output spectrum. The LO is generated by an integrated 20-bit fractional-n frequency synthesizer with tuning resolution down to 26Hz. The internal lowpass filters are programmable from 4MHz to 40MHz, covering all common transponder channel bandwidths. The VGA stages deliver over 80dB of gain range to account for downlink path loss effects such as rain fade, foliage obstruction, polarization loss and antenna de-pointing loss.

ODU and IDU radios designed for commercial VSAT systems leverage highly integrated, application-specific analog semiconductors complemented by high-performance RF building blocks. This combination delivers the size, cost, and performance requirements needed in broadband satellite-backhaul applications. For higher data throughput, next-generation VSAT systems will take advantage of HTS satellites operating at Ka-band, where a greater amount of spectrum is available. This advance, in turn, drives demand for new RF-analog solutions that can meet the bandwidth, dynamic performance, size, and cost requirements of emerging small-cell backhaul deployments.

Conclusion

4G cellular networks are evolving to a HetNet topology with access layer coordination among macro-cell base stations, different classes of small-cell base stations, and distributed antenna systems. HetNet deployments improve network capacity and coverage to deliver higher data throughput and excellent quality of experience for mobile broadband users. Meanwhile, backhaul transport is emerging as a critical HetNet element that brings together mobile users, radio access networks, and the core network. Wireless backhaul is an important tool in the wireless service provider backhaul "toolbox" and will be relied upon more heavily for 5G access in coming years.

PTP microwave and broadband satellite technologies are two common wireless backhaul alternatives deployed across the radio access network. As base-station capacity and throughput increase to support growing mobile data demand, backhaul capacity must also increase. And as base-station size and power decrease, so must backhaul solutions. As such, wireless backhaul systems will continue relying on RF analog integration and RF building-block solutions to achieve high spectral efficiency, smaller form factor, and lower operating power.

Related Parts		
MAX19681	12-Bit, 1.5Gsps High-Dynamic Performance DAC	
MAX2015	0.1GHz to 3GHz, 75dB Logarithmic Detector/Controller	Free Samples
MAX2016	LF-to-2.5GHz Dual Logarithmic Detector/Controller for Power, Gain, and VSWR Measurements	Free Samples
MAX2091	50MHz to 500MHz Analog VGA, 1735MHz to 1935MHz Upconverting Mixer with Image Filtering, Threshold Alarm Circuit, and Error Amplifier for Level Control	Free Samples
MAX2092	700MHz to 2700MHz Analog VGA with Threshold Alarm Circuit and Error Amplifier for Level Control	Free Samples
MAX2112	Complete, Direct-Conversion Tuner for DVB-S2 Applications	Free Samples
MAX2870	23.5MHz to 6000MHz Fractional/Integer-N Synthesizer/VCO	Free Samples
MAX2871	23.5MHz to 6000MHz Fractional/Integer-N Synthesizer/VCO	Free Samples
MAX2880	250MHz to 12.4GHz, High-Performance, Fractional/Integer-N PLL	Free Samples

MAX5879	14-Bit, 2.3Gsps Direct RF Synthesis DAC with Selectable Frequency Response

More Information
For Technical Support: https://www.maximintegrated.com/en/support
For Samples: https://www.maximintegrated.com/en/samples
Other Questions and Comments: https://www.maximintegrated.com/en/contact

Application Note 6545: https://www.maximintegrated.com/en/an6545
APPLICATION NOTE 6545, AN6545, AN 6545, APP6545, Appnote6545, Appnote 6545