How Bluetooth® HDT and FEM Technology Are Transforming Hearing Aid Design

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Before Bluetooth®, hearing aids functioned as standalone audio devices, with built-in microphones capturing environmental sound, amplifying and equalizing it, and delivering it through a speaker coupled into the ear canal. As smartphones became central to everyday communication and media consumption, users increasingly expected their hearing aids to connect wirelessly for hands-free calling and audio streaming, capabilities that traditional designs couldn't provide. This transition drove the move toward Bluetooth-enabled hearing aids, which leverage wireless connectivity and multi-audio features available on modern smartphones. However, not all hearing aids with Blueooth technology offer the same capabilities or performance.

Early wireless hearing aids relied on Bluetooth Classic, formally known as Bluetooth Basic Rate/ Enhanced Data Rate (BR/EDR). BR/EDR supports audio streaming with data rates in the roughly 1–3 Mbps range and enables acceptable downlink voice quality, but it comes with significantly higher power consumption.

Bluetooth Low Energy (LE) addresses these constraints by offering substantially lower power consumption and a radio architecture optimized for small, battery-constrained devices such as hearing aids. Bluetooth LE-based designs enable reliable audio streaming at lower data rates, typically up to 2 Mbps in LE 2-Mbps mode, while maintaining the low current consumption necessary for all-day wear. As Bluetooth LE audio capabilities continue to expand, hearing aids have progressed from basic streaming to true hands-free operation, with the hearing aid's own microphone array capturing the user's voice and sending it back to the phone over the Bluetooth LE uplink.

Features	Bluetooth Classic	Bluetooth Low Energy	BLE High Data Throughput (HDT)
Frequency band	2.4 GHz (2.402-2.48 GHz)		
Year of first release	1999 (Bluetooth 1.0)	2010 (LE 4.0)	2024 (draft)
Number of channels (Channel bandwidth)	79 (1 MHz)	40 (2 MHz)	40 (2 MHz)
Data rate and modulation technique	EDR PHY (8 DPSK): 3 Mbps EDR PHY (π/4 DQPSK): 2 Mbps BR PHY (GFSK): 1 Mbps	LE modulations: GFSK LE 2M PHY: 2 Mbps LE 1M PHY: 1 Mbps LE Coded PHY (S=2): 500 Kbps LE Coded PHY (S=8): 125 Kbps	HDT2: π/4-QPSK (2 Mbps) HDT3: π/4-QPSK (3 Mbps) HDT4: 8 PSK (4 Mbps) HDT6: 16 QAM (6 Mbps) HDT7.5: 16 QAM (7.5 Mbps)
RX sensitivity	≤ -70 dBm	≤ -70 dBm	≤ -75 dBm
Common applications	Primarily audio, with capability to support BLE-based applications with higher power consumption	IoT sensors, wearables, beacons, Auracast, and LE audio	IoT sensors, wearables, beacons, Auracast, and LE audio
Power consumption	Higher	Ultra-low power for IoT, moderate for LE audio	For a given data rate, HDT is an improvement over LE
Communication	Point-to-Point	Point-to-Point, Broadcast, Mesh	
Positioning features	Not present	Advertising, Direction finding, distance (RSSI & Channel sounding)	

Table 1. At-a-glance comparison of Bluetooth protocol specifications

Looking forward into 2027 and beyond, next generation hearing aids are expected to adopt Bluetooth Low Energy High Data Throughput (HDT) to further enhance call clarity, reduce latency, and extend battery life. Bluetooth HDT supports multiple data-rate modes up to 7.5 Mbps [1,2], enabling significantly higher throughput than current Bluetooth LE implementations and, along with forward error correction, contributing to improved link robustness and range. Compared with today's Low Energy (LE) 2-Mbps mode, HDT can deliver up to a four-fold increase in throughput and provides roughly 2.5 times the throughput of Bluetooth Classic. This increased bandwidth enhances audio quality and minimizes latency while improving energy efficiency. According to Bluetooth Special Interest Group (SIG) performance data, HDT also offers notable range improvements: when operating at comparable data rates—specifically LE 2-Mbps versus HDT2—HDT demonstrates approximately a 5-dB link-budget advantage, translating to an estimated 70% increase in effective coverage range.

Looking ahead, Bluetooth HDT is also projected to enhance Auracast™ broadcast audio [3], enabling higher-quality public audio transmission and more immersive assistive listening experiences. These advances allow future hearing-aid platforms to deliver clearer conversations, smoother streaming, and more reliable wireless performance.

Battery Considerations for Hearing-Aid Platforms

Most hearing aids with Bluetooth technology rely on rechargeable lithium-ion batteries, with capacity determined by factors such as device size, usage patterns, and overall system design. For users who prefer disposable batteries, Zinc-Air cells in sizes 675, 13, and 312 remain the most common choice due to their high energy density and suitability for long-duration applications.

Silver-oxide batteries, once common in early miniature hearing aids, are now largely phased out. Zinc-Air chemistry offers both higher capacity and lower cost, making it a better fit for modern digital and Bluetooth-enabled devices. Although silver-oxide cells have excellent shelf life and can still be appropriate for very small, infrequently used devices, they are no longer standard in contemporary hearing-aid designs.

Type	Capacity (mAh)	Size (d x h, mm)	Color Code	Hearing Aids Style
675	540-640	11.6 x 5.4	Blue	BTE, Cochlear implants
13	230-285	7.9 x 5.4	Gold	BTE, ITE
312	120-160	7.9 x 3.6	Burgundy	Mini BTE, ITE, ITC
10	60-90	5.8 x 3.6	Yellow	ITC, CIC
5	30-40	5.8 x 2.1	Red	CIC
Nomenclature: Behind the ear (BTE), in the ear (ITE), in the canal (ITC), and completely in the canal (CIC)				

Table 2. Common Zinc-Air one-time use battery characteristics

SoC Architecture in Hearing Aids with Bluetooth Wireless Technology

As shown in Figure 1, modern Bluetooth LE-based hearing aids rely on a highly integrated system-on-chip (SoC) that consolidates most of the device's audio, power-management, and wireless processing functions. These SoCs typically include interfaces for multiple microphones and speakers, on-chip battery-charging and power-regulation circuitry, and advanced audio-processing blocks that support noise reduction and user-specific listening profiles [4,5].

On the wireless side, the SoC incorporates the Bluetooth LE transceiver which supports the Hearing Access Profile (HAP), Auracast broadcast audio, and compatibility with platform-specific standards such as Apple's Made for iPhone (MFi) program and Android's Audio Streaming for Hearing Aids (ASHA). This high level of integration enables compact designs and efficient operation, forming the core of today's hearing aid architectures.

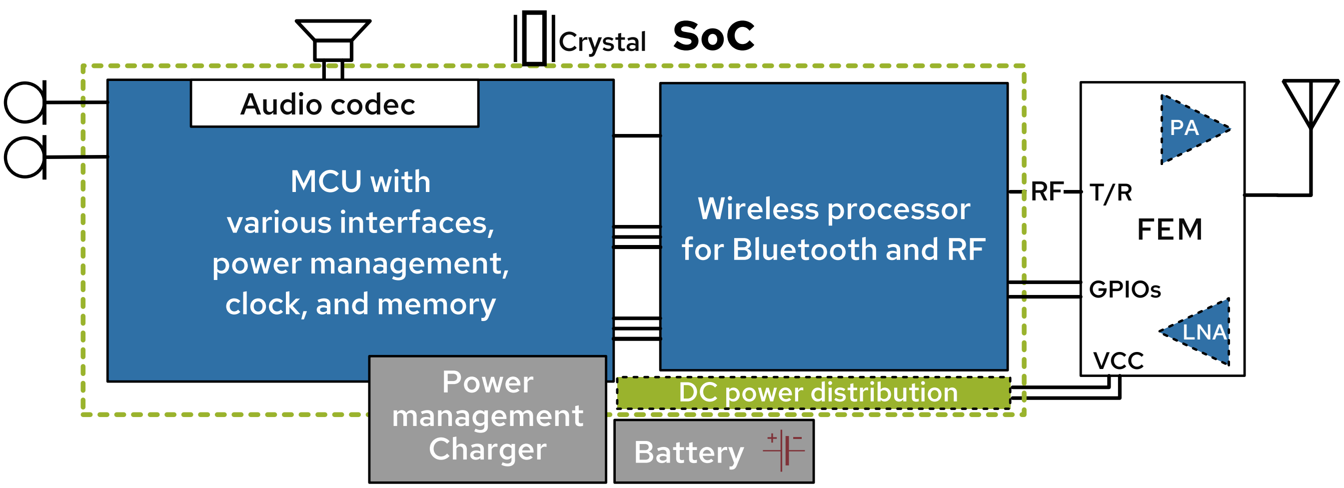

Figure 1. Functional representations of a Bluetooth hearing aid system

Why Add a FEM?

Bluetooth LE hearing aids typically radiate up to +10 dBm of RF power at the antenna, but the system must also account for losses introduced along the path from the SoC to the antenna. These include PCB trace losses, switch and matching-network losses, filter insertion loss, and variability in antenna efficiency caused by tight form-factor constraints across different hearing-aid models.

While the SoC can operate efficiently when delivering approximately −4 dBm to +4 dBm of output power, these integrated RF stages often cannot overcome system-level losses or maintain robust wireless performance across all operating conditions. For this reason, a radio-frequency front-end module (FEM) is often added to enhance output power, improve receiver sensitivity, and stabilize performance across a wide range of usage scenarios.

The term FEM can be somewhat misleading, as it suggests a traditional packaged module. In hearing-aid applications, the FEM is actually a highly compact RF IC—often as small as 1.32 mm × 1.32 mm with a height of only 0.35 mm and a 9- or 12-pin configuration. This tiny footprint allows designers to integrate the FEM alongside the SoC and supporting components within a system-in-package (SiP), enabling higher RF performance without compromising overall form factor or battery life.

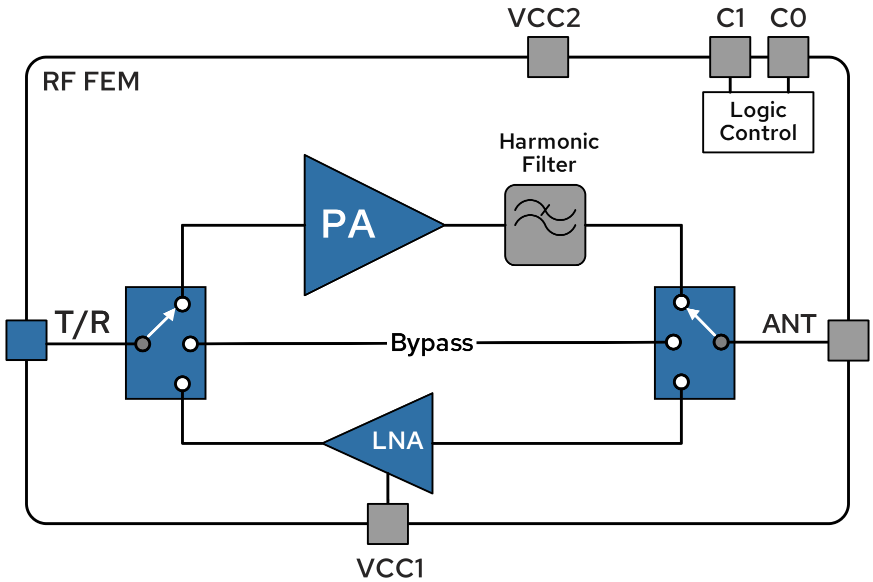

Figure 2. Typical FEM with TX, RX, Bypass, and sleep modes

A typical Bluetooth LE FEM, illustrated in Figure 2, integrates the key RF blocks needed to enhance the transmit and receive performance of a hearing aid with Bluetooth technology. These blocks typically include a power amplifier (PA), harmonic filtering, a low-noise amplifier (LNA), transmit/receive bypass paths, and low-power operating modes such as sleep or shutdown.

Incorporating a FEM provides several system-level advantages. On the transmit side, the PA supports output power levels above +10 dBm while maintaining high efficiency—often 40% or better—helping extend battery life even under increased link-budget demands. These devices are designed for low quiescent current and can operate from a wide range of supply voltages, allowing designers flexibility in how the FEM is powered.

On the receive side, the integrated LNA provides additional gain with a low noise-figure (NF), which improves overall sensitivity and helps maintain a reliable connection in challenging RF environments. Bypass mode allows the system to route signals directly between the SoC and antenna with only a few microamps of current, minimizing power consumption during low-demand conditions. A dedicated shutdown mode, typically drawing around 0.1 µA, further reduces standby/sleep power and contributes to longer overall battery life.

Choosing the Right FEM

Selecting a FEM that maintains high efficiency across a range of SoC platforms and battery conditions is essential. Figure 3 shows common interface configurations, demonstrating how the FEM connects between the SoC transceiver and the antenna and how supply voltage can be drawn either from the SoC's DC-DC converter or directly from the battery.

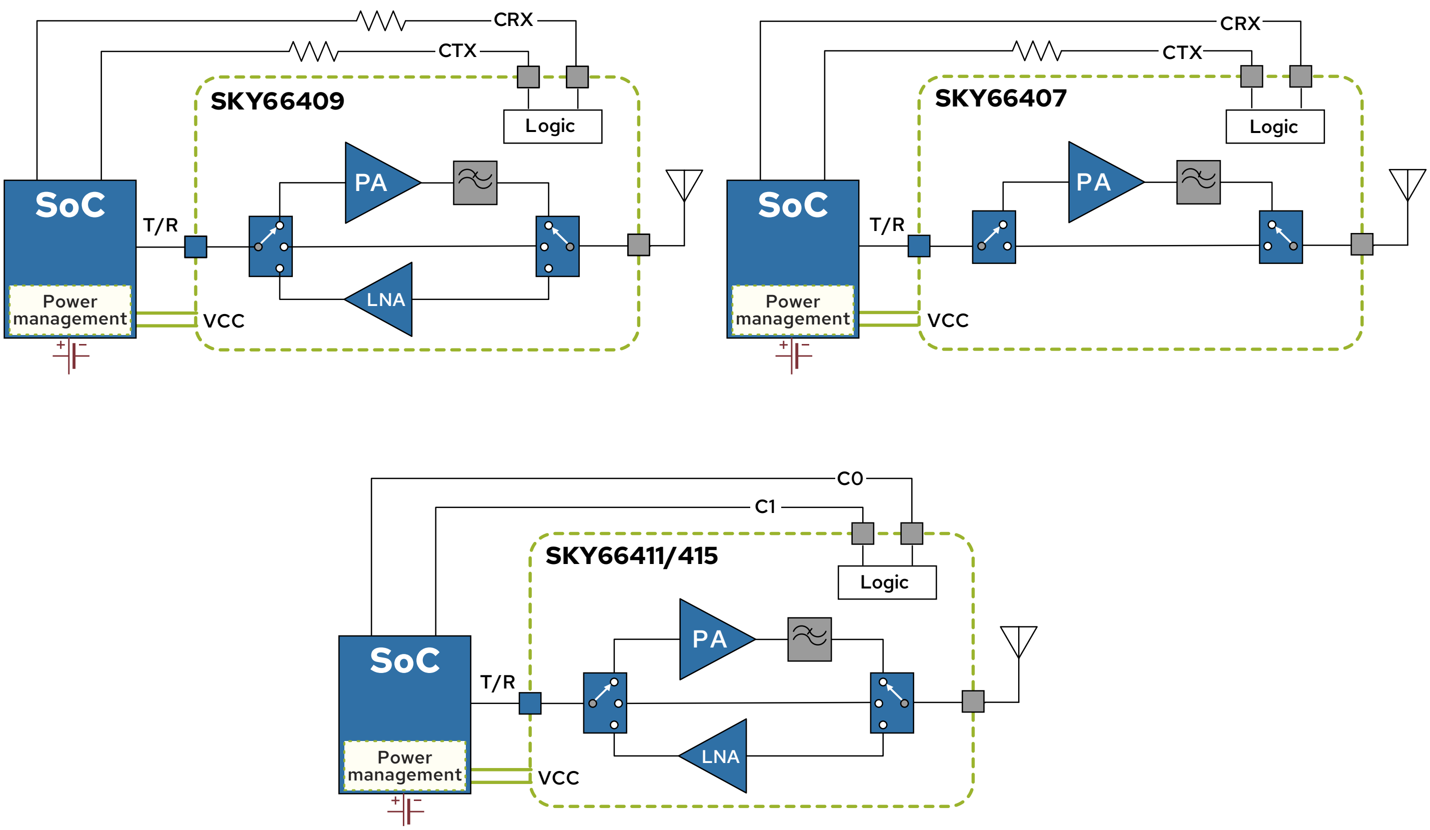

Figure 3. Typical interface configurations between the SoC and FEM

New FEM designs must evolve alongside rapidly advancing Bluetooth standards. As of June 2024, Bluetooth HDT2, HDT3, and HDT4 have become mandatory features [2], and with continued revisions, future devices are expected to incorporate support for HDT6 and HDT7.5.

These higher-throughput modes place additional demands on the RF front end. To meet these requirements, FEMs such as the SKY66409 are being adopted because they deliver higher output power, maintain robust linearity under advanced modulation schemes, and preserve efficiency even at elevated average power levels. These characteristics help ensure that hearing-aid designs can support HDT7.5 data rates without sacrificing battery life or link reliability.

Beyond HDT performance, Skyworks offers several FEM options that provide designers with flexibility across Bluetooth HDT and Bluetooth LE-only system architectures. The SKY66409 provides output power levels up to +15 dBm for Bluetooth LE, +10.5 dBm for Bluetooth Classic, HDT 2/3/4, and +9.5 dBm for HDT 6/7.5, all within a compact 1.25 mm × 1.7 mm × 0.35 mm CSP package and an operating range of 1.7–3.6 V, making it well-suited for battery-powered HDT-enabled hearing-aid platforms.

	Bluetooth HDT					
Bit rate → / Parameters ↓	2 Mb/s	3 Mb/s	4 Mb/s	6 Mb/s	7.5 Mb/s	Units
HDT designation	HDT2	HDT3	HDT4	HDT6	HDT7.5	
Mandatory/optional as of June 2024 DIPDr19	Mandatory	Mandatory	Mandatory	Optional	Optional	
Modulation	π/4-QPSK	π/4-QPSK	8PSK	16QAM	16QAM	
LE symbol rate	2	2	2	2	2	Msym/s
Forward error correction coding rate	1/2	3/4	2/3	3/4	15/16	
Max data rate	2	3	4	6	7.5	Mbps
EVM limit	-10	-13	-16	-19	-22	dB
PTX (fTX ± 3 MHz)	-10					dBm
PTX (fTX ± 4 MHz)	-20					dBm
PTX (fTX ± 5 MHz)	-20					dBm
PTX (fTX ≥ 6 MHz)	-30					dBm

Table 3. Bluetooth HDT data rates and modulation techniques. The PTX rows convey HDT spectral mask, which matches that of Bluetooth LE

For Bluetooth LE-focused designs operating from 2.4 V SoCs, the SKY66411 provides +8 dBm output power at 2.4 V (+10 dBm at 3 V) with greater than 40% efficiency, a 2.2 dB noise-figure LNA, sub-μA sleep current, and <1 μs switching time, all within a compact 1.32 mm × 1.32 mm × 0.35mm CSP package. With its wide 1.7–3.3 V operating range and efficient low-voltage performance, it aligns well with hearing-aid architectures that emphasize low-power Bluetooth LE connectivity.

The SKY66415 offers similar size and performance benefits to the SKY66411 but is optimized for SoCs operating around 1.8 V and delivers +11 dBm, making it an effective choice for Bluetooth LE-only designs where battery life is a primary constraint.

Together, these FEM options give designers the ability to match RF performance, efficiency, and size to the specific demands of both Bluetooth LE-only and Bluetooth HDT next-generation hearing aids.

Conclusion

Bluetooth-enabled hearing aids continue to advance as wireless standards evolve and as users increasingly rely on direct connectivity to their smartphones and other audio sources. The industry's transition from Bluetooth Classic to Bluetooth LE has enabled lower power consumption, support for hands-free calling and platform-specific streaming protocols.

As Bluetooth HDT becomes adopted across smartphones, future hearing-aid platforms will be able to support higher-quality voice/audio transmission, reduced latency, and more reliable performance through dual-mode operation of Bluetooth LE and Bluetooth HDT. These improvements will help make features like hands-free communication, voice-isolation modes, and assistive listening more robust and broadly available, while enabling new capabilities such as Auracast and shared audio.

Meeting these performance targets requires careful RF design. Although modern SoCs integrate much of the signal-processing and wireless functionality, incorporating a compact front-end module remains a practical way to extend range, maintain link stability, and preserve battery life—especially as higher-throughput modes place greater demands on transmit power and linearity.

Together, advancements in Bluetooth LE standards, SoC integration, FEM technology, and smartphone audio capabilities are shaping the next generation of hearing-aid designs, enabling more capable, power-efficient devices that deliver a consistently improved user experience.

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