5 Cochlear Implants in Clinical Use Worldwide Today

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5.1 The Working Principles of the Cochlear Implant

The Cochlear Implant consists of externally worn audio processor and the implant that is surgically placed under the skin on the surface of mastoid bone. The audio processor is worn comfortably behind the ear. The flexible electrode array is inserted into the cochlea. The cochlea is the part of the inner ear that converts sound waves into nerve signals which the brain processes as hearing. The apical region of the cochlea is responsible for detecting low-pitched sounds and the basal region is responsible for detecting high-pitched sounds. The cochlea is lined with thousands of sensory cells known as hair cells which detects the sound waves and send the sound information as nerve signals to the auditory nerve to the brain. For individuals with severe to profound sensorineural hearing loss, most of the hair cells do not function normally and are not able to send these nerve signals properly. A CI system bypasses the non-functioning hair cells by using electrical pulses that sends sound signal to spiral ganglia and then to the auditory nerve. To achieve this, the audio processor detects environmental sounds and digitally converts them into coded electrical signals. Audio processor transmits these signals through the skin to the implant by a communication coil. The implant translates these coded signals into electrical pulses which are transmitted along the electrode array to stimulate specific locations of the cochlea responsible for specific pitches. This targeted stimulation across the whole cochlea provides more accurate pitch perception for better sound quality.

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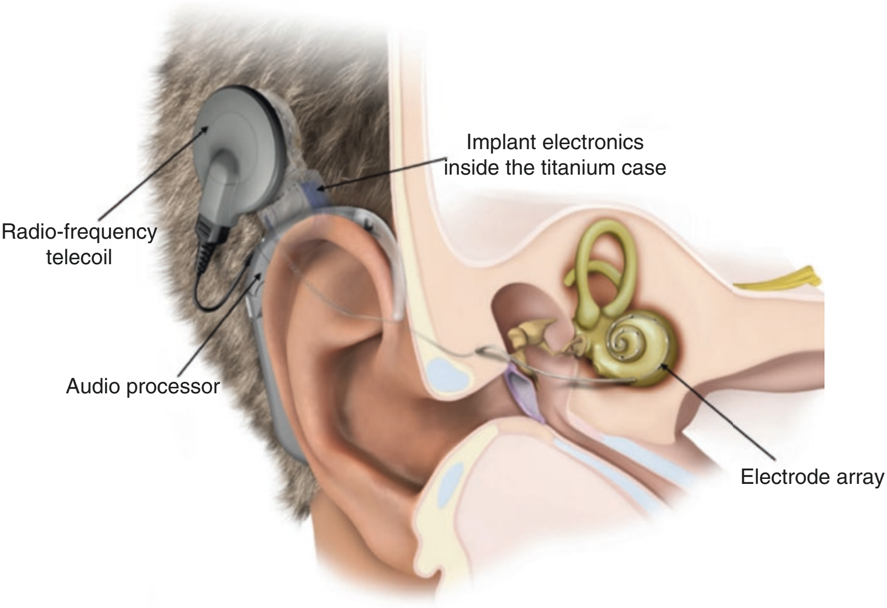
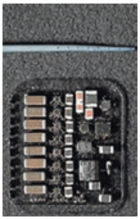


Fig. 5.1 Working principles of cochlear implant (Video 5.1)

By mimicking the natural function of hair cells, these pulses can deliver sound signals to spiral ganglia and to the auditory nerve. These signals are then transmitted by the auditory nerve to the brain, where they are interpreted as sound (Fig. 5.1).

5.2 MED-EL

5.2.1 Evolution of Implants and Processors

 World's first microelectronic multi-channel CI—1977	 Six- and four-channel implant variants—1978	 COMBI 40 system with eight channels—1994

 COMBI 40+ with 12 channels—1996	 PULSAR CI—2004	 Titanium SONATA CI—2006
 Titanium CONCERTO CI. Titanium case thinner than SONATA—2008	 SYNCHRONY CI with MRI compatible implant magnet—2014	 SYNCHRONY-2 CI with central exit electrode lead and MRI compatible implant magnet—2019

 Small portable audio processor—1979	 Small body-worn processor—1979	 Speech processor featuring an ear-level microphone—1989
 World's first behind-the-ear (BTE) audio processor—1991	 CIS PRO+ processor—1995	 TEMPO+ BTE audio processor—1999

 World's first DUET speech processor having hearing aid component to amplify low-frequency sound signals—2005	 OPUS audio processor having a sleek, switch-free design—2006	 OPUS 2 audio processor—2010
 RONDO single-unit processor—2013	 SONNET audio processor—2014	 RONDO 2 audio processor—2017
 RONDO 3 audio processor—2020		

5.2.2 Implants

Like any other CI brands, MED-EL also offers implants with implant electronics protected in a titanium case. The electronics inside the titanium case is of utmost importance.

SONATA implant was the first of its kind in MED-EL CI system and it is still in existence in several markets (Fig. 5.2).

CONCERTO implant was designed 25% thinner than the SONATA implant and both of these implants are compatible with up to 1.5 Tesla MRI, without the need for magnet removal (Fig. 5.3).

Fig. 5.2 SONATA

Fig. 5.3 CONCERTO

SYNCHRONY implant was designed with a revolutionized implant magnet design that can spin inside the magnetic case in response to any external magnet field making it a highly compatible magnet design up to 3 Tesla MRI. The rotatable, self-aligning magnet greatly reduces torque to increase patient comfort during MRI scans. SONATA, CONCERTO, and SYNCHRONY implants have the electrode lead exit from the side of the implant (Fig. 5.4).

SYNCHRONY 2 implant is the latest implant design that has the 3 Tesla MRI compatible magnet design and has the electrode lead exit from the central location of the implant.

The magnet from all these four implants can only be removed from the bottom side of the implant, making dislocation of the magnet due to trauma almost impossible. CONCERTO PIN and SYNCHRONY PIN implants feature titanium fixation pins to secure the placement of the implant for outstanding stability (Fig. 5.5).

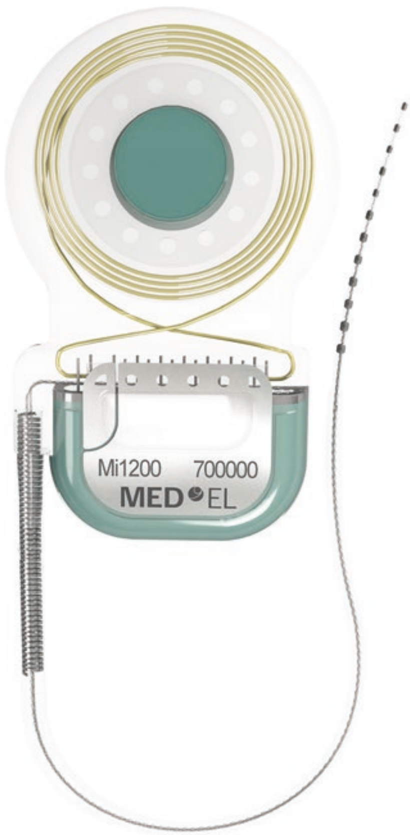
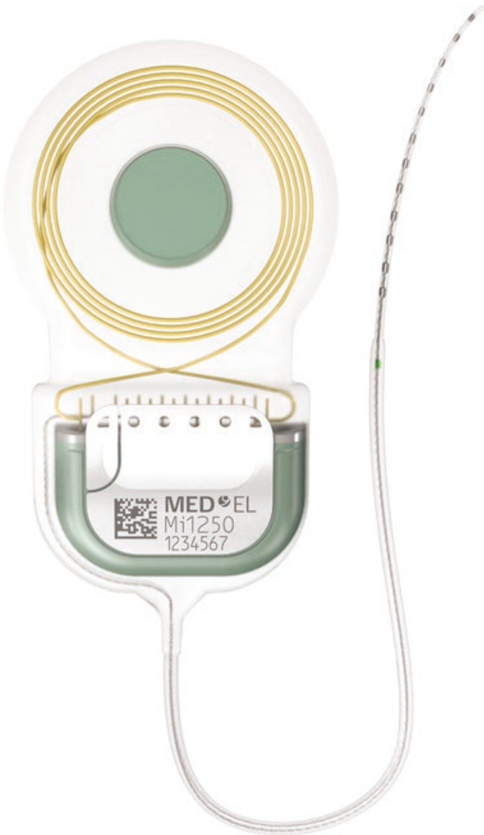


Fig. 5.4 SYNCHRONY

Fig. 5.5 SYNCHRONY 2



Safety Capacitors: All these four implant variants from MED-EL have one thing in common in its electronics design, which is the safety capacitors for every individual stimulating channels. Safety capacitors act like filters in filtering out any unsafe direct current components, if there will be any such component coming out of the implant electronics, safeguarding the intra-cochlear neuronal elements and preventing the platinum contact pads from dissolving.

5.2.3 Audio Processors and Accessories

MED-EL offers audio processors in two different variants, namely, *behind-the-ear* (BTE) and single-unit processor as shown. From the body-worn type processor, MED-EL upgraded it to BTE type in the early 1990s.

OPUS 2 is one of the earliest designs that are in commercial existence since 2010 that carries dual-loop automatic gain control (AGC) function. AGC is essential in attenuating sound signal above 1.2 kHz and enhances sound signals below 1.2 kHz offering better speech understanding to the listeners. OPUS 2 design came up with

XS battery pack making it the thinnest and lightest audio processor in the market at that time (Fig. 5.6).

SONNET was the next generation BTE audio processor that was introduced in 2014 that incorporated dual microphone offering better directionality to the users. Also, the SONNET had a new feature, wind noise reduction (WNR) which in combination with the dual microphone, offering a much clearer hearing experience to the users (Fig. 5.7).

Fig. 5.6 OPUS 2

Fig. 5.7 SONNET

In 2019, *SONNET 2* BTE processor was introduced that incorporated three additional features, namely, transient noise reduction (TNR), ambient noise reduction (ANR), and adaptive intelligence (AI) making it the most advanced BTE audio processor in the market (Fig. 5.8).

RONDO was the first all-in-one audio processor, the battery pack, control unit, and the radio frequency telecoil all-in-one unit. MED-EL was the CI company to design the single-unit audio processor and brought it to the market in the year 2013 (Fig. 5.9).

Fig. 5.8 SONNET 2

Fig. 5.9 RONDO

RONDO 2 was the second-generation single-unit processor that was designed slightly thinner and lighter than RONDO. RONDO 2 was designed for wireless charging of the battery without the need for battery removal and it was again the industry first at that time. Both RONDO and RONDO 2 are implemented with AGC function (Fig. 5.10).

In 2020, *RONDO 3* was introduced in the market that has all the features including AGC, WNR, TNR, ANR, and AI, along with wireless charging of the batteries (Fig. 5.11).

Fig. 5.10 RONDO 2

Fig. 5.11 RONDO 3

5.2.4 Electric-Acoustic Stimulation (EAS)

In some patients, the high frequency (HF) responsible hair cells are permanently damaged. This may occur due to variety of reasons, including aging, noise-related hearing loss (HL), genetics, medication side effects, and different diseases, causing severe to profound HL in the HF region. However, the low-frequency (LF) residual hearing with mild to moderate HL could still be utilized in such patients through a sound amplification device, like hearing aid (HA). The exact frequency range and the degree to which the HL occurs can be detected from the pure tone audiogram of the patient, tested in the quiet condition. Figure is a typical audiogram of an extended indication (indication 2) of a partially deaf patient with severe to profound HL in the HF region which extends from 1500 to 8000 Hz, and mild to moderate HL from LF to mid-frequencies in the range between 125 and 1500 Hz. A normal hearing is referred to when the hearing threshold is within 25 decibels (dB) of HL across all frequencies (Fig. 5.12).

The length of the electrode array must be shorter just to cover the HF region with electrical stimulation leaving the LF region for acoustical amplification using hearing aids (Fig. 5.13).

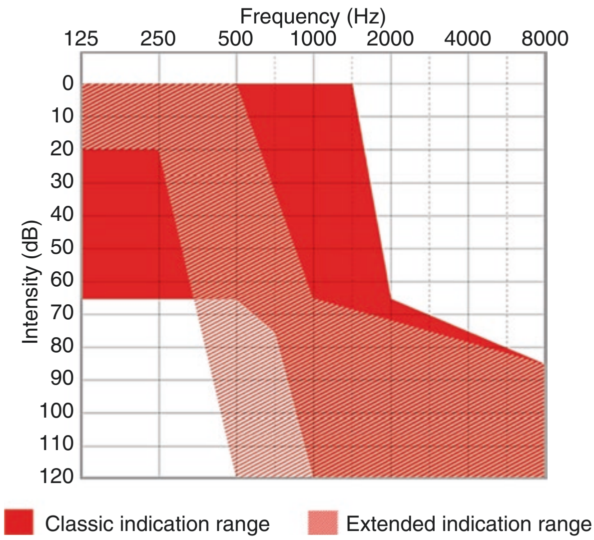


Fig. 5.12 Typical audiogram of a partially deaf patient with severe to profound HL in the HF region: indication from the earlier times when the functional LF residual hearing cut-off was kept at 500 Hz which was extended to 1500 Hz under expanded indication criteria

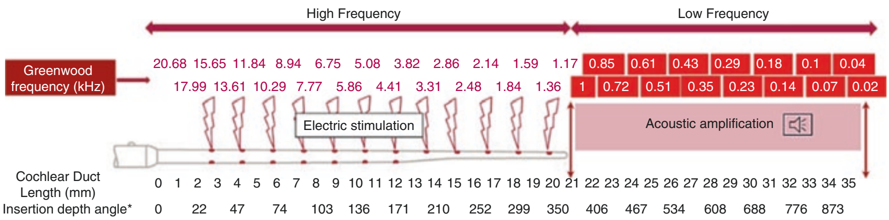


Fig. 5.13 Schematic representation of electric stimulation in the HF region and acoustic amplification in the LF region in an average-sized cochlea

MED-EL's EAS hearing system consists of implant stimulator with a shorter length electrode array in the range of 24 or 20 mm and *behind-the-ear* (BTE) SONNET EAS audio processor that is combined with the hearing aid (HA) as a unified audio processor. The SONNET EAS audio processor sends the amplified acoustic signal through the earmold into the ear canal (Fig. 5.14).

Fig. 5.14 SONNET EAS

SONNET EAS processor offers

- Directional microphones
- Six-channel acoustic amplification
- Gain of up to 48 dB
- Maximum power output of 118 dB SPL.

The timing of both the electric and acoustic signals is matched, which enables a full, rich perception of sound.

5.2.5 MED-EL Accessories

MED-El offers accessories to control the audio processors and to link it with other audio streaming devices. In 2010, MED-EL introduced a remote control (*FineTuner*) to control the OPUS 2 audio processor mainly for adjusting the volume and program selection. SONNET, SONNET 2, and RONDO 3 audio processors can be connected to any audio streaming devices using *AudioLink*, a Bluetooth connectivity device (Fig. 5.15).

Fig. 5.15 FineTuner and AudioLink

5.2.6 Electrodes

FLEX series carries five different electrode array lengths.

- FLEX SOFT is used in patients with profound hearing loss across all frequencies.
- FLEX28 is used in patients with profound hearing loss or with some low-frequency residual hearing.
- FLEX26 is used in patients with profound hearing loss or with some low-frequency residual hearing.
- FLEX24 and FLEX20 are mainly for the patients with good functional low-frequency residual hearing. These two short length electrodes are used to electrically stimulate the basal turn of the cochlea and the low-frequency region is amplified using hearing aid.

The FLEX electrode arrays have the apical five contacts arranged in a single line configuration making the electrode tip highly flexible to minimize the intra-cochlear electrode insertion trauma (Fig. 5.16).

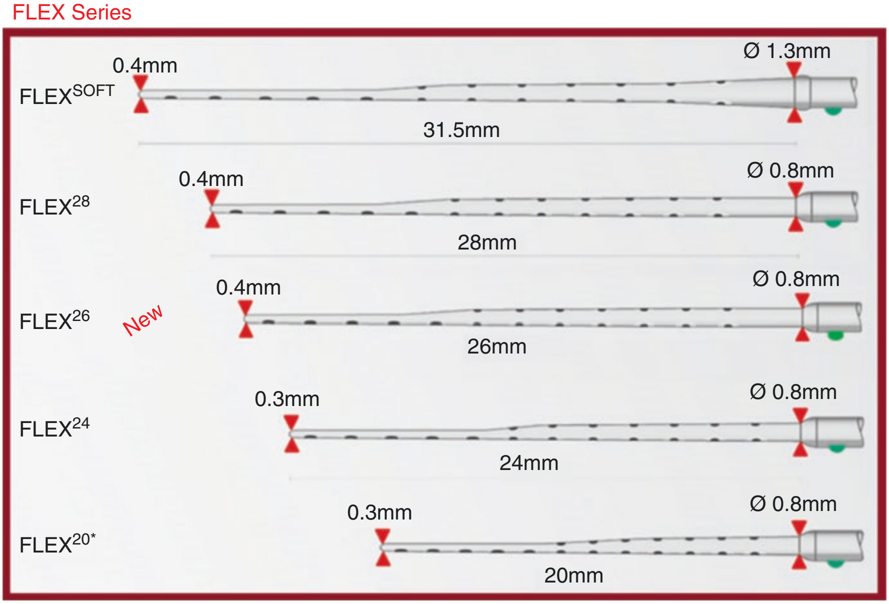


Fig. 5.16 Flex electrodes

FORM series carries two different electrode array lengths.

- FORM24 is mainly for Mondini's deformation type (IP type II) cochlea.
- FORM19 is for severely deformed incomplete partition (IP type I).

Both IP type I and IP type II are mostly characterized with enlarged vestibular aqueduct or enlarged internal auditory canal, posing the risk of cerebrospinal fluid (CSF) gusher. The CORK insertion stopper could assist the operating surgeon to seal the cochlea (Fig. 5.17).

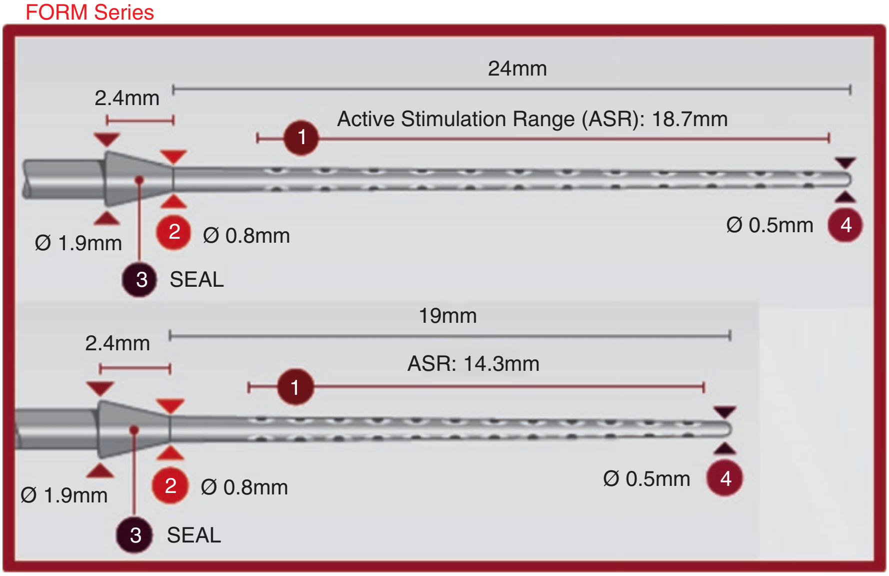


Fig. 5.17 FORM electrodes

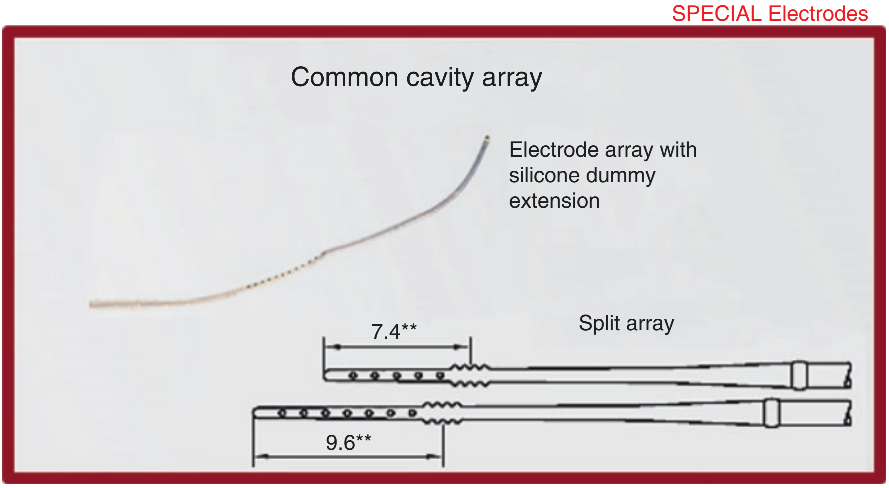


Fig. 5.18 Special electrodes

Special electrodes including the SPLIT array and common cavity array are only available upon a special request (Custom Made Device).

The SPLIT electrode is designed for fully ossified cochlea. Ossified cochlea does not offer a chance for the operating surgeon to place a regular electrode array in the cochlear lumen. For the SPLIT electrode array placement, the surgeon has to drill two channels in the ossified cochlea to place the two branch arrays.

Common cavity array is specifically for the common cavity deformation, where this array would offer a nice loopy placement inside the cavity (Fig. 5.18).

5.2.7 Signal Processing Strategies in MED-EL's Audio Processor

MED-EL's audio processors (OPUS 2, SONNET, SONNET 2, RONDO, RONDO-2, and RONDO-3) have front-end processing strategies that model/mimic the functionality of external and middle ear covering the directionality and filtering processes. The sound coding strategies are the ones that model/mimic the inner-ear functionality.

Front-end processing is brought under the term Automatic Sound Management (ASM). OPUS 2, RONDO, and RONDO 2 processors have ASM 1.0, that includes the automatic gain control (AGC), which is essential to attenuate high-level signal and enhances low-level signal, enabling the CI user to hear even a very soft sound signal. ASM 2.0 was the next general front-end processing, which includes new features microphone directionality (MD) and wind noise reduction (WNR) in addition to AGC. ASM 2.0 is available in SONNET audio processor. ASM 3.0 is the current generation front-end processing, which includes ambient noise reduction (ANR), transient noise reduction (TNR), and adaptive intelligence (AI) in addition to AGC, MD, and WNR from ASM 1.0 and 2.0. SONNET 2 and RONDO 3 are equipped with ASM 3.0.

MED-EL's sound coding strategy is based on continuous interleaved sampling (CIS) that was proposed by Prof. Blake Wilson in 1999, from the Duke University. The Fine Structure Processing (FSP) strategy is an advanced version of CIS strategy that includes phase-locking of low-frequency signals to the neurons in the apex of the cochlea where they are naturally tuned to process low-frequency signals. The FSP can be applied to the apical two channels only. FS4 was a next generation sound coding strategy that extended the FSP to the apical four channels. In both FSP and FS4 strategies, only one of the apical channels would fire electrical pulse at a time. FS4-p is the latest sound coding strategy that would enable more than one apical channel to fire electrical pulse at a time. All the audio processors of MED-EL that are in clinical use can be made to use any of the sound coding strategies that are mentioned above.

5.3 Cochlear

5.3.1 Evolution

- 1979 A medical device group Nucleus, Cochlear, and the Australian government partnered together to develop a commercially available cochlear implant.
- 1982 The first commercial Nucleus implant was released, and the recipient was Graham C
- 1985 The Nucleus Mini22 implant with wearable sound processor was the first multi-channel device to receive FDA approval.
- 1998 ESPrit the first multi-channel behind-the-ear processor was introduced.
- 2000 Nucleus 24 Contour perimodiolar electrode array was introduced.
- 2005 Nucleus Freedom system released.

- 2008 Nucleus freedom available for N22 implants. Cochlear Hybrid Sound processor introduced for electric and acoustic stimulation.
- 2016 Cochlear launched Slim Modiolar Electrode the worlds thinnest lightest full-length perimodiolar electrode.
- 2016 Kanso introduced smallest lightest off-the-ear sound processor.

5.3.2 Implant Generations (Figs. 5.19 and 5.20)

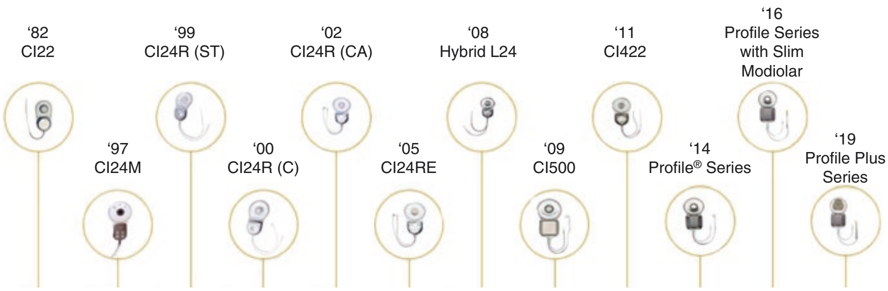


Fig. 5.19 Implants

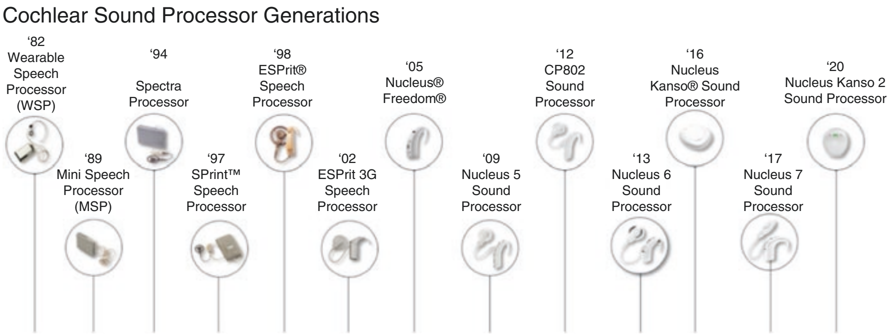


Fig. 5.20 Processor

Fig. 5.21 Nucleus® CI24R(ST)

5.3.3 Implants

5.3.3.1 Nucleus® CI24R(ST) (Fig. 5.21)

- Simplified for Surgery
- Smaller design
- Re-modeled receiver/stimulator
- Vertically aligned exit leads
- Proven Nucleus® Performance
- Established electrode technology
- Demonstrated recipient performance

5.3.3.2 Nucleus® CI24R(C) (Fig. 5.22)

- Contoured for Performance
- 22 half-banded electrodes designed to be safely placed adjacent to the modiolar wall
- Contoured for Safety
- Array designed without invasive bands or positioners
- Simplified for surgery
- Smaller implant with circular pedestal for easier drilling

Fig. 5.22 Nucleus® CI24R(C)

Fig. 5.23 Nucleus CI24R(CA)

5.3.3.3 Nucleus® CI24R(CA) (Fig. 5.23)

Proven reliability of the CI24R receiver/stimulator [1]

The Nucleus® 24 Contour Advance™ features the unique Contour™ Electrode with Softip™, designed to preserve the delicate structures of the cochlea, and aid in consistent perimodiolar positioning [2, 3]. Intelligently engineered geometry, softness, and flexibility enable the Softip™ to glide smoothly through the lumen of the cochlea while minimizing lateral wall forces [3]. Smooth insertion improves consistency of perimodiolar positioning, as the tip enables the electrode array to easily settle in its resting position.

It is recommended that surgeons use the Advance Off-Stylet™ (AOS) insertion technique (see over) to realize the full benefits of the Softip™ design.

5.3.3.4 Nucleus® CI24RE (ST) Cochlear Implant (Fig. 5.24)

- Receiver stimulator in titanium casing
- Removable magnet for MRI safety
- MRI safe at 3.0 Tesla with magnet removed
- Implant coil, enabling telemetry
- Two extracochlear electrodes for different stimulation modes, and high performance.

Fig. 5.24 Nucleus® CI24RE (ST)

Fig. 5.25 Hybrid L24

5.3.3.5 Hybrid L24 Cochlear Implant (Fig. 5.25)

Cochlear™ Hybrid™ System is a new treatment option available to address the unique needs of patients with severe to profound high frequency hearing loss. This exciting technology provides access to high frequency information via electrical stimulation to improve speech perception abilities. At the same time, Hybrid retains and integrates acoustically useful low-frequency hearing that may lead to additional benefits such as the ability to listen in the presence of background noise and to appreciate music.

The Cochlear Hybrid System is the first truly integrated electro-acoustic stimulation solution available for those with severe to profound high frequency hearing loss. The Nucleus® Hybrid L24 is the surgically implanted component of the Hybrid System and is designed to restore hearing in higher frequencies through electrical stimulation. The Hybrid L24 implant uses the same technology as the benchmark setting Nucleus Freedom™ cochlear implant. Since the release of the first multi-channel system in 1982, Cochlear has produced several generations of cochlear implants, with each successive generation of implant being more reliable than the last. Over that time the improvements made in implant technology have resulted in improved hearing outcomes. The Hybrid L24 implant continues in this tradition and provides significant benefit for your patients.

Fig. 5.26 Nucleus CI422

5.3.3.6 Nucleus CI422 Cochlear Implant (Fig. 5.26)

- Receiver/stimulator in titanium casing for high impact resistance
- Removable magnet for MRI safety
- MRI safe at 3 Tesla with magnet removed. Non-magnetic plug to assist MRI procedures
- Two extracochlear electrodes for different stimulation modes, and high performance telemetry

5.3.3.7 Nucleus® CI632 (Fig. 5.27)

Nucleus Profile Plus with Slim Modiolar electrode

The thinnest implant body with no pedestal designed to minimize bone excavation and skin protrusion

Implant coil enabling telemetry

Titanium casing for impact resistance

Symmetrical side-by-side exit leads from main casing. Same procedure for left and right ear.

Removable magnet for MRI safety to minimize image distortion. MRI at 1.5 and 3.0 Tesla with magnet in place.

Fig. 5.27 Nucleus CI632

5.3.4 Audio Processors

5.3.4.1 Nucleus Freedom Sound Processor

New automatic phone detection through Auto Telecoil for optimized phone use—this unique and patented feature is only available on Cochlear's CP810 Sound Processor.

Dual omnidirectional microphones—these sophisticated microphones capture more sound and enhance directionality, while improving hearing performance outcomes.

5.3.4.2 Nucleus CP802 Sound Processor (Fig. 5.28)

The CP802 Sound Processor has been designed for humid and dusty climates and to withstand the rough and tumble of everyday life. It is tough and reliable.

The CP802 has been designed to be simple, so individuals feel confident wearing and using it in any situation.

Fig. 5.28 Nucleus CP802

5.3.4.3 Affordable to Use

Cochlear's CP802 Sound Processor has been designed to be affordable. Everyone wants to live their life their way—to talk, laugh, sing, and live without compromise.

So you, or your child can become more involved in everyday life such as sports activities, sharing a joke with friends or telling your family about their day.

5.3.4.4 Connectivity

- Telecoil: This can be used to improve their hearing in a wide range of situations, such as: on the telephone, in cinemas, churches, and meeting rooms (where there is a hearing loop installed).
- FM: The CP802 includes compatible components that allow it to pick up signals from FM systems so your child can hear the teachers voice more clearly.
- Programming: Custom Sound™ Suite 4.3 or higher.

5.3.4.5 Nucleus® CP810 Sound Processor (Fig. 5.29)

SmartSound™—offers customized settings for four different listening environments:

- *EVERYDAY*—designed for everyday listening situations such as at home or in the office or classroom.
- *NOISE*—designed for noisy environments such as crossing a busy road, or at a party.

- *FOCUS*—designed for focused listening when the speaker is in front and background noise is present, such as at a café.
- *MUSIC*—designed for listening to live or recorded music.

New automatic phone detection through Auto Telecoil for optimized phone use—this unique and patented feature is only available on Cochlear's CP810 Sound Processor.

Dual omnidirectional microphones—these sophisticated microphones capture more sound and enhance directionality, while improving hearing performance outcomes.

Fig. 5.29 Nucleus CP810

5.3.4.6 Water Resistance

When using a rechargeable battery module, the CP810 Sound Processor has a dust and ingress protection rating of IP57.

When using a standard battery module (with disposable batteries) the CP810 Sound Processor has a rating of IP44. IP57 and IP44 are rated according to International Standard IEC 60529.

5.3.5 Nucleus 6 Sound Processor (Fig. 5.30)

Built on a completely new microchip platform with five times the processing power of its predecessor (the Cochlear Nucleus CP810 Sound Processor), the CP910 is able to support significant advances in sound processing that deliver new levels of hearing performance.

SmartSound iQ, our most sophisticated sound management system yet, has a range of individual technologies that are designed to work together seamlessly to meet the user's needs in every listening environment. Even better, it can do this automatically, so they do not have to worry about it.

Fig. 5.30 Nucleus CP910

5.3.5.1 Hearing Performance

- *Quiet*: For appreciating soft sounds such as soft incidental speech and environmental sounds in quiet environments.
- *Noise*: For noisy environments such as large crowds, the roar of traffic, or the hum of machinery, when it is still important to hear incidental speech.
- *Speech:* For conversations in relatively quiet environments, like family discussions around the dinner table. Speech in Noise such as a café or restaurant where there is a lot of other competing conversation happening.
- *Wind:* For enjoying the windy outdoors without the distracting noise.
- *Music:* For when the user wants to balance the need to understand lyrics with the broader music experience.

5.3.5.2 Hybrid Mode

For those who have residual hearing, the CP910 is capable of operating both as a hearing aid and cochlear implant system simultaneously and seamlessly.

In a few simple steps, a hearing professional can swap the earhook on the sound processor with one that accommodates the acoustic hearing aid component. Natural hearing is boosted by the hearing aid and complemented by the cochlear implant.

5.3.5.3 Water Resistance

The sound processor has an IP57 rating for protection against failure from dust and temporary immersion in water when it is worn with a rechargeable battery module, a coil and coil cable, a closed accessory socket, and no acoustic component.

When worn in Hybrid mode with an acoustic component and a standard tamper resistant battery module, the sound processor is IP44 rated for protection against failure from splashing water or access of foreign objects 1.0 mm in diameter or larger.

The CP910 also has an advanced water-repellent coating.

5.3.5.4 Nucleus CP920 (Fig. 5.31)

The Cochlear Nucleus CP920 Sound Processor uses sophisticated technology to deliver hearing performance across a range of listening environments automatically.

For those preferring to be more involved in monitoring or managing their hearing, the CP920 Sound Processor can communicate wirelessly with two optional remote management accessories: the Cochlear Nucleus CR210 Remote Control and the Cochlear Nucleus CR230 Remote Assistant.

Fig. 5.31 Nucleus CP920

5.3.5.5 Hybrid Mode

For those who have residual hearing, the CP920 is capable of operating both as a hearing aid and cochlear implant system simultaneously and seamlessly.

In a few simple steps, a hearing professional can swap the earhook on the sound processor with one that accommodates the acoustic hearing aid component. Natural hearing is boosted by the hearing aid and complemented by the cochlear implant.

The sound processor has an IP57 rating for protection against failure from dust and temporary immersion in water when it is worn with a rechargeable battery module, a coil and coil cable, and no acoustic component.

When worn in Hybrid mode with an acoustic component and a standard tamper resistant battery module, the sound processor is IP44 rated for protection against failure from splashing water or access of foreign objects 1.0 mm in diameter or larger.

The CP920 also has an advanced water-repellent coating.

5.3.5.6 Nucleus Kanso Sound Processor (Fig. 5.32)

- Simple, discreet, off-the-ear sound processor with the proven technology of Nucleus 6.
- Kanso helps recipients hear with clarity using SmartSound iQ with SCAN and dual microphones and is compatible with Cochlear True Wireless™ devices.
- Kanso is dust and splash resistant.
- SmartSound iQ with SCAN
- Dual microphones
- IP54 rating for water and dust resistance
- Seven magnet strengths available
- LED status monitoring

Fig. 5.32 Nucleus Kanso sound processor

- Compatible with Cochlear Nucleus CR210
- Remote Control and CR230 Remote Assistant
- Compatible with Cochlear True Wireless devices
- FM compatibility available with the Cochlear Wireless Mini Microphone 2+*
- Telecoil optimized for room loops

5.3.5.7 Nucleus 7 Sound Processor (Fig. 5.33)

Delivering clinically proven hearing outcomes, the Nucleus 7 Sound Processor is the smallest, lightest, and only cochlear implant sound processor offering connectivity and control directly from a user's smartphone.

With the Nucleus Smart App, recipients can take control of their hearing like never before. Made for iPhone connectivity allows recipients to stream calls, music, and entertainment directly to their sound processor from their iPhone, or wirelessly from their Android™ device via the Cochlear Wireless Phone Clip.

Meanwhile, Cochlear's most advanced sound management system—SmartSound iQ with SCAN—helps recipients hear their best even in noisy environments.

Fig. 5.33 Nucleus 7 sound processor

Fig. 5.34 Kanso 2 sound processor

5.3.5.8 Nucleus Kanso 2 Sound Processor (Fig. 5.34)

- Smallest off-the-ear cochlear implant sound processor
- SmartSound iQ with SCAN

- ForwardFocus (if enabled by a clinician)
- Dual omnidirectional microphones
- Wireless inductive charging
- Integrated rechargeable lithium-ion battery
- IP rating for water and dust resistance: IP68~
- Waterproof with Aqua+
- Six magnet strengths available with Profile Plus series implant, seven available for compatible prior implant generations
- LED status monitoring
- Compatible with the Nucleus Smart App
- Compatible with Cochlear Nucleus CR310 Remote Control
- Direct streaming from compatible Apple and Android devices#
- Streaming from other Bluetooth®-enabled devices via the Cochlear Wireless Phone Clip
- Compatible with Cochlear True Wireless™ devices

5.3.6 Nucleus® Freedom® Sound Processor

The availability of multiple coding strategies and flexible parameter choices, allows clinicians to customize an individual's speech processor program (MAP) which results in significant improvements in hearing performance. The Freedom sound processor delivers a broad range of speech coding strategies including ACE, SPEAK, and CIS for optimal hearing outcomes.

ACE™: Advanced Combination Encoders is a unique family of strategies introduced with the Nucleus 24 implant series, which provides a wealth of both pitch and timing information and has been found to provide the best outcomes for the majority of Nucleus recipients. ACE is a high rate roving strategy using many channels. ACE combines the strengths of SPEAK and CIS to improve both temporal and spectral representation of the speech signal.

CIS: Continuous Interleaved Sampling presents high fixed rate stimulation to a relatively limited set of channels. The use of high rate stimulation provides important information on the timing of speech. CIS is especially useful for recipients with a limited number of available electrodes.

SPEAK: An interleaved pulsatile strategy. It delivers stimulation at a moderate rate and dynamically selects the number and location of electrodes to be activated, depending on the intensity and frequency characteristics of speech. It is rich in spectral information that has been proven to provide excellent outcomes for recipients. SPEAK provides excellent energy efficiency.

In addition to three speech coding strategies, Freedom also offers SmartSound™ pre-processing technologies that have been shown to significantly increase speech intelligibility and perception. SmartSound models natural hearing by adjusting audibility overall, as well as by frequency. Louder frequencies can be reduced for comfort while softer sounds can be increased. This helps ensure that recipients will hear complex sounds like speech and music easily, completely and comfortably.

5.3.7 Nucleus CP802 Sound Processor

The CP802 speech processor offers ACE, CIS, and SPEAK digital speech coding strategies.

ACE™: Advanced Combination Encoders is a unique family of strategies introduced with the Nucleus 24 implant series, which provides a wealth of both pitch and timing information and has been found to provide the best outcomes for the majority of Nucleus recipients. ACE is a high rate roving strategy using many channels. ACE combines the strengths of SPEAK and CIS to improve both temporal and spectral representation of the speech signal.

CIS: Continuous Interleaved Sampling presents high fixed rate stimulation to a relatively limited set of channels. The use of high rate stimulation provides important information on the timing of speech. CIS is especially useful for recipients with a limited number of available electrodes.

SPEAK: an interleaved pulsatile strategy delivers stimulation at a moderate rate and dynamically selects the number and location of electrodes to be activated, depending on the intensity and frequency characteristics of speech. It is rich in spectral information that has been proven to provide excellent outcomes for recipients. SPEAK provides excellent energy efficiency.

In addition to three speech coding strategies, CP 802™ also offers SmartSound™ pre-processing technology that results in significant increase in speech intelligibility and perception with the help of inbuilt dual microphones. SmartSound™ models natural hearing by adjusting audibility overall, as well as by frequency. Louder frequencies can be reduced for comfort while softer sounds can be increased. This helps ensure that recipients will hear complex sounds like speech and music easily, completely and comfortably.

5.3.8 Early and Recent Speech Processor and Speech Coding

The Nucleus Freedom speech processor consists of the transmitting coil and the BTE processing unit and controller. The modular design of the speech processor allows recipients to use a BTE or Body-worn controller. The main BTE processing unit contains all the relevant speech processing and MAP functions and is therefore unaffected by changing the controller. The controller contains the batteries, user-adjustable controls, and an LCD screen. The BTE controller uses three Zinc Air disposable batteries or a Lithium-ion rechargeable pack. A two-battery BTE controller is also available. The Body-worn controller uses two AAA Alkaline or rechargeable batteries. The BTE processing unit contains a custom digital integrated circuit containing four parallel digital signal processing (DSP) units, a microcontroller, and memory.

The ultralow power custom DSP architecture is capable of performing more than 180 million operations per second, allowing for future input processing and speech coding upgrades. The parallel processing architecture uses much less power than would be required if a single processing unit was used. Up to four MAPs can be stored in the processor. Each MAP is independent of the others, thus can differ in

T-SPL and C-SPL levels, SmartSound options, and other MAP functions. The unit also contains two microphones, an omnidirectional and a directional. In normal operation the directional microphone is used. The new SmartSound beamformer option, Beam, uses both microphones.

The Freedom processor can be programmed with any of the speech coding strategies: SPEAK, ACE, and CIS. The stimulation rate for SPEAK is 250 Hz per channel. Stimulation rates for ACE and CIS are between 250 Hz and 3.5 kHz per channel.

Year	Sound processor	Speech coding strategy	Reference
1982	Wearable Speech Processor (WSP)	F0F2 speech coding strategy F0F1F2 (introduced in 1986)	• Dowell, R. C., Blamey, P. J., Seligman, P. M., Brown, A. M., & Clark, G. M. (1986). Speech recognition performance with a two-formant coding strategy for a multi-channel cochlear prosthesis. Australian Journal of Audiology, (suppl.2), 11.
1989	Mini Speech Processor (MSP)	MPEAK	• Skinner MW, Holden LK, Holden TA, et al. Performance of postlinguistically deaf adults with the Wearable Speech Processor (WSP III) and Mini Speech • Processor (MSP) of the Nucleus Multi-Electrode Cochlear Implant. Ear Hear 12:3–22, 1991. • Holden LK, Skinner MW, Holden TA. Speech recognition with the MPEAK and SPEAK speech coding strategies of the Nucleus Cochlear Implant. Otolaryngol Head Neck Surg. 1997 Feb;116(2):163–7. https://doi.org/10.1016/s0194-5998(97)70319-x. PMID: 9051058. • Skinner MW, Fourakis MS, Holden TA, Holden LK, Demorest ME. Identification of speech by cochlear implant recipients with the Multipeak (MPEAK) and Spectral Peak (SPEAK) speech coding strategies. I. Vowels. Ear Hear. 1996 Jun;17(3):182–97. https://doi.org/10.1097/00003446-199606000-00002. PMID: 8807261.
1994	Spectra Processor	SPEAK	• Skinner MW, Clark GM, Whitford LA, Seligman PM, Staller SJ, Shipp DB, Shallop JK, Everingham C, Menapace CM, Arndt PL, et al. Evaluation of a new spectral peak coding strategy for the Nucleus 22 Channel Cochlear Implant System. Am J Otol. 1994 Nov;15 Suppl 2:15–27. PMID: 8572106.

Year	Sound processor	Speech coding strategy	Reference
1997	Sprint™ Speech Processor	ACE, SPEAK, and CIS	• Pasanisi E, Bacciu A, Vincenti V, Guida M, Berghenti MT, Barbot A, Panu F, Bacciu S. Comparison of speech perception benefits with SPEAK and ACE coding strategies in pediatric Nucleus CI24M cochlear implant recipients. Int J Pediatr Otorhinolaryngol. 2002 Jun 17;64(2):159–63. https://doi.org/10.1016/s0165-5876(02)00075-7. • Skinner, Margaret & Holden, Laura & Whitford, Lesley & Plant, Kerrie & Psarros, Colleen & Holden, Timothy. (2002). Speech Recognition with the Nucleus 24 SPEAK, ACE, and CIS Speech Coding Strategies in Newly Implanted Adults. Ear and hearing. 23: 207–23. https://doi.org/10.1097/00003446-200206000-00005. • Wilson BS, Finley CC, Lawson DT, et al. Better speech recognition with cochlear implants. Nature 352:236–238, 1991a. • Skinner, MW, Arndt, PL, Staller, SJ. Nucleus 24 advanced encoder conversion study: performance versus preference. Ear Hear. 2002;23(suppl): 2S–17S.
1998	ESPrit® Speech Processor[a]	SPEAK ACE (up to 9 kHz—introduced in 2000)	• Note: N22 ESPrit did not have ACE • Patrick JF, Busby PA, Gibson PJ. The Development of the Nucleus® FreedomTM Cochlear Implant System. Trends in Amplification. 2006;10(4):175–200. https://doi.org/10.1177/1084713806296386
2002	ESPrit 3G Speech Processor[a]	ACE, SPEAK, and CIS	• Note: N22 ESPrit 3G did not have ACE and CIS • Patrick JF, Busby PA, Gibson PJ. The Development of the Nucleus® FreedomTM Cochlear Implant System. Trends in Amplification. 2006;10(4):175–200. https://doi.org/10.1177/1084713806296386
2005	Nucleus® Freedom® Sound Processor[a]	ACE, ACE(RE)[b], CIS, CIS(RE)[b], SPEAK, MP3000 (introduced in 2010).	• Patrick JF, Busby PA, Gibson PJ. The Development of the Nucleus® FreedomTM Cochlear Implant System. Trends in Amplification. 2006;10(4):175–200. https://doi.org/10.1177/1084713806296386 • Balkany T, Hodges A, Menapace C, Hazard L, Driscoll C, Gantz B, Kelsall D, Luxford W, McMenomy S, Neely JG, Peters B, Pillsbury H, Roberson J, Schramm D, Telian S, Waltzman S, Westerberg B, Payne S. Nucleus Freedom North American clinical trial. Otolaryngol Head Neck Surg. 2007 May;136(5):757–62. https://doi.org/10.1016/j.otohns.2007.01.006. PMID: 17478211. • Büchner, Andreas & Beynon, Andy & Szyfter, Witold & Niemczyk, Kazimierz & Hoppe, Ulrich & Hey, Matthias & Brokx, Jan & Eyles, Julie & Van de Heyning, Paul & Paludetti, Gaetano & Zarowski, Andrzej & Quaranta, Nicola & Wesarg, Thomas & Festen, Joost & Olze, Heidi & Dhooge, Ingeborg & Müller-Deile, Joachim & Ramos, Angel & Smoorenburg, Guido. (2011). Clinical evaluation of cochlear implant sound coding taking into account conjectural masking functions, MP3000™. Cochlear implants international. 12:194–204. https://doi.org/10.1179/1754762811Y0000000009.

Year	Sound processor	Speech coding strategy	Reference
2009	Nucleus 5 Sound Processor	ACE, ACE(RE)[b], CIS, CIS(RE)[b], SPEAK, MP3000 (introduced in 2010).	• Jace Wolfe, Erin C. Schafer (2010), Basic terminology of Cochlear Implant Programming in Programming Cochlear implants, 1st edition. Plural Publishing.
2012	Nucleus CP802 Sound Processor	ACE, ACE(RE)[b], SPEAK	• No new speech coding—not specific to speech coding strategies but for performance with CP802, this article is available: • Singh, S., Vashist, S., & Ariyaratne, T. V. (2015). One-year experience with the Cochlear™ Paediatric Implanted Recipient Observational Study (Cochlear P-IROS) in New Delhi, India. Journal of otology, 10(2), 57–65. https://doi.org/10.1016/j.joto.2015.09.002
2013	Nucleus 6 Sound Processor[a]	ACE, ACE(RE)[b], CIS, CIS(RE)[b], SPEAK, MP3000.	• Jace Wolfe, Erin C. Schafer (2015), Basic terminology of Cochlear Implant Programming in Programming Cochlear implants, 2nd edition. Plural Publishing.
2016	Nucleus Kanso® Sound Processor	ACE, ACE(RE)[b], CIS, CIS(RE)[b], SPEAK, MP3000.	• No new speech coding—not specific to speech coding strategies but for performance with Kanso, this Cochlear whitepaper article is available: • D1110229 Philips, B., Plasmans A., Dhoogeb, I (2016) Comfort and listening benefits of the Kanso off-the-ear sound processor in children. (Sponsored by Cochlear).
2017	Nucleus 7 Sound Processor[a]	ACE, ACE(RE)[b], CIS, CIS(RE)[b], SPEAK, MP3000.	• No new speech coding
2020	Nucleus Kanso 2 Sound Processor	ACE, ACE(RE)[b], CIS, CIS(RE)[b], SPEAK, MP3000.	• No new speech coding

[a] Only SPEAK available when used with N22 implants. ACE, CIS, and MP3000 cannot be programmed with N22 implants

[b] Note: CIS(RE) and ACE(RE) only available for CI24RE/Freedom implant models and later

5.4 Advanced Bionics

5.4.1 History of Implant Evolution (Figs. 5.35 and 5.36)

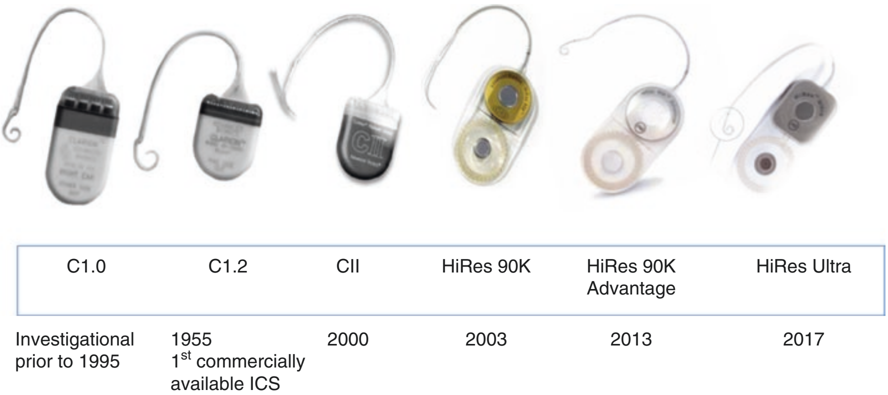


Fig. 5.35 Implant evolution

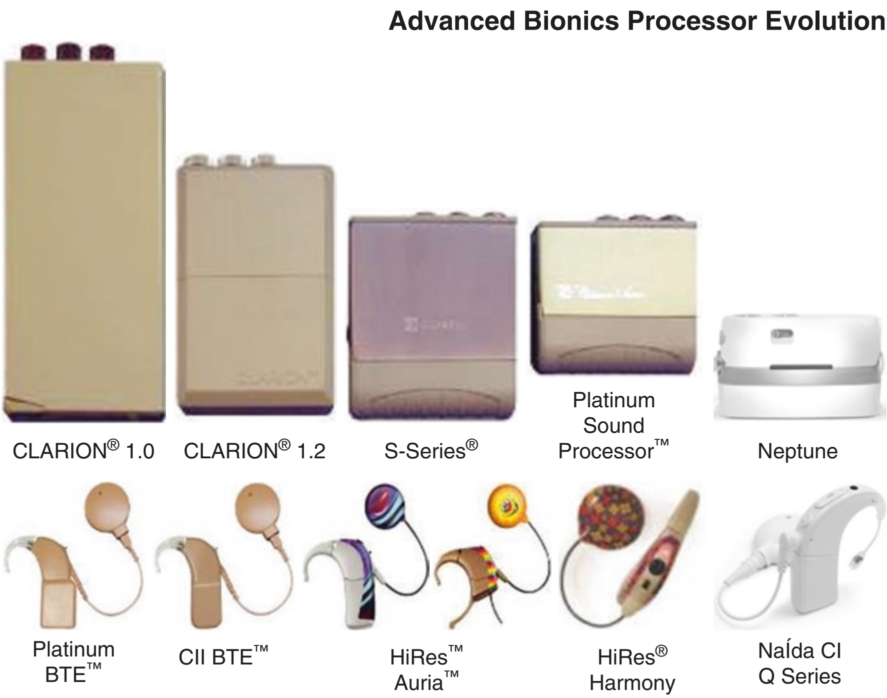


Fig. 5.36 Processor evolution

5.4.1.1 HiRes™ Ultra (Fig. 5.37)

- Minimal Drilling: A shallow 1 mm ramped recess or surface mount makes it suitable for all—adults and children
- 3 T MRI Compatible with magnet removal and 1.5 T with magnet in place
- Titanium Implants
- Exceeding the industry standard for impact resistance
- 16 Active electrodes resulting into 120 stimulation sites
- 2 Integrated ground electrodes

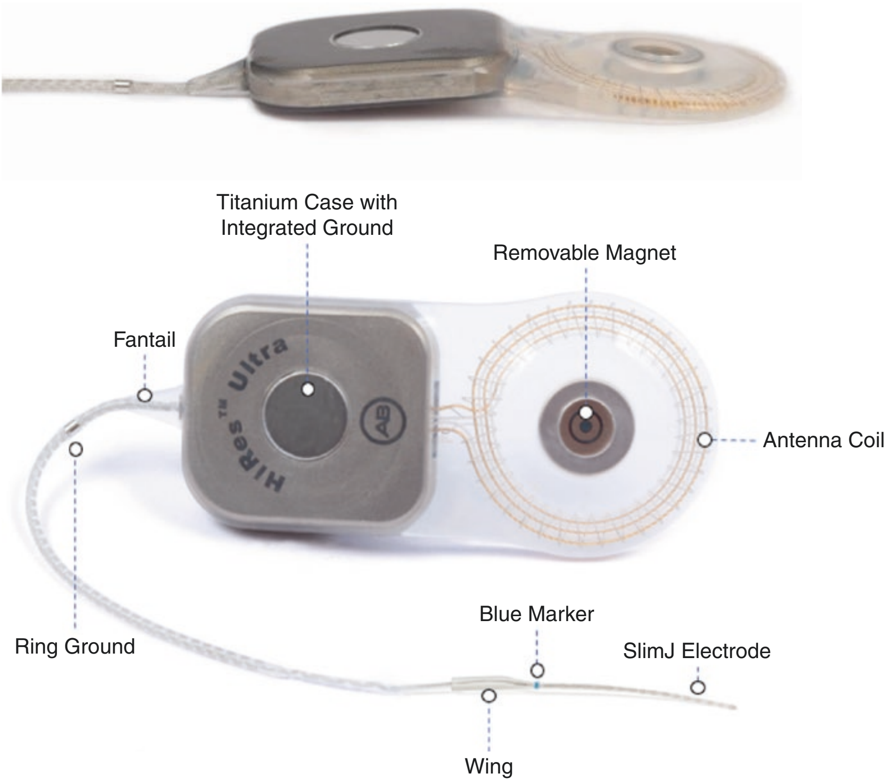


Fig. 5.37 HiRes Ultra side and front veiw

5.4.2 Advanced Bionics Implant's Technology

- The 16 independent current sources allowing stimulation of up to 120 stimulation sites
- A digital processor capable of up to 10 million operation per second
- An update rate of the audio signal of 90K times per second
- Stimulates up to 83,000 pps. Highest in the Industry.
- Widest IDR of 80 dB
- IntelliLink for safety
- Impact resistance up to 6 J Strongest in the Industry
- Upgradeable electronics platform without additional surgery (Figs. 5.38, 5.39 and 5.40)

Fig. 5.38 Naida CI Q Series Sound Processor

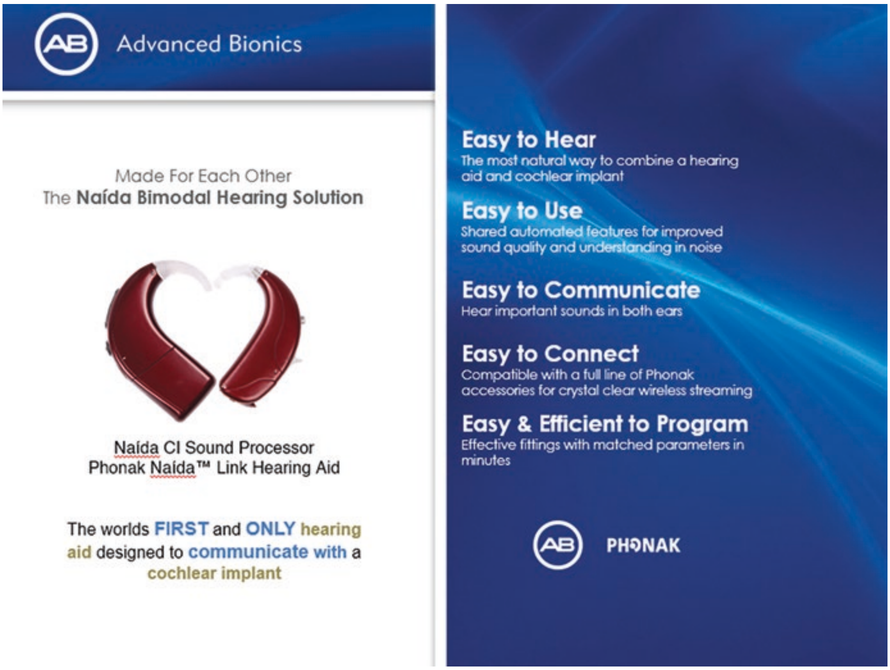


Fig. 5.39 Phonak

Fig. 5.40 Phonak

Naida CI Q90	Naida CI Q70	Naida CI Q30
Auto UltraZoom		
StereoZoom		
EAS ready		
SoundRelax	SoundRelax	
EchoBlock	EchoBlock	
WindBlock	WindBlock	
QuickSync	QuickSync	
DuoPhone	DuoPhone	
ZoomControl	ZoomControl	
UltraZoom Feature	UltraZoom Feature	UltraZoom Feature
ClearVoice	ClearVoice	ClearVoice
AutoSound	AutoSound	AutoSound
HiRes Fidelity 120 Sound Processing	HiRes Fidelity 120 Sound Processing	HiRes Fidelity 120 Sound Processing
HiRes Optima Sound Processing	HiRes Optima Sound Processing	HiRes Optima Sound Processing
Most focused binaural Automated beamformer and EAS capabilities	Bilateral and Bimodal technology for hearing with two ears	Outstanding performance in Noise and Wireless connectivity

5.4.3 Electrodes

HiFocus SlimJ : A thin atraumatic lateral wall electrode

HiFocus Mid-Scala : Atraumatic Mid-Scala cochlear placement

Each electrode has:

16 planar electrodes Non-stimulating marker(s)

The ability to reload ALL the electrodes for re-insertion.

HiFocus Electrodes design:

- minimize forces on cochlear tissue
- optimal mid-scala cochlear placement*
- designed for cochlear structure preservation (Figs. 5.41, 5.42, 5.43 and 5.44)

Fig. 5.41 Electrodes

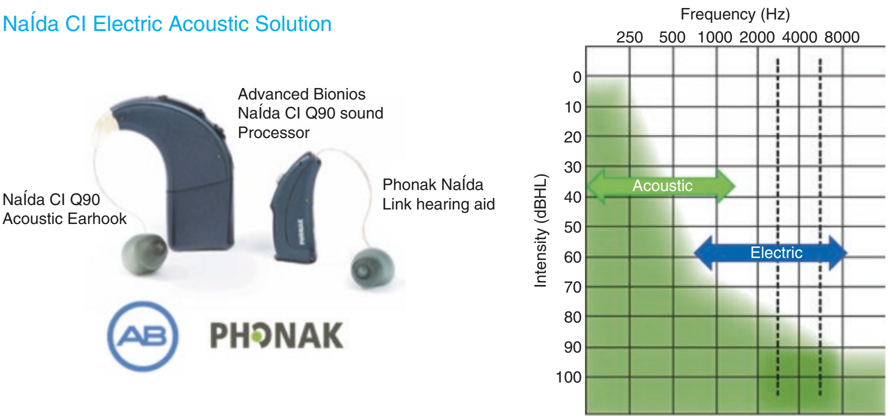


Fig. 5.42 EAS

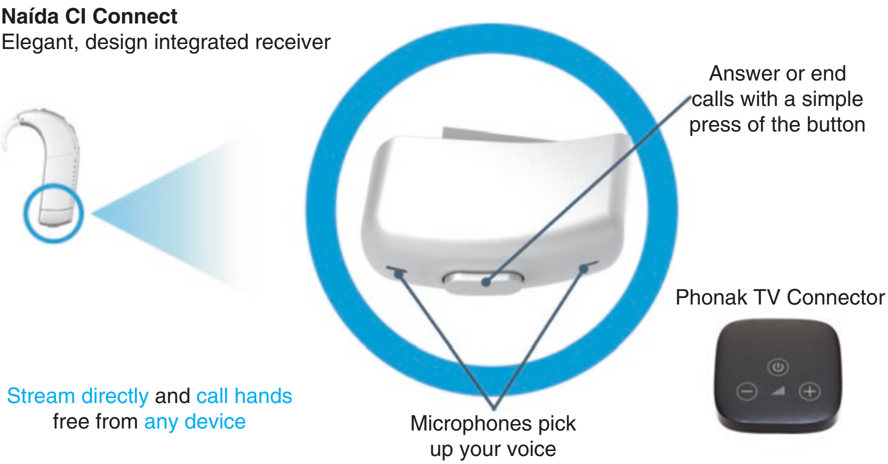


Fig. 5.43 Naida CI connect

Fig. 5.44 Accessories

5.4.4 Speech Processing

Advanced Bionics (AB) has a gamut of patented cochlear implant technologies. They have the highest number of sound coding strategies as well and kept innovating since 1993 till date. A list of Speech coding strategies by AB are:

- ClearVoice
- SoftVoice
- HiRes Optima-S
- HiRes Optima-P
- HiRes-S with Fidelity 120
- HiRes-P with Fidelity 120
- HiRes-S

- HiRes-P
- CIS
- MPS
- SAS

AB was the first in the world to have included a fast hi-resolution processing strategy which took care of the temporal processing in the sound dimensions. HiRes-P was able to stimulate at 82,500 Pulses Per Second, making it the world's fastest speech coding strategy. AB has a unique option of either stimulating via sequential or paired method. Paired is stimulating two electrodes at a time with a gap of eight electrodes. HiRes-S or P are 16 channel coding strategies.

In 2005, AB became the first again in the CI industry to have virtual channels. They were able to steer the current with independent current sources and have 120 stimulation sites in the cochlea via their strategy of HiRes-S or P with fidelity 120. In 2013, they moved ahead with HiRes Optima which does the same along with battery saving capabilities of 50–109%.

AB is also the first and only in the CI industry to have a noise-reduction algorithm coding strategy called ClearVoice since 2009. It improves the SNR by 6–18 dB and looks to control the steady-state noise in the environment which are continuous in nature. This acts at medium to high noise levels. In 2019, they yet again launched the first and only coding algorithm for soft-noise called the SOftVoice, which acts of soft level noises. Example like the small humming sounds in the environment and it enhances the soft speech or whispered speech in a conversation. These are powerful speech coding strategies to give the widest IDR of 80 dB, highest frequency spectrum of 120 virtual channels, and fastest stimulation of upto 82,500 PPS along with noise-reduction strategies to make the SNR much better.

The legacy and new implants can also run old strategies of SAS, CIS, and MPS. However, they are not used in today's generation implants by matter of choice as 120 virtual channels prove much more beneficial.

5.5 Oticon

5.5.1 History and Evolution

Oticon Medical has developed a wide range of implants and currently markets Neuro Zti, the latest generation of implants released at the end of 2015. Historically, the implant casings used to be made of ceramics but Titanium and Zirconia, a very resistant alloy, are now widely used.

First multi-channel cochlear implantation in France by Prof. Chouard

The first implant marketed by Oticon Medical (Neurelec at that time) was the Digisonic DX10, the first multi-channel cochlear implant.

Digisonic DX10—the first digital multi-channel cochlear implant—1992 (Fig. 5.45).

Fig. 5.45 DX 10

Fig. 5.46 Digisonic SP—20 channel implant—2004

Digisonic SP, with an exclusive first-generation screw fixation system and 20 channels, has been the first worldwide marketed Oticon Medical implant. Production has just stopped in 2020 (Fig. 5.46).

Digisonic Binaural implant has been developed to cover additional user needs.

At last, the most recent implant is Neuro Zti, with a unique second-generation screw fixation system shown to be particularly safe and efficient in a clinical environment (with drilling required to securely fixate the implant). Neuro Zti casing is made of titanium and Zirconia, a very resistant and radiofrequency transparent material, allowing an embedded removable magnet in a rigid monobloc structure making Neuro Zti the implant with the smallest surgical footprint allowing a minimally invasive approach. It provides an extra cochlear ground electrode with a unique stimulation strategy, based on loudness coding in duration (not time coding) and a unique pulse shape to have a safe, precise, effective, and power efficient stimulation.

5.5.2 Implants

Oticon Medical has developed a wide range of implants and currently markets Neuro Zti, the latest generation of implants, and released at the end of 2015. Historically, the implant casings used to be made of ceramics but Titanium and Zirconia, a very resistant alloy, are now widely used (Fig. 5.47).

Fig. 5.47 Neuro Zti

The first implant marketed by Oticon Medical (Neurelec at that time) was the *Digisonic DX10*, the first multi-channel cochlear implant.

Digisonic SP, with an exclusive first-generation screw fixation system and 20 channels, has been the first worldwide marketed Oticon Medical implant. Production has just stopped in 2020.

Digisonic Binaural implant have been developed to cover additional user needs.

At last, the most recent implant is Neuro Zti, with a unique second-generation screw fixation system shown to be particularly safe and efficient in a clinical environment (with drilling required to securely fixate the implant). Neuro Zti casing is made of titanium and Zirconia, a very resistant and radiofrequency transparent material, allowing an embedded removable magnet in a rigid monobloc structure making Neuro Zti the implant with the smallest surgical footprint allowing a minimally invasive approach [4, 5]. It provides an extra cochlear ground electrode with a unique stimulation strategy, based on loudness coding in duration (not time coding) and a unique pulse shape to have a safe, precise, effective, and power efficient stimulation [6–9].

5.5.3 Audio Processors and Accessories

Oticon Medical currently markets two types of CI BTE (Behind-the-ear) sound processors.

Saphyr Neo launched in 2013 with additional new coding strategy (Crystalis XDP) with, for the first time, implementation of a post processing compression to avoid sound input distortion due to common AGC systems. This brought a more clear and comfortable hearing. The Voicetrack™ feature, aiming at preserving speech signals by reducing background noise, while still allowing the listener to detect important background information was also implemented in Saphyr Neo.

Neuro 2, launched in 2018. It has been carefully designed to be the smallest and the most beautiful CI sound processor. And it is a success, with not less than eight international design awards and significantly smaller than any other CI sound processor ever marketed [10]: Miniaturization to its maximum. The extra long rechargeable battery life, the unique BTE showing highest water and dust protection (IP 68) [11] without any extra protection, the extra strong and discreet antenna cable (reinforced with Aramid fiber, a next generation Kevlar™)…make it very appealing for professionals and patients. The Streamer XM wireless Bluetooth-based connectivity gateway completes the offer.

Based on Oticon Inium sense chipset and Brainhearing (providing high end audiological outcomes while reducing the listening effort), Neuro 2 processing offer uses CAP (Coordinated Adaptive Processing) technology (see next section for further information) and allows to provide an advanced balanced hearing bimodal option and unique directionality possibilities with the Free focus Speech omni mode, an exclusive light directional mode inspired from the natural “pinna effect” with frequency cut-off allowing better performance in conversations.

5.5.4 Saphyr Neo Collection

Better speech understanding in noise with Voice Track and Crystalis XDP.

Saphyr Neo launched in 2013 with additional new coding strategy (Crystalis XDP) with, for the first time, implementation of a post processing compression to avoid sound input distortion due to common AGC systems. This brought a more clear and comfortable hearing. The VoicetrackTM feature, aiming at preserving speech signals by reducing background noise, while still allowing the listener to detect important background information was also implemented in Saphyr Neo (Fig. 5.48).

Fig. 5.48 Saphyr Neo

5.5.5 Neuro 2 Sound Processor

Neuro 2, launched in 2018. It has been carefully designed to be the smallest and the most beautiful CI sound processor. And it is a success, with not less than eight international design awards and significantly smaller than any other CI sound processor ever marketed: Miniaturization to its maximum. The extra long rechargeable battery life, the unique BTE showing highest water and dust protection (IP 68) without any extra protection, the extra strong and discreet antenna cable (reinforced with Aramid fiber, a next generation KevlarTM)…make it very appealing for professionals and patients. The Streamer XM wireless Bluetooth-based connectivity gateway completes the offer (Fig. 5.49).

Fig. 5.49 Neuro 2

5.5.6 Neuro 2 Processor and Dynamo Bimodal

Based on Oticon Inium sense chipset and Brainhearing (providing high end audiological outcomes while reducing the listening effort), Neuro 2 processing offer uses CAP (Coordinated Adaptive Processing) technology and allows to provide an advanced balanced hearing bimodal option and unique directionality possibilities with the Free focus Speech omni mode, an exclusive light directional mode inspired from the natural "pinna effect" with frequency cut-off allowing better performance in conversations (Fig. 5.50).

Fig. 5.50 Neuro 2 DYNAMO BIMODAL

5.5.7 Electrodes

5.5.7.1 Neuro Zti^{EVO}

Medium sized straight lateral wall electrode array (24 mm active length), EVO designed to preserve the fragile structures of the cochlea with a smooth surface, small diameter, thin end, and a highly flexible apical tip. Evo is typically used in implantations in normal cochleas with residual hearing. Its shape-conforming design goes from 1, 5 mm at the base to 1, 2 mm at the apex and provides push-rings to make it easy to grasp, to push during the insertion, and to mechanically seal the cochlea. The insertion forces are reduced by 32% compared to the CLA version (Fig. 5.51).

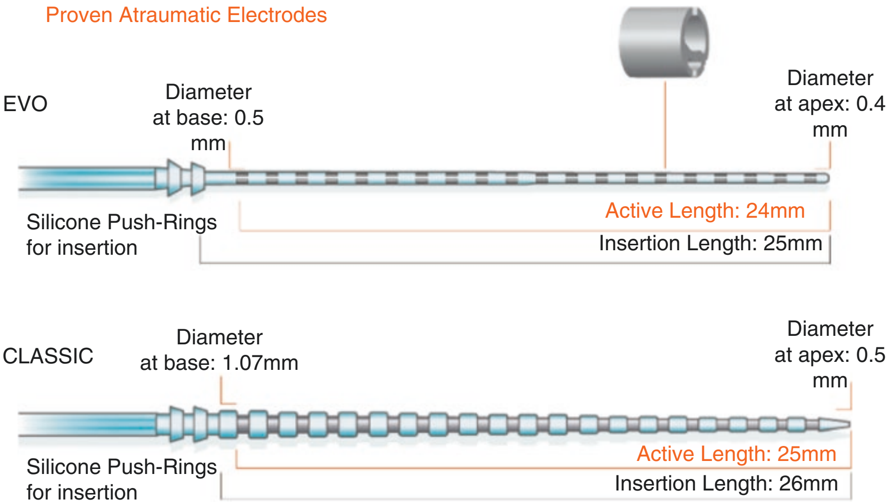


Fig. 5.51 Zti electrode

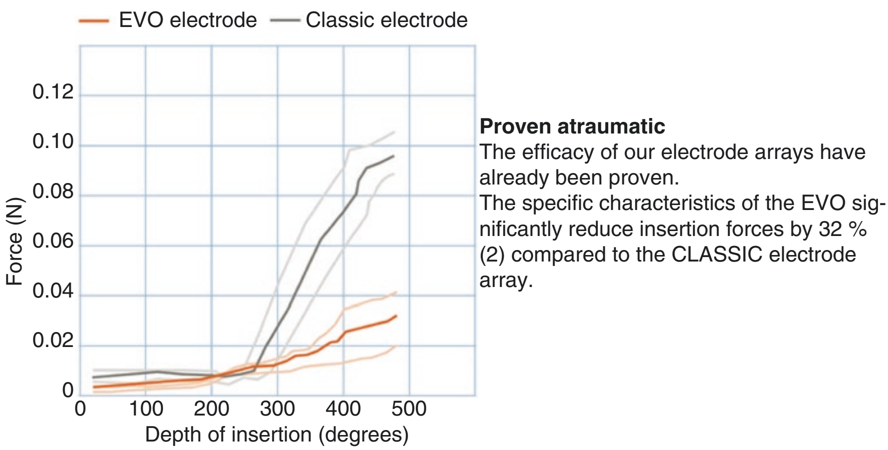


Fig. 5.52 Comparison EVO and Classic electrodes

5.5.7.2 Neuro Zti[CLA]

Medium sized straight lateral wall electrode array (25 mm active length), CLA has an optimized stiffness profile with silicone rings along the electrode array that make it compatible with typical and difficult insertions and/or for ossified cochleas. The push-rings at the base provide a “safe” point to manipulate and hold the array (Fig. 5.52).

5.5.8 Signal Processing

Latest Oticon Medical sound processors use the CAP (Coordinated Adaptive technology).

5.5.8.1 Front-End and Back-End Processing

The signal processing chain implemented in Coordinated Adaptive Processing can be seen in (Fig. 5.53) and shown to provide better speech understanding even in challenging situations [12, 13].

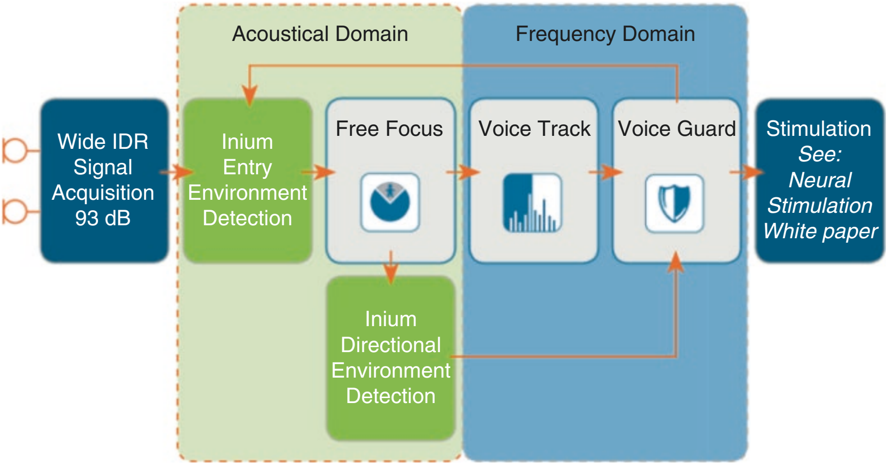


Fig. 5.53 Signal processing

In CAP, sound processing starts with a wide input Dynamic Range (IDR) dual microphone signal acquisition, in order to benefit from the richest sound possible entering the processing chain. The Inium Sense™ environment detection system then offers real-time analysis of the acoustic environment, selecting the idea directionality mode of the Free Focus adaptive directionality technology, together with a dedicated wind noise-reduction algorithm. The signal is then transformed to the frequency domain and VoiceTrack™ reduces noise in selected spectral channels. Finally, VoiceGuard™ applies dedicated multiband instantaneous output compression, based on the analysis of the environment detection system. The VoiceGuard™ sound compression system preserves 95% of the speech information [12, 14] before processing so the sound signal is enriched in every listening situation.

The entire system is constantly adapting its behavior to the listener's actual acoustic environment. The information is then transferred by forward telemetry to the Neuro Zti implant.

CAP aims to automatically deliver the perfect coordination and balance between its different sound processing tools in order to allow access to maximum speech audibility and sound clarity in every listening situation. Two main ideas led the path to the development of Coordinated Adaptive Processing:

1. Deliver the richest sound experience possible to cochlear implant users by capturing sounds from the environment over the widest possible dynamic range and apply sound processing algorithms without introducing or propagating distortion.
2. Maximize speech and sound quality in every listening situation, by integrating a unique combination of hearing instrument algorithms and cochlear implant dedicated sound treatments, driven by continuous monitoring of the acoustic environment.

5.5.9 Sound Coding

Loudness coding, a unique technology, is done in duration. Physiological coding of loudness is naturally using a temporal code, as a higher density of action potentials (with similar amplitude) on the auditory nerve is observed for louder sounds. Auditory nerves do not use amplitude coding, as action potential has similar amplitudes. Loudness coding in durations has shown to be at least as efficient as more commonly used time coding [15].

The coding strategies implemented in a sound processor define how sound is transformed into electrical stimulation and distributed to the various electrodes.

MPIS CAP The MPIS CAP strategy (Main Peak Interleaved Sampling) is a multiband spectral extraction strategy coupled with Coordinated Adaptive Processing: An automatic backend multiband compression function (Voice Guard). A preselected number of electrodes are stimulated per acquisition frame. An anti-crosstalk function has also been implemented to minimize interaction between electrodes (so two adjacent electrodes cannot be stimulated at the same time). An environment detection system drives CAP features: directionality, wind noise reduction, and Voice Guard. This strategy is mainly recommended for patients in whom neural survival is thought to be limited.

Crystalis CAP The Crystalis coding strategy is a multiband spectral extraction strategy coupled with Coordinated Adaptive Processing: An automatic backend multiband compression function (Voice Guard) and stimulation of a selected number of electrodes per acquisition frame. Stimulation of adjacent electrodes together with an enhanced high pitch frequency filtering mechanism is applied to provide as much information as possible to the patient. An environment detection system drives CAP features: Directionality, wind noise reduction, and Voice Guard.

Recent preliminary results from the MHH Medical School in Hannover [14] indicate that the Coordinate Adaptive Processing (CAP) sound coding strategy allows Oticon Medical CI users to achieve excellent speech understanding in the most critical cases, that is to say in the presence of background noise and after a long period of hearing deprivation.

MPIS XDP The MPIS CAP strategy (Main Peak Interleaved Strategy) is a multiband spectral extraction strategy, which has a multiband compression function (XDP). A pre-selected number of electrodes are stimulated per acquisition frame. An anti-crosstalk function has been implemented to minimize interaction between electrodes (so two adjacent electrodes cannot be stimulated at the same time).

Crystalis XDP The Crystalis coding strategy is a multiband spectral extraction strategy, which has a multiband compression function (XDP). A pre-selected number of electrodes are stimulated per acquisition frame. Stimulation of adjacent electrodes together with an enhanced high pitch frequency filtering mechanism is applied to provide as much information as possible to the patient.

As shown, XDP strategies resulted in improved intelligibility both in quiet and in noise compared to previous generations of coding strategies [16].

Recently Oticon Medical's parent company Demant announced its intention to divest Oticon Medical and therefore has negotiated an agreement to sell Oticon Medical to Cochlear.

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