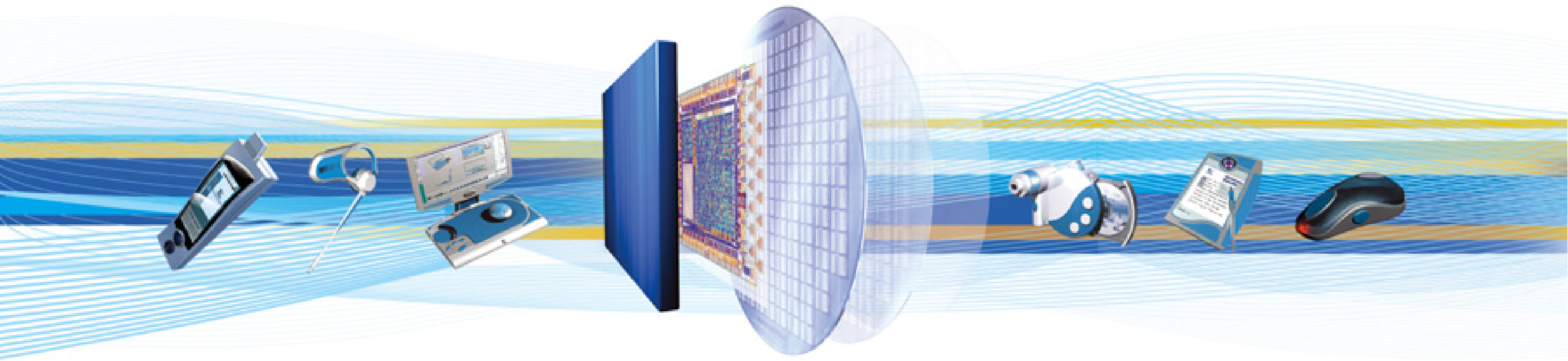
BlueCore™

Electromechanical Design Considerations of Hands-free Car kits

Application Note

December 2006



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1 Introduction

Growing legislation requiring drivers to make hands-free mobile phone calls is fuelling the demand for after-market **Bluetooth**®-enabled hands-free car kits. These kits enable drivers to make safer phone calls while driving. Consumers require excellent performance, so manufacturers want to meet their demands and ensure market acceptance.

Two types of hands-free car kits are popular:

- Compact monolithic electronic devices, where the microphone and the speaker are housed in the same casing as the electronics. These are essentially after-market kits, sometimes referred to as do-it yourself (DIY) kits.
- Bundled pieces of hardware, where the microphone and the speaker are mounted in different locations inside the vehicle. These may be OEM products, dealer installed systems or after-market kits.

Bluetooth hands-free car kits are designed to deal with the inherent issues of echo and environmental noise. The audio quality depends on using a combination of the following during system design:

- signal processing techniques
- mechanical and acoustical engineering

The design considerations described in this document are based on actual field usage of DIY Bluetooth hands-free kits. This application note describes the basic design considerations relating to audio performance that should be examined during engineering process. These guidelines will help set performance expectations of various design considerations and various trade-offs.

2 Compact Hands-free (DIY) Kit Design Considerations

2.1 Overview

DIY hands-free kits are popular because of their portability, ease of installation (by the end customer) and low cost. Portability of a hands-free kit means it must perform in acoustical environments that are not well defined (e.g. the reverberation characteristics or the level of the background noise). Designers, therefore, need to find a favourable solution, which performs in different vehicle environments. In addition, the close proximity of the loudspeaker to the microphone poses challenges to achieve good echo cancellation and noise reduction. The distance between the microphone and loudspeaker is shorter (10 times or more) than the distance between the talker and the DIY kit. Hence, the signal level from the loudspeaker is stronger at the microphone than the signal levels of the desired speech. Extracting speech and discarding the echo signals is difficult and requires signal processing techniques.

A fine quality Bluetooth Hands-free kit has the following features:

- Excellent echo cancellation
- Excellent reduction of background noise
- Excellent frequency response for microphone and loudspeaker
- Low acoustic and mechanical coupling between the loudspeaker and the microphone
- Good sound quality from the loudspeaker
- Good isolation from wind
- Easy to install and use
- Compact size
- Rugged

This application note focuses on the aspects of a Bluetooth hands-free kit that effect audio performance.

A well-designed Bluetooth hands-free kit supports smooth operation during and between the different states encountered during a typical telephone call. These states include single talk in the send or receive direction double talk and Idle (no one talking). Smooth operation is critical in reducing the fatigue encountered by both the far-end and near-end talkers. A poorly designed hands-free kits will make telephone calls difficult and reduces customer satisfaction.

This application note considers:

- Hardware considerations, e.g. placement of the physical components of the hands-free kit
- Digital signal processing considerations
- Limitations and problems encountered using the components in certain combinations
- Methods to enhance the performance of the Bluetooth hands–free kit
- Aspects of echo cancellation and noise reduction techniques (CSR's Clear Voice Capture (CVC) modules)
- Design considerations regarding signal processing capabilities provided by the CVC modules.

3 Transducers and Electronic Hardware

The characteristics and placement of the transducers, the microphone and loudspeaker, with its associated circuitry, are important in determining the quality of the hands-free kit.

3.1 Microphone Considerations

Microphone(s) in a hands free kit require special attention in order to operate effectively. Specifically, the following microphone characteristics are needed to obtaining good performance:

- The frequency response should be relatively flat in the required frequency range (usually 300Hz to 3400Hz)[1].
- The dynamic range should be large enough to pick up the speech of the user and not clip the audio signal when the loudspeaker(s) is set to maximum volume.
- The microphone should be uni-directional with the maximum sensitivity directed towards the intended speech source (talker). This reduces the amount of echo and noise that will be heard at the far end (the person at the other end of the call)
- The microphone sensitivity should be large enough to limit the effects of electrical and RF interference.
- The structural attachment of the microphone should be designed to isolate it from mechanical vibrations either from the loudspeaker or due to the place of the hands-free kit.
- A wind screen protecting the microphone from wind buffeting due to open windows or HVAC (Heating, Ventilation and Air Conditioning) system.
- A grill or opening to the microphone, which is design so, it will not adversely affect the microphones performance.
- The distance between the microphone and the user (talker) which is smaller than 50 cm (21 in) when used in a vehicle.

In addition, to these characteristics, care should be taken as to where the microphone will be located. Structures such as steering wheels, dashboard components, gear shifters, cup holders, and instrument pods will reflect, diffract and distort the acoustic wave (signal). This can reduce the effectiveness of the microphone and should be considered in the design of the hands-free kit.

Commonly available microphones have directivity patterns shown in Figure 3.1 and Figure 3.2. When using uni-directional microphones it is important to follow these recommendations:

- The microphone should be oriented to have greatest sensitivity towards the driver when the kit is installed.
- When using unidirectional microphones, it is very important not to block ports leading to the microphone. Restriction to these openings changes the acoustic properties of the microphone and leads to poor and unexpected performance.
- Extreme caution must be exercised with dipole directivity pattern (see Figure 3.3) because this directivity can pick up undesired noise (e.g. noises from open side windows).,

[1] See ITU_T recommendations P.310

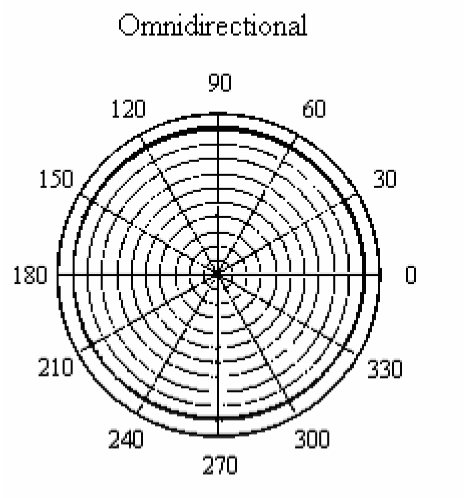

Figure 3.1: Default Directivity Pattern for Automotive Powered DIY Kits

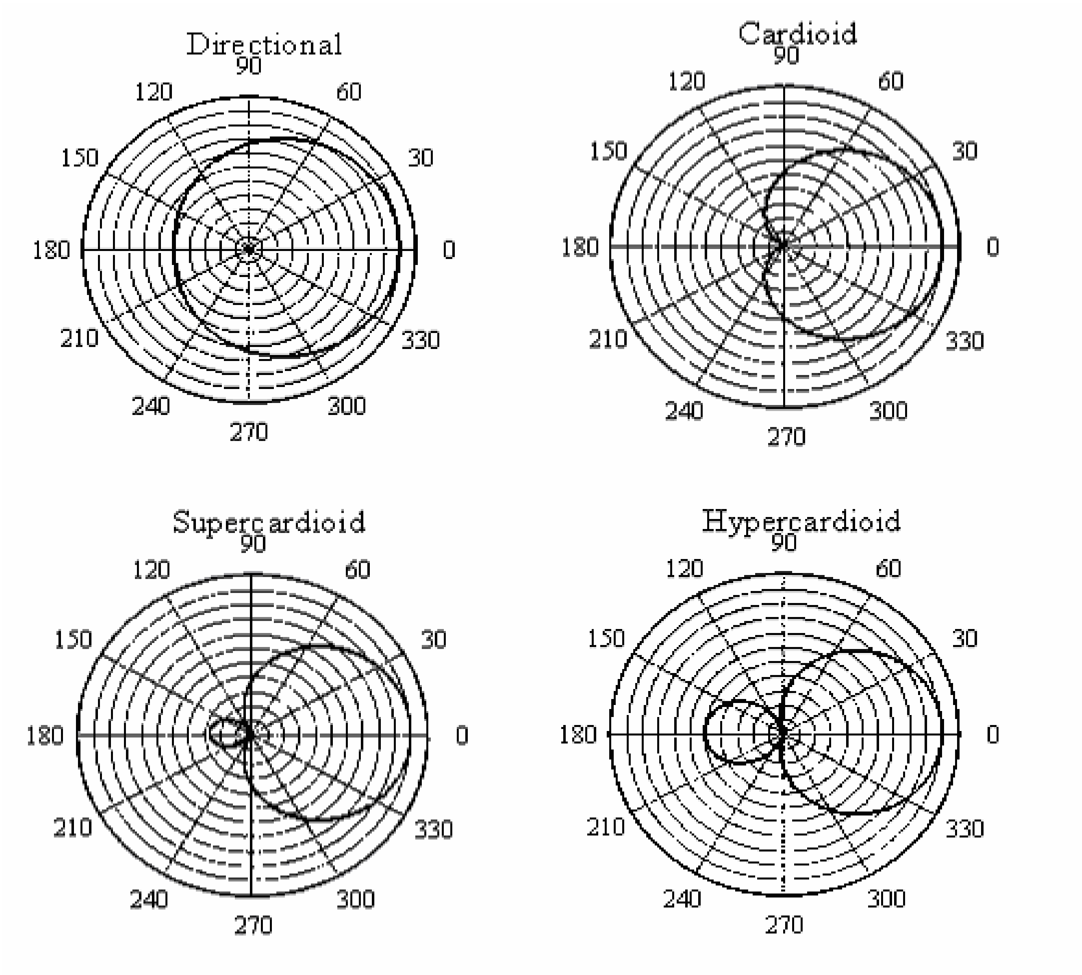

Figure 3.2: Directivity Patterns of Directional Microphones

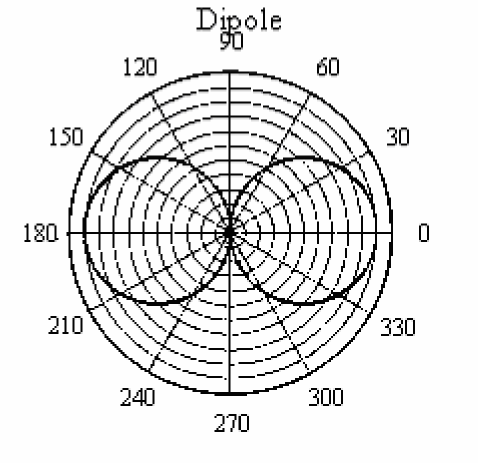

Figure 3.3 Directivity Pattern Unsuitable for DIY Kits

3.2 Loudspeaker Considerations

Like microphone, the characteristics of the loudspeaker affect the overall performance of the hands free kit. The frequency response of the loudspeaker should be flat in the required frequency range (usually 300Hz to 3400Hz)[1]. The speaker system, which includes the housing, should have its maximum directivity aligned towards the listener. In addition, reducing the amount of sound directed towards the microphone will increase the performance of the kit.

The loudspeaker system, including the audio amplifier, should not exhibit non-linear characteristics in the entire acoustic and audio range where the hands-free kit is to perform. Figure 3.4 shows various linearity characteristics exhibited by a loudspeaker. A linear, non-linear and unacceptable loudspeaker are shown. The unacceptable speaker is suffering from high noise floor and poor dynamic range. These and other non-linear characteristics can be due to poor design, low quality, and may appear after the speaker is in-service due to environmental stresses. The greater the linearity of the loudspeaker the better the echo and noise reduction algorithms will perform.

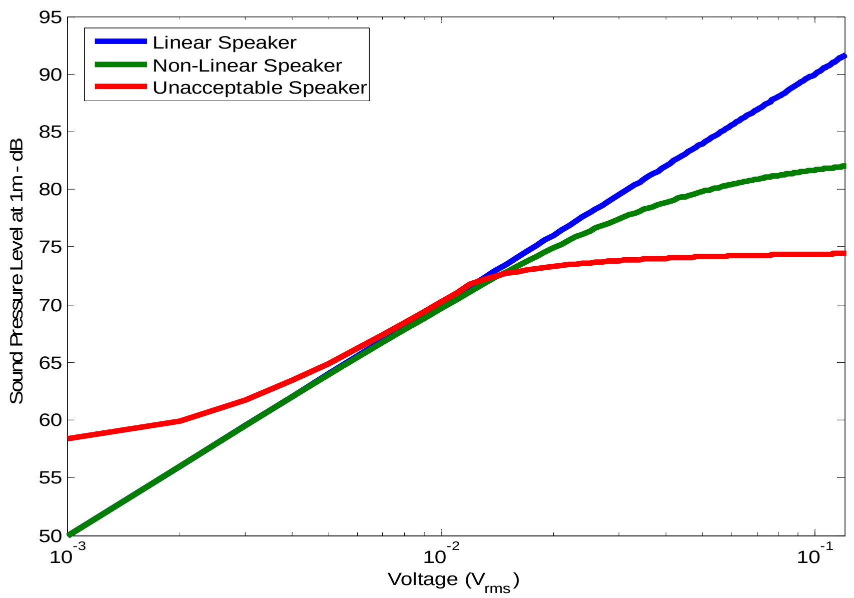

Figure 3.4 Non-linear Characteristics Exhibited by a Speaker

[1] See ITU_T recommendation P.310

3.3 Electromechanical Design Considerations

Determine the placement of the microphone and the speaker using:

1. Application-level considerations
2. Functional-level considerations

3.3.1 Microphone Placement Relative to Speech Source

The design of the hands free kit should ensure that the greatest directivity of the microphone is pointed in the direction of the talker (speech source). Improper positioning of the microphone to the speech source can occur due to the covering of the microphone by other structures inside the vehicle, such as the dashboard. This could lead to dramatic reduction in the speech-to-noise levels and reduce the operating performance.

Figure 3.5 shows good microphone placement for a visor-mounted design. The microphone has good exposure to the speech source.

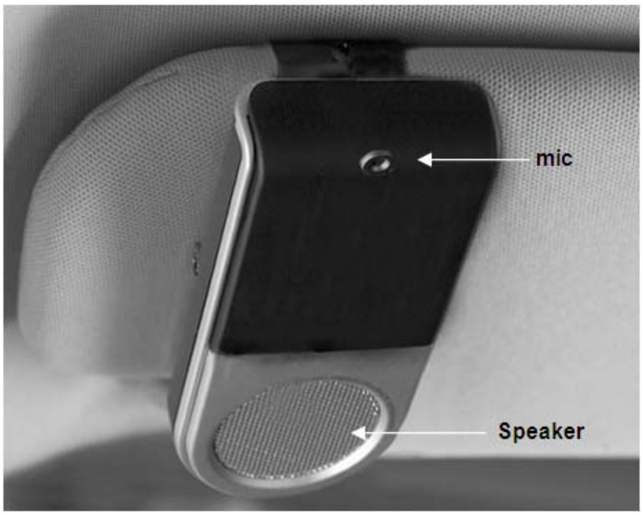

Figure 3.5: Good Microphone Exposure to Speech Source (Visor-Mounted DIY Kit)

3.3.2 Avoiding Mechanical Coupling of Vibrations into the Microphone

Mechanical coupling between the speaker and microphone should be avoided. It usually occurs when the speaker and microphone are mounted on the same electronic PCB (see Figure 3.6). This mechanical coupling is due to vibrations from the speaker being conducted to the microphone through the coupling media. This causes feedback in the system and deteriorates performance. Mechanical decoupling can be achieved by designing a mechanical isolator, for example a vibration dampener between the microphone and speaker. The mechanical isolator has to be designed for the specific hands-free kit, otherwise unexpected results can occur. Improper use of a mechanical isolator can significantly increase mechanical coupling, i.e. can make the structure resonant. Alternately, the microphone and the speaker can be mounted on different PCB boards with flexible wires running between them, again care must be used to select wires that don't couple the PCB boards or resonant.

The microphone should be isolated from the vibrations produced in the vehicle. The proper use of isolation materials can help prevent the conduction of vibrations from the vehicle into the microphone; this in turn,helps to reduce the transient noise picked up by the hands-free kit. Transient noises are hard to eliminate. Figure 3. 6 shows a PCB mounted microphone with mechanical isolation using a foam mounting. Additonally complete mechanical isolation can be achieved by using flexible wires connecting the microphone to the PCB board

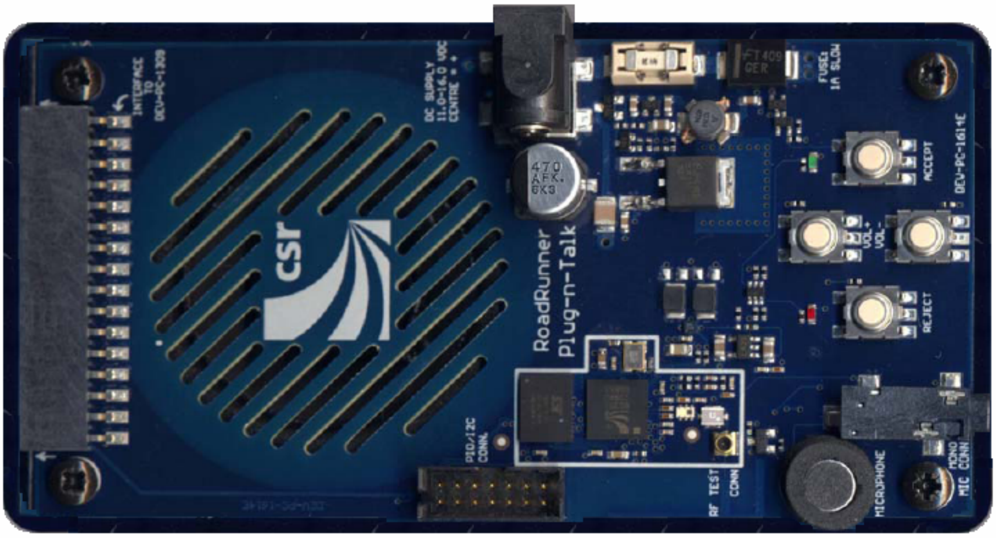

Figure 3.6: Mechanical Coupling of the Microphone and the Speaker

3.3.3 Minimising Acoustic Coupling between the Loudspeaker and the Microphone

Acoustic coupling between the speaker and microphone should be minimised. The strategic placement of the speaker and microphone can help reduce this coupling. When acoustic coupling is unavoidable, the microphone signal should not clip or distort when the loudspeaker's volume level is set to maximum. The microphone sensitivity should provide good (10% of full scale) signal levels of the required speech source with the speaker gain set to its maximum level for echo feedback (for normal speech levels by the far end talker).

3.4 Electronic Considerations

DIY hands-free kits usually have greater mechanical and acoustic coupling because of the close proximity of the microphone to the loudspeaker and the sharing of a common housing. The signal level at the microphone due to the loudspeaker is significantly larger than the signal level from the speech source. It should be expected that there would be users who set volume level to maximum because:

- the freedom to position the DIY kit wherever the user wants to put it
- the frequency response of the loudspeaker
- the vehicle's ambient noise

This means that the electronic hardware should have sufficient dynamic range to handle huge swings in signal levels without deterioration.

Digital gains of the signal can be used; however all analogue gains should be exhausted before relying on digital gains to adjust the signal levels of the microphone and speaker to improve the performance of the echo cancellation. Performance tradeoffs are required if gain adjustments and huge signal swings (maximum 120dB SPL peak with 1% THD) cannot be accommodated without distortions.

Performance tradeoffs might include:

- Switching to half-duplex mode from full-duplex mode (and vice versa)
- Preserving the quality of near end speech while maintaining adequate echo cancellation for situations in which both users are speaking at once

The speaker/power amplifier combination should not distort when the maximum volume level is set. At the same time, the microphone and microphone circuitry should not clip the signal.

4 Signal Processing Techniques

4.1 Near End and Far End Systems

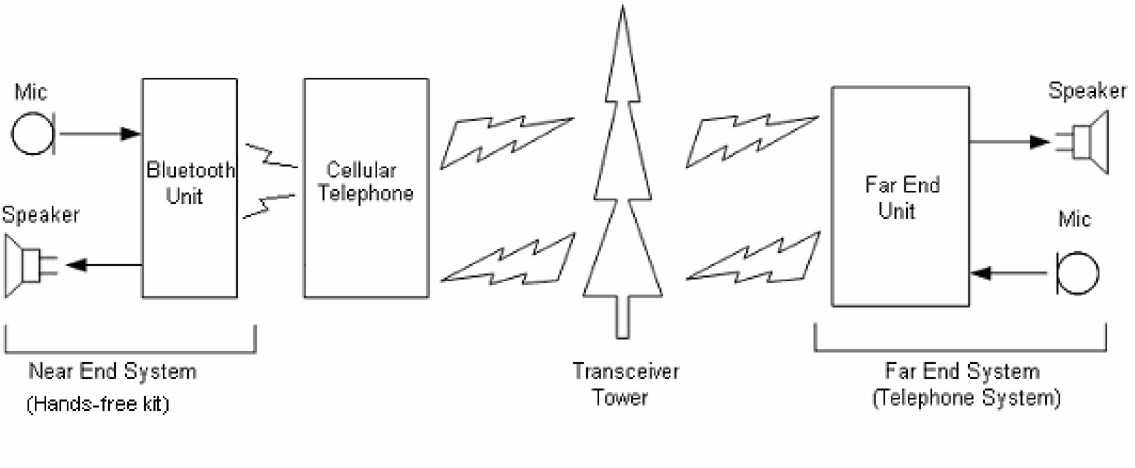

Figure 4.1: Near End and Far End Systems

In Figure 4.1, is a basic diagram the shows the typical use case for a hands free kit. In this case, the hands-free kit is considered as the near end. The far end is another telephone used at the other end of the call chain.

The Bluetooth unit consists of a Bluetooth hands-free kit paired with a Bluetooth cellular phone. The signal from the Bluetooth phone is transmitted to a cell phone tower. The cellular network then properly routes this signal to the far end unit. Similarly, the signal from the far end unit is received by the Bluetooth cellular phone from the cellular network.

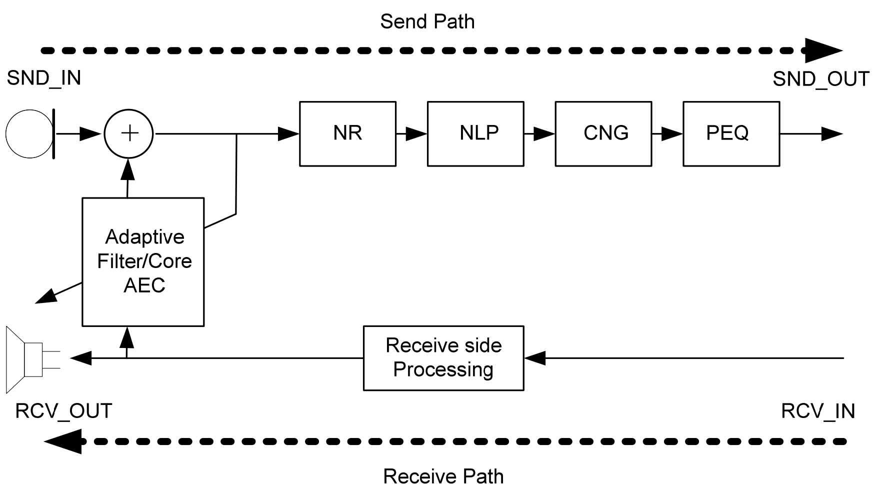

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Figure 4.2: Signal Processing Components at Near End

Figure 4.2 shows the signal processing blocks usually used in a hands-free system.

The microphone signal, at SND_IN in Figure 4.2, must be processed before transmission to the far end. This signal path is referred to as the send path. Most of the hands free signal processing occurs on the send path which may included the following :

- acoustic echo cancellation (AEC)
- noise reduction (NR): helps to reduce the transmission of acoustic noise.
- special processing of non-linear signals (NLP) to reduce the degradation of the audio signal

- comfort noise generation (CNG)
- parametric equalization (PEQ): adjusts the frequency response along the send path to improve far end performance.

The signal transmitted from the far-end and enters RCV_IN in Figure 4.2, is referred to as receive path. In the hands free kit this signal may be processed before it is sent to the loudspeaker. This signal is the reference signal for the echo canceller.   When the loudspeaker is of poor quality and exhibits non-linear characteristics, soft-clipping or other signal processing can be used in the receive path to limit the impact on sound quality.

4.2 CVC Modules

This section describes the three primary modules in the CVC portfolio that have a major impact on the overall intelligibility and speech quality of the hands-free system:

- NR
- AEC
- PEQ

4.2.1 Noise Reduction (NR), using a One-Microphone Solution

Speech communication can often occur in noisy environments. Since the microphone in a hands-free kit is not positioned next to the talker's mouth, the speech-to-noise ratio will be less than what is found with a standard handset. Extracting clean speech from this signal is of paramount importance to enhance the intelligibility and quality of speech.

Single-microphone techniques can handle noise sources that have stationary or quasi-stationary characteristics. DIY kits are generally built using a single microphone so exposure to transient noise and wind buffeting must be minimised.

NR is an advanced signal processing technique that utilises the differential statistical characteristics of noise and speech signals to reduce the noise in the signal. Noise sources with stationary or quasi-stationary statistics include fan noise, constant road noise, water noise and automotive engine noise. Noise sources that have non-stationary characteristics include rattling road noises, wind buffeting, rain noise and whizzing vehicular noise. CVC-NR is not designed to eliminate other speech sources or music sources in the background that have non-stationary statistics..

4.2.2 Acoustic Echo Cancellation (AEC)

The acoustic signal from the loudspeaker is picked up by the microphone of the hands-free kit (at the near end) is perceived as echo at the far end (see Figure 4.2). Echo cancellation is obtained by an algorithm which uses the receive signal to remove the echo in the send path. This algorithm determines the transfer function of the acoustic path from the loudspeaker to the microphone and then modifies the signal from the microphone by subtracting its estimate of the echo signal. Because AEC algorithm is designed with an acoustic model, mechanical coupling of the loudspeaker to the microphone deteriorates the performance of the system.

The AEC is a linear adaptive system, with provisions to handle some non-linearities. This means that the greater the non-linearity's found in the echo path equates to a reduction in performance of the echo canceller.

Double talk occurs when both the near end and far end talkers speak simultaneously. When this happens, the acoustic path could be inaccurately modelled and hence the echo could be transmitted during this condition. The problem is compounded if the speaker is very closely coupled (acoustically) to the microphone. This requires tradeoffs in the performance of the echo canceller to operate in full-duplex mode during the double talk conditions.

4.2.3 Parametric Equalisation (PEQ) and Frequency Shaping

The frequency response of the send path signal may not be flat or have the required spectral characteristics. The PEQ adjusts the frequency response of the send path signal. Figure 4.3 shows a signal modified by the PEQ to improve frequency response to enhance the quality of speech heard on the far end..

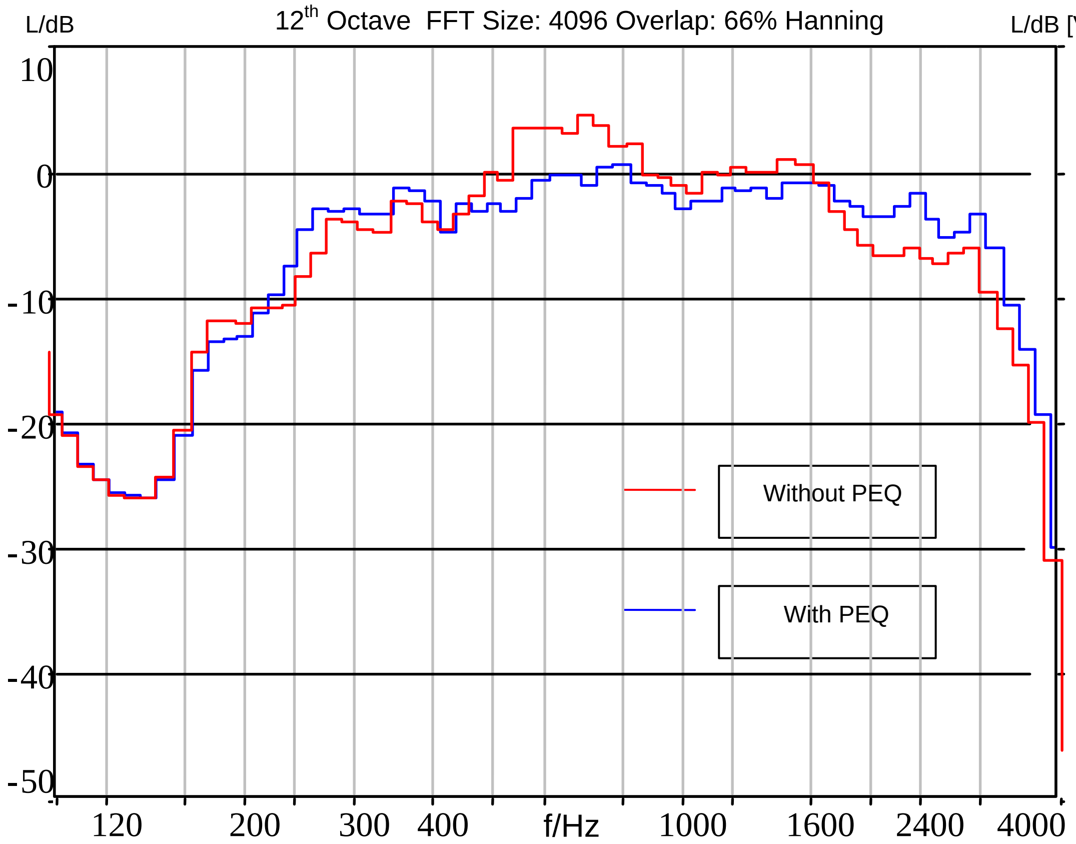

Figure 4.3: Frequency Shaping with PEQ

5 Summary

When designing a Bluetooth hands-free car kit consider the following.

Ensure that the microphone:

- Has linear characteristics
- Has good sensitivity and dynamic range
- Is exposed minimally to non-stationary and transient noise sources
- Is mechanically isolated from the loudspeaker
- Is mechanically isolated from the vehicle
- Has reduced acoustical coupling with the loudspeaker
- Does not clip with loudspeaker volume set to maximum
- Is close to the intended speech source
- Has its greatest sensitivity (directivity) positioned towards the talker

Ensure that the speaker:

- Has linear characteristics in its full range of operation
- Is not mechanically coupled to microphone
- Has reduced acoustical coupling with the microphone
- Has 1% or less Total Harmonic Distortion (THD)

Rely on signal processing techniques:

- To reduce noise
- To eliminate echo
- To help smooth the frequency response with the use of equalization techniques

Costly or non-feasible propositions for signal processing techniques include:

- Improving speech quality of a distorted (e.g. clipped) audio signal
- Eliminating the signal picked up by the microphone due to mechanical coupling with the loudspeaker Compensating for a poor quality loudspeaker
- Compensating for a poor quality microphone

Document References

Document	Reference
▪ *ITU-T recommendations: Transmission characteristics for telephone band (300 - 3400Hz) digital telephones*	▪ P.310 (2003). To view all ITU-T recommendations see the ITU website www.itu.int

Terms and Definitions

AEC	Acoustic Echo Canceller
BlueCore™	Group term for CSR's range of Bluetooth wireless technology chips
Bluetooth®	Set of technologies providing audio and data transfer over short-range radio connections
CNG	Comfort Noise Generator
CSR	Cambridge Silicon Radio
CVC	Clear Voice Capture (CSR's portfolio of software modules)
DIY kit	Do-IT-Yourself kit
ITU	International Telecommunication Union
Mic	Microphone
NLP	Non-Linear Processor
NR	Noise Reduction
PCB	Printed Circuit Board
PEQ	Parametric Equaliser
RCV_IN	Receive In signal at the near end (loudspeaker input)
RCV_OUT	Receive Out signal at the near end (loudspeaker output)
SND_IN	Send In signal at the near end (microphone input)
SND_OUT	Send Out signal at the near end (microphone output after processing)
Spkr	Speaker
SPL	Sound Pressure Level
TCL	Terminal Coupling Loss
THD	Total Harmonic Distortion

Document History

Revision	Date	History
1	26 OCT 06	Original publication of this document
2	13 DEC 06	Updates to whole document

BlueCore™

Bluetooth Hands-free Car Kit Design Considerations

Application Note

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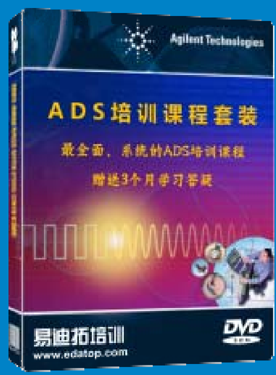

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