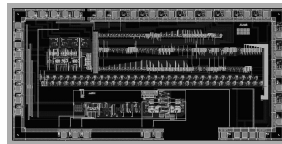# ADVANCED ELECTRONIC FEATURES FOR HEARING AIDS AND OTHER PORTABLE DEVICES

IEEE Circuits & Systems Society
The Dallas Section

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OVERVIEW

I.   HEARING AID TRENDS

II.   RESEARCH GOALS

III.   VOLUME CONTROL RECEIVER

IV.   PROGRAMMABLE INTERFACE RECEIVER

V.   ACTIVE NOISE CONTROLLER (ANC)

VI.   PROJECT CONTRIBUTIONS

HEARING AID TRENDS

- Present:
  - ➡ Perceived invisibility
  - ➡ More than 80% sales correspond to in-the-ear (ITE) and completely-in-the-canal (CIC) devices
  - ➡ Some HA models are programmable
- Future:
  - ➡ Better Performance
  - ➡ More advanced features
  - ➡ Adjustable (i.e., programmable, flexible)
  - ➡ Additional signal processing (i.e., noise cancellation)
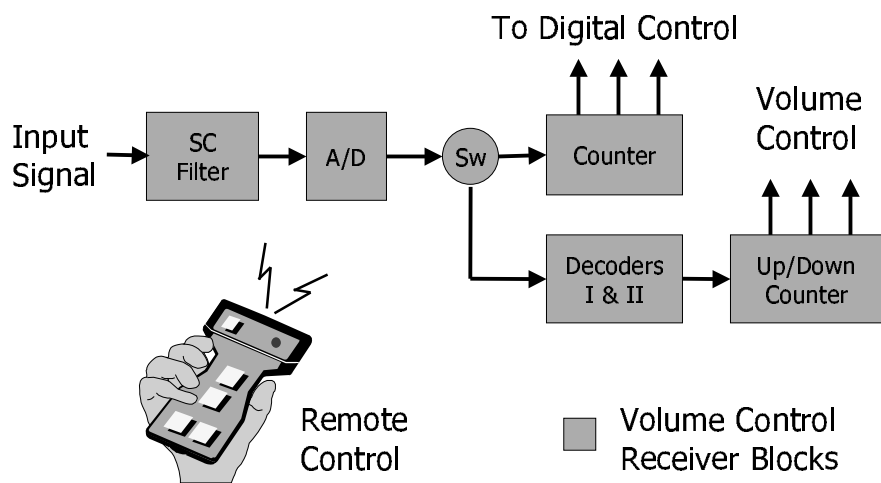
II. RESEARCH GOALS

- Research objective is to design, implement & test three (3) novel hearing aid features:

  - ➡ Volume Control Receiver, detects incoming signals (audio range) and controls the output of the HA

  - ➡ Programmable Interface Receiver, decodes signals and stores preprogrammed settings for each user

  - ➡ Noise Reduction System, improves hearing capabilities and speech intelligibility in noisy environments

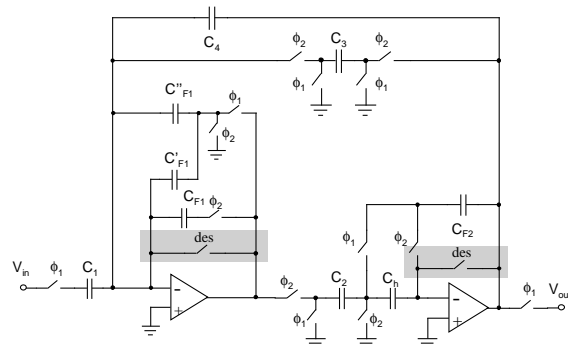- Each feature should perform independently, but blocks must be minimized when implemented together

III. VOLUME CONTROL RECEIVER

● Volume Control Receiver, detects incoming signals (audio range) and controls the output of the HA

➥ Input signal is converted from analog to digital

➥ Area and power efficient

➥ Decodes two (2) commands, which increase & decrease the hearing aid volume

➥ Uses standard Dual-Tone-Multi-Frequency (DTMF) tones, which are in the audio range

Volume Control Receiver Diagram

To Digital Control

Input Signal → | SC Filter | → | A/D | → (Sw) → | Counter |

Volume Control

| Decoders I & II | → | Up/Down Counter |

Remote Control

▢ Volume Control Receiver Blocks
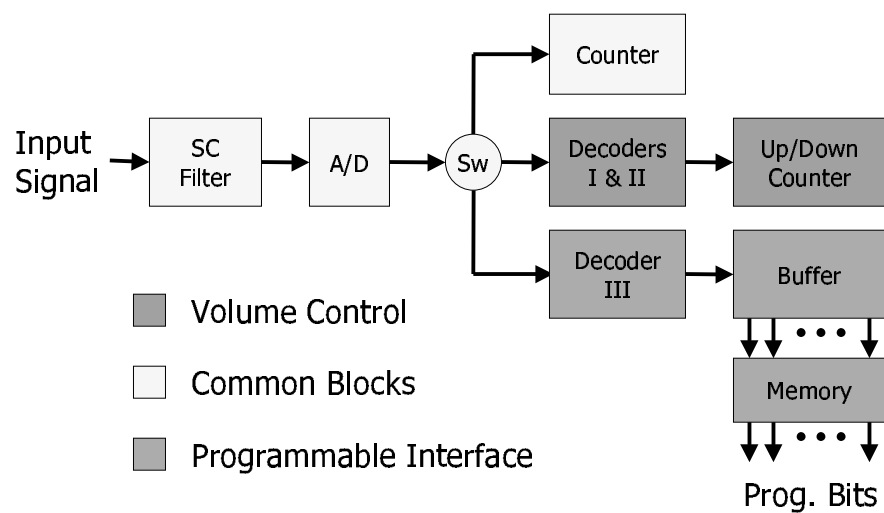
Switch Capacitor Bandpass Filter

- Four (4) variable center frequencies
- Area efficient (including offset cancellation)
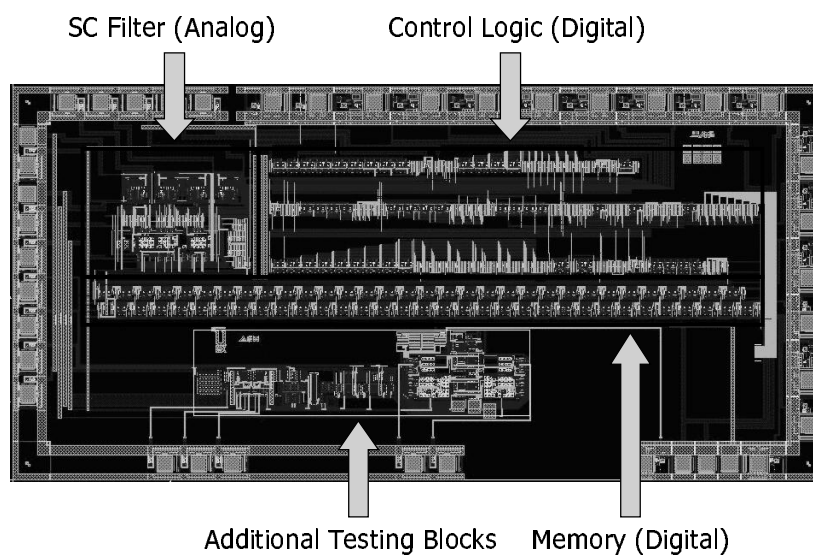- Additional reset switches across each amplifier

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IV. PROGRAMMABLE INTERFACE RECEIVER

- Programmable Interface Receiver, decodes signals and stores preprogrammed settings for each user

  ➡ Shares several components with previous design

  ➡ Decodes two (2) security codes with variable selectivity

  ➡ Stores up to 45 bits, which can be easily upgraded

  ➡ Stores filter frequency/gain compensation & automatic-gain-control (AGC) settings

Combined Receiver Diagram

Input Signal → SC Filter → A/D → Sw

Sw → Counter

Sw → Decoders I & II → Up/Down Counter

Sw → Decoder III → Buffer → Memory → Prog. Bits

■ Volume Control
□ Common Blocks
■ Programmable Interface

Combined Receiver Layout

SC Filter (Analog)   Control Logic (Digital)

Additional Testing Blocks   Memory (Digital)

Combined Receiver IC Implementation

- Fabricated & tested using 1.2μm AMS technology

- Layout area: 3,000μm x 1,000μm

- Total power consumption: 1.5mWatts

- Blocks implemented:

  ➡ Custom Digital Blocks

  ➡ Amplifiers in Weak Inversion

 ➡ Programmable Switched-Capacitor Filter
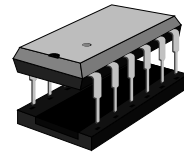
V. ACTIVE NOISE CONTROLLER (ANC)

- Noise Reduction System, improves hearing capabilities and speech intelligibility in noisy environments

  ➡ Combined FIR/IIR topology with analog blocks

  ➡ Maximum (IIR) and stable cancellation (FIR) for all common environments

  ➡ Moderate order filter (because of tradeoffs between accuracy and size)

  ➡ Requires separate reference input for noise source

  ➡ LMS adaptive algorithm was implemented, but it could be modified to realize other algorithms
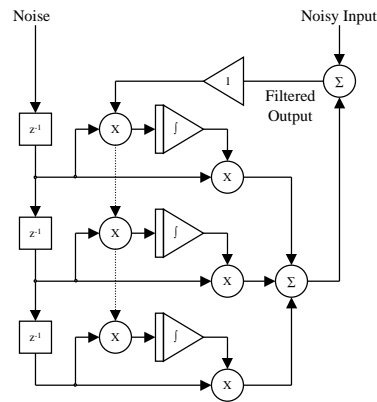
ANC System Diagram
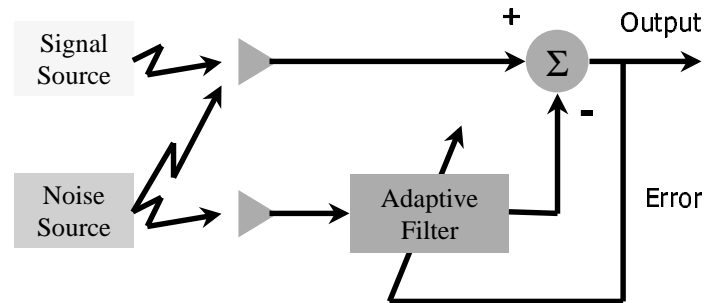
✔ Improves speech intelligibility

✔ Reduces undesired background noise

Combined FIR/IIR ANC System Diagram
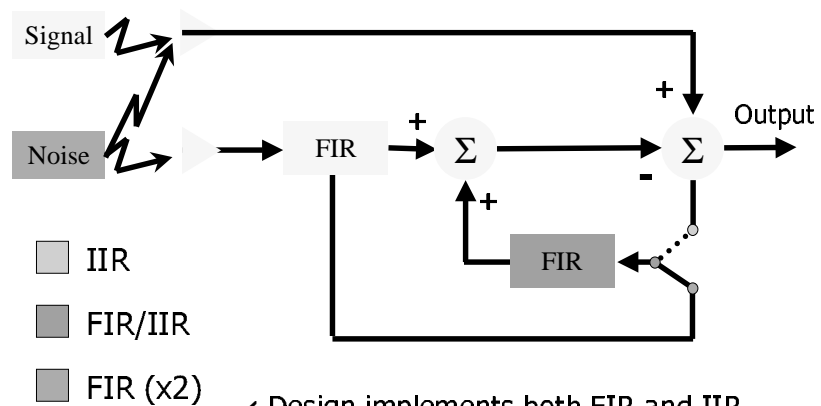
✔ Design implements both FIR and IIR
Filters (with automatic or manual control)

Actual Implementation (FIR Block)

- LMS adaptive algorithm implementation

ANC Building Blocks

- Building blocks have following characteristics:
  - Analog implementation
  - Non-multiplexed system configuration
  - Implemented with $1.2\mu m$ AMI technology

- Following blocks are described in more detail:
  - A. Fully Differential Amplifier
  - B. Four Quadrant Multiplier
  - C. Switched Capacitor Summer
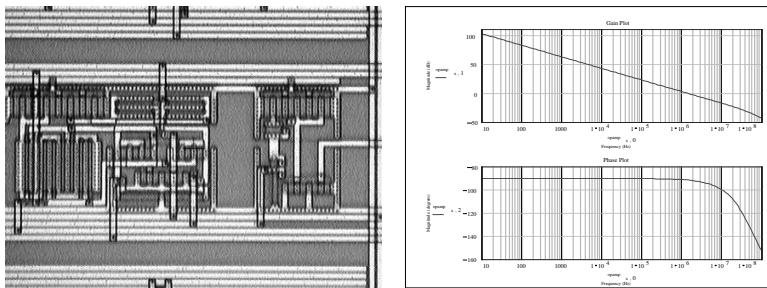 - D. Switched Capacitor Delay Line

A. Fully Differential Amplifier Diagram
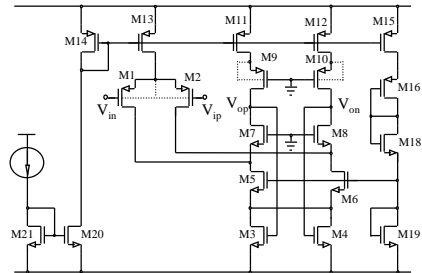
- ✔ Fully differential folded cascode structure
- ✔ Simple and effective continuos common mode feedback (CMFB)
- ✔ Area efficient (reasonable transistor ratios)

FD Amplifier Characteristics

- ✔ Maximum PSRR (Power Supply Rejection Ration)
- ✔ High DC gain
- ✗ Reduced Common Mode (CM) Range

FD Amplifier Layout and Results

Amplifier   Biasing Circuit
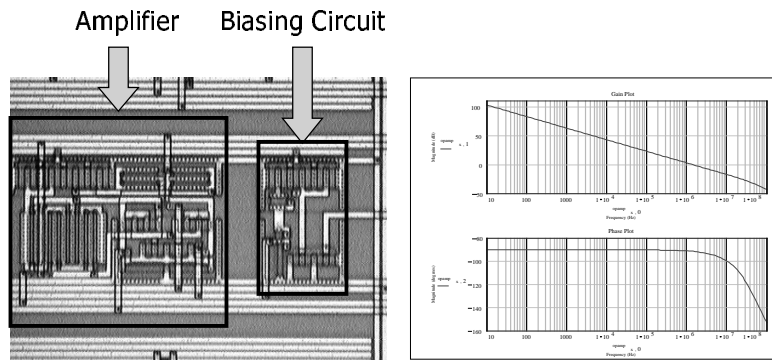
- Area efficient: 106μm x 127μm
- Interdigited layout for the differential pair and current mirrors (each transistor divided into even numbers)

B. Fully Differential Multiplier
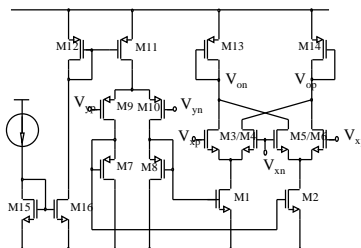
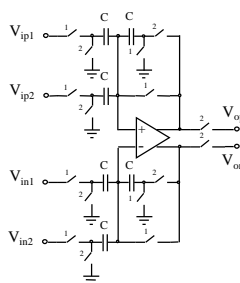

- Valid for all four (4) quadrants
- Crossed-coupled inputs
- Better linearity and wider input range

FD Multiplier Layout and Results
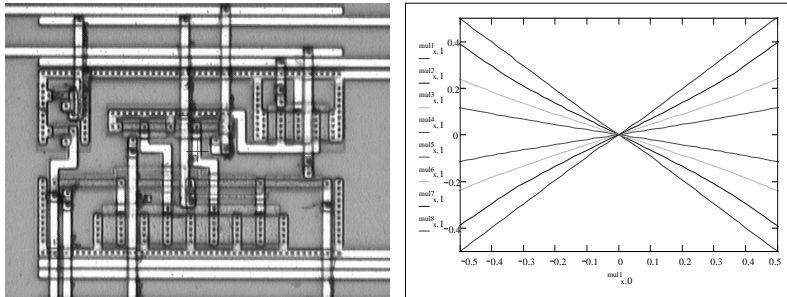
- Compact layout implementation: 76μm x 123μm
- Same biasing circuit as Fully Differential Amplifier
- High linearity for specified input range

C. Switched Capacitor Summer

- ✔ Simple fully differential configuration
- ✔ Can be used for multiple inputs (i.e., 30)
- ✘ All inputs must be summed every clock cycle
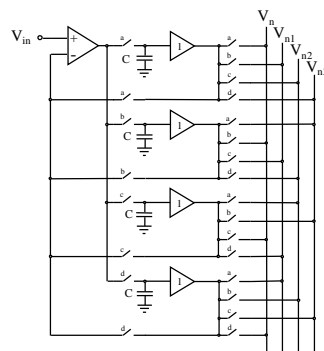 (critical when several inputs are required)
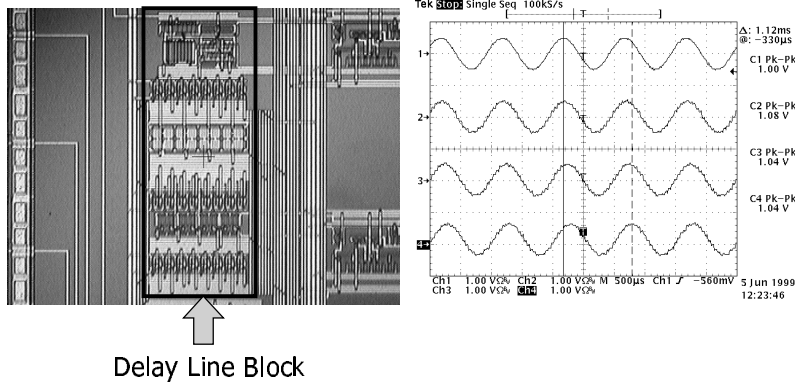
SC Summer Layout and Results
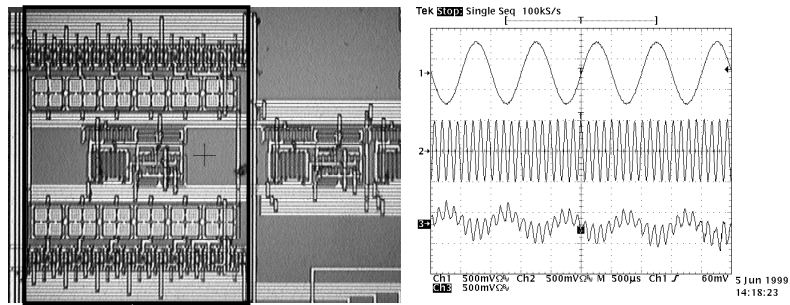
SC Summer

- Very efficient power consumption (one amplifier)
- Moderate layout area: 342μm x 260μm

D. Discrete Time Delay Line Block

- Only One robust amplifier and several simple buffers are needed

Delay Line Layout and Results


Delay Line Block

- Excellent power efficiency due to single amplifier usage
- No error accumulation because each delayed output is generated directly from the input signal

ANC System Results Summary

- FIR with known weights was used to generate desired signal
  - ➡ Initial weights set to: 0.4, -0.3 & 0.1
- ANC System was used to mimic FIR with known weights
  - ➡ White noise was used as the input signal for FIR with known weights and FIR with LMS algorithm
  - ➡ Results were similar for all cases:
    - ✔ Top level simulations with SIMULINK
    - ✔ SPICE simulations with macromodels
    - ✔ SPICE simulations with complete models
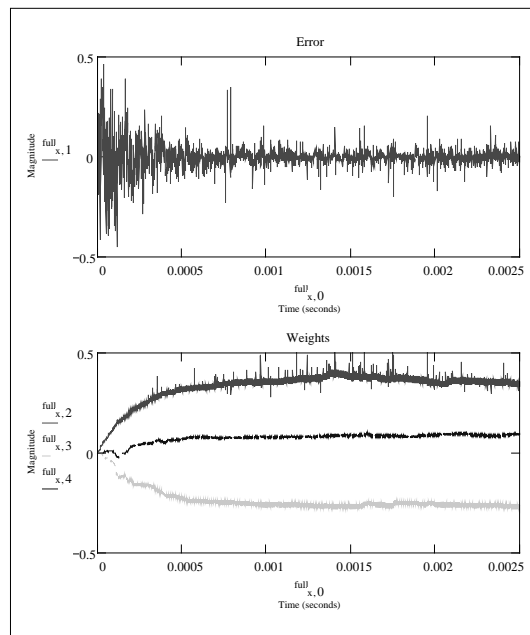   - ✔ Experimental results from fabricated prototypes

SIMULINK Results
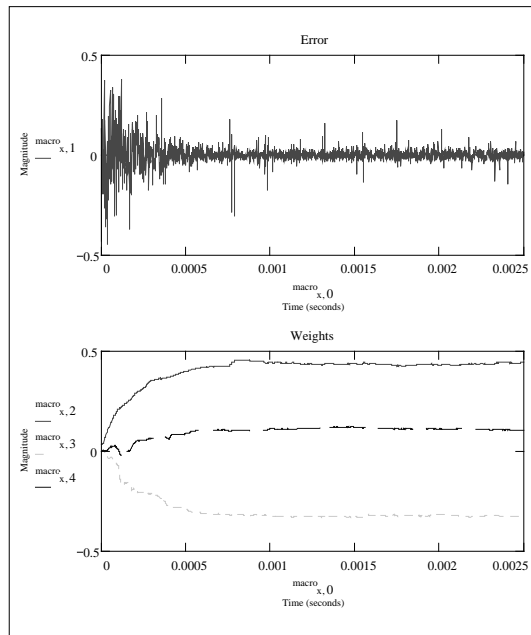
Difference between desired and filtered signals

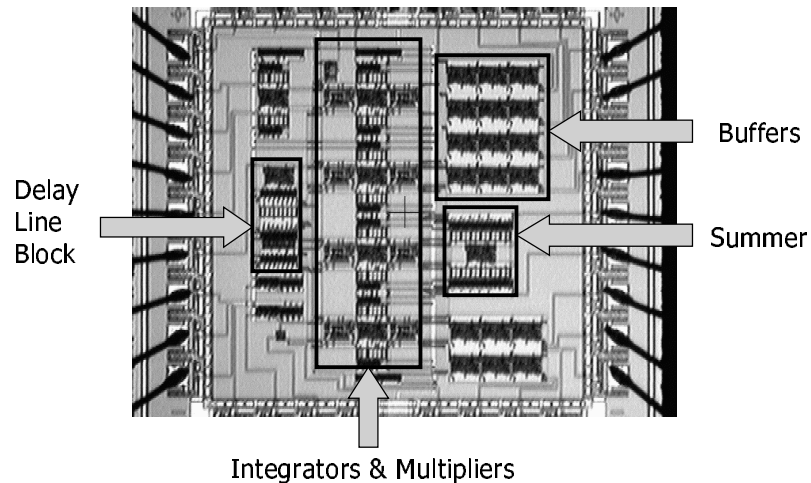Weights converge to: 0.4, -0.3 & 0.1

SPICE Results*

Difference between desired and filtered signals

Weights converge to: 0.4, -0.3 & 0.1 Final values varied slightly (consistent with lab results)

*with complete models

ANC System Layout

Buffers

Delay
Line
Block

Summer

Integrators & Multipliers

ANC System IC Implementation

- ANC was fabricated on a 2000μmx2000μm microchip using AMI technology
- Experimental Results:
  - ➡ Prototype converged to: 0.39, -0.28 & 0.12
  - ➡ Final values varied slightly (1% to 2%)
- Possible configurations:
  - ➡ System can be connected externally to implement a FIRs with several more weights: 30 taps
  - ➡ Implementation of a IIR is also possible
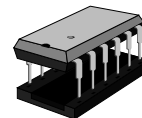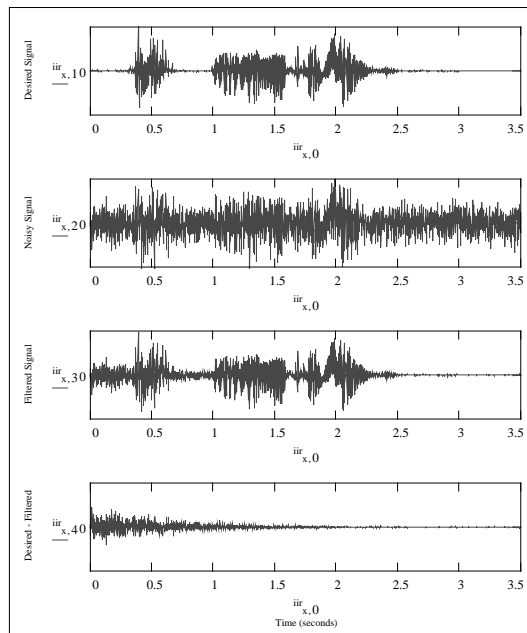
FIR Results
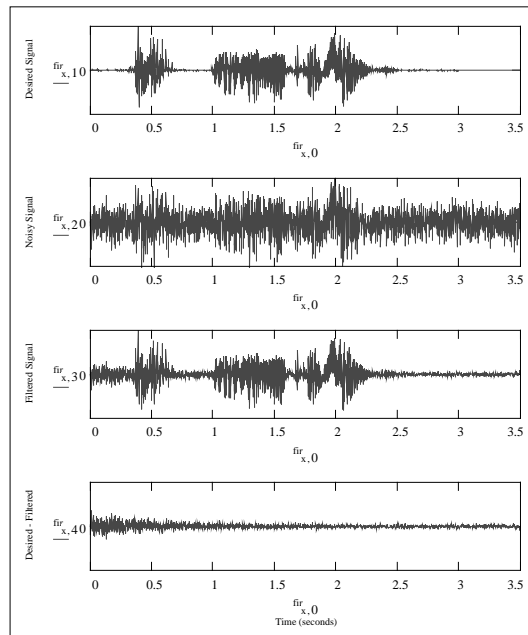
Desired Signal

Noisy Signal

Filtered Signal

Difference between
Desired and Filtered
Signals

IIR Results

Desired Signal

Noisy Signal

Filtered Signal

Difference between
Desired and Filtered
Signals

VI. PROJECT CONTRIBUTIONS

- System engineering approach that transforms ideas into practical system implementations
- Three original system designs that meet demand and consumer/marketing expectations
- Successful implementation of analog and digital designs on single microchips (true mixed-signal circuits)
- Comprehensive and compact system solutions:
  - Volume Control Receiver requires only one filter (similar receivers require at least two filters)
  - Programmable Interface can be upgraded and requires only additional digital logic (not extra analog blocks)

Project Contributions (Continued)

- Complete analog ANC system was implemented and tested on a single microchip
- ANC system is capable of implementing FIRs and IIRs
- Consists of several outstanding blocks such as amplifiers, multipliers, integrators, summers and delay line blocks:
  - High performance with moderate power consumption
  - Fully differential implementation
- Designs can be implemented in several other applications: cell phones, headphones, portable audio players, hearing protection devices, home and office electronics