

INFORMATION TO USERS

This manuscript has been reproduced from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps. Each original is also photographed in one exposure and is included in reduced form at the back of the book.

Photographs included in the original manuscript have been reproduced xerographically in this copy. Higher quality 6" x 9" black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.

UMI

A Bell & Howell Information Company
300 North Zeeb Road, Ann Arbor MI 48106-1346 USA
313/761-4700 800/521-0600

NOTE TO USERS

**The original manuscript received by UMI contains broken,
and/or light print. All efforts were made to acquire the
highest quality manuscript from the author or school.
Microfilmed as received.**

This reproduction is the best copy available

UMI

The Physiological Basis of Glottal Electromagnetic Micropower
Sensors (GEMS) and Their Use in Defining an Excitation Function
for the Human Vocal Tract

By

Gregory Clell Burnett

B.S. Physics (Southwest Missouri State University) 1991

M.A. Physics (Rice University) 1994

DISSERTATION

Submitted in partial satisfaction of the requirements for the degree of

DOCTOR OF PHILOSOPHY

in

Applied Science

in the

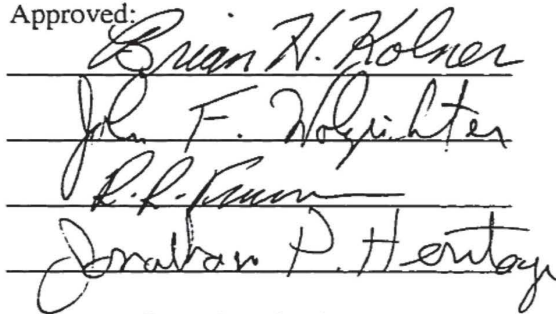
OFFICE OF GRADUATE STUDIES

at the

UNIVERSITY OF CALIFORNIA

DAVIS

Approved:



Committee in charge

January, 1999

-i-

UMI Number: 9925723

Copyright 1999 by
Burnett, Gregory Clell

All rights reserved.

UMI Microform 9925723
Copyright 1999, by UMI Company. All rights reserved.

This microform edition is protected against unauthorized
copying under Title 17, United States Code.

UMI
300 North Zeeb Road
Ann Arbor, MI 48103

Copyright by
Gregory Clell Burnett
1999

-ii-

The physiological basis of Glottal Electromagnetic Micropower
Sensors (GEMS) and their use in defining an excitation function
for the human vocal tract

Abstract

The definition, use, and physiological basis of Glottal Electromagnetic Micropower Sensors (GEMS) is presented. These sensors are a new type of low power (< 20 milliwatts radiated) microwave regime (900 MHz to 2.5 GHz) multi-purpose motion sensor developed at the Lawrence Livermore National Laboratory. The GEMS are sensitive to movement in an adjustable field of view (FOV) surrounding the antennae. In this thesis, the GEMS has been utilized for speech research, targeted to receive motion signals from the subglottal region of the trachea. The GEMS signal is analyzed to determine the physiological source of the signal, and this information is used to calculate the subglottal pressure, effectively an excitation function for the human vocal tract. For the first time, an excitation function may be calculated in near real time using a noninvasive procedure.

Several experiments and models are presented to demonstrate that the GEMS signal is representative of the motion of the subglottal posterior wall of the trachea as it vibrates in response to the pressure changes caused by the folds as they modulate the airflow supplied by the lungs. The vibrational properties of the tracheal wall are modeled using a lumped-element circuit model.

Taking the output of the vocal tract to be the audio pressure captured by a microphone and the input to be the subglottal pressure, the transfer function of the vocal tract (including the nasal cavities) can be approximated every 10-30 milliseconds using an autoregressive moving-average model. Unlike the currently utilized method of transfer function approximation, this new method only involves noninvasive GEMS measurements and digital signal processing and does not demand the difficult task of obtaining precise physical measurements of the tract and subsequent estimation of the transfer function using its cross-sectional area.

The ability to measure the physical motion of the trachea enables a significant number of potential applications, ranging from very accurate pitch detection to speech synthesis, speaker verification, and speech recognition.

2.1.2. Removing the filter response from the GEMS signal

Statement of the problem

One of the first questions posed when we were first experimenting with the GEMS was this: Are we seeing the undistorted position return from the object that is causing most of the signal reflection or are the filters used in the GEMS distorting the signal significantly? We already know that the GEMS signal is representative of the position of a reflector, but is there anything else that could be affecting the signal? An even better question might be “Why are there any filters at all in the GEMS receiver?” We will answer the final question first and this might help us understand the first two.

The GEMS has filters in it so that we may have both a cleaner signal and higher resolution of the magnitude of the signal. The GEMS is limited to about ± 4 Volts in its output, and is quite sensitive to motion of any kind. The filters were necessary to get rid of all the low-frequency motion taking place inside its “bubble” of sensitivity. The bubble for the GEMS in air is about 30 cm thick (starting from the surface of its case) and is distributed nonuniformly about the antennae (see the transmitted antenna pattern in Section 2.1.1). When the antennae are placed near the trachea, the GEMS is able to detect many kinds of low frequency motion: the jaw and tongue moving, the blood coursing through arteries and veins, the vertical motion of the glottis as speech begins and ends, and any motion of the GEMS itself with respect to the neck and trachea. Since we are interested in the vibration of tissues due to speech, the frequencies of interest are from 80 Hz up to about 5 kHz. Therefore a highpass analog filter was used with a 3 dB frequency of 80 Hz. Then the lower frequencies do not interfere with the signals of interest, and we may use the full ± 4 Volt range for the glottal signal.

In the future we are considering doing away with the analog filter and replacing it with a linear phase (no distortion) digital filter. However, this comes at a price in dynamic range, for if there are large low frequency signals the glottal signal will not have as much “room to expand”. It is also possible that the low frequency signal would be large enough to saturate the GEMS’s amplifiers, further distorting the signal. Figure 2.7

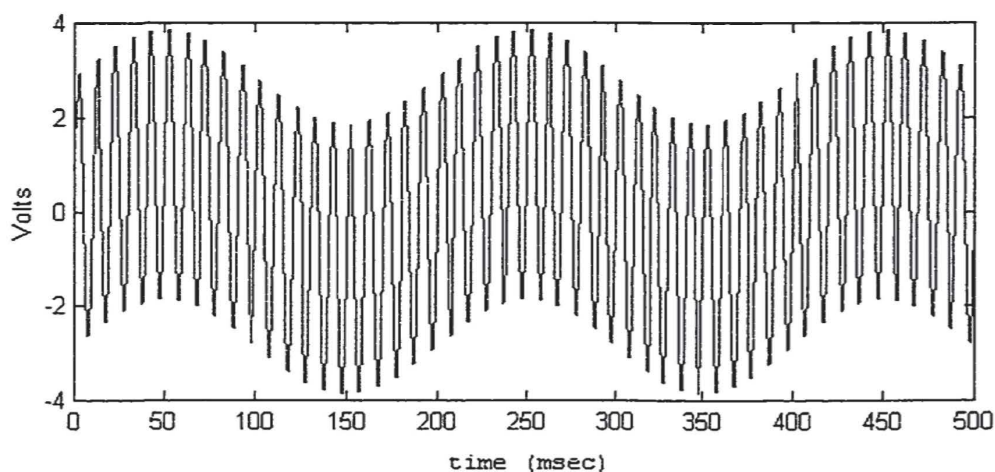


Figure 2.7. Example demonstrating how a low frequency signal can cause voltage amplitude resolution for a high frequency signal to degrade.

demonstrates how magnitude resolution may be lost. There is a 5 Hz signal with magnitude ± 1 V (perhaps the chin moving) and a 100 Hz speech signal “riding on top” of the 5 Hz signal at ± 3 V. Resolution can be lost if the overall signal amplitude requires a higher setting on the A/D. For example, if we use a 12-bit A/D, we have 4096 bins of magnitude resolution. This can be used for any of a number of ranges depending on the A/D and the application. Normal ranges are ± 5 , ± 2.5 , ± 1 , ± 0.5 , ± 0.25 , and ± 0.1 Volts. For a ± 2 Volt glottal signal, a setting of ± 2.5 Volts on the A/D may be used and the resolution is $5 / 4096 = 1.22$ mV/bin. For a ± 2 Volt glottal signal on top of a ± 1 Volt jaw signal, the next setting (± 5 Volts) on the A/D must be used. Then the resolution on

the signal is halved to 2.44 mV/bin. This loss of resolution would seem to discourage post-processing with digital filters. However, a digital filter has many advantages. A digital filter's parameters are easily manipulated and it can be designed to have linear phase, so there is no need for an anticausal post-filter to remove the distortion caused by the initial highpass filter. As long as reasonable magnitude resolution is available, it is a superior method. However, analog filters are so inexpensive and widely used they may continue to be utilized for some time.

So we now tackle the first question. Are the analog filters distorting the GEMS signal reflected from the tracheal wall? To get an idea of the amount of distortion we will determine the magnitude and phase response of the GEMS electronics. We can use this information to build a digital model that approximates the experimentally determined response. Finally, we digitally invert the model to construct an "inverse filter", which will be used to reconstruct the original undistorted GEMS position signal.

Determining the frequency response of the GEMS electronics

This is accomplished by injecting sine waves into the receiver end of the GEMS and then sampling the input and output. The magnitude and phase response at that frequency can then be calculated using a mathematical computational tool such as MathWorks' Matlab by measuring the frequency of the input and the resulting phase shift of the output. For accurate results, many different input frequencies should be used. In the experiment I conducted, a sweeping frequency generator was used to vary the frequency continuously between 20 Hz and 5 kHz. The total sweeping time was 12 seconds and was sampled at 20 kHz for good time resolution of the signals.