peaks during segments of speech. The output spike event rate is about 1.2Hz during nonspeech and is about 20Hz during speech. Fig. 11 also shows intermediate signals which are inverted as needed to show increases in current upwards. V_{sq} is the log of the audio power current from the squaring circuit; V_{lp} is the log of the bandpass internal lowpass current node. V_{rect} is the log of the neuron input current which is the half-rectified bandpass filter output.

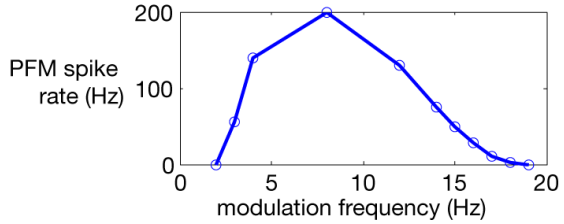

Fig. 10 Measured modulation transfer function.

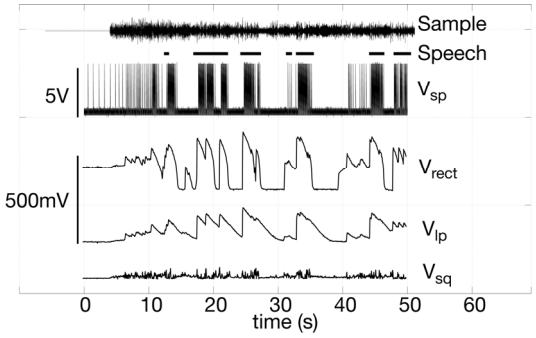

Fig. 11 Measured spike raster response to input speech-non-speech sound sequence at average 75dB SPL. The manually marked speech segments are shown.

4. DISCUSSION

Fig. 12 is a table of specifications. The background PFM output rate of about 1Hz could leave a microcontroller almost completely asleep: Assuming a wakeup time of 5us and a processing time of another 20us per event, the active duty cycle would be 25us/s=25e-6. If the controller burned 5uA sleeping and 20mA active, the average controller current consumption would be only 5.5uA. The SD circuit at 155uA would dwarf the controller consumption. Still, a pair of 2Ah AA batteries would power the system for more than a year.

Although this functional silicon is encouraging, innovations are required to reach sub-100uW power levels. As in much prior work, the microphone preamplifier still consumes the majority of the total power. Also, the simulation-based estimation of bias currents which are then hardwired is too inflexible for prototype silicon and calls for some degree of programmability. In future work, the SD wakeup chip will be integrated with a microcontroller to explore the feasibility of a complete speech detector system.

5. ACKNOWLEDGEMENTS

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Process	1.6um 2M 2P CMOS
Supply voltage	3V
Die size	2.2x2.2mm^2
SD circuit size, incl. biasing	1.6mm^2
Supply current	155uA (SD circuit, 48uA, Microphone 107uA)
Power consumption	465uW
Microphone preamp output with 65dB SPL sound input and Rf=220kOhm	100mVRMS
Zero modulation PFM rate	1.2Hz
Peak PFM rate during speech	23Hz

Fig. 12 Specifications.