**Modelling the glottal flow: the mathematical approach**

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On the basis of the source-filter theory (Fant, 1960), the glottal flow modelling is of much importance for taking into account voice quality aspects in the analysis and synthesis process. The glottal flow can be derived from physical models, such as the well-know two-mass model, or from direct mathematical computation. The physical approach allows to understand the biomechanical properties of the vocal folds vibratory behavior but it is inadequate for high-quality speech synthesis. On the opposite, the mathematical approach is inadequate for the understanding of vocal folds mechanical properties, but it is very efficient for speech analysis and synthesis purposes.

The latter approach is developed here. It consists in an attempt to mimic the glottal flow signal with the help of mathematical functions and a set of few parameters defined in the temporal domain. The possibilities and limitations of the main glottal flow models - Klatt (Klatt & Klatt, 1990), LF (Liljencrants & Fant, 1985), R++ (Veldhuis, 1998) - are presented. The Klatt model is the simplest one for computation purpose, but it does not allow the modification of the glottal pulse asymmetry. The LF model is more complex, as it requires the solving of an implicit equation, but it allows to reproduce a wider range of glottal pulse shapes. The R++ model is a good compromise between computational efficiency and degree of freedom.

An unified set of parameters is proposed, which are related to temporal events: fundamental period T0, amplitude of voicing Av, open quotient Oq, asymmetry coefficient a_m , and return phase quotient Qa. The spectral properties of glottal flow models are analytically derived from the temporal equations and studied in the abrupt closure case. It is shown that open quotient and asymmetry coefficient mostly affect the low-frequency part of the spectrum (below 2 kHz), whereas the return phase quotient controls the spectral slope. The amplitude of voicing is similar to a gain control. The perceptual relevance of open quotient and asymmetry coefficient is studied by measuring just-noticeable differences on synthetic singing voice sounds.

Finally, the glottal flow parameter space is studied in the temporal and spectral domains, in relation with real speech. It is shown that the glottal flow models can account for the relaxed versus pressed phonation axis.