Control parameters of a generalized vibrato model with modulations of harmonics and residual

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♪ Acoustics'08 Paris — July 04, 2008

Introduction

- goals:
  - better understanding of vibrato
  - cues for high-quality & realtime vibrato control & synthesis
  - offline model for transformations
  - listening tests to validate the model
- context: ANR project (ANR-05-BLAN-0097-01), *Consonnes* (control of natural and synthetic sounds), Axis II: digital models (for realtime synthesis)
- work in progress: not a 'final' model, but another step
- today's focus: control parameters for sound transformations

Vibrato

Definition

Vibrato is

- a "pulsation in pitch, intensity and timbre" [Seashore, 1932]
- a vibrating quality of musical sounds, corresponding to:
  i) fundamental frequency modulations (FM)
  ii) global amplitude modulations (AM)
  iii) spectral envelope modulations (SEM)

  which alone or in combination enrich timbre

Verfaille, Guastavino, Depalle; *Perceptual Evaluation of Vibrato Models*, Colloquium on Interdisciplinary Musicology, Montréal, 2005

Vibrato

Vibrato components

- fundamental frequency modulations:
  - changes of perceived pitch
  - alone: amplitude modulations of harmonics when sweeping the SE
  - eg. voice ♪ [Sundberg, 1987], bowed strings [Mathews & Kohut, 1973]
- global amplitude modulations:
  - changes of sound intensity and loudness
  - alone: same AM for all harmonics
  - eg. woodwinds (saxophone ♪, flute ♪)
- spectral envelope modulations (with implicit AM):
  - spectral enrichment (brightness)
  - second source of harmonics' amplitude modulations
  - eg. brass (trumpet ♪), woodwinds and voice

Vibrato

Past research

Previous vibrato model (2005):

- represents partials of the entire vibrato note
- focuses on SEM, and combines:
  - 2 levels of sinusoidal modeling (2-LSM): additive parameters of the deterministic part modeled with an additive model

    Marchand, Raspaud, *Enhanced Time-Stretching Using Order-2 Sinusoidal Modeling*, Proc. Int. Conf. on Digital Audio Effects, Naples, pp. 76–82, 2004

  !!! used only for the 1st partial frequency, as in [Gilbert, Simons, Terroir, 2005]
  - spectral envelope interpolation between 2 extrema envelopes using panned-wave synthesis

    Maher, Beauchamp, *An Investigation of Vocal Vibrato for Synthesis*, Applied Acoustics, 30, pp. 219–45, 1990

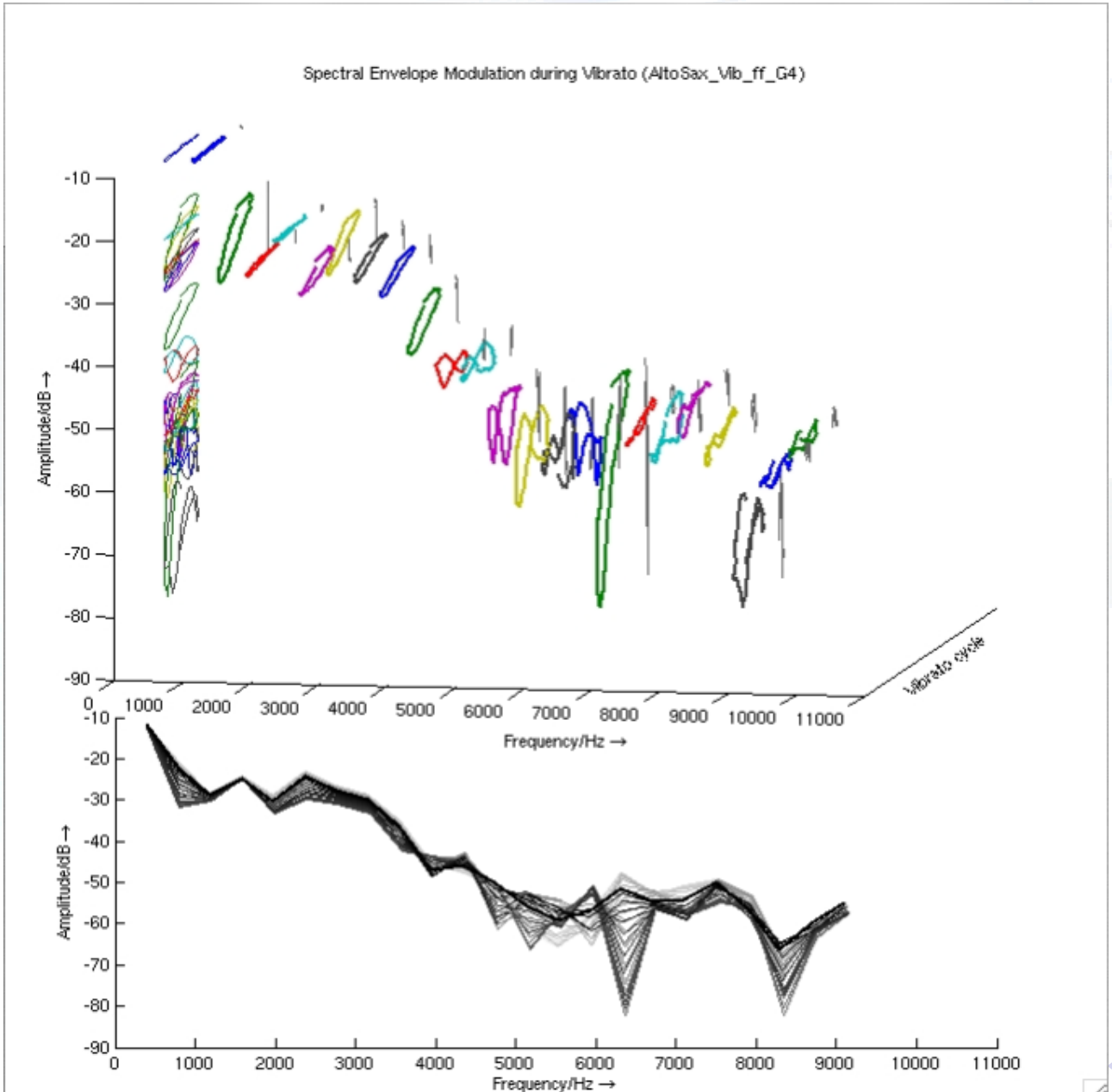
Perceptual evaluations of vibrato models for saxophone:

- [Verfaille, Guastavino, Depalle, 2005]: AM/FM/SEM vs. AM/FM
- [Guastavino, Verfaille, 2007]: pairwise comparison among:
  - AM only (cross-synthesis) G4
  - FM only (cross-synthesis) G4
  - modeled AM/FM/SEM (cross-synthesis) G4

(morphing between vibrato G4 and flat sound G4)

Observations

Spectral envelope modulation



Observations

Spectral envelope modulation

Hypothesis: SEM may result from

1. variable spectral sampling of admittance as F_0 varies,
2. coupling between the excitation and the resonating body, and/or
3. varying controls $\Longrightarrow$ subtle changes of the system's structure

Example of flute:

- air pressure modulations (diaphragm/throat)
- changes in global amplitude, F_0 and spectral enrichment

Panned Wave Synthesis:

- interpolation between 2 extrema SE [Maher, Beauchamp, 1990]

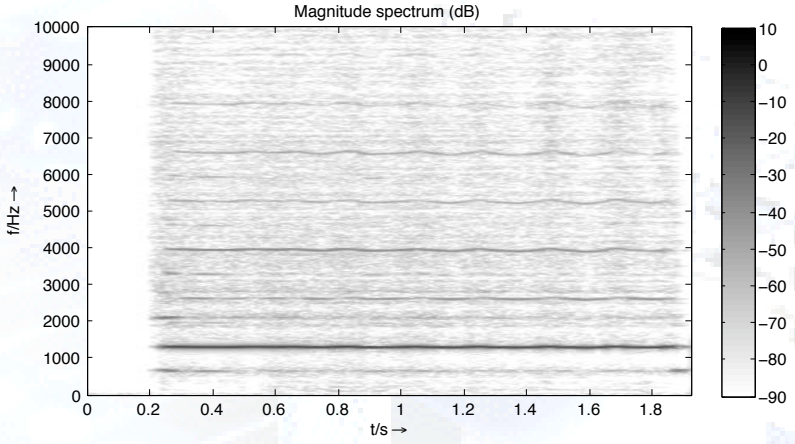
\+ for simple periodicity of harmonics' amplitude

\− for harmonic sweeping peaks/valleys of the SE (double/triple periodicity)

$\Longrightarrow$ issue to be addressed by the model

Observations

Residual (noise + 'sub-harmonics')



In wind instruments (shakuhachi):

- residual exhibits AM due to air pressure modulations
- upper register: residual = noise + 'sub-harmonics'

Pilot test on shakuhachi sounds:

- AB comparison (same/different task): original harmonics + amplitude modulated (D_6, *ff* ♪) vs de-modulated residual (D_6, *ff* ♪)
- E_4, D_5, E_5, A_5, D_6, E_6; *ff*/*mf* (RWC Musical Instr. Sound database)

  Goto, Hashiguchi, Nishimura, Oka, *RWC Music Database: Music Genre Database and Musical Instrument Sound Database*, Proc. 4th Int. Conf. on Music Information Retrieval, pp.229–30, 2003
- participants are able to discriminate the two

!!! limitations: 4 participants! + SE transformations with STFT

- residual to be spectrally modeled for transformation & synthesis

Observations

A more complete definition

Previous definition: for harmonics only!

- **Vibrato** is a vibrating quality of musical sounds, corresponding to:
  i) fundamental frequency modulations (FM)
  ii) global amplitude modulations (AM)
  iii) spectral envelope modulations (SEM)

  which alone or in combination enrich timbre

Observations

A more complete definition

"New" definition: for harmonics + residual (noise + 'sub-harmonics')!

- **Vibrato** is a vibrating quality of musical sounds, corresponding to:
  i) fundamental frequency modulations (FM)
  ii) global amplitude modulations (AM)
  iii) spectral envelope modulations (SEM)

  which alone or in combination enrich timbre
- those modulations concern both sound components:
  harmonics (FM/AM/EM) and residual if any ('sub-harmo.' FM/AM, SEM)

Generalized vibrato model

Model improvements

2005 model:

- pros:
  - explicitly accounts for SEM with Panned Wave Synthesis
  - appropriate for morphing
    (1st sine of AM/FM/SEM applied to non-vibrato sounds)
- cons:
  - morphing only (no time-scaling available)
  - sinusoid models for $F_0(t)$, $E(t)$ only
  - partials' AM with double- and triple-periods are lost

2008 model: recently added

- 2-LSM of all partials' amplitude and frequency
- account for partials' AM with single-/double-/triple-periods
  as many SE / cycle as needed (2/4/6)
- residual transformation (no synthesis yet)

Generalized vibrato model

A combination of models

- (harmonic) partials:

Generalized vibrato model

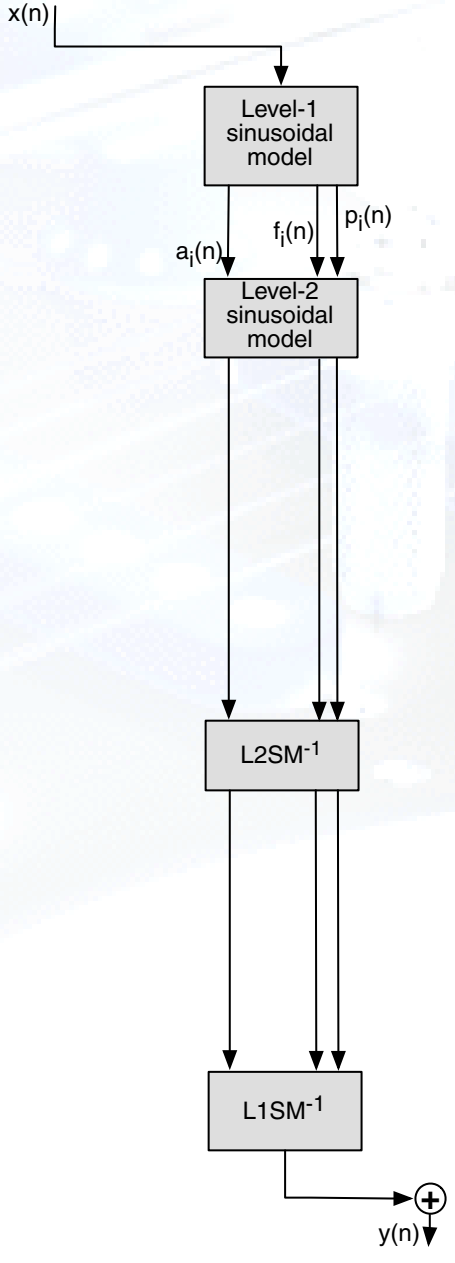
A combination of models

- (harmonic) partials:
  - level 1 sinusoidal model

Generalized vibrato model

A combination of models

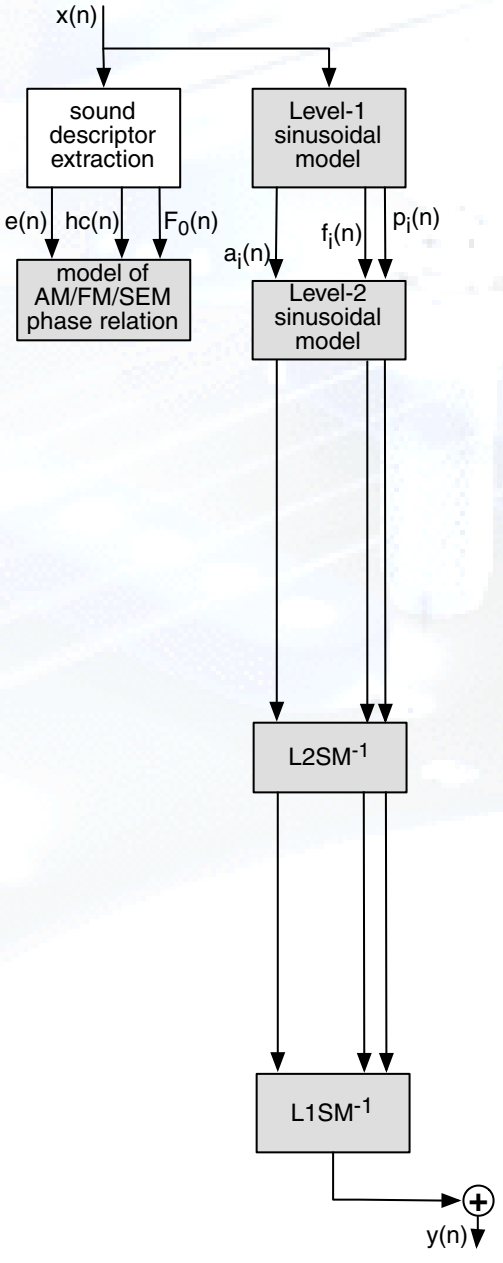
- (harmonic) partials:
  - level 1 sinusoidal model
  - level 2 sinusoidal model



Generalized vibrato model

A combination of models

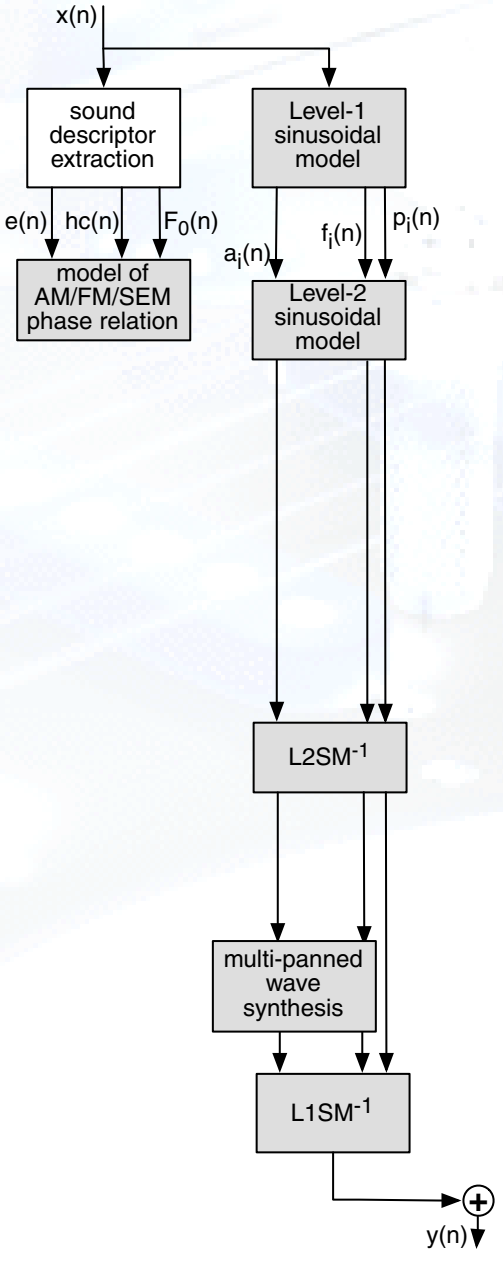
- (harmonic) partials:
  - level 1 sinusoidal model
  - level 2 sinusoidal model
  - component phase relation model



Generalized vibrato model

A combination of models

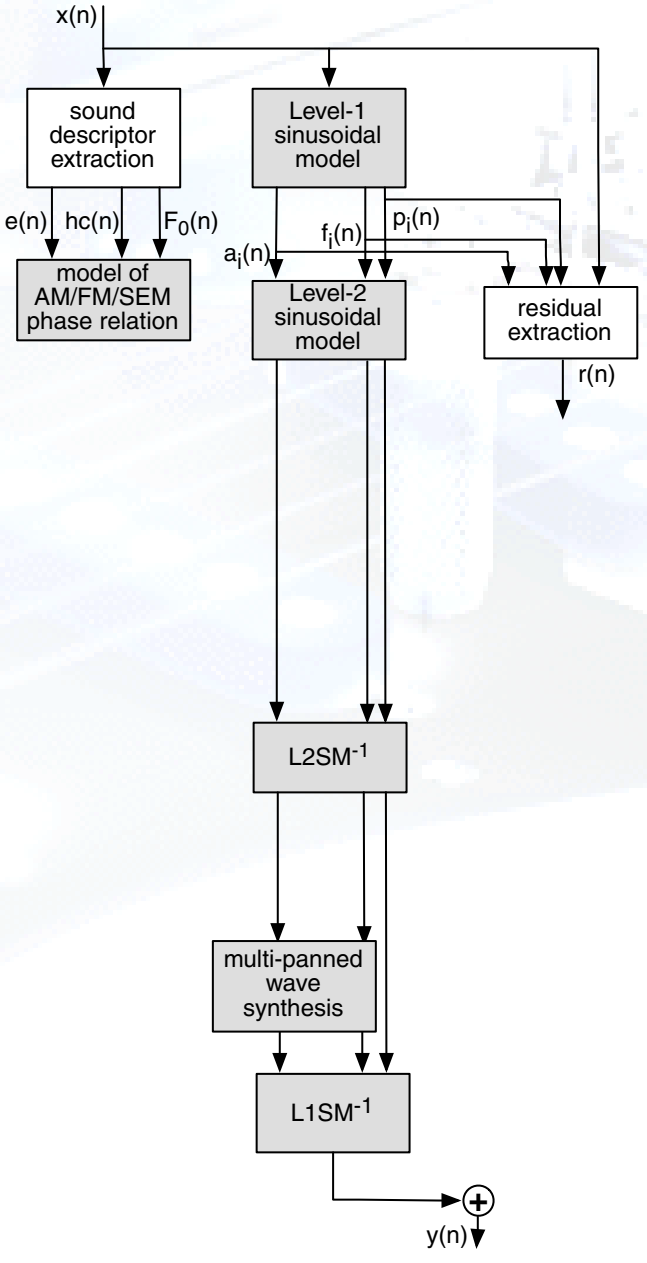
- (harmonic) partials:
  - level 1 sinusoidal model
  - level 2 sinusoidal model
  - component phase relation model
  - multi-panned wave synthesis



Generalized vibrato model

A combination of models

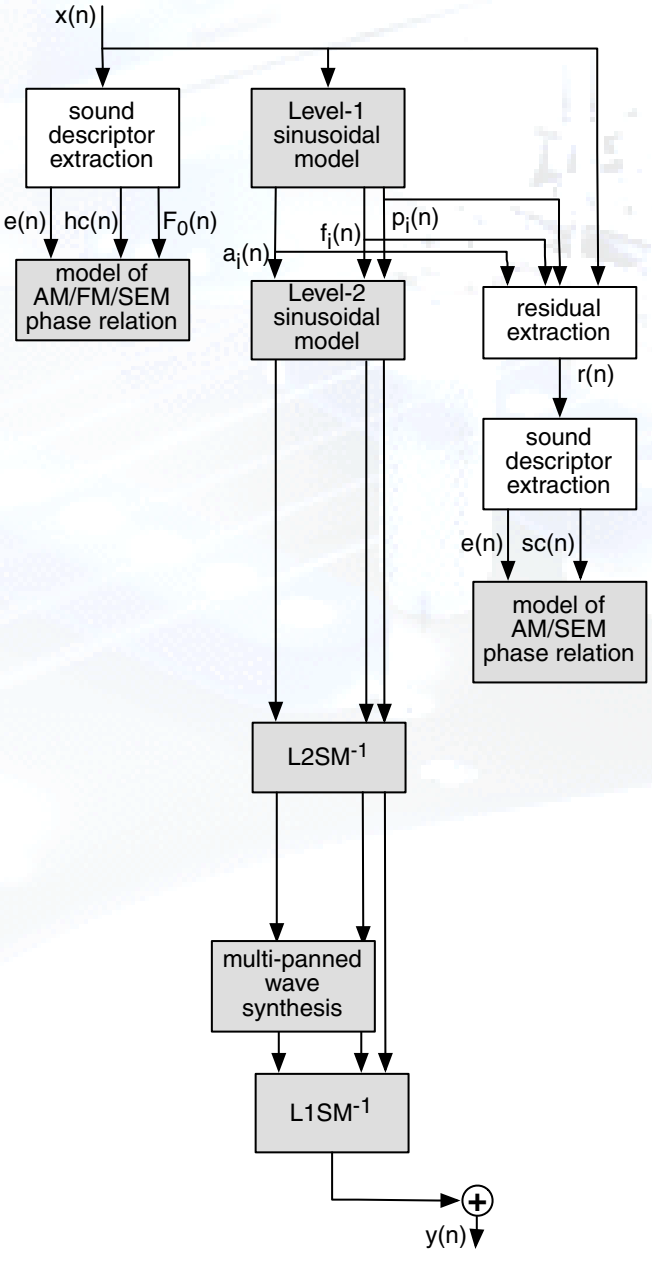
- (harmonic) partials:
  - level 1 sinusoidal model
  - level 2 sinusoidal model
  - component phase relation model
  - multi-panned wave synthesis
- residual:



Generalized vibrato model

A combination of models

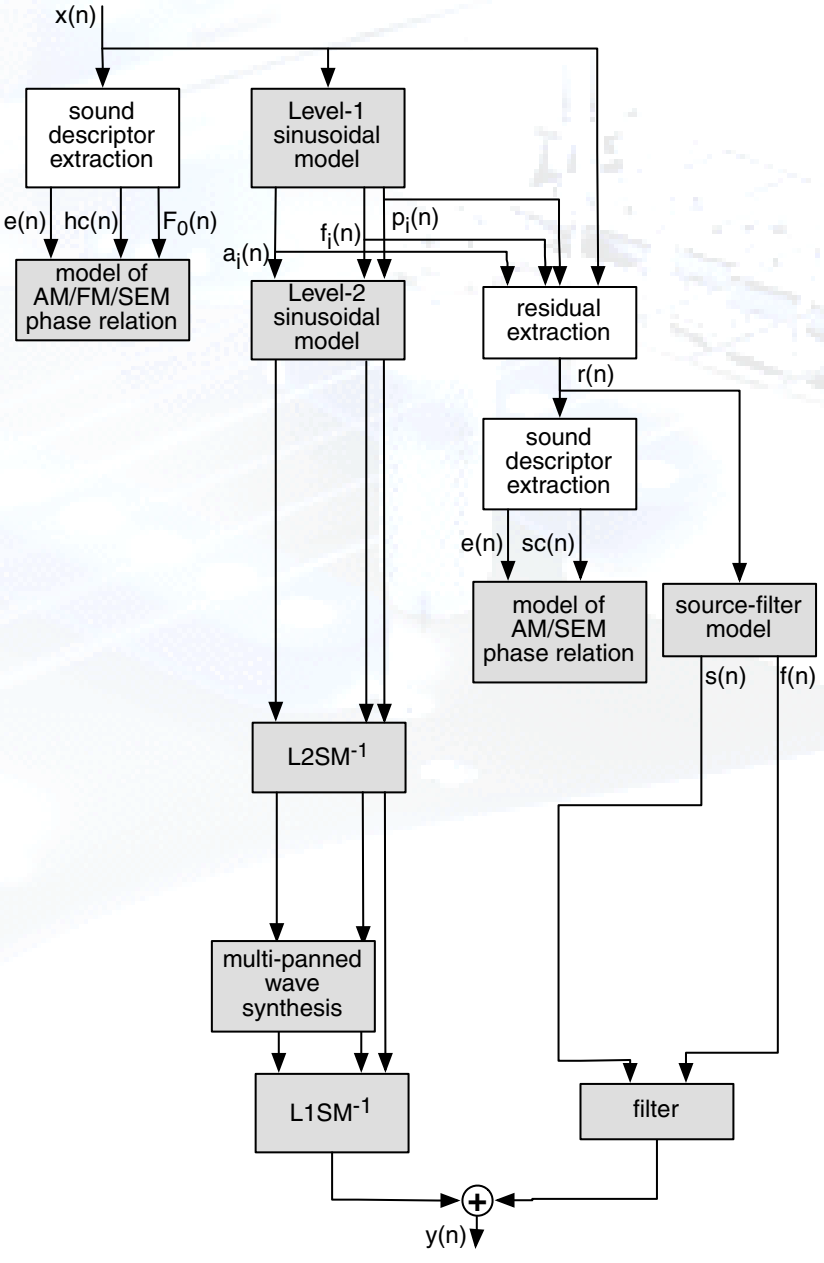
- (harmonic) partials:
  - level 1 sinusoidal model
  - level 2 sinusoidal model
  - component phase relation model
  - multi-panned wave synthesis
- residual:
  - sound descriptors modelling



Generalized vibrato model

A combination of models

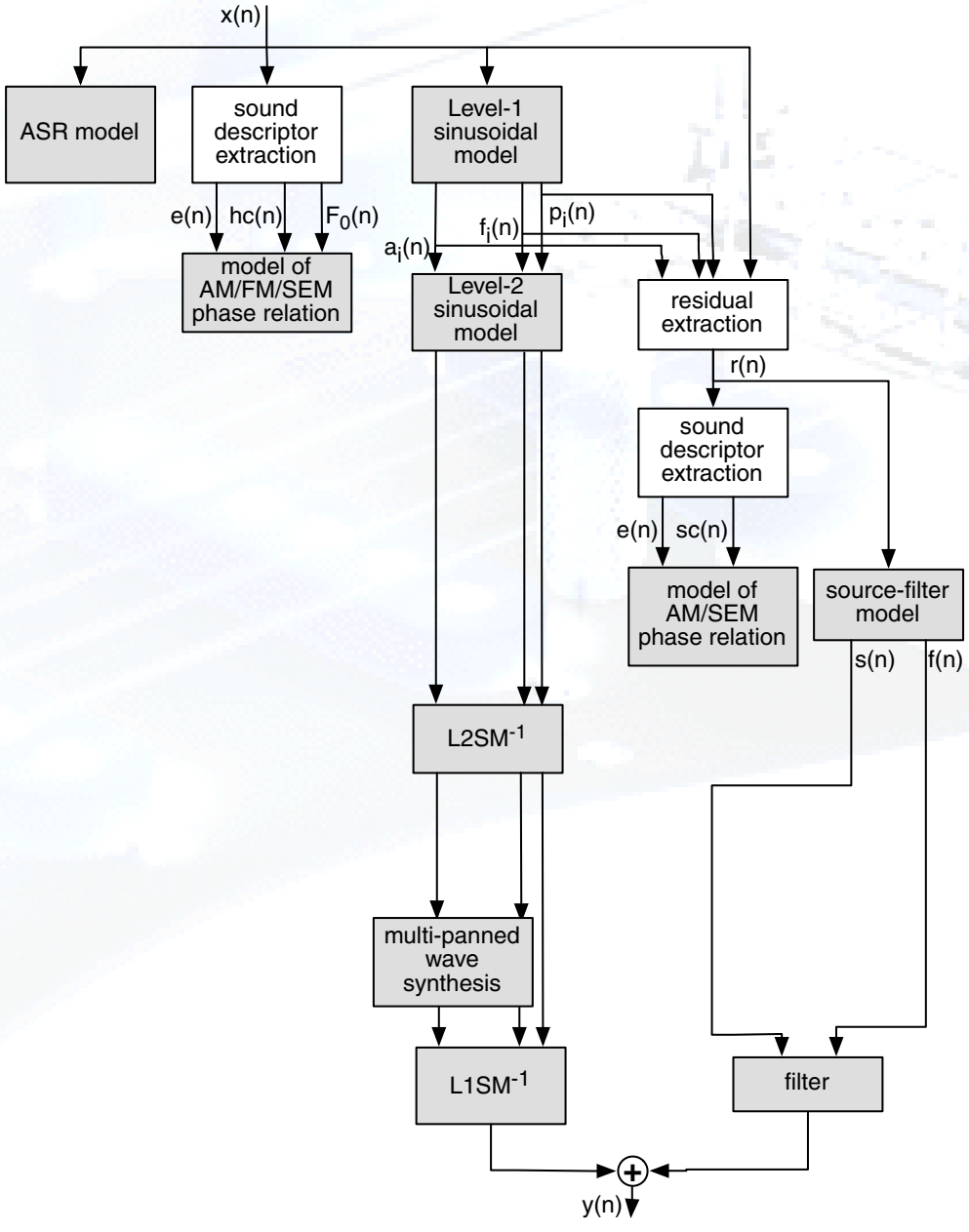
- (harmonic) partials:
  - level 1 sinusoidal model
  - level 2 sinusoidal model
  - component phase relation model
  - multi-panned wave synthesis
- residual:
  - sound descriptors modelling
  - source-filter



Generalized vibrato model

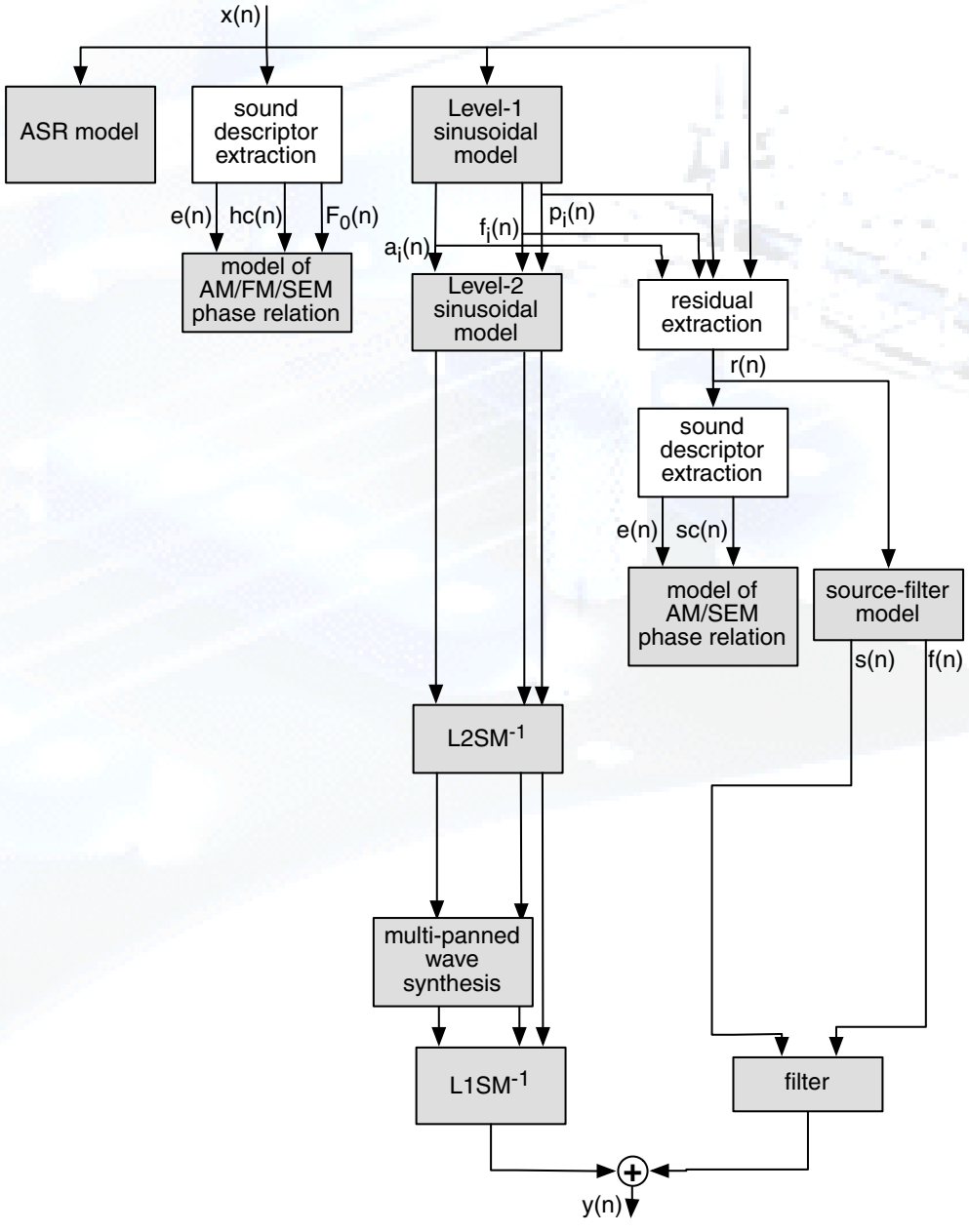
A combination of models

- (harmonic) partials:
  - level 1 sinusoidal model
  - level 2 sinusoidal model
  - component phase relation model
  - multi-panned wave synthesis
- residual:
  - sound descriptors modelling
  - source-filter
- ASR: vibrato time segments



Generalized vibrato model

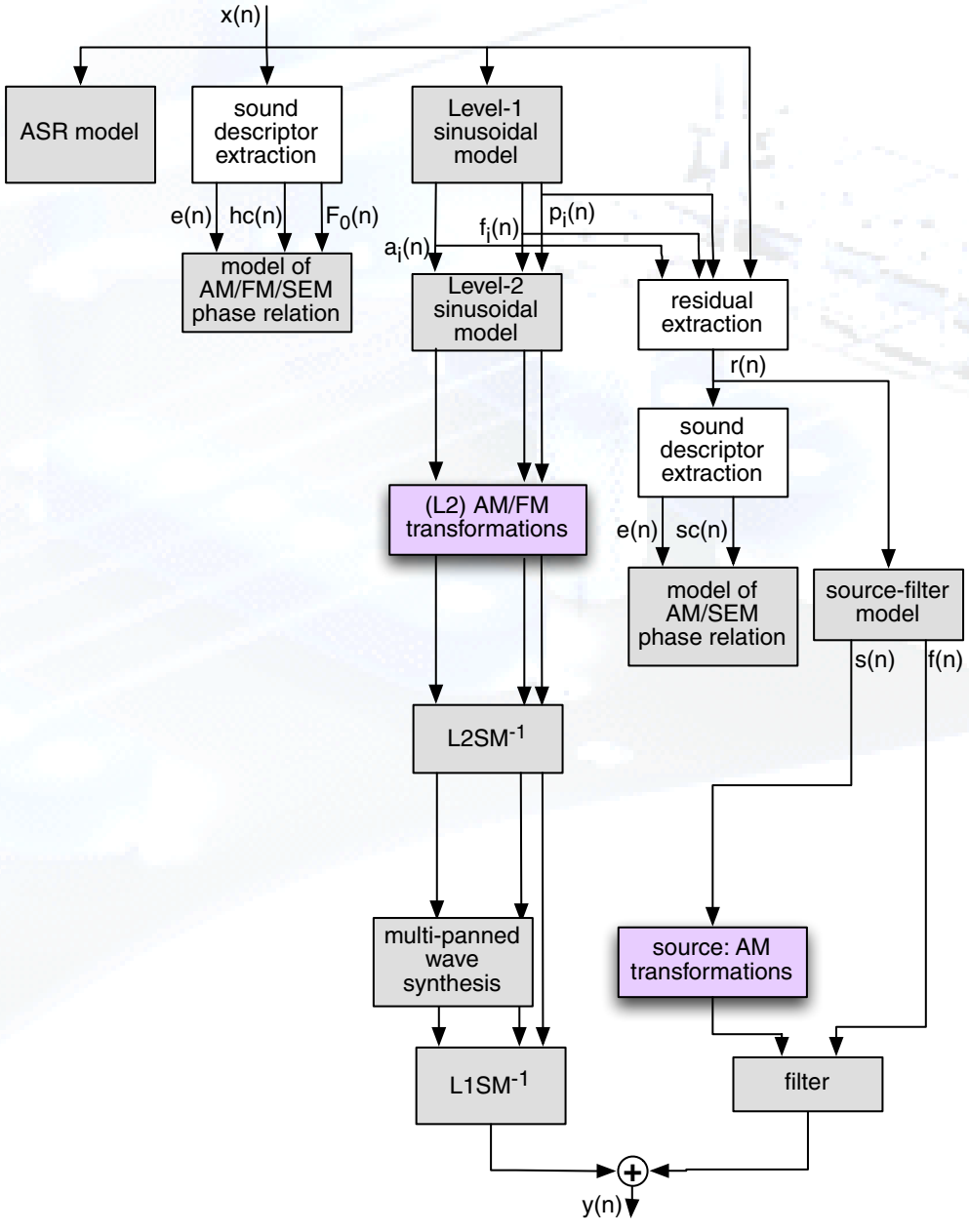
Sound transformations enabled



Generalized vibrato model

Sound transformations enabled

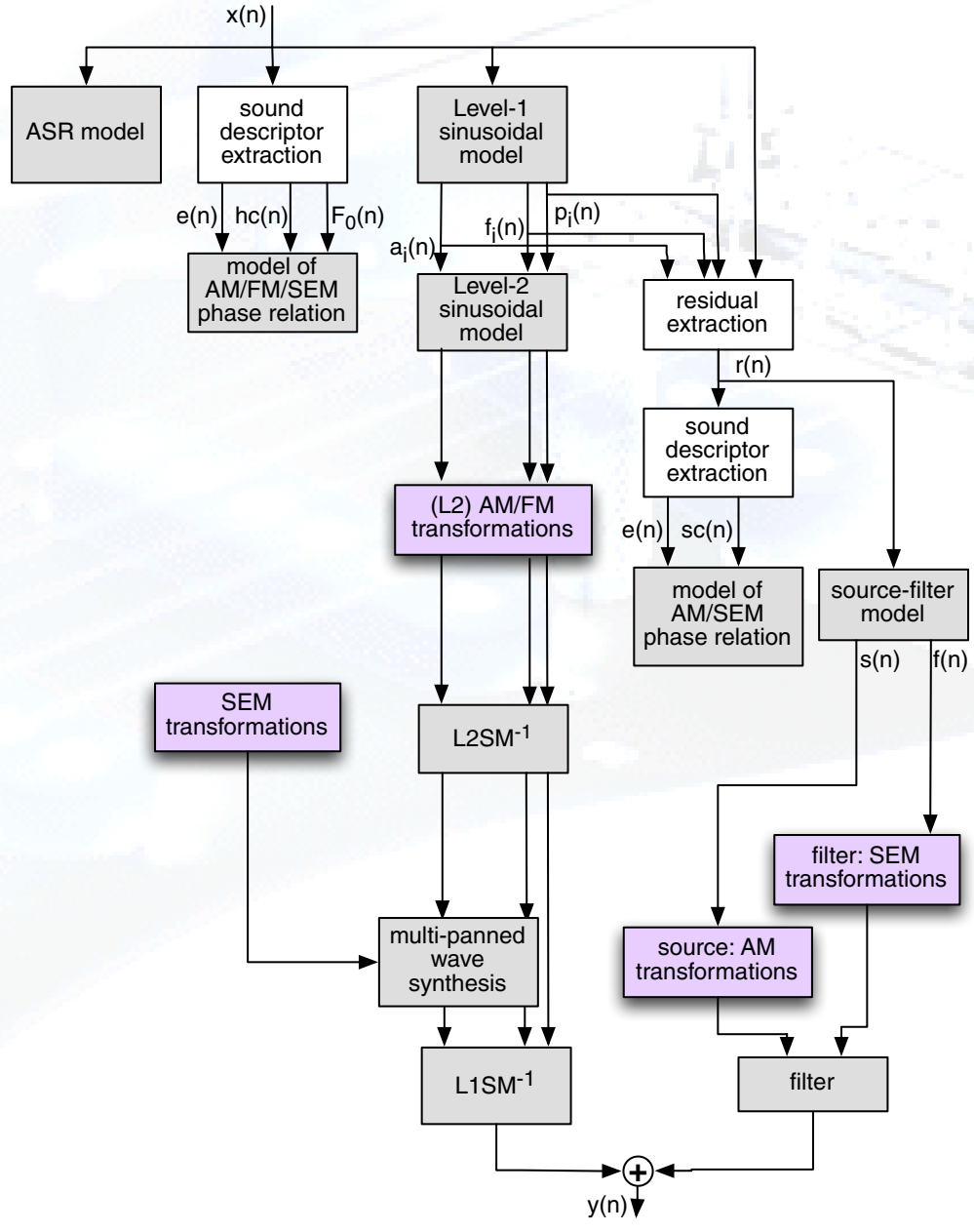
- AM/FM: faster/slower, deeper/softer, a/symmetrical



Generalized vibrato model

Sound transformations enabled

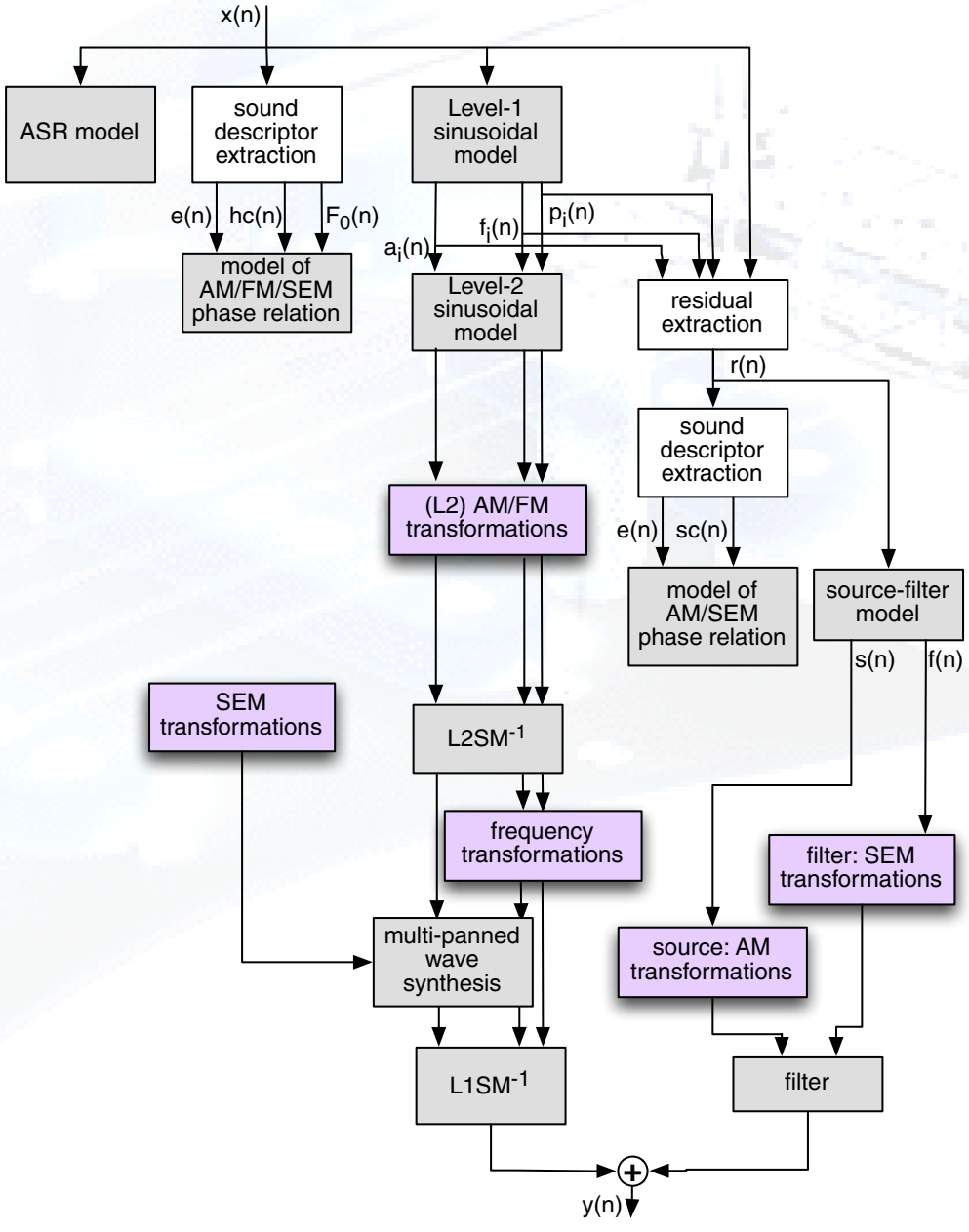
- AM/FM: faster/slower, deeper/softer, a/symmetrical
- SEM: idem



Generalized vibrato model

Sound transformations enabled

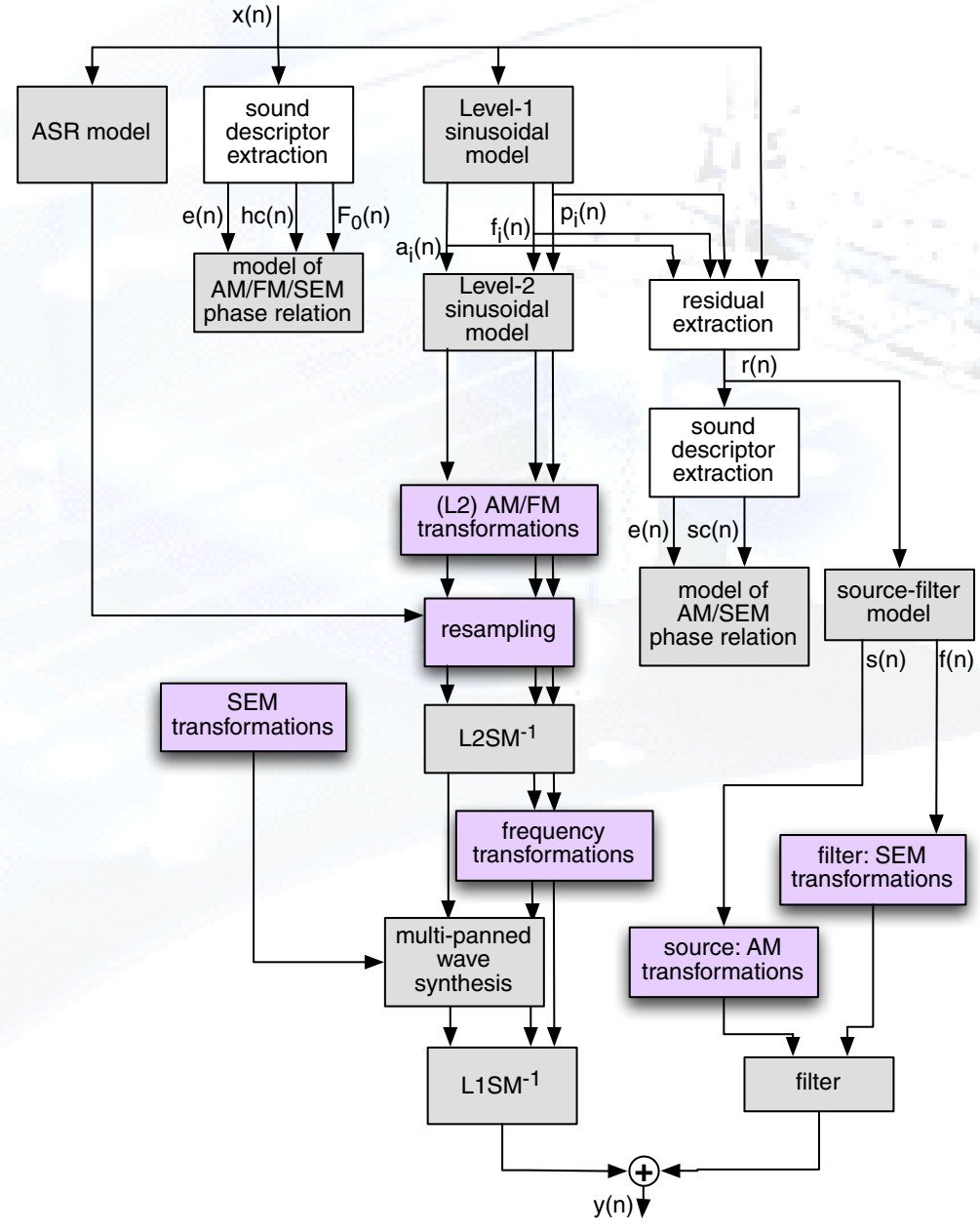
- AM/FM: faster/slower, deeper/softer, a/symmetrical
- SEM: idem
- frequency scaling (SE preservation)



Generalized vibrato model

Sound transformations enabled

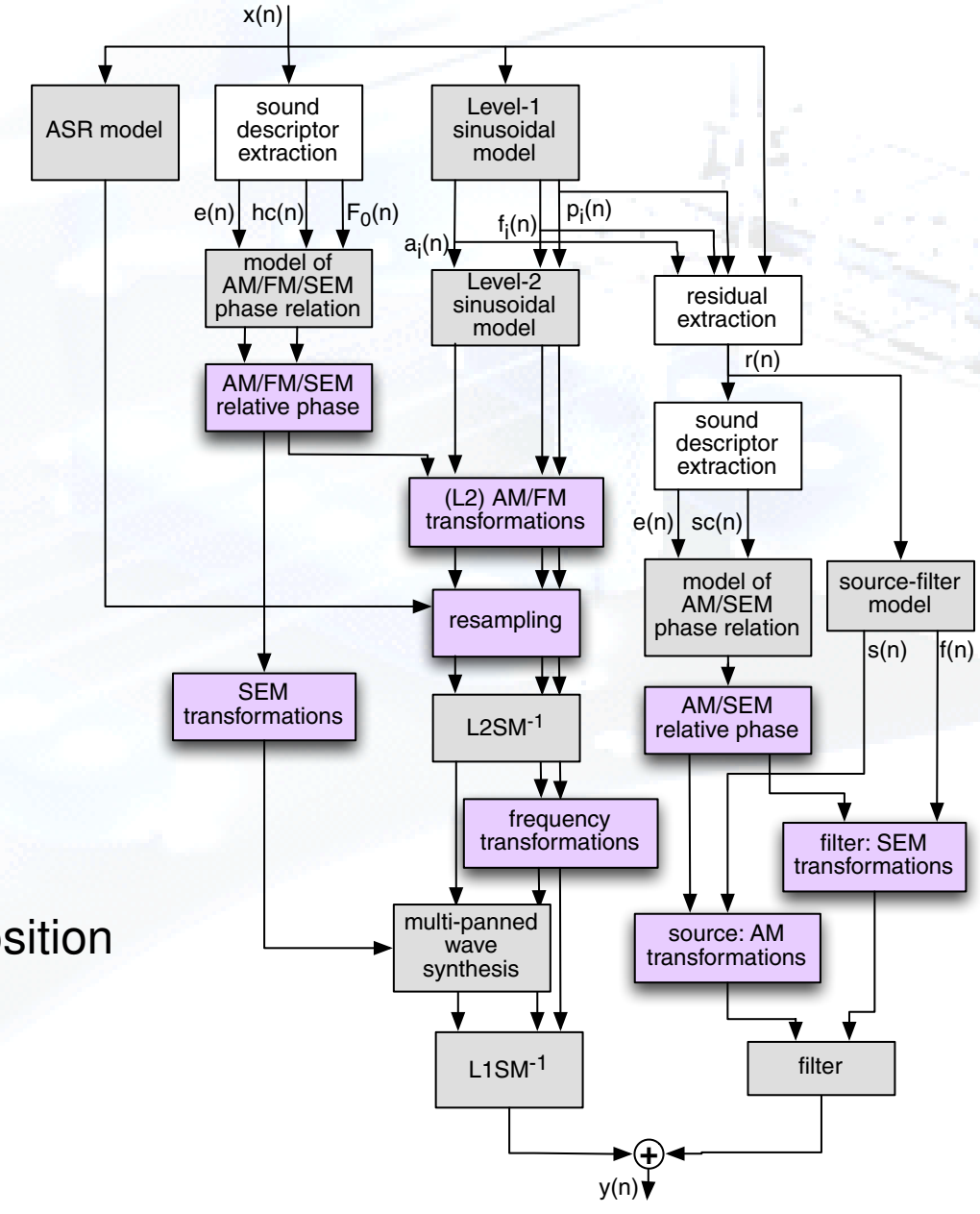
- AM/FM: faster/slower, deeper/softer, a/symmetrical
- SEM: idem
- frequency scaling (SE preservation)
- longer/shorter



Generalized vibrato model

Sound transformations enabled

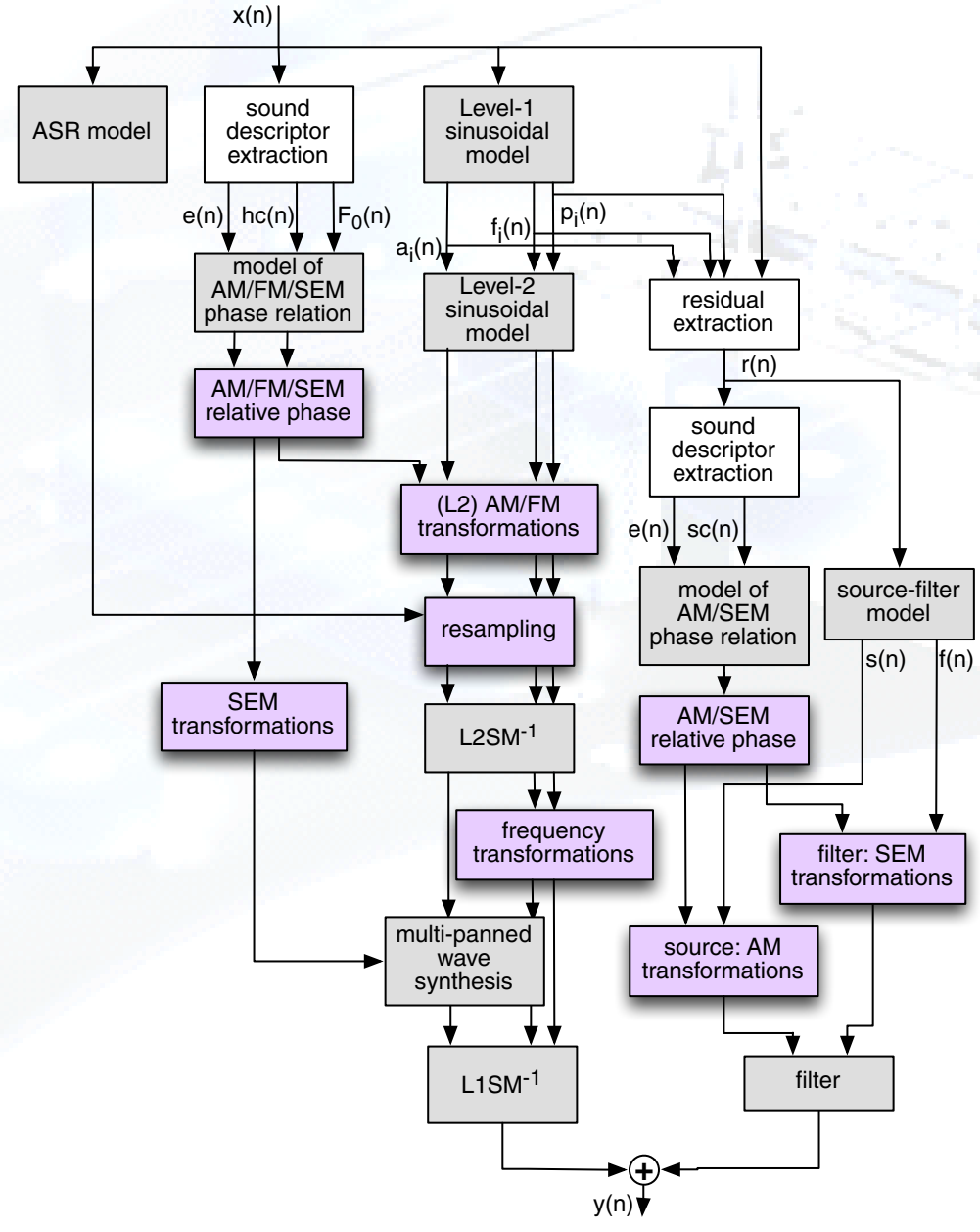
- AM/FM: faster/slower, deeper/softer, a/symmetrical
- SEM: idem
- frequency scaling (SE preservation)
- longer/shorter
- AM/FM/SEM phase (de)synchronization/opposition



Generalized vibrato model

Explicit control parameters

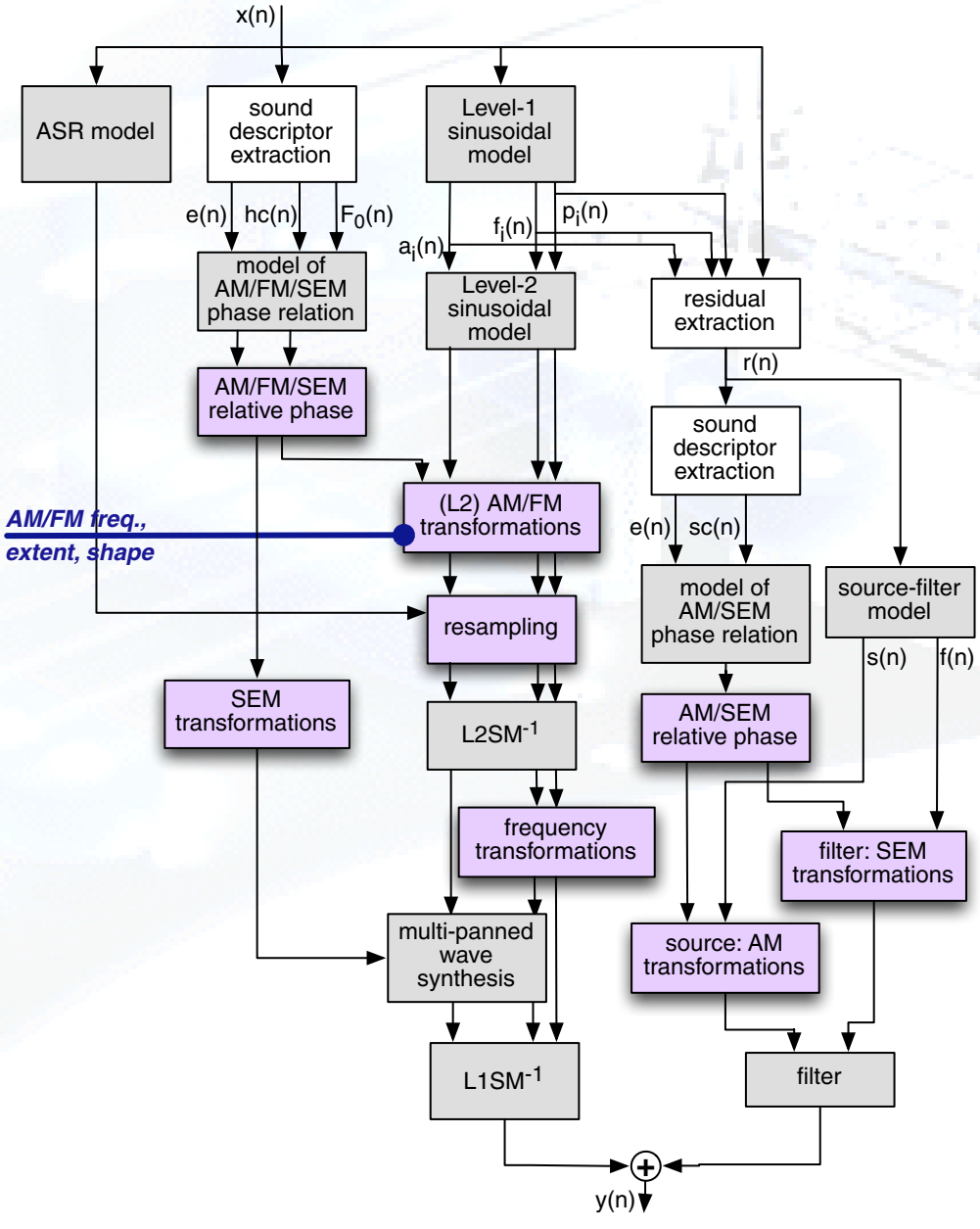
- (harmonic) partials:



Generalized vibrato model

Explicit control parameters

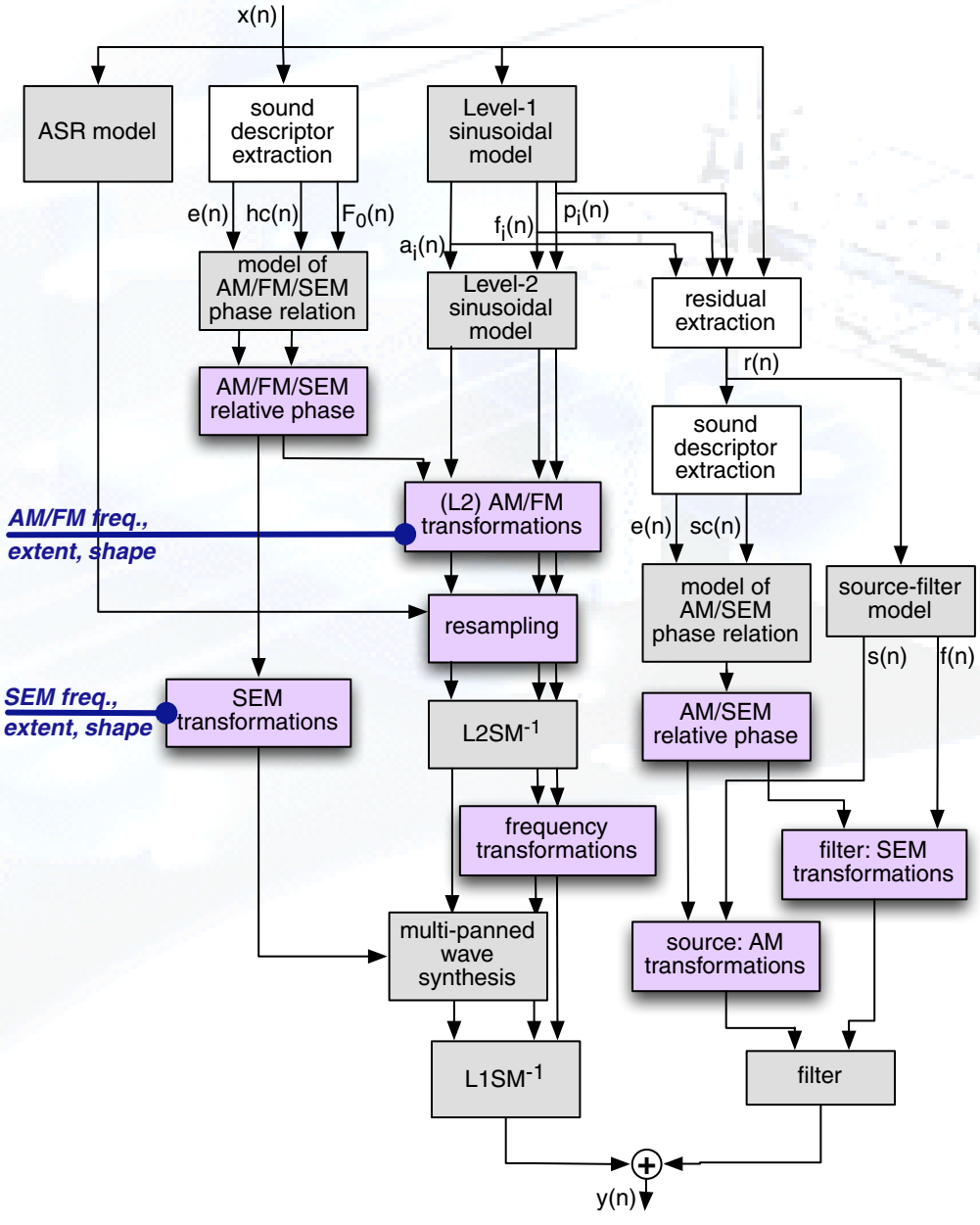
- (harmonic) partials:
  - AM/FM



Generalized vibrato model

Explicit control parameters

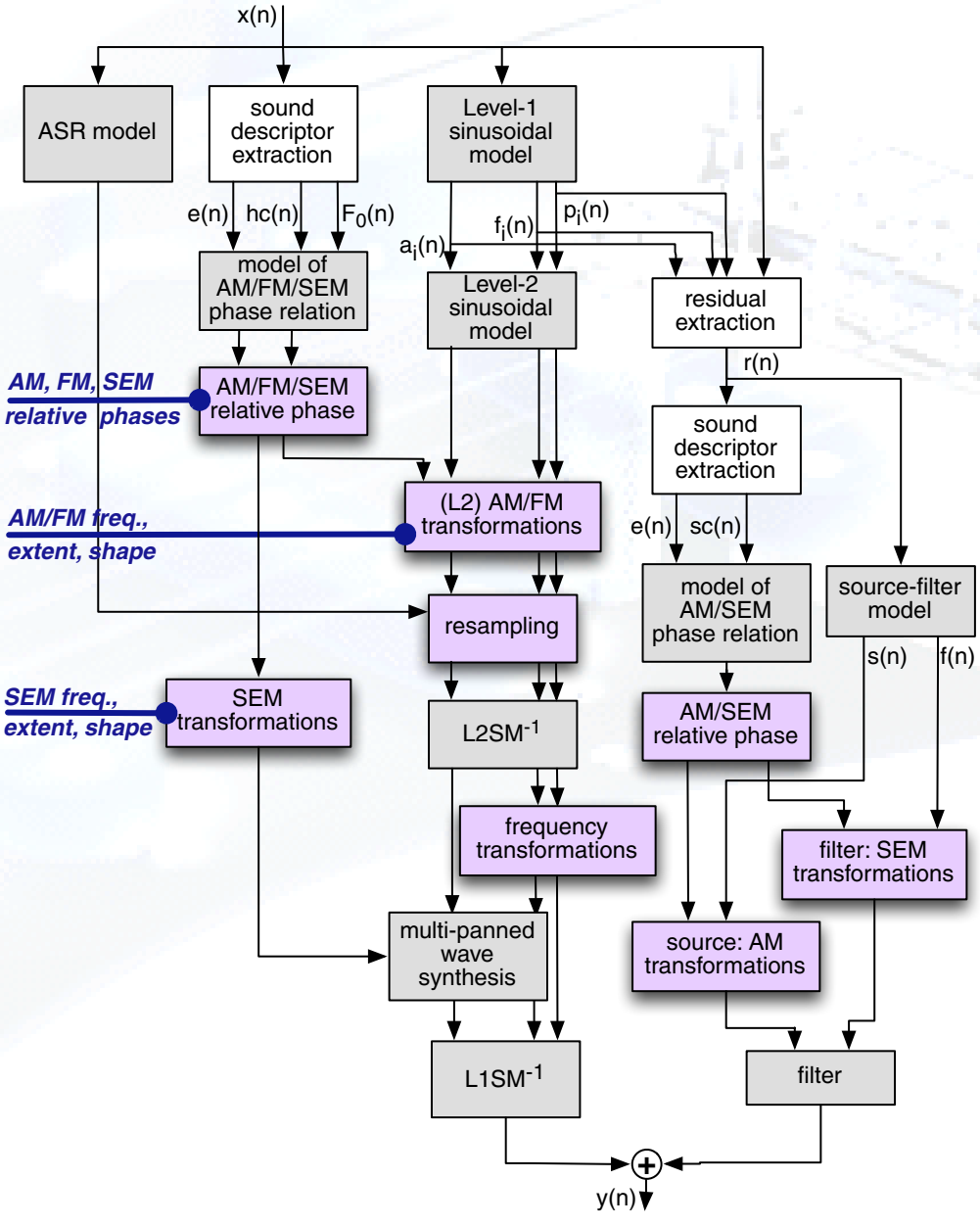
- (harmonic) partials:
  - AM/FM
  - SEM



Generalized vibrato model

Explicit control parameters

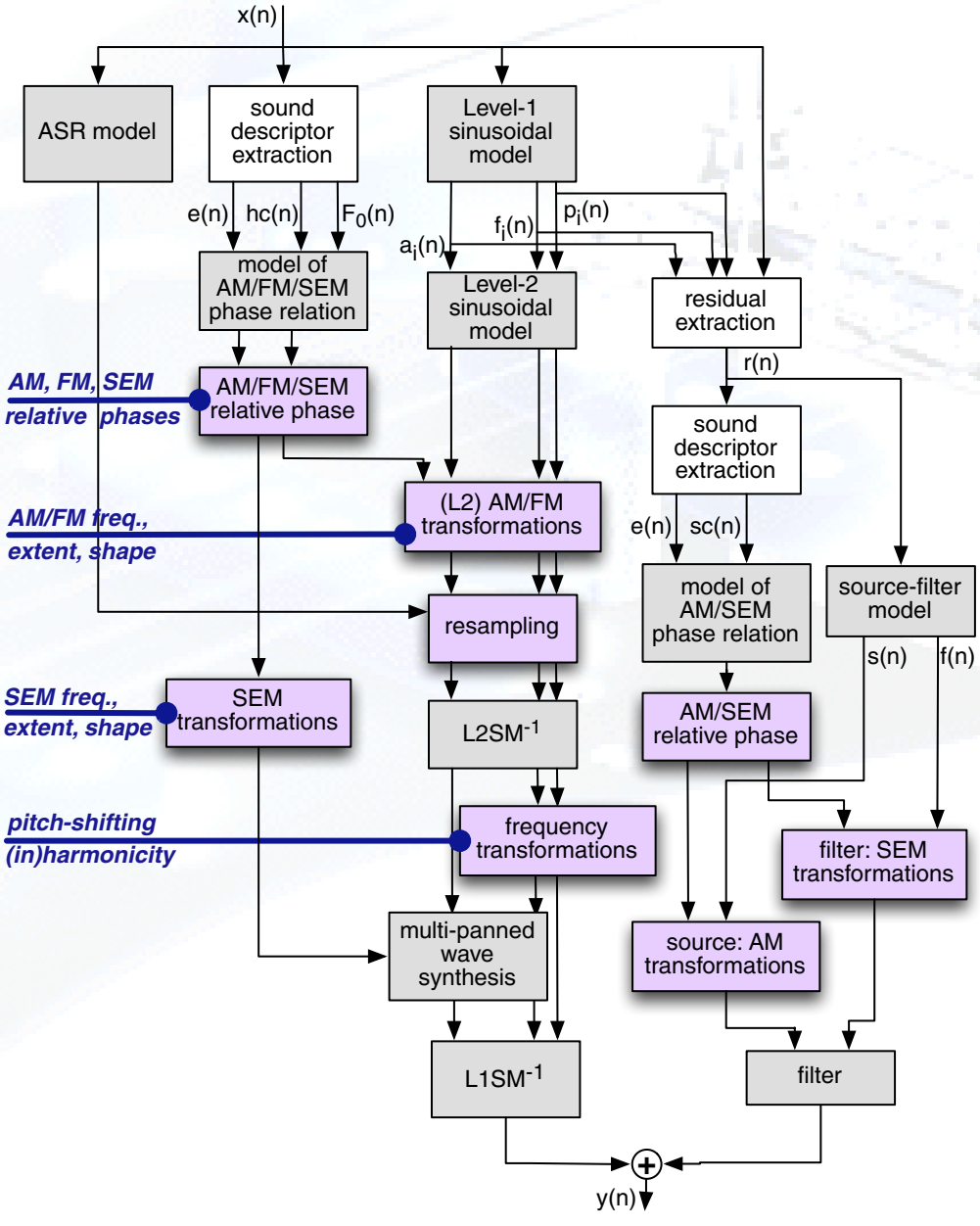
- (harmonic) partials:
  - AM/FM
  - SEM
  - AM/FM/SEM rel. phase



Generalized vibrato model

Explicit control parameters

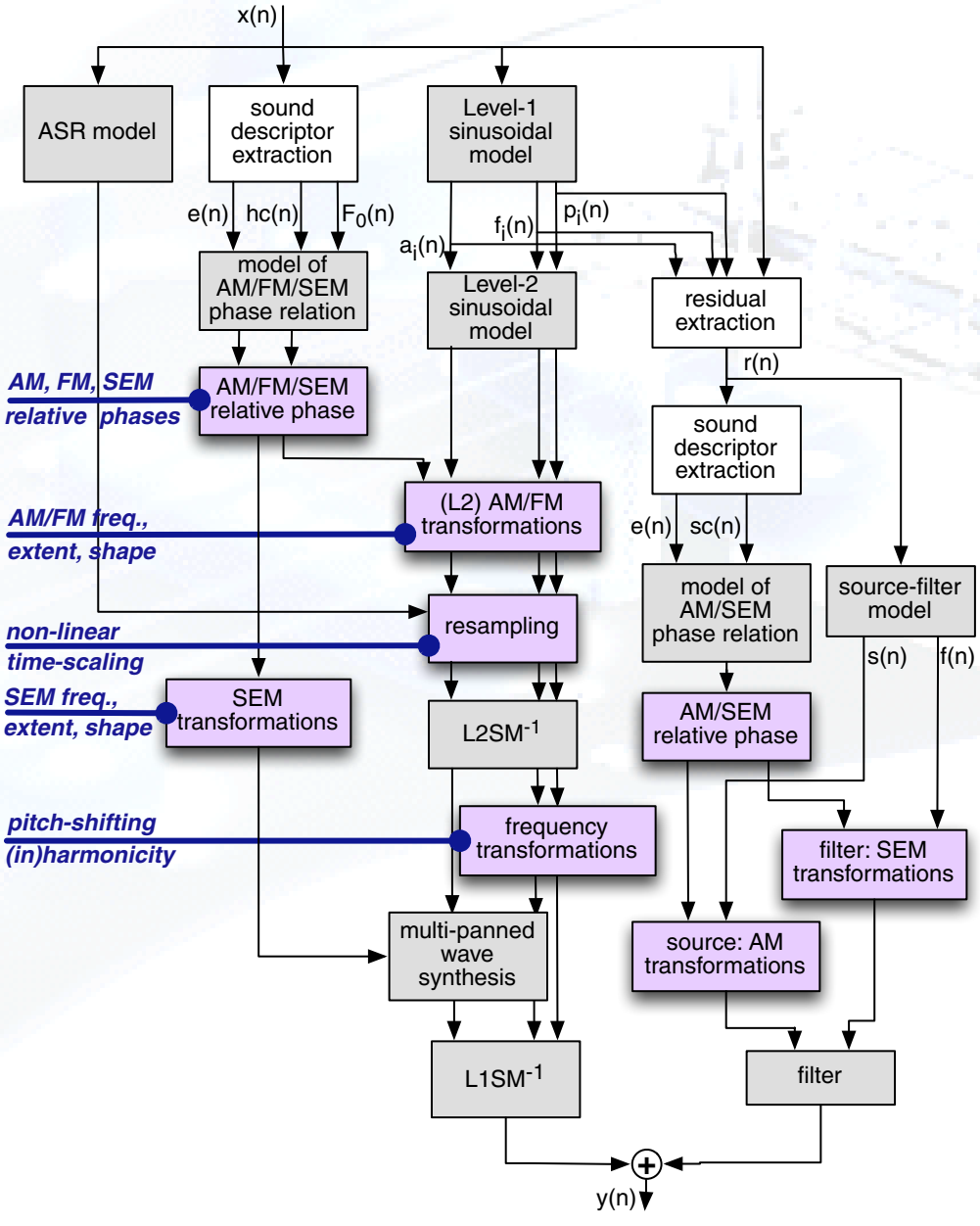
- (harmonic) partials:
  - AM/FM
  - SEM
  - AM/FM/SEM rel. phase
  - (non-linear) frequency-scaling



Generalized vibrato model

Explicit control parameters

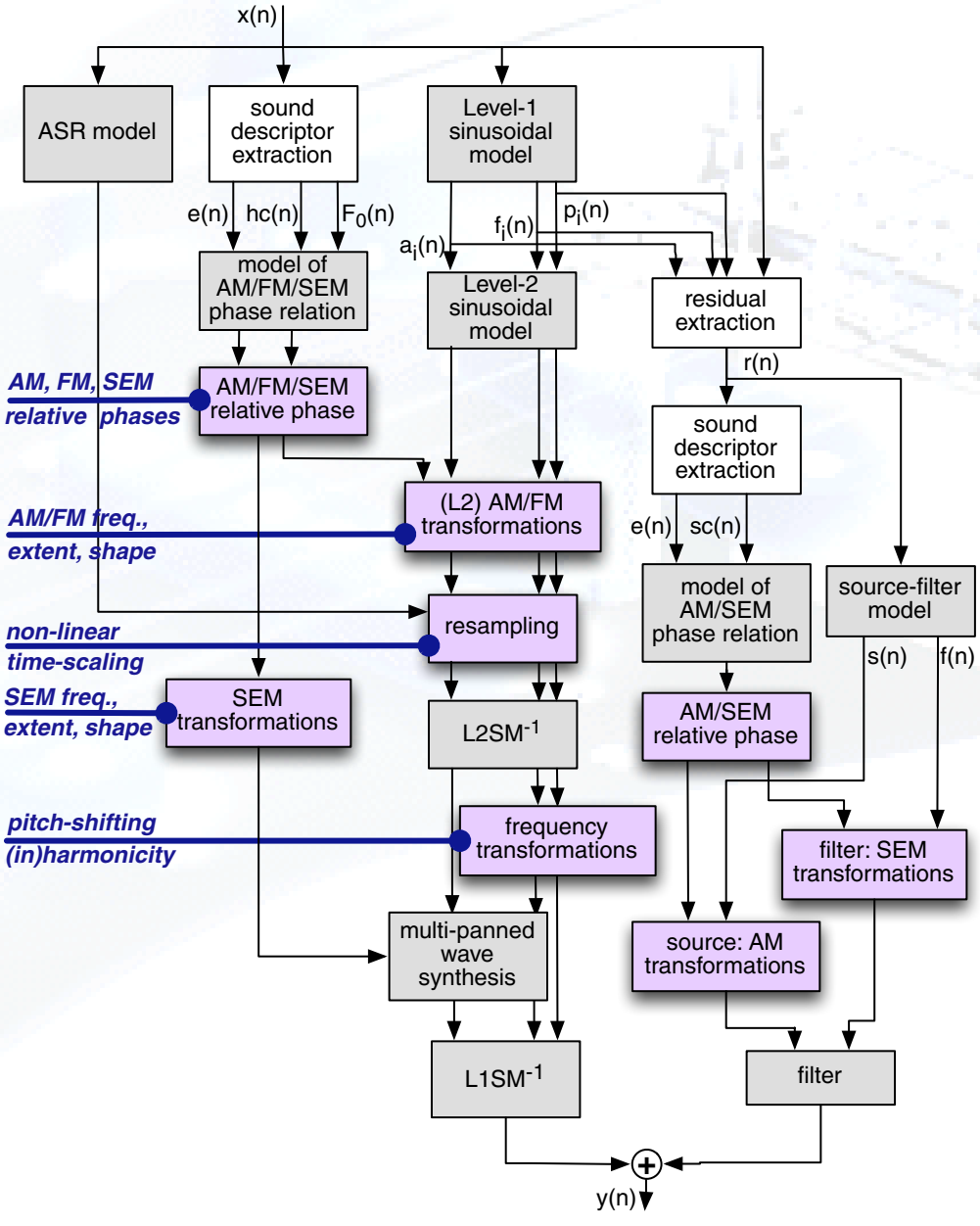
- (harmonic) partials:
  - AM/FM
  - SEM
  - AM/FM/SEM rel. phase
  - (non-linear) frequency-scaling
  - time-scaling ratio



Generalized vibrato model

Explicit control parameters

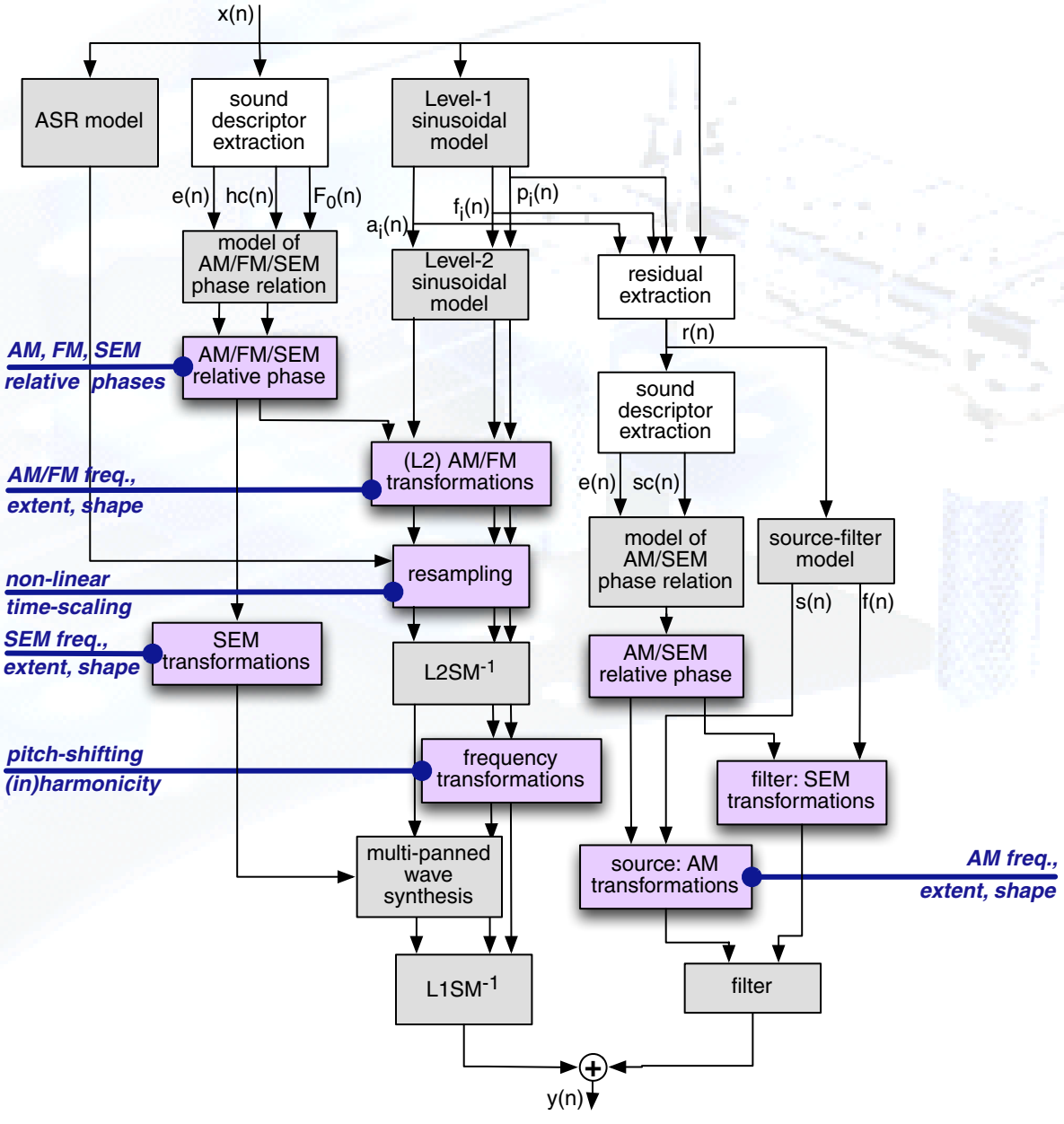
- (harmonic) partials:
  - AM/FM
  - SEM
  - AM/FM/SEM rel. phase
  - (non-linear) frequency-scaling
  - time-scaling ratio
- residual:



Generalized vibrato model

Explicit control parameters

- (harmonic) partials:
  - AM/FM
  - SEM
  - AM/FM/SEM rel. phase
  - (non-linear) frequency-scaling
  - time-scaling ratio
- residual:
  - AM



Generalized vibrato model

Explicit control parameters

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  - AM/FM/SEM rel. phase
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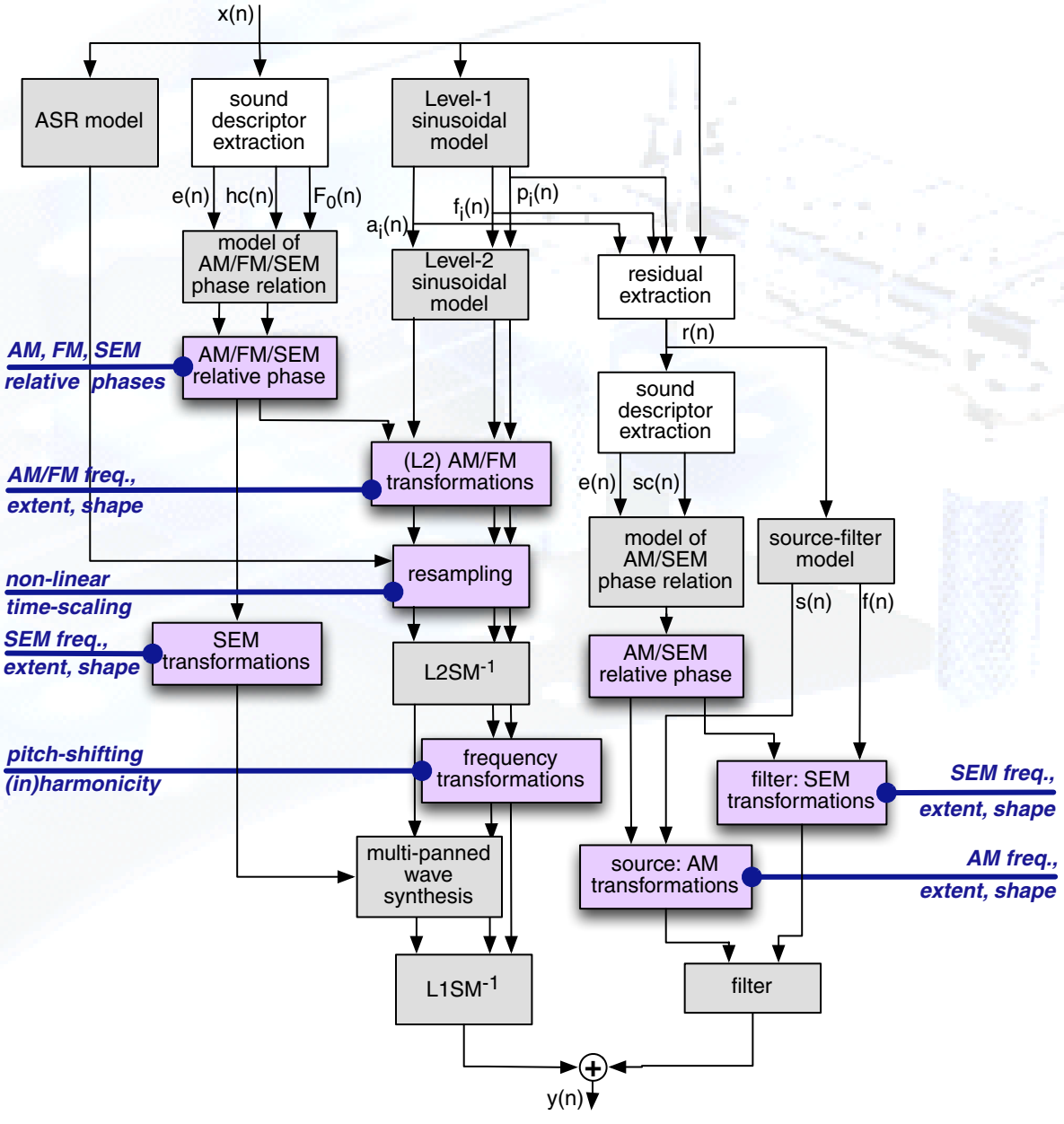
  - time-scaling ratio
- residual:
  - AM
  - SEM



Generalized vibrato model

Explicit control parameters

- (harmonic) partials:
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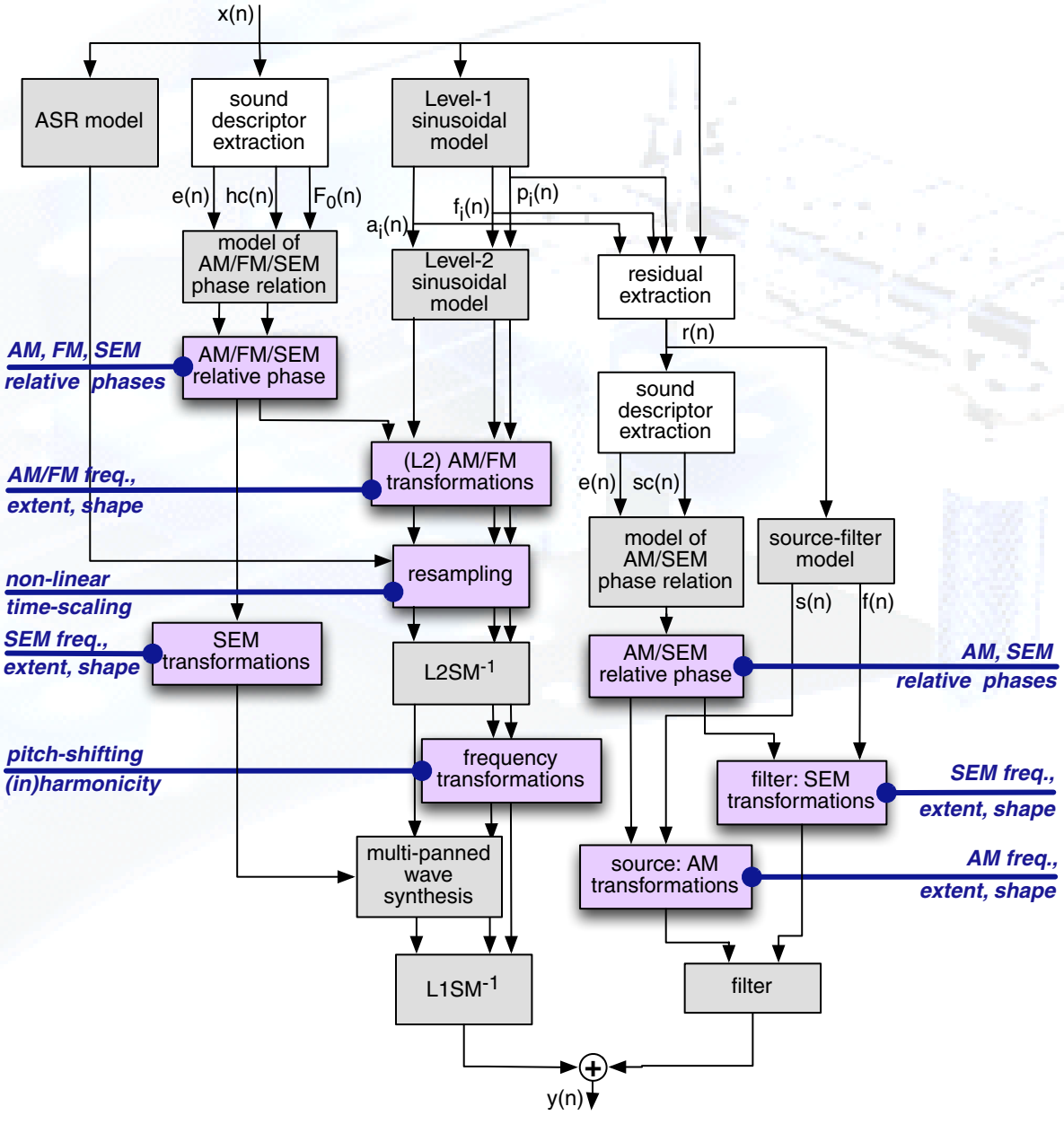
- residual:
  - AM
  - SEM
  - AM/SEM rel. phase



Conclusions

(Towards a) generalized vibrato model:

- addresses the various components of vibrato sounds
- explicitly identify control parameters
- complex vibrato sound transformations

!!! very sensitive to settings & analysis quality; 2-LSM time consuming

(necessary) improvements:

- trend + modulation model using 'polysin' [Raspaud, Marchand, Girin, 2005]
- account for different note transition strategies [Desain, Honing, 1996]
- residual representation, eg AM/SEM of stochastic part + 'sub-harmonics'

Examples of use: studies on

- perceptual evaluation for various instruments, vibrato components
- verbal descriptors for intuitive control of vibrato parameters
- parameter configurations in relation to sound quality and naturalness as a function of instrument, pitch and dynamics

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