# Subtractive Synthesis & Formant Synthesis

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- Topics:

- Subtractive Synthesis
- Formant Synthesis

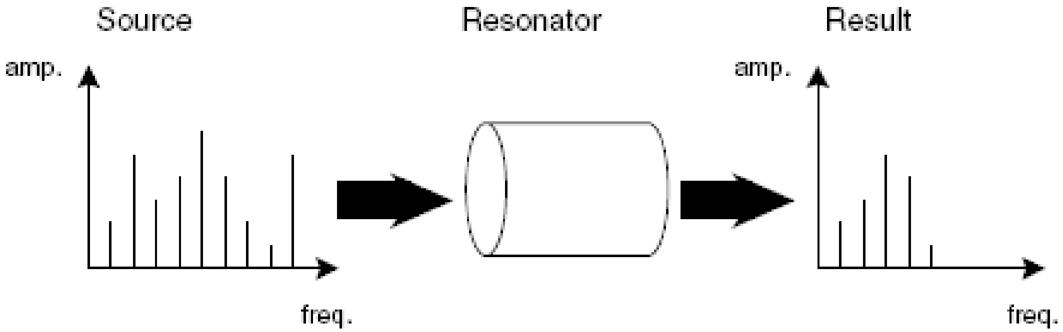
## Subtractive synthesis

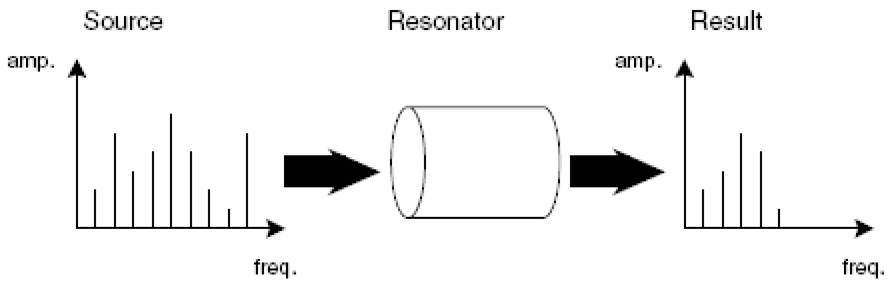
- Most musical instruments can be modelled as a resonating chamber stimulated by acoustic waveforms with certain spectral and temporal properties

- Subtractive synthesis is based upon the principle that th behaviour of an instrument is determined by two main components: **excitation source** and **resonator**

- The role of excitation is to produce a raw signal that will be shaped by the resonator

- A variety of spectra can be obtained by varying the acoustic properties of the resonator





- The technique is called “subtractive” because the resonator alters the spectrum of the excitation source by subtracting unwanted partials of its spectrum while favouring the resonation of others

- From a signal processing point of view, the resonator acts as a filter (or bank of filters) applied to an excitation signal

- Subtractive synthesis has been successfully used to model percussion-like instruments and the human voice

- The implementation of a subtractive synthesiser generally uses a **signal generator** with a rich spectrum to act as an excitation source and a **bank of filters** to simulate a resonating chamber

- Excitation - two types of signals are commonly used: **noise** and **pulse** generators

- Both  are rich signals; i.e., in terms of variety of partials

- Noise generators – produce a large number of random partials within a brad bandwidth

- Pulse generators – produce periodic waveforms, or *train of pulses*, at specific frequencies, with high energy partials. The spectrum of a pulse is determined by the ratio of the pulse width to the period of the signal …

- … the smaller the ratio, the narrower the pulse and therefore the higher the energy of the high-frequency partials

# Introduction to filters for subtractive synthesis

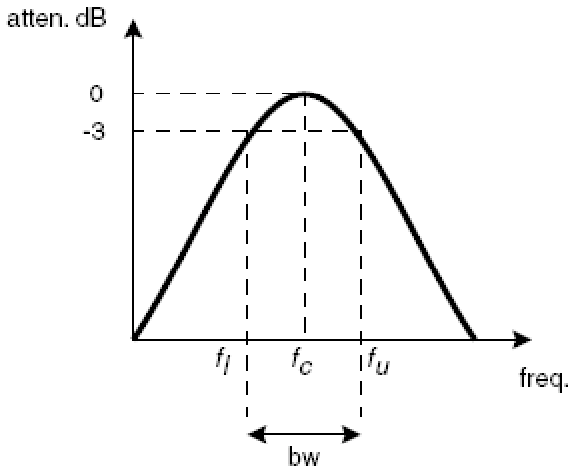
- In general, any device that performs some sort of transformation on the spectrum of a signal is a filter

- Here we refer only to filter that cut off  or favour the resonance of specific components of the spectrum

- In this case, there are 4 types of filters:
  - LPF = Low-Pass Filter
  - HPF = High-Pass Filter
  - BPF = Band-Pass Filter
  - BRF = Band-Reject Filter

- The basic building block of a subtractive synthesiser is the BPF

- Two parameters are used to specify the characteristics of a BPF:
  - passband centre frequency ($f_c$)
  - bandwidth of the resonance (*bw*)

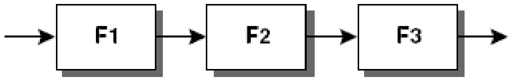


•*bw* is the difference between the upper and the lower cut off frequencies; that is the frequencies at which the power transmitted by the filter drops to one half of the maximum power transmitted in the passband (about -3dB)

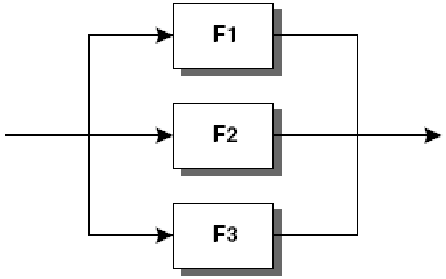
- The resonator component of a subtractive synthesiser usually requires a composition of interconnected BPFs in order to produce the desired spectrum

- There are two basic combinations for filter composition: **parallel** and **serial** (or cascade) connections

- In serial connection, the specification of one filter's passband does not guarantee that there will be significant energy transmitted in that passband. If any of the previous filters of the cascade has been significantly attenuated in that frequency range, then the response will be affected



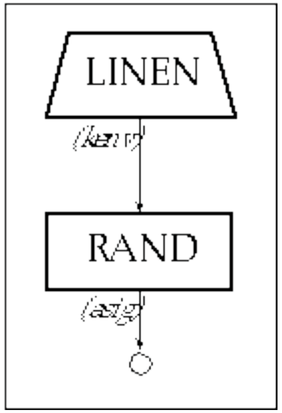
Cascade filter composition



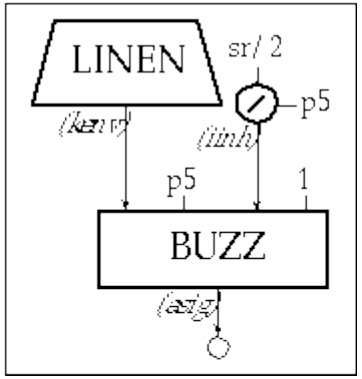
Parallel filter composition

# Examples of subtractive synthesis

## Sources of excitation:



**fischman_1105** uses Csound's **rand** unit to produce white noise …



… and uses Csound's **buzz** unit to produce a pulses train with as many harmonics as possible in relation to the sampling rate (**sr**)

**(Fischman)**

# Example dodge_520

- Produces “glissandoing” noise bands. It uses oscillators to produce a range of time variations in center frequency and bandwidth

- The amplitude for the left oscillator is fed a ratio of the highest to lowest center freq and that of the right oscillator the range of bandwidth change

- The freq of the oscillators determine the duration of the variations

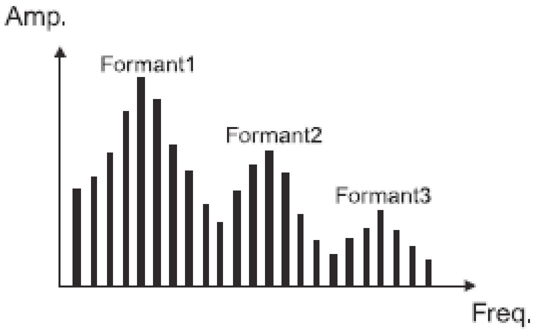
# Example dodge_525

- Serial BPF architecture to impart resonances to the signal at center freqs of 500, 1500 and 3000 Hz

- The balance unit estimates the power in the signals at the input and output for rectification

## Formant synthesis

- The spectral contour of vocal-like sounds has the appearance of a patterns of ‘hills and valleys’ technically called formants



- Subtractive synthesis is one the synthesis techniques capable of synthesising formants

- Each formant is associated with the response of a BPF

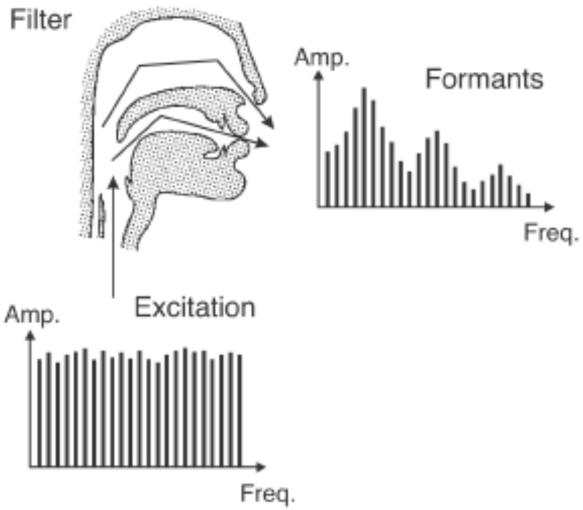
- A parallel composition of BPFs set to different responses to filter a source excitation signal

- The subtractive synthesis of formants is determined by two mains components: excitation and resonator

- The excitation produces a raw signal that is shaped by the resonator

- Excitation:
  - **voicing source** = produces a quasi-periodic vibration, vibration of the vocal tract

  - **noise source** = produces turbulence, to simulate an airflow past a constriction or a relatively wide separation of the vocal folds



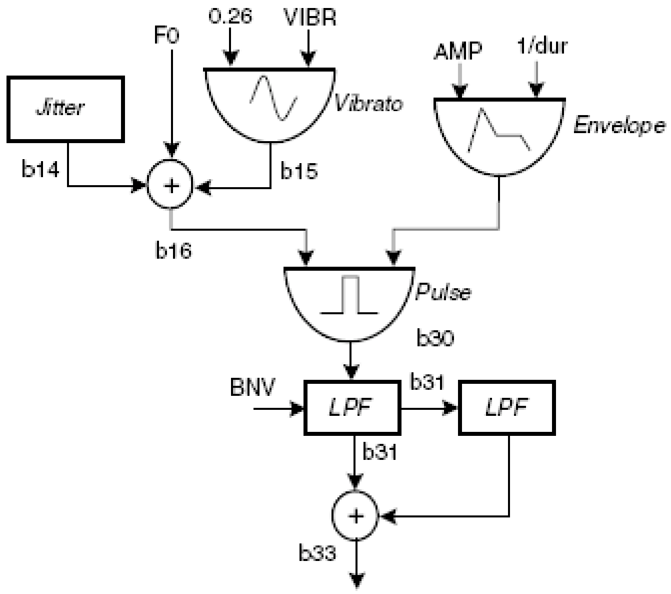
# Voicing source

- Jitter and vibrato are very important for voicing sound quality; they add a degree of non-uniformity to the fundamental frequency of the excitation

- **Jitter** = difference in fundamental frequency from one period of the sound to the next; normally varies at random between -6% and +6% of the fundamental

- The example below coded in **Cmusic** calculates this by adding the results from 3 random number generators, whose values are produced by interpolating periodic random values

```
ran b10 0.02 0.05Hz d d d;
ran b11 0.02 0.111Hz d d d;
ran b12 0.02 1.219Hz d d d;
adn b13 b10 b11 b12;
mult b14 b13 F0;            // b14=jitter factor
```

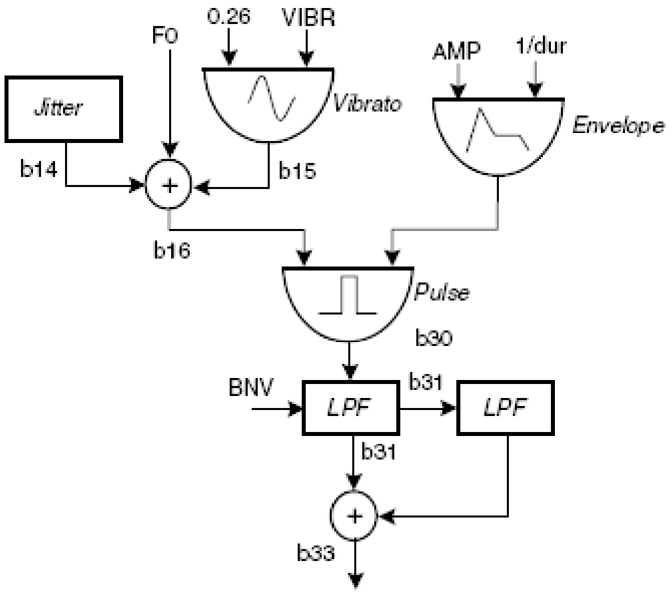


## Voicing source

- Vibrato = freq modulation of the fundamental

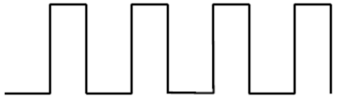
- Width of vibrato is the amplitude of the modulating freq and rate is the freq of the modulating freq, normally set to a value between 5.2Hz and 5.6Hz

```
osc b15 0.26 VIBR f2 d;    // b15=vibrato
adn b16 b15 b14 F0;        // b16=freq+jitter+vibrato
```



# Voicing source

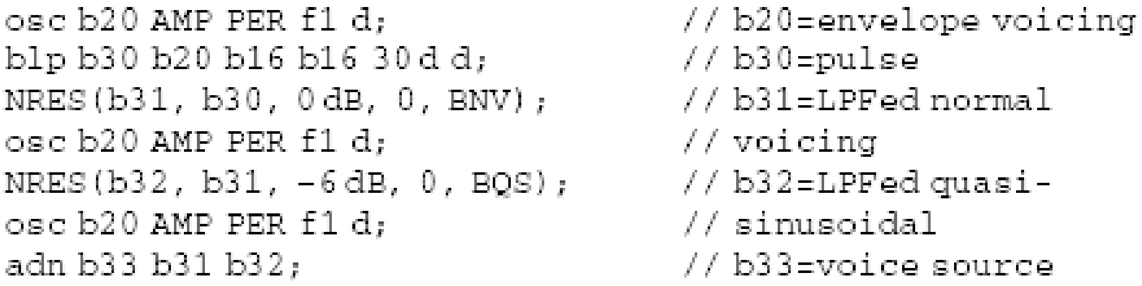
- Pulse generator = periodic waveform with great energy in the harmonics



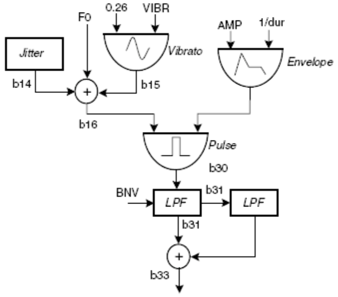
- Humans control excitation by adjusting the muscles of the larynx and the resulting airflow has a waveform like this

- In order to simulate the production of such excitation, the pulse train is sent through 2 LPFs in series

- The cutoff for the 1st filter is set to an octave above the fund freq and the cutoff for the second is set approx 1 octave above the cutoff of the 1st

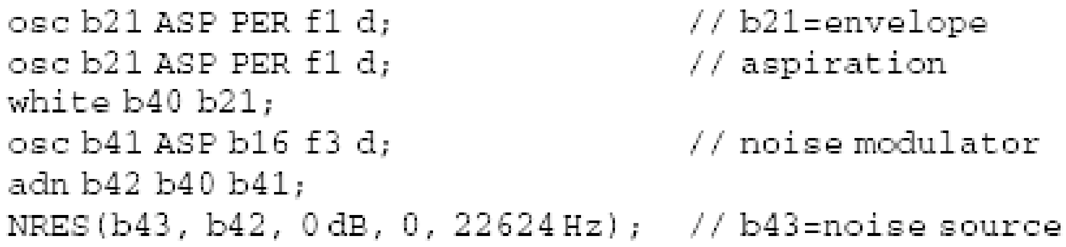


```
osc b20 AMP PER f1 d;                // b20=envelope voicing
blp b30 b20 b16 b16 30d d;           // b30=pulse
NRES(b31, b30, 0dB, 0, BNV);         // b31=LPFed normal
osc b20 AMP PER f1 d;                // voicing
NRES(b32, b31, -6dB, 0, BQS);        // b32=LPFed quasi-
osc b20 AMP PER f1 d;                // sinusoidal
adn b33 b31 b32;                     // b33=voice source
```

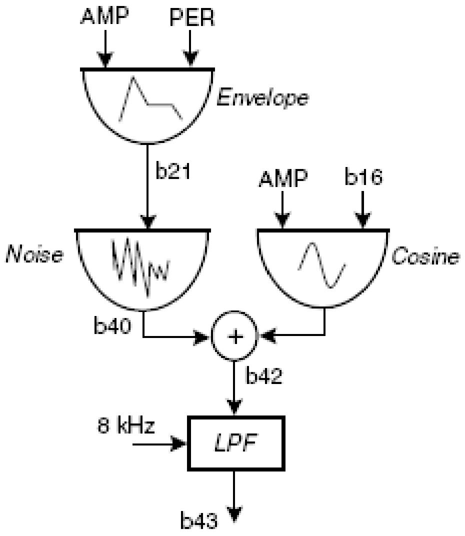


# Noise source

- Produced using a random number generator, an offset modulator and a LPF



```
osc b21 ASP PER f1 d;                  // b21=envelope
osc b21 ASP PER f1 d;                  // aspiration
white b40 b21;
osc b41 ASP b16 f3 d;                  // noise modulator
adn b42 b40 b41;
NRES(b43, b42, 0 dB, 0, 22624 Hz);    // b43=noise source
```

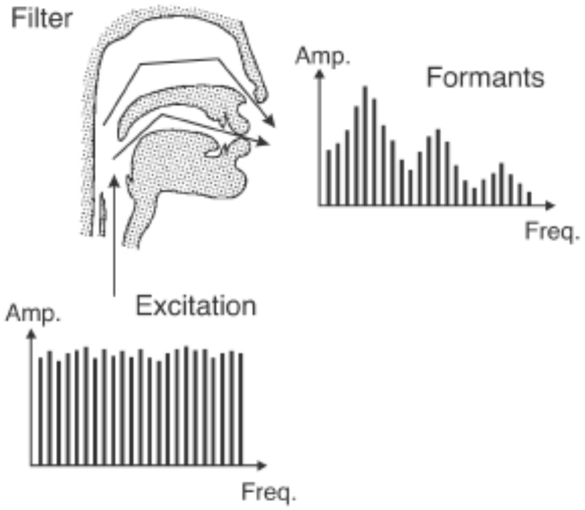


## Resonator

- The vocal tract can be thought of as a pipe from the vocal folds to the lips plus a side-branch leading to the nose, with a cross-section area which changes considerably

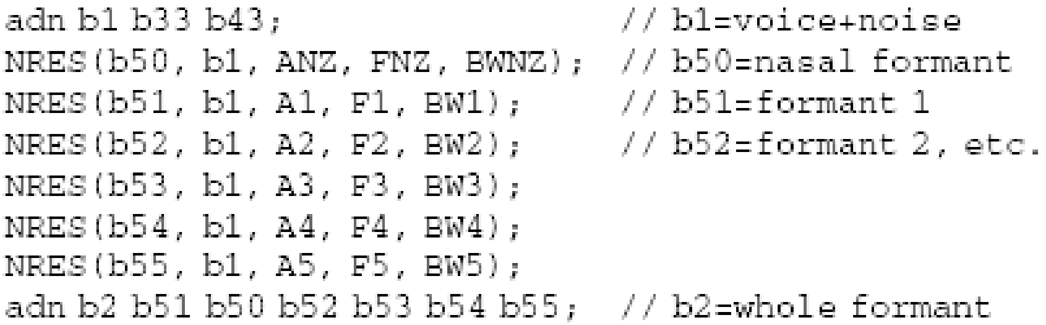
- The length and shape of the track determine the resonance

- Resonance can be tuned by changing the shape of the tract during phonation

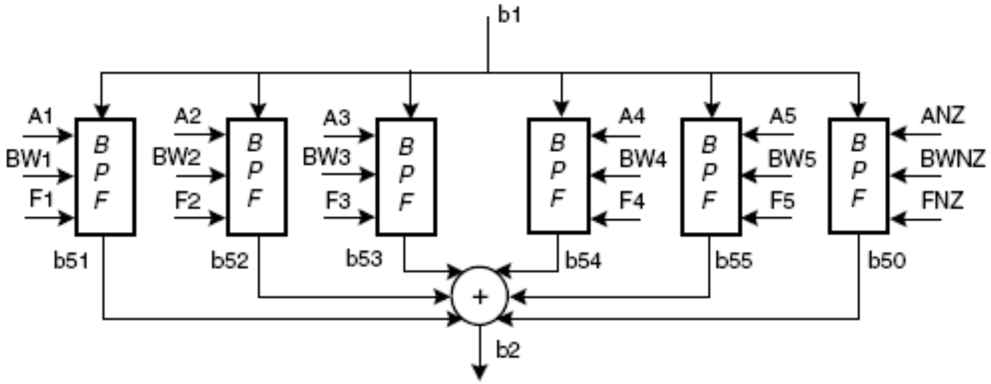


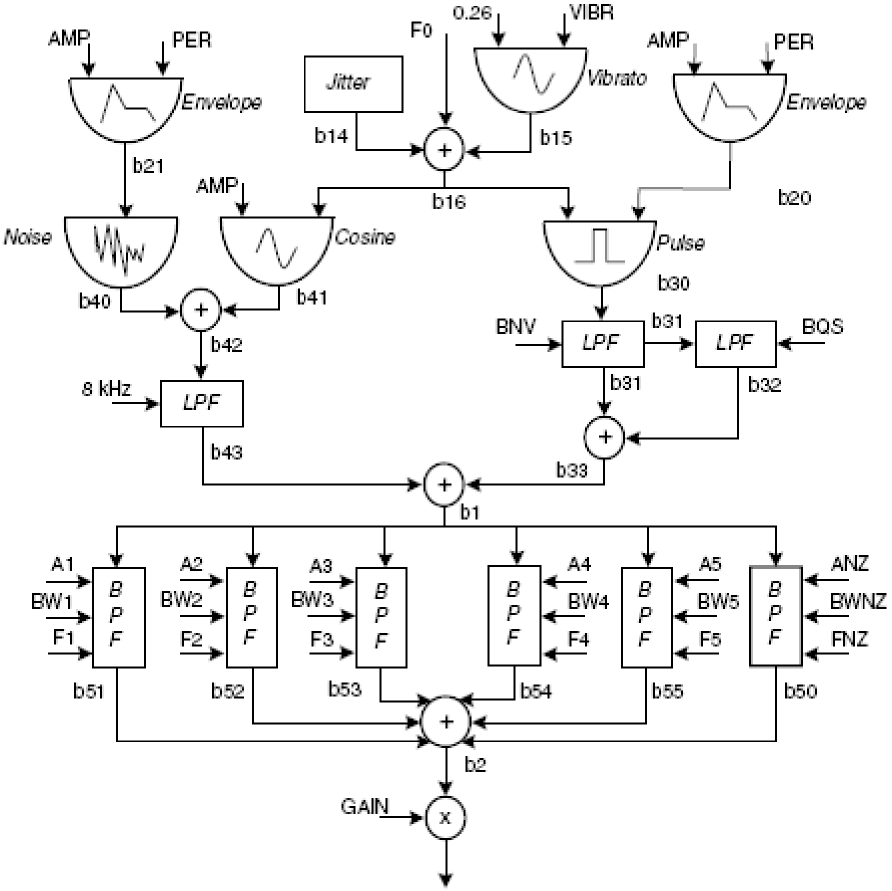
## Resonator

- 5 BPF are appropriate for simulating a vocal tract
- A 6th BPF can be used to simulate the nasal cavity



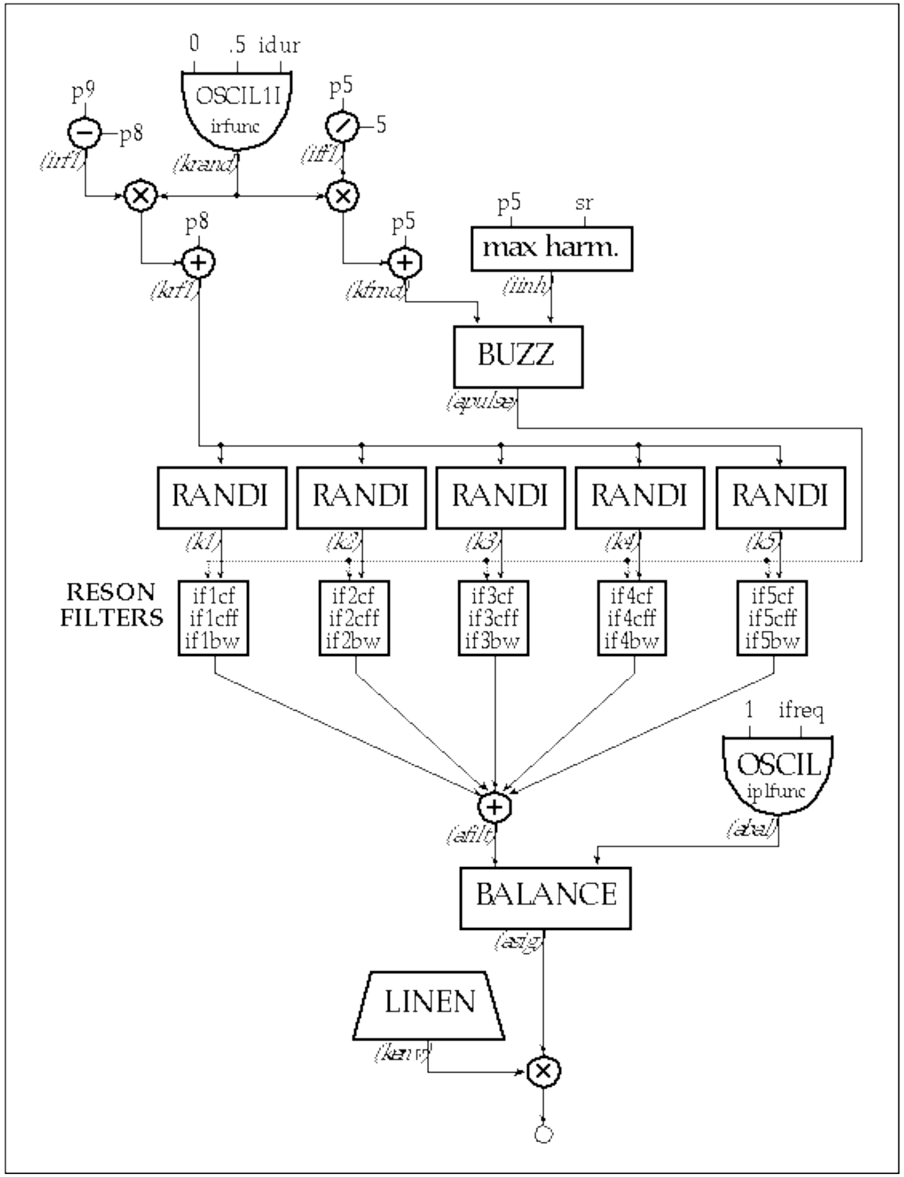
```
adn b1 b33 b43;                  // b1=voice+noise
NRES(b50, b1, ANZ, FNZ, BWNZ);   // b50=nasal formant
NRES(b51, b1, A1, F1, BW1);      // b51=formant 1
NRES(b52, b1, A2, F2, BW2);      // b52=formant 2, etc.
NRES(b53, b1, A3, F3, BW3);
NRES(b54, b1, A4, F4, BW4);
NRES(b55, b1, A5, F5, BW5);
adn b2 b51 b50 b52 b53 b54 b55;  // b2=whole formant
```




AMP
PER
Envelope
b21
Jitter
F0
0.26
VIBR
Vibrato
b14
b15
AMP
PER
Envelope
b16
b20
AMP
Noise
Cosine
Pulse
b40
b41
b30
b42
BNV
LPF
b31
LPF
BQS
8 kHz
LPF
b31
b32
b43
b33
b1
A1
BW1
F1
B P F
A2
BW2
F2
B P F
A3
BW3
F3
B P F
B P F
A4
BW4
F4
B P F
A5
BW5
F5
B P F
ANZ
BWNZ
FNZ
b51
b52
b53
b54
b55
b50
b2
GAIN
x

# Example fishman_1107

Produces sound resembling human voice



(Fischman)