



## Can do this in two ways ...

- As shown, with a tunable bandpass filter
  cheap to implement, slow to run
- Or, with a *filter bank* 
  - A set of bandpass filters whose centre frequencies are distributed over a desired frequency range
  - fast because of parallel processing but expensive in hardware
- Exotic fact you can ignore
  - an Fourier analysis can be thought of as implementing a filter bank

# What filter properties affect the output of a filterbank?

- ????
- ???? of filters in a filter bank determines the resolution of the spectrum
- Need to space filters relative to ????

• Why?

- don't want holes in the spectrum
- could miss spectral components

How the properties of a filter bank influence signals through it: I. Resolution in frequency

Consider a signal that consists of two sinusoids reasonably close in frequency, which are to be analysed in a filter bank.

## Filtering through narrow filters



9

### Filtering through wide filters A more extreme example wide band filters narrow band filters gain (dB) (Bb olts ain 200 500 Frequency (Hz) frequency (Hz) 500 300 400 600 700 frequency (Hz) 200 500 800 200 500 800 Frequency (Hz) 13 14 Wide band filters Narrow band filters 500 Hz filter output 500 Hz filter output input wave input wave time (ms) time (ms) 580 Hz filter output 15 time (ms) 15 time (ms) 500 Hz + 580 Hz 500 Hz + 580 Hz time (ms) 580 Hz filter output time (ms)



## Bandwidth & Damping

- Two ways of describing the same thing:
  - **Narrow** Bandwidth = **Low** Damping
  - Wide Bandwidth = High Damping



21

23

## Summary

- Bandpass filters with a long impulse response have narrow frequency responses.
- Bandpass filters with a short impulse response have broad frequency responses.

How the properties of a filter bank influence signals through it: II. Resolution in time

Consider a signal that consists of two impulses reasonably close in time, which are to be analysed in a filter bank.

## Filtering through a wide filter







# Wide-band (300 Hz) filtering at 200, 250, 300, 350 and 400 Hz Image: Comparison of the comp

Time (ms)

# What does a filter bank do to a speech waveform?



a 6-channel filter bank

Narrow bands of speech at different frequencies: Individual outputs from a filter bank



Of course, you need many more filters in the filter bank than seven.



## What can you use filter banks for?



Other than spectral analyses ...

## To make spectrograms or voiceprints ...

user=unknow file=bkba01	n title= 07.sfs s	The green toma peaker= token=	toes are	small.				
Time (s) 0	iuluud	0.2.1		L  0.8.1	li:	սենե	ուկ։սո	<u></u>
10500 - 5	copy(1.0	1)						SP.02
10000			÷			-m	ALC: NO.	
9588 -	1 1		(R) 1		1	NA.	SSARDS	
9000	1 1		- 60		6	122	<b>SCINK</b>	
8500			10	1.1.1.4	N	142	0.00MP	
8000	11		Mar.	1.11 年降	8	He.	<b>BRARK</b>	
7500 -	10 1		<b>B</b> (1)		8	181	ALC: NO DE	
7000	11 1		10		10	100	SUMM	
6500 -	11 1	14.264	12	- Crash	N. K.L.	1	SIGNE	
6000 -				16154	N	380	<b>MARKE</b>	
Hz 525590			2		Ren and	200	ROBARS	
5000 -			8		8	12	(LAND)	
4500			10		13	<b>M</b> 8	随时代	
4000 -		1.40.05	R	anteriol	A Louis	MG	<b>WAYSAN</b>	
3500 -		CHANNEL	MIL	13000	那些机时间。	193.1	制用的制	WHY SALE
3000 -		ANNUM.	91.1		C. States	1.44	10.2694	A MANAGEMENT
2500 -		100000000000000000000000000000000000000	1996	(S. ANDIA	1973 MA			Villennin
2000 -	11 1	1989 Manual Contraction	18.1					
1500 -	11	-	PANE.		A REPORT	NET HAL		
1000		THE MANNE	1 199	TRANS.		3		1 Million Street
500 -	March 1	and the second second	- Ba	E MANNE		16. 周期		ALL
Time (s) 0	.0	0.2	0.6	0.8	1.0	1.2	1.4	1.6 1.8

## To make a graphic equaliser ...





To process sounds for a multi-channel cochlear implant (an electronic filter bank substitutes for the basilar membrane)



## In hearing aids ...

Shape the spectrum of incoming sounds to compensate for the hearing loss

frequency regions with bigger loss get greater gain

a graphic equaliser!

38

# In computational models of the auditory periphery.



Imagine that each afferent auditory nerve fibre has a bandpass filter attached to its input. <sup>39</sup>