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## Multiplexage pour les nuls

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*en préparation du workshop "multiplexage X-IFU" - Sept. 2016*

**MULTIPLEXAGE  
POUR  
LES NULS**

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# Outline

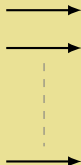
- 1 Basic multiplexing considerations
- 2 Multiplexing/Demultiplexing of *tones*
- 3 Technological considerations

# Multiplexing general

## Transmission of N signals over 1 channel

**INFORMATION**

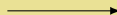
N data/signals



Multiplexer

**TRANSMISSION**

**One** channel



Introduced for telegraphy at the end of the 19<sup>th</sup> century and widely applied in **telecommunications** during the 20<sup>th</sup> century :

*several telephone calls may be carried using one wire*

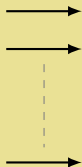


# Multiplexing general

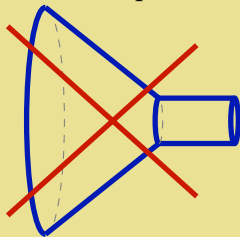
## Transmission of N signals over 1 channel

INFORMATION

N data/signals



Multiplexer



TRANSMISSION

One channel



*That is **not a real multiplexer**, because this need to reduces - **Data compression** - the transmitted informations to use the **same output channel capacity***



# Multiplexing general

Transmission of  $N$  signals over 1 channel **with HIGHER "capacity"**

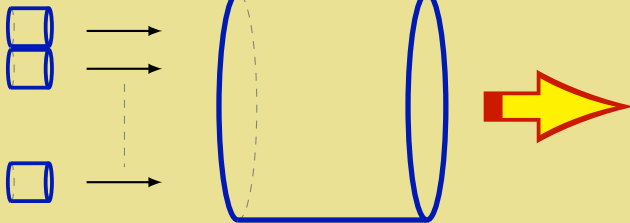
**INFORMATION**

**TRANSMISSION**

$N$  data/signals

Multiplexer

**One channel**



*To transmit  $N$  signals via One channel, **the "channel" must provides better performances** than for a single signal transmission.*



# Multiplexing notice



To transmit N signals *via* one channel, **the "channel" must provides better performances** than for a single signal transmission.

- ⇒ The increasing of the required performances is directly linked to the number N of multiplexed signals.
- ⇒ The affected performances are both :
  - Band Width
  - Dynamic / Signal to Noise Ratio

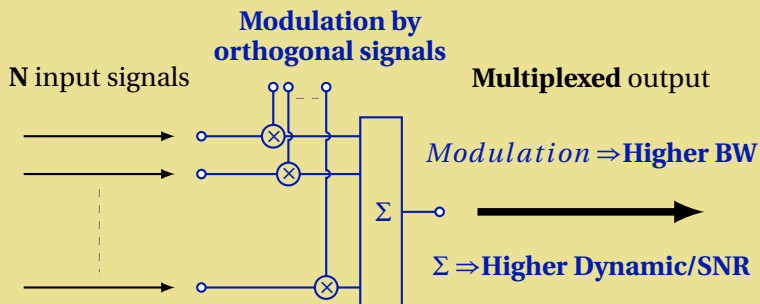
the multiplexing **divides the capacity of the high-level communication channel** into several **low-level sub-channels**, one for each message, signal or data to be transmitted.



# Multiplexing as a modulation

*There are intersections between modulation and multiplexing*

Multiplexing = **modulation of input signals by orthogonal signals:**



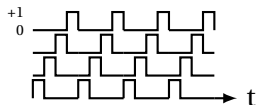
Orthogonal : **boxcar functions** or **carriers at different frequencies**.  
 Orthogonality ⇒ demultiplexer **able to recover each input signal without interference from the other**.



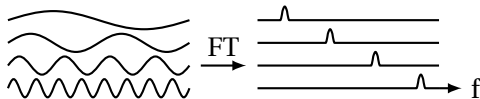


# Orthogonal functions

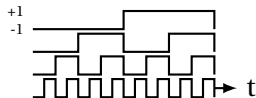
- boxcar functions  $\equiv$  **sampling**



- carriers  $\equiv$  **modulation**



- linear codes\*  $\equiv$  **coding**



\* as used for error-detection/correction code. Especially, Hadamard/Walsh code could be used for multiplexing.

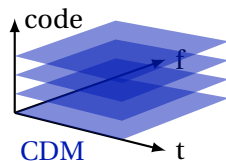
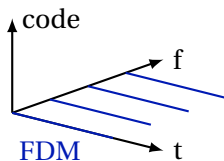
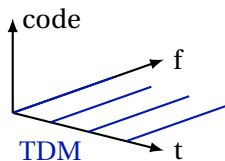


# Multiplexing type *vs* standard modulations

- Multiplexing
  - **Time Domain Multiplexing (TDM)**
  - **Frequency Domain Multiplexing (FDM)**
    - Wave length Domain Multiplexing for optical fiber
  - **Coded Domain Multiplexing (CDM)**
- Coding
  - Amplitude Shift Keying (ASK)
  - Frequency Shift Keying (FSK)
  - Coded Division Multiple Access (CDMA)



# Code as a third dimension ?



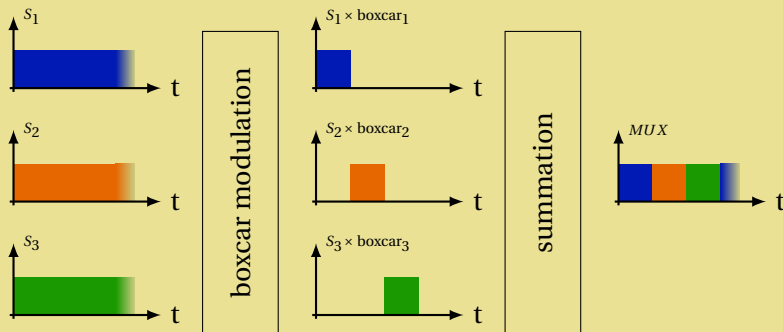
## Multiplexing $\Rightarrow$ spread spectrum

- Code is represented as a third dimension even if this is **not necessarily a physical dimension**.
- CDM is usually used to **spread the spectrum** of the multiplexed signal. But the code dimension is often a repartition both in time, in frequency and some times in amplitude.



# Time Domain Multiplexing (TDM)

Time slot of **limited duration** of each input signal ( $S_x$ ) is **summed**



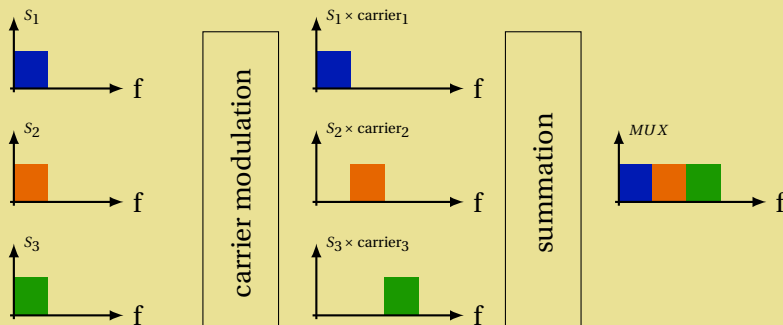
- Requires a specific boxcar (time shifted) modulation / signal
- *Limited duration*  $\equiv$  **sampling**

$\Rightarrow$  increasing of the bandwidth  
= risk of noise aliasing



# Frequency Domain Multiplexing (FDM)

Frequency **transposition** of each input signal ( $S_x$ ) is **summed**

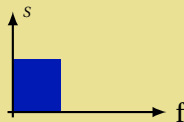


- Requires a specific frequency carrier / signal
- *Summation*  $\equiv$  increasing the **bandwidth** and the **dynamic**

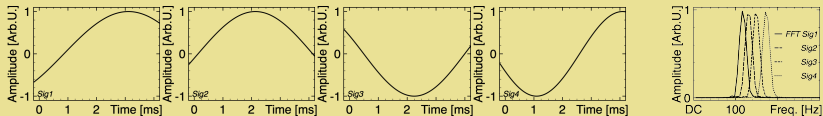


# Sine waves multiplexing

until now, signal has been represented as a time or freq. *"tophat"*

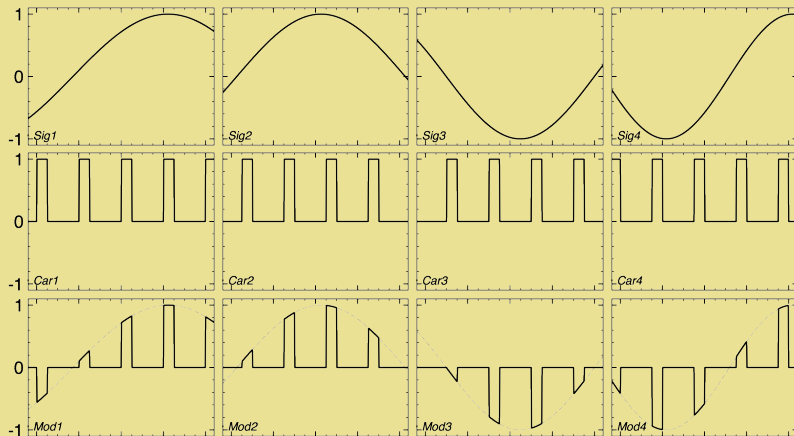


from now, signals will be represented as **4 sine waves**



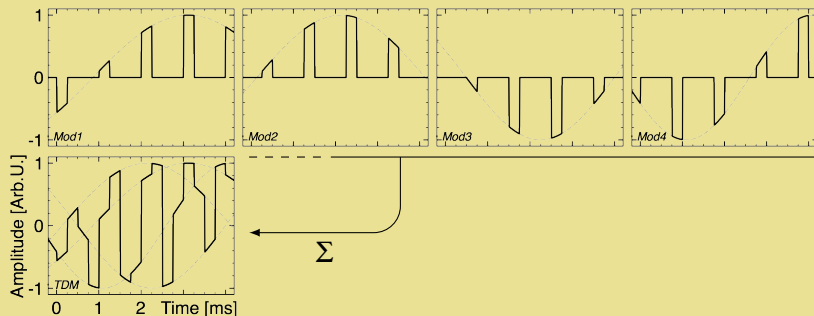
# Time Domain/Division Multiplexing - TDM

## Modulation - Sampling



# Time Domain/Division Multiplexing - TDM

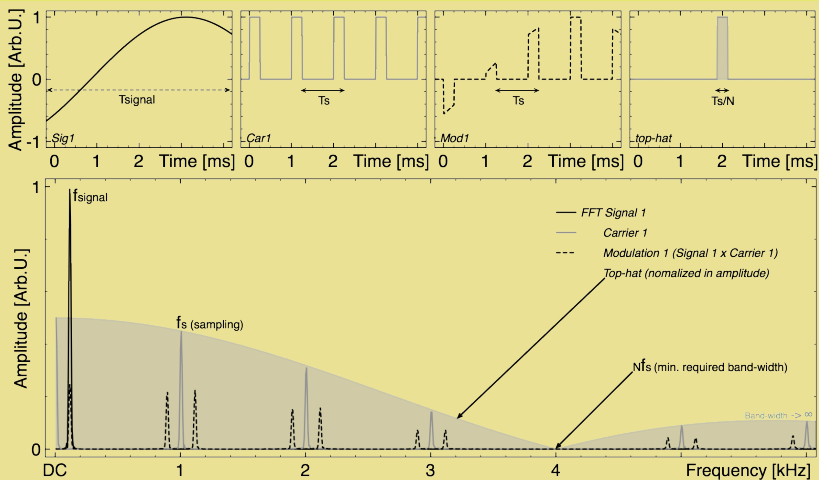
## Summation - multiplexing





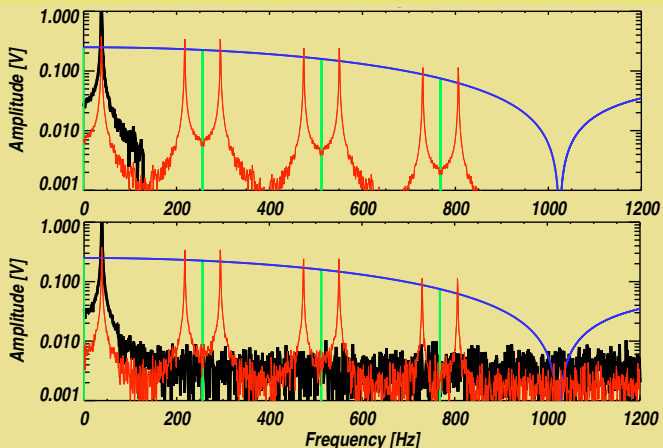
# Time Domain/Division Multiplexing - TDM

Spectrum occupancy :  $BW_{TDM} > N \times f_s > 2 \times N \times BW_{Sig}$



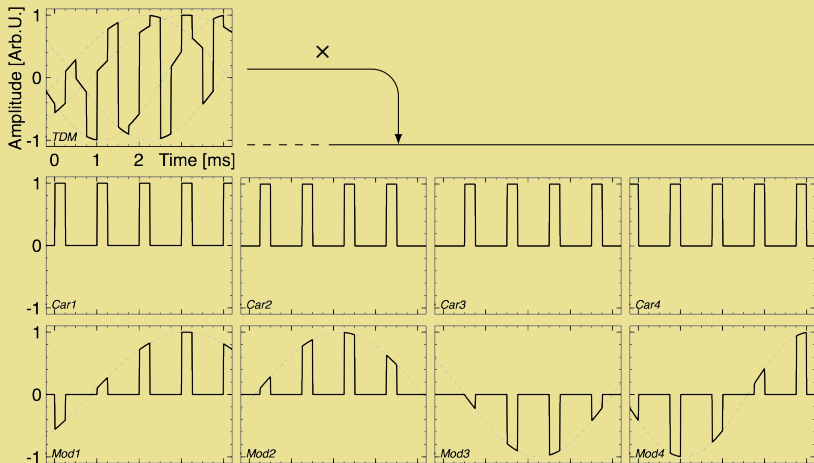
# Time Domain/Division Multiplexing - TDM

Shannon-Nyquist Unsatisfied  $\Rightarrow$  Alias the unfiltered white noise



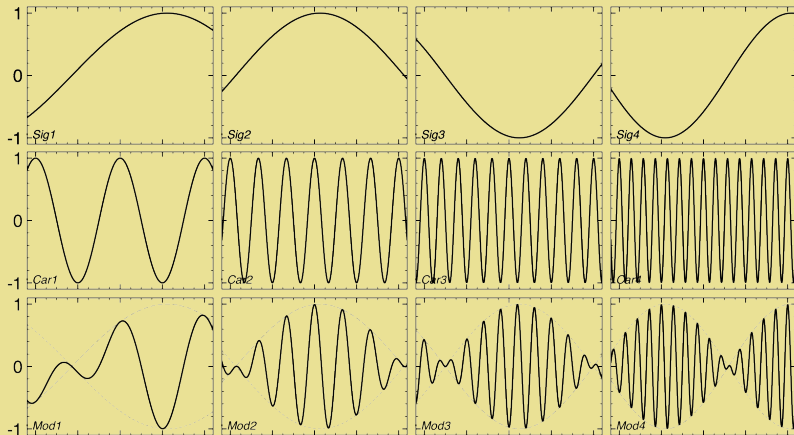
# Time Domain/Division Multiplexing - TDM

## demultiplexing before sample & hold and filtering



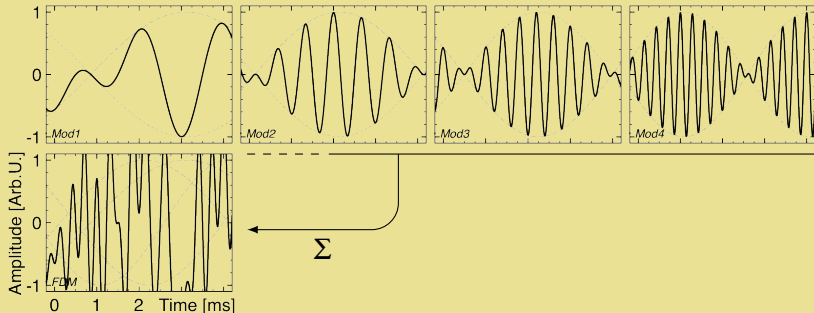
# Frequency Domain/Division Multiplexing - FDM

## Modulation - Frequency transposition



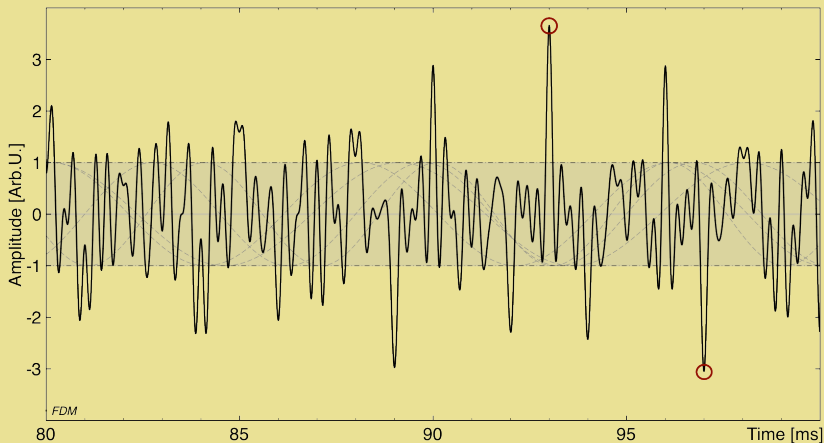
# Frequency Domain/Division Multiplexing - FDM

## Summation - multiplexing



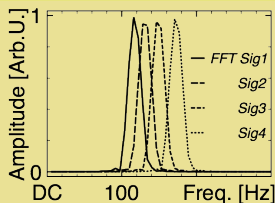
# Frequency Domain/Division Multiplexing - FDM

## Increasing of the amplitude of the multiplexed signal

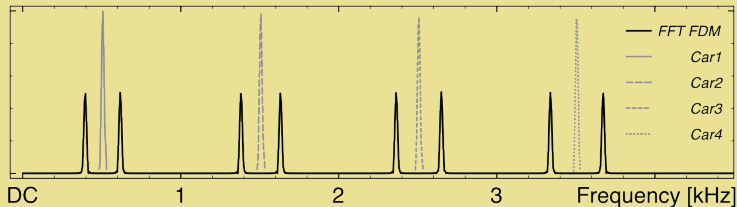


# Frequency Domain/Division Multiplexing - FDM

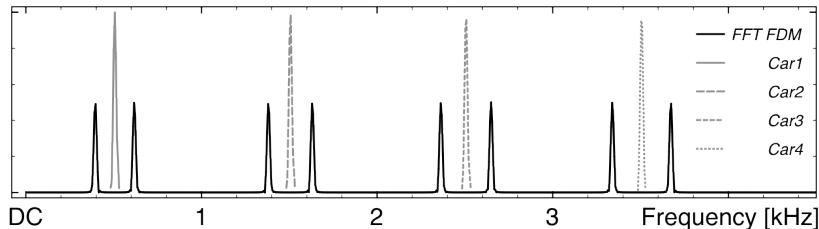
Spectrum occupancy :  $BW_{FDM} > 2 \times N \times BW_{Sig}$



Multiplexing



# Frequency Domain/Division Multiplexing - FDM



## Aliasing of the unfiltered signal and white noise

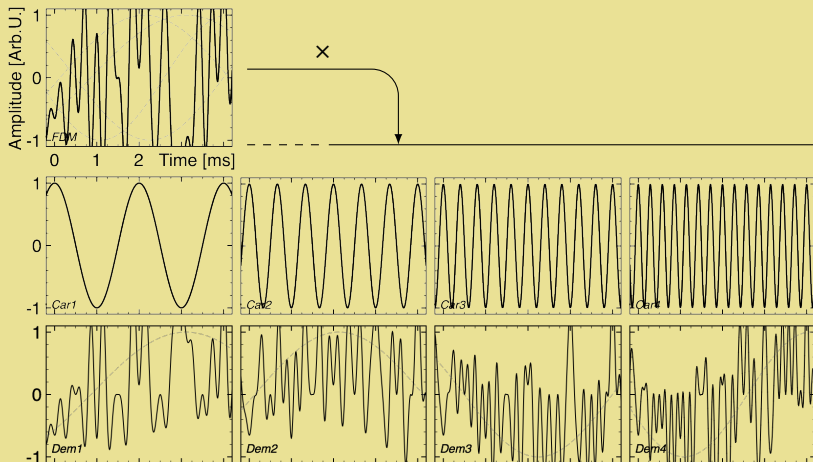
As for TDM, there is a "Shannon-Nyquist" law (modulation *vs* sampling) which need to limit the signal (and noise) to a bandwidth below an half of the carriers frequency separation





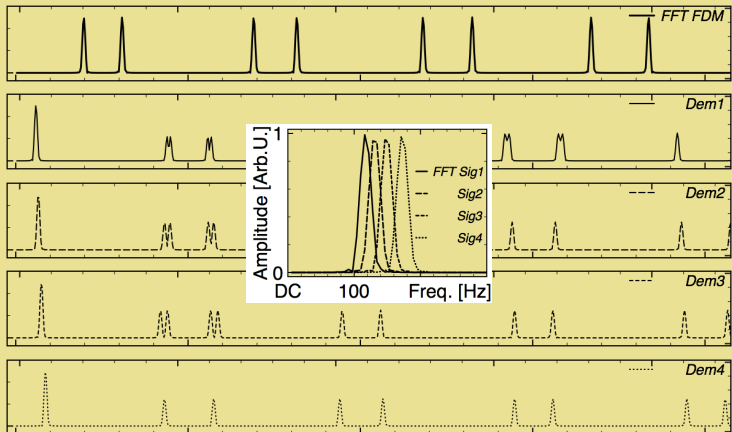
# Frequency Domain/Division Multiplexing - FDM

## demultiplexing before filtering



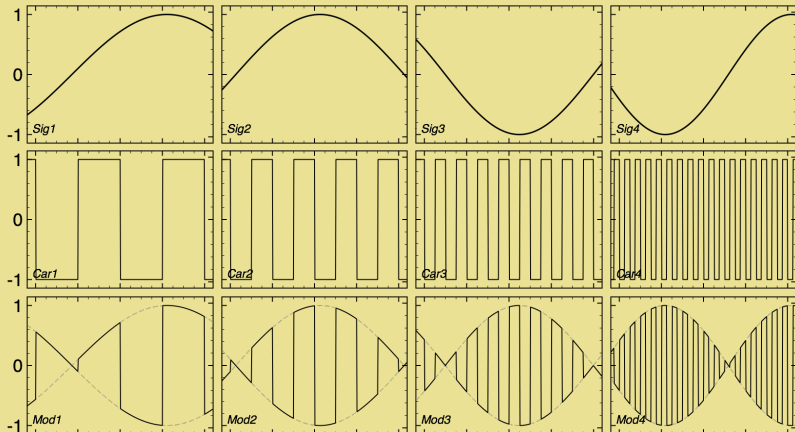
# Frequency Domain/Division Multiplexing - FDM

## demultiplexing in the frequency domain



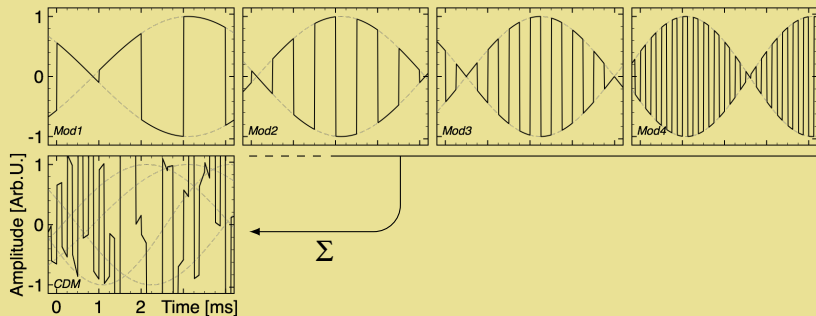
# Coded Domain/Division Multiplexing - CDM

## Modulation - Coding



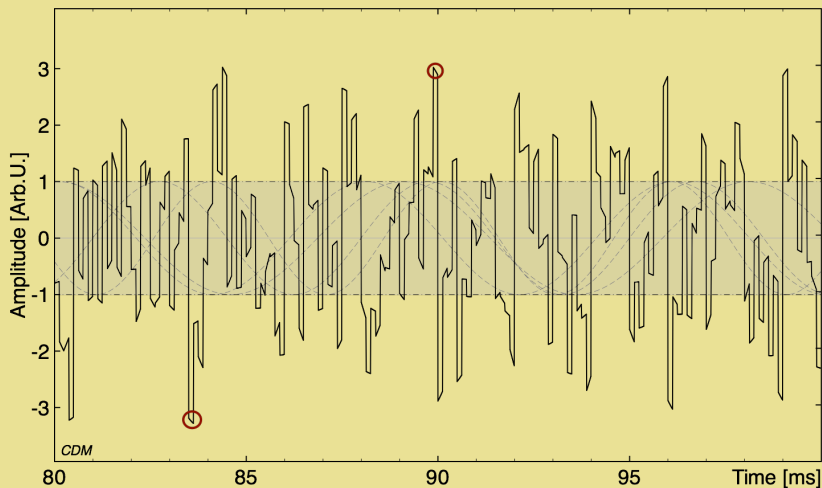
# Coded Domain/Division Multiplexing - CDM

## Summation - multiplexing



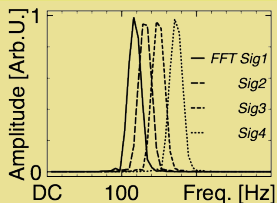
# Coded Domain/Division Multiplexing - CDM

## Increasing of the amplitude of the multiplexed signal

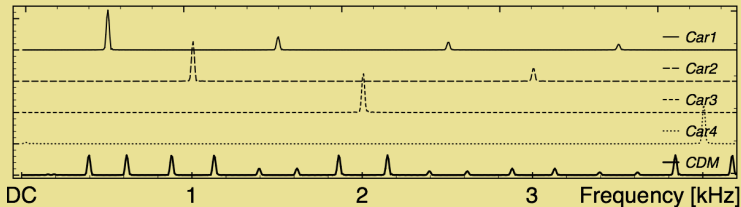


# Coded Domain/Division Multiplexing - CDM

Spectrum occupancy :  $BW_{FDM} > 2 \times N \times BW_{Sig}$

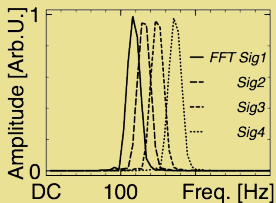


Multiplexing

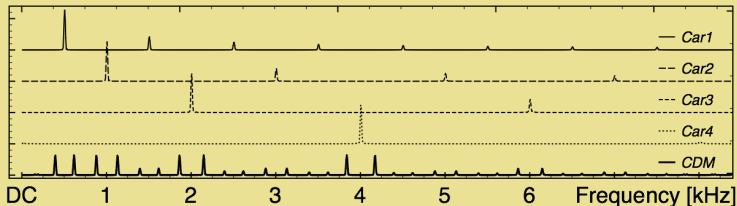


# Coded Domain/Division Multiplexing - CDM

Spectrum occupancy : wide "spread" spectrum

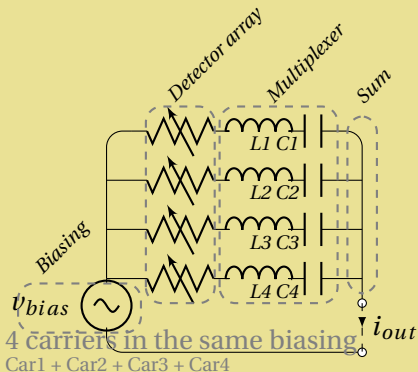
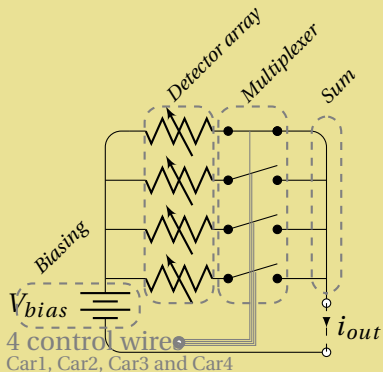


Multiplexing



# TDM vs FDM principle

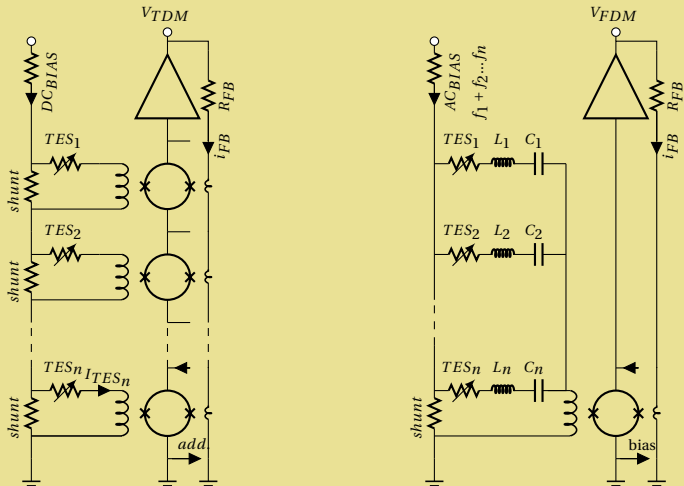
## Multiplexer 1D



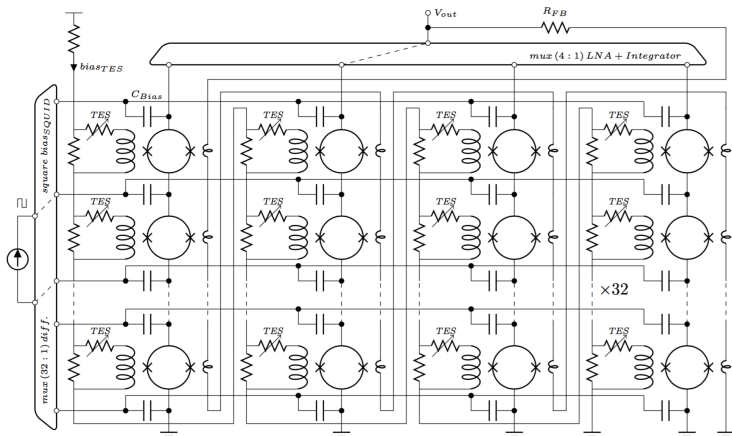


# TDM vs FDM with SQUID 1D

## Multiplexer 1D

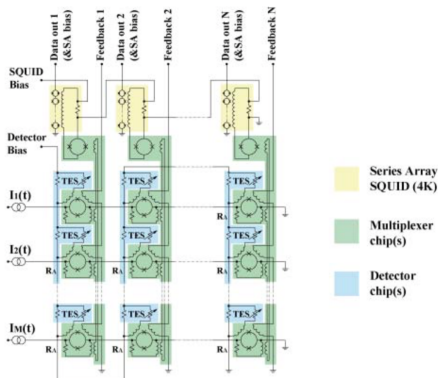
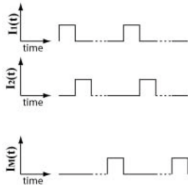


# TDM for QUBIC (APC) 2D

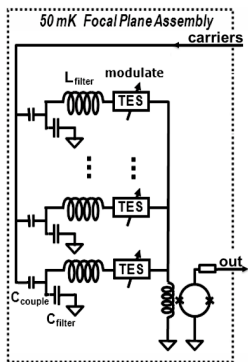


# TDM by NIST 2D

## Boxcar Modulation Functions (can be from Cryogenic CMOS MUX)



# FDM by SRON 1D



# CDM by NIST 1D

