

# 飛翔体のVLBI群遅延計測に適した信号形態についての検討

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# Spacecraft Navigation

## R&RR + VLBI

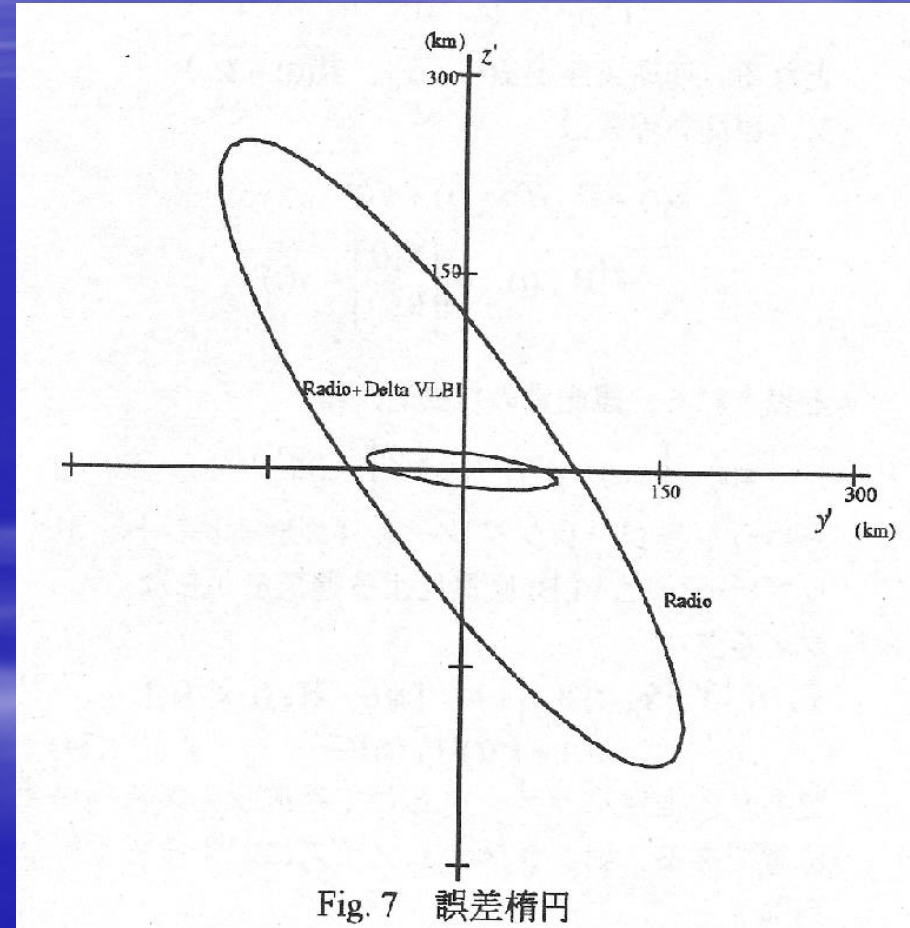
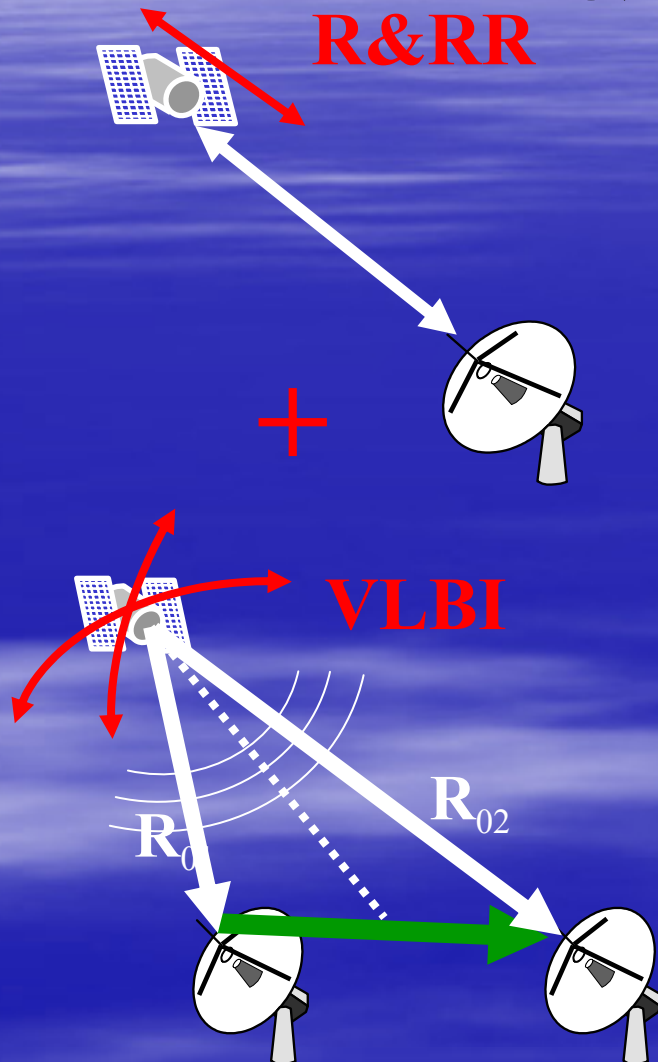
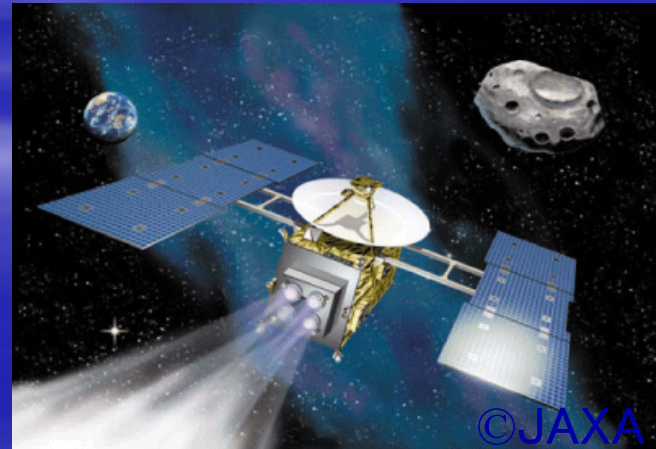
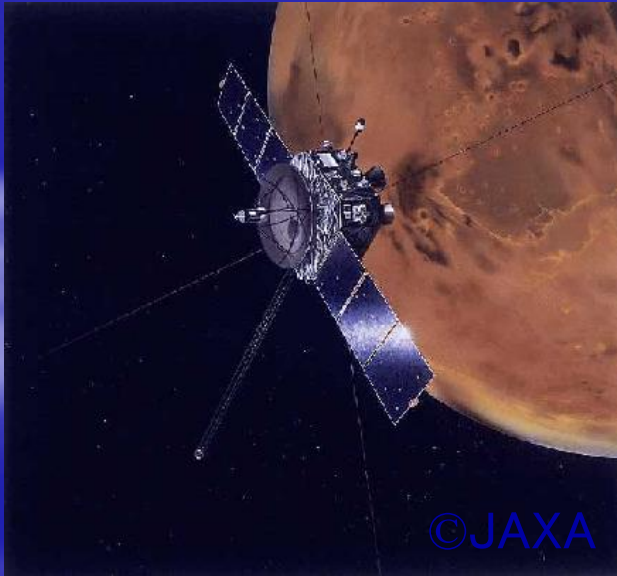


Fig. 7 誤差楕円

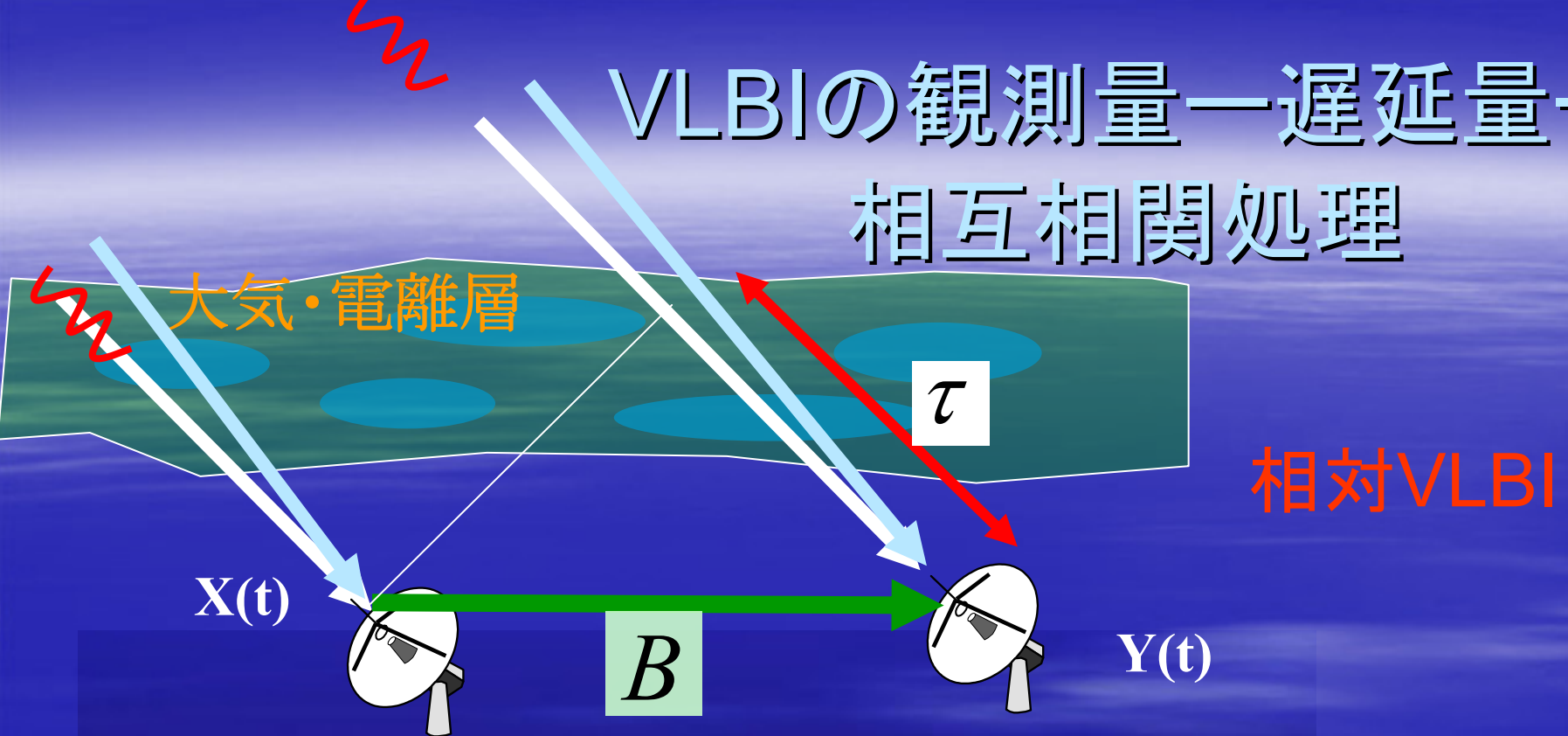
# VLBIの分解能

- 群遅延分解能30ps (500MHz帯域 クエーサ観測)
- 1000km基線: 2ミリ秒角 ~ 1.3km@1AU
- 10000km基線: 0.2ミリ秒角 ~ 130m@1AU

$$d\theta = \frac{cd\tau}{B}$$



# VLBIの観測量—遅延量— 相互相関処理



$$R(\tau) = \frac{1}{A} \int^T x(t)y(t + \tau)dt$$

$$d\theta = \frac{cd\tau}{B}$$

$$\tau = \tau_g + \tau_{atm} + \tau_{ion} + \tau_{ins}$$



**Usuda 64m**



**Mizusawa 10m, 20m**



**Tsukuba 32m**



**Aira 10m**



**Kashima 34m**



**Yamaguchi 32m**

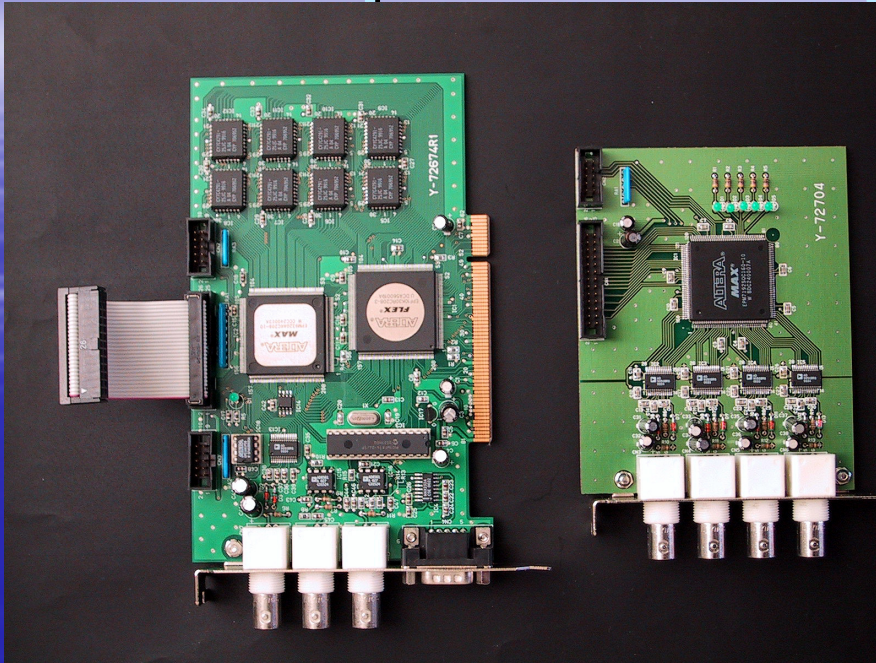


**Uchinoura 34m**



**Chichi 10m**

# Data Acquisition System: K5/VSSP

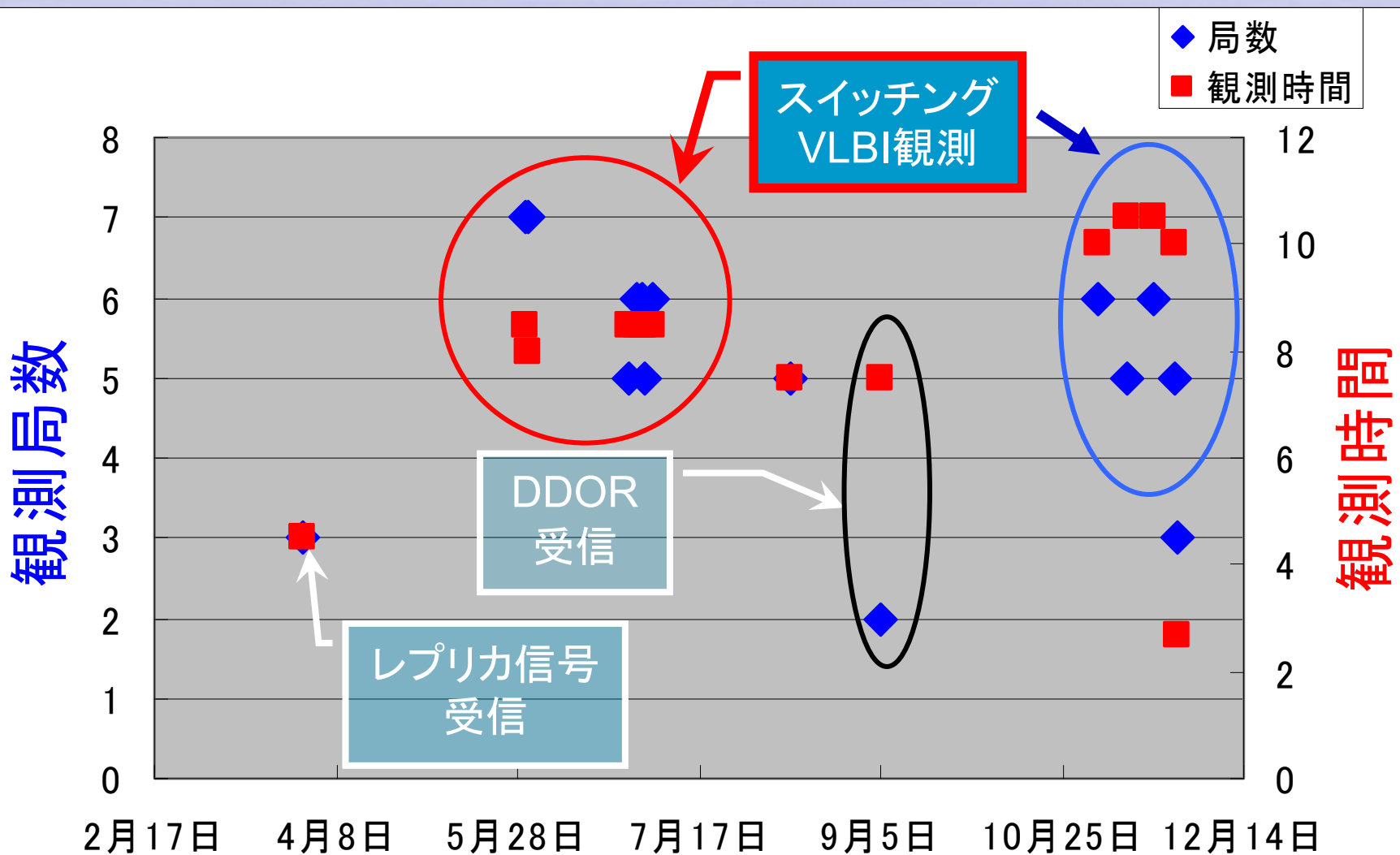


## K5 VLBI System

- Sampling rate: 40k-16MHz
- Quantization bit: 1-8bit
- 4ch/board
- 10MHz, 1PPS inputs
- Max rate: 64Mbps/board

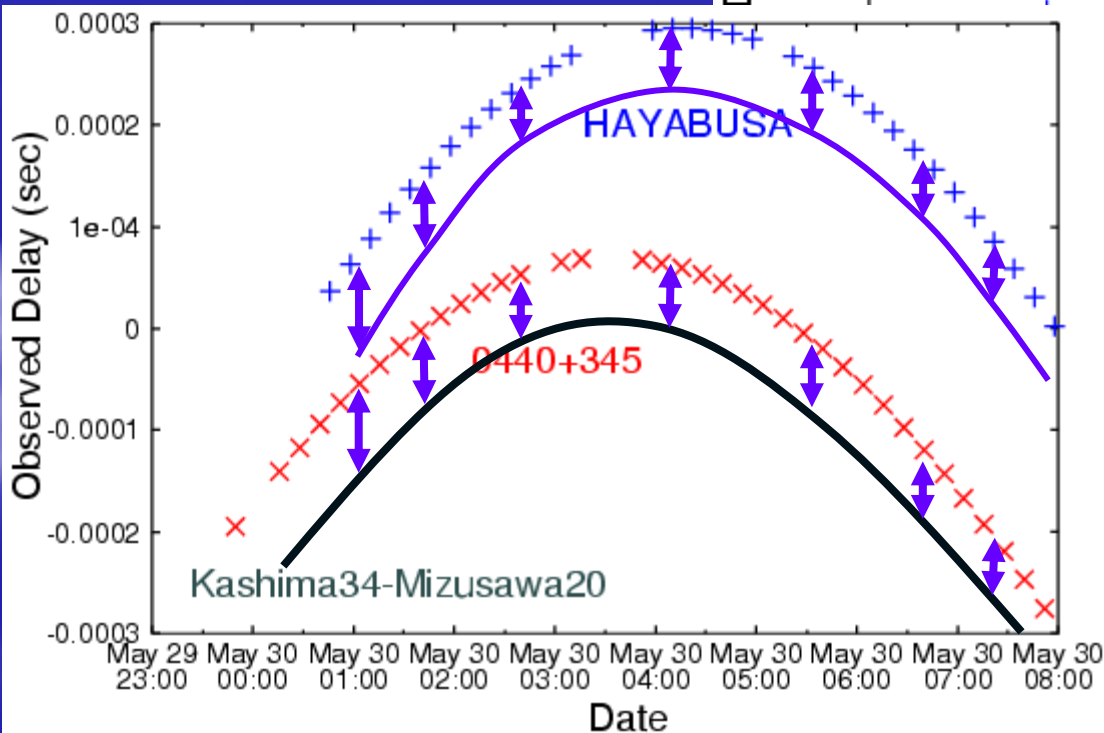
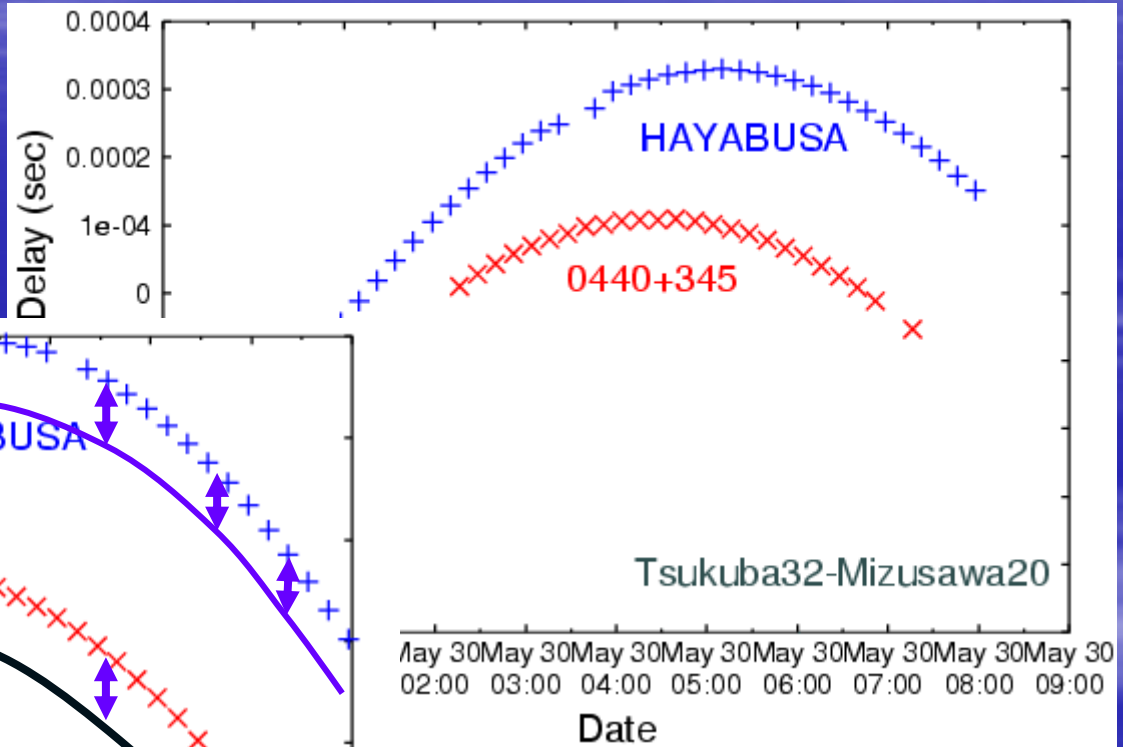


# 2005年のハヤブサ観測



# Group delay: Delta-VLBI

May 30 2005  
Spacecraft: HAYABUSA  
0440+345: 14.6 deg. Away  
Switching cycle: 12 min.



June 28 - July 4 2005  
Spacecraft: HAYABUSA  
0440+345: 6 deg. Away  
Switching cycle: 8 min.

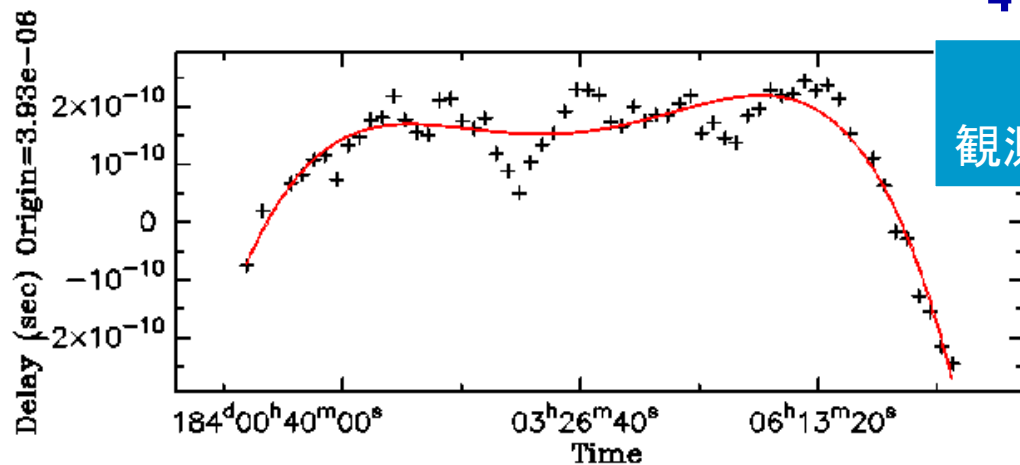


# Kashima34m-Tsukuba32m

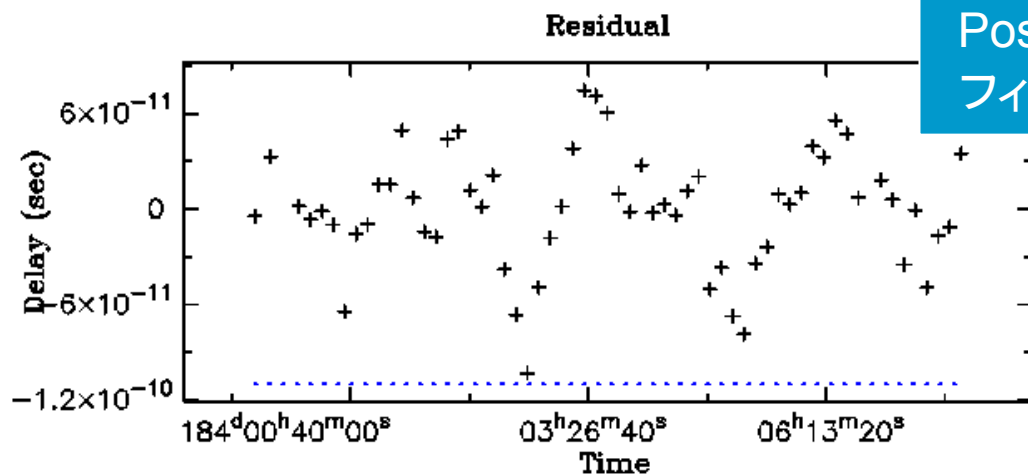
## Quasor Delay

$\sim \pm 60\text{ps}$

4 July 2005



O-C  
観測値—理論値

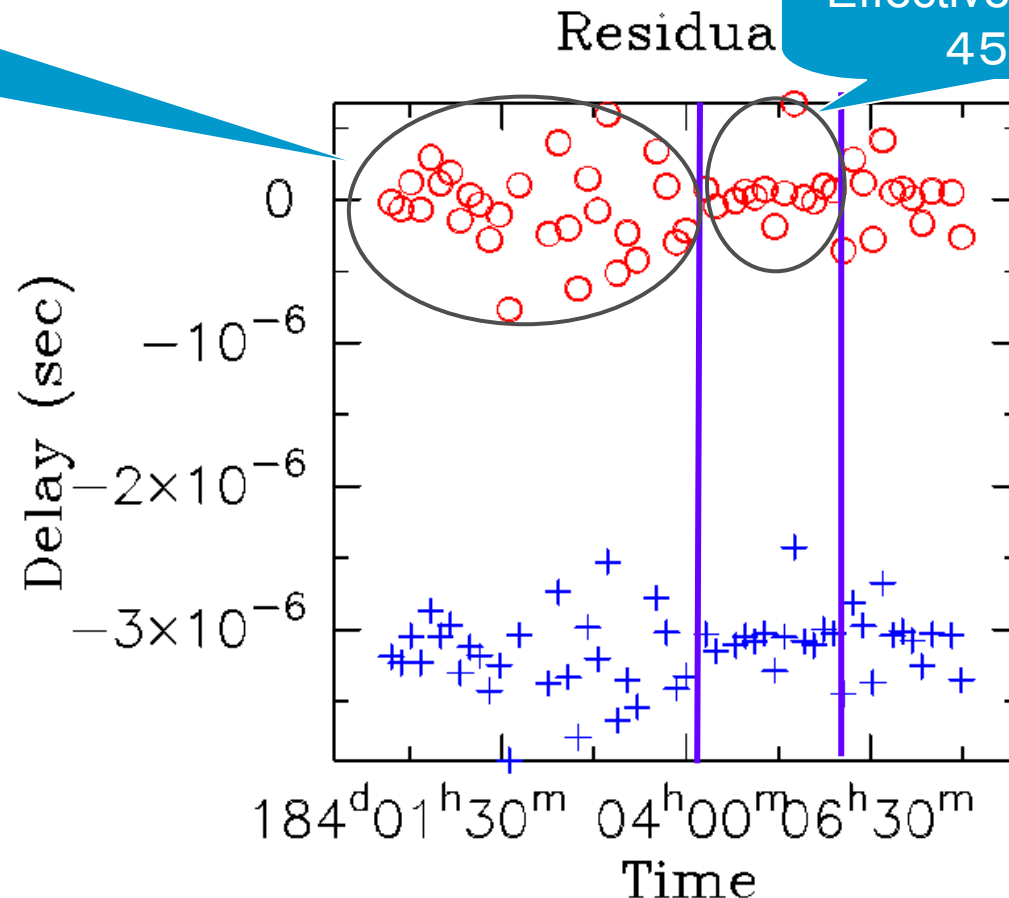


Post-Fit Residual  
フィッティング残差

# Tsukuba32m – Mizusawa10m Delay of HAYABUSA

Telemetry  
Effective Bandwidth  
100kHz

Range  
Effective Bandwidth  
450kHz

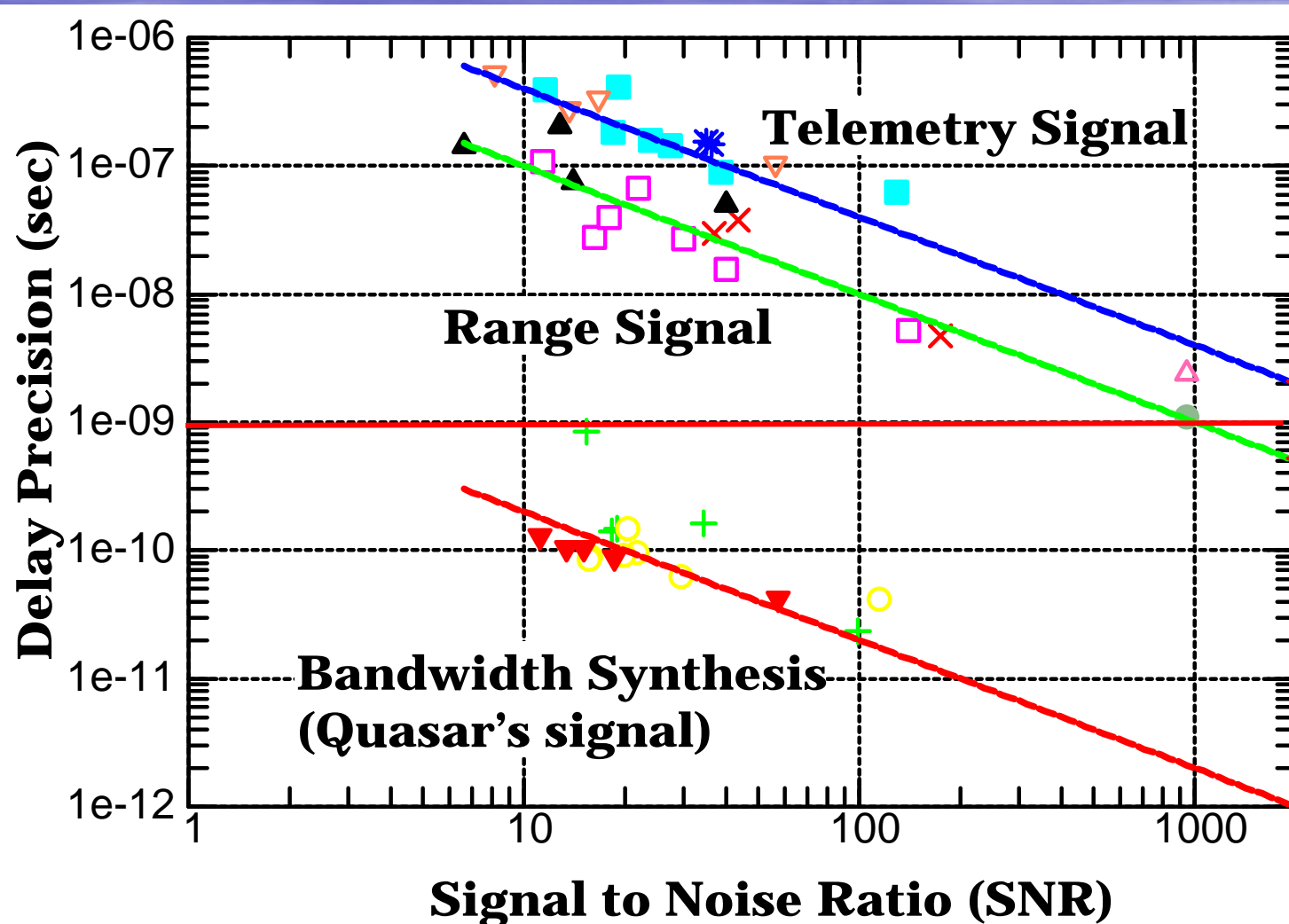


Atm. and Clock  
correction  
Before and  
After

# Precision of Group Delay

$$\sigma_{\tau} = A / (\text{SNR} \times \text{Effective Bandwidth})$$

5/30~7/4のHYBS観測

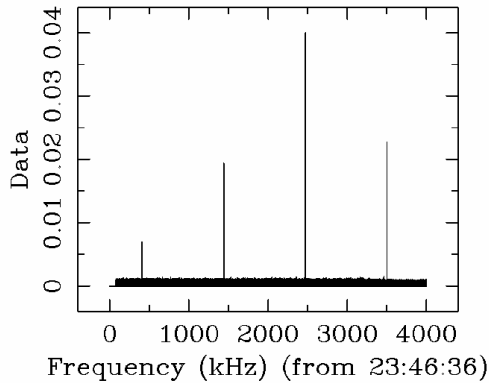


Delay  
precision  
Target

# Observable: Group Delay

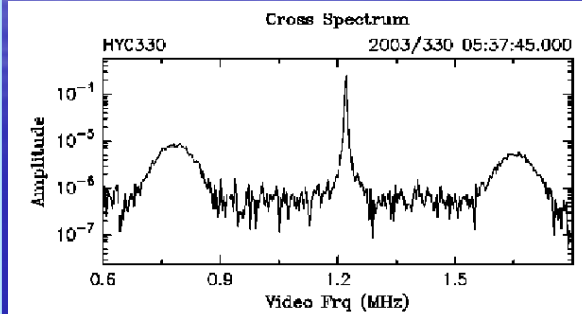
## DDOR signal

0.000 - 1.000 sec.  
8e+03 kHz-1bit Auto Cor Spectrum



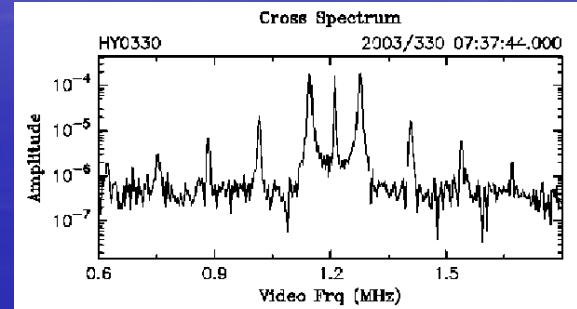
Effective Bandwidth  
450kHz

## Range signal



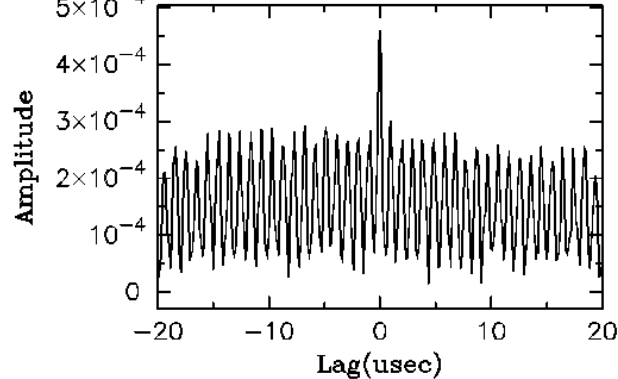
Effective Bandwidth  
100kHz

## Telemetry Signal



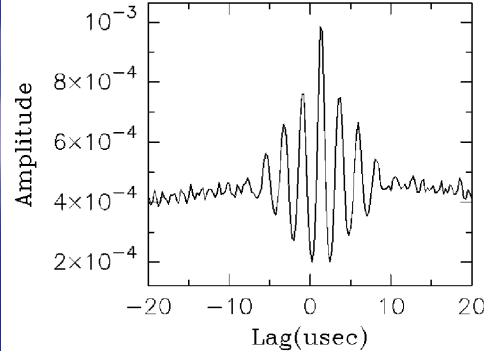
## Fringe

HY5247 2005/248 00:10:34.000



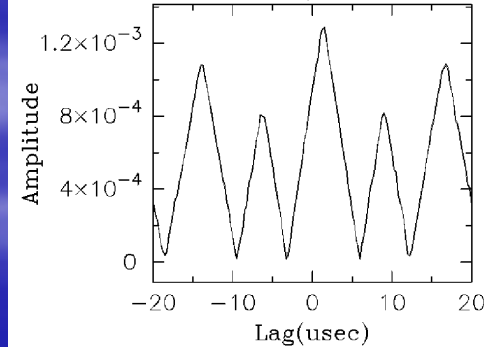
## Fringe

HY0330 2003/330 05:37:45.000



## Fringe

HY0330 2003/330 07:37:44.000



# 相互相関関数

$$\begin{aligned} R(\tau) &= \frac{1}{A} \int^T s(t)s(t + \tau)dt \\ &= \frac{1}{A} \int S(f)S^*(f)e^{j2\pi f\tau} df \\ &= \frac{1}{A} \int |S(f)|^2 e^{j2\pi f\tau} df \end{aligned}$$

パワースペクトルが同じなら、時間波形が違ってても相互相関関数は同じ。

# 群遅延計測精度向上には？

$$\sigma_{\tau} = \frac{A}{(SNR \times EffectiveBandwidth)}$$

## 1. 広帯域出力方式

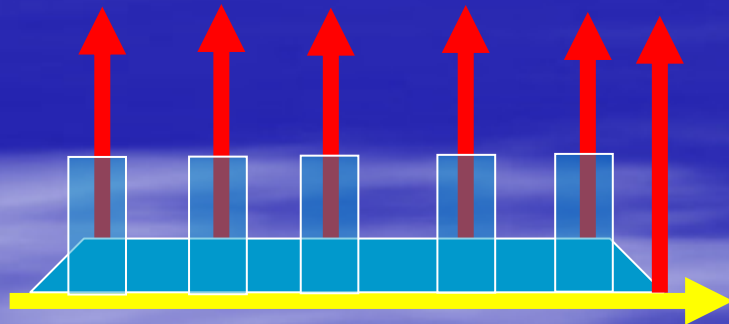
- ☹ 探査機側送信出力の制限
- ☹ 単位周波数あたりの信号小

## 2. 周波数掃引方式

- ☺ 信号近傍でC/N比が高い
- ☹ 帯域全体を相関処理する場合  
SNRは1と同じ

## 3. マルチトーン方式

- ☹ 信号のC/N比は中程度
- ☺ 信号の周波数が固定ならフィルタリングでSNR改善可能

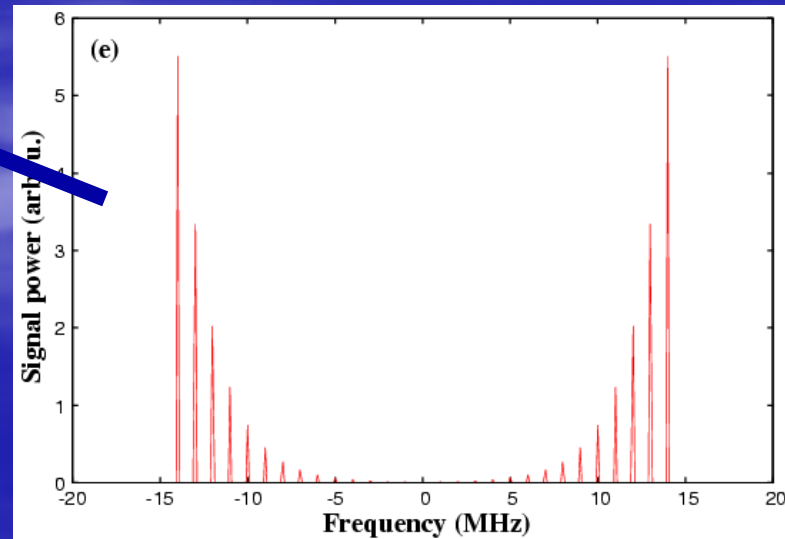
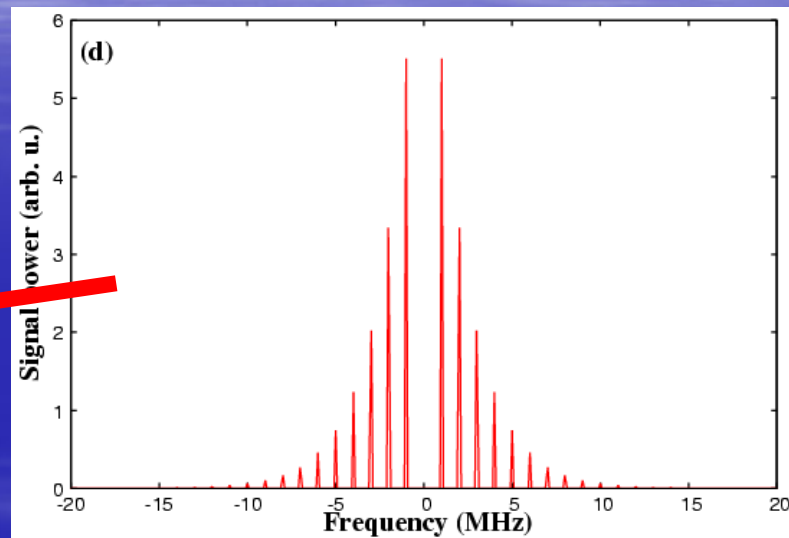
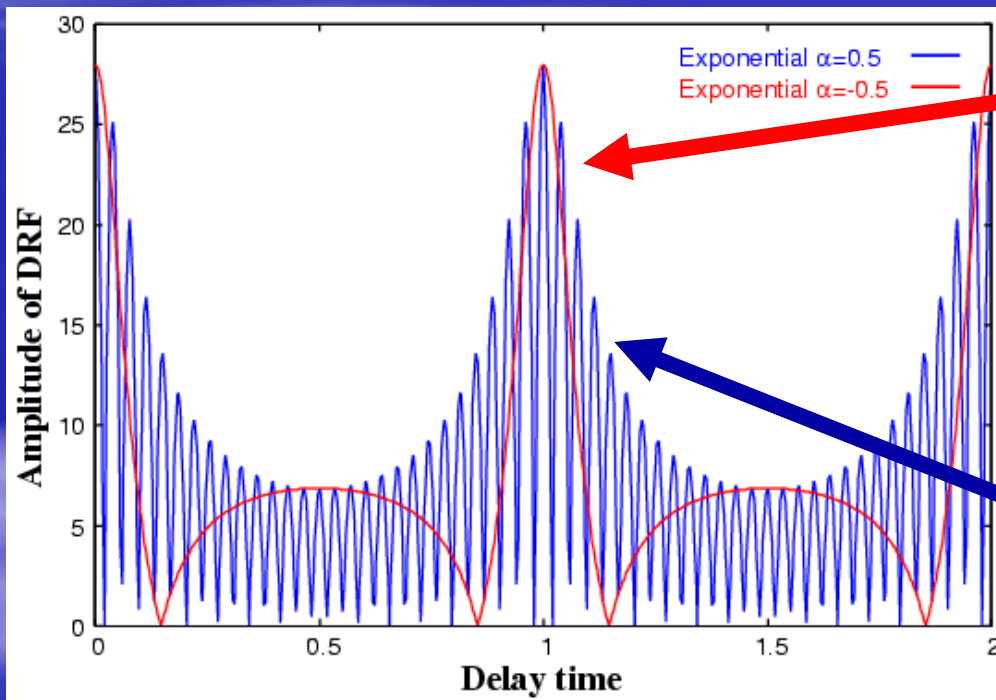


周波数軸

# 信号帯域と相互相関関数(例1)

## パワースペクトル

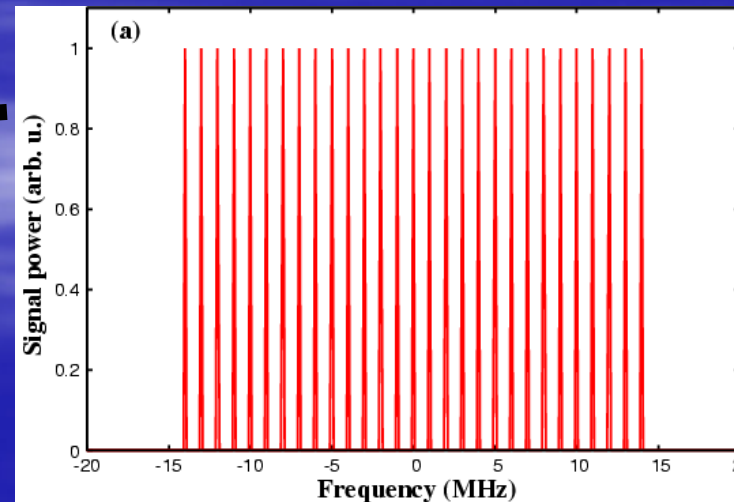
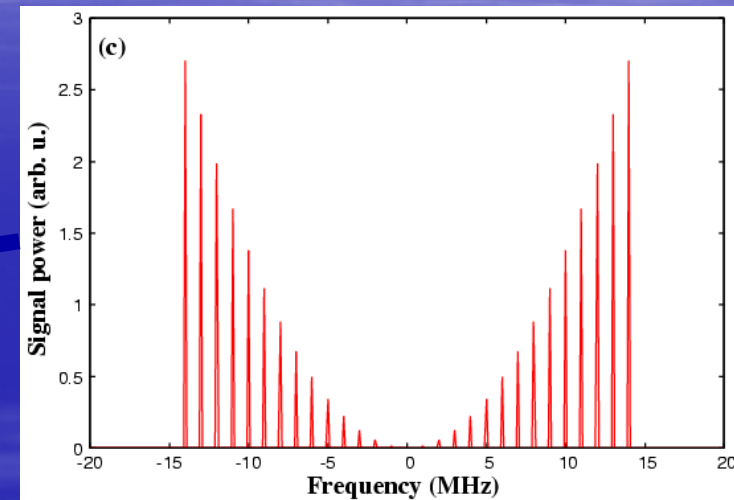
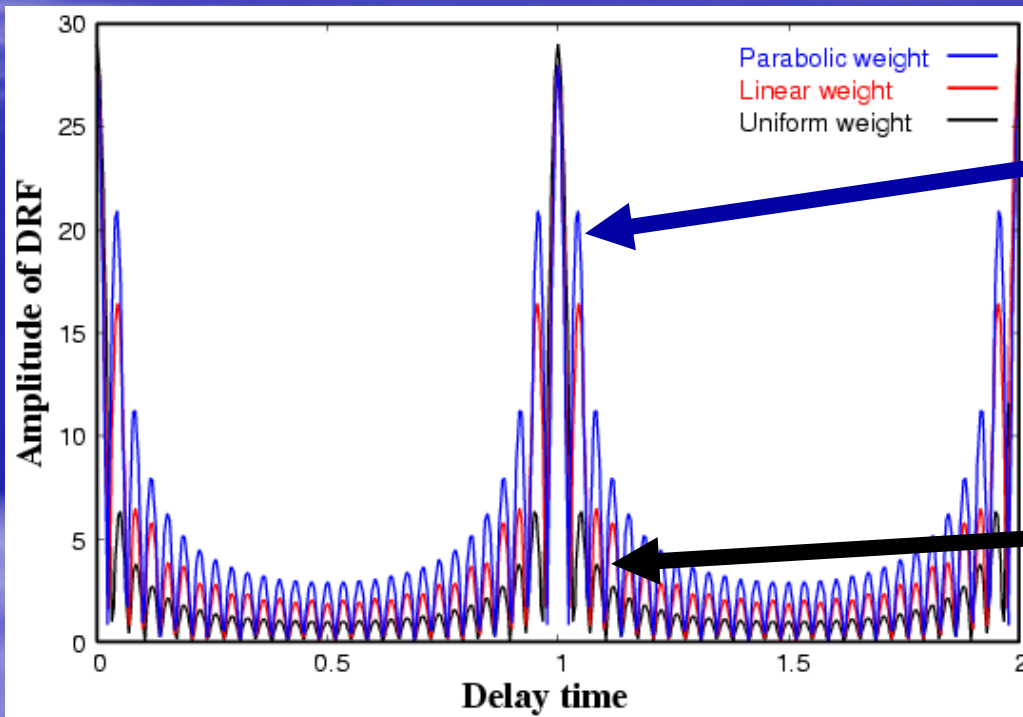
### 相互相関関数



# 信号帯域と相互相関関数(例2)

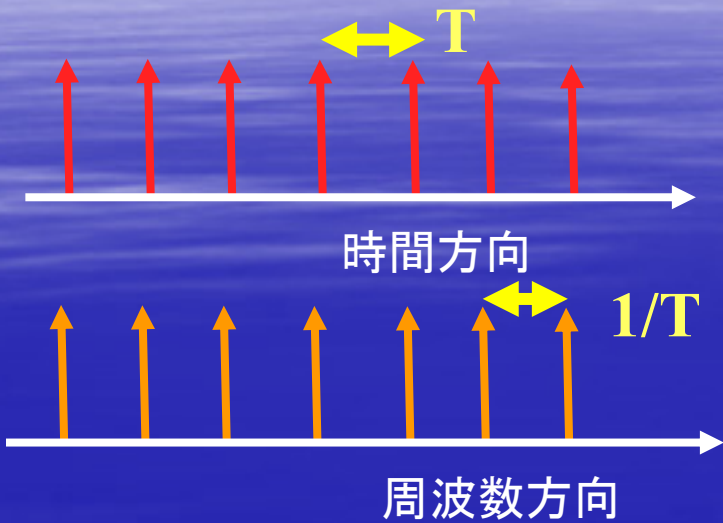
パワースペクトル

相互相関関数



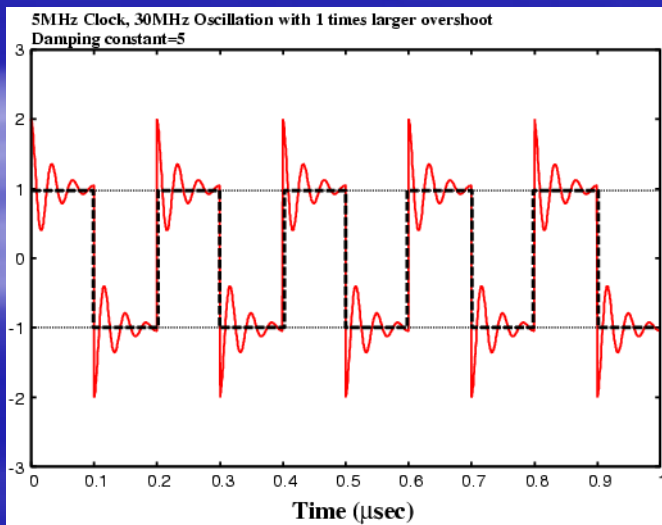


# どのような時間波形で実現できるか



## 1. COMBトーン発生器

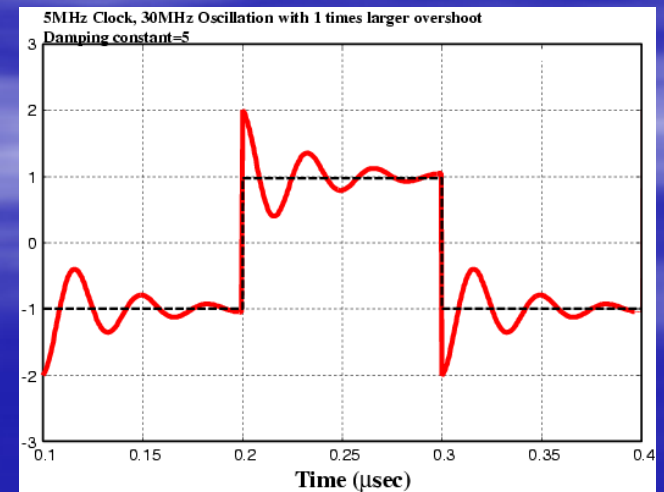
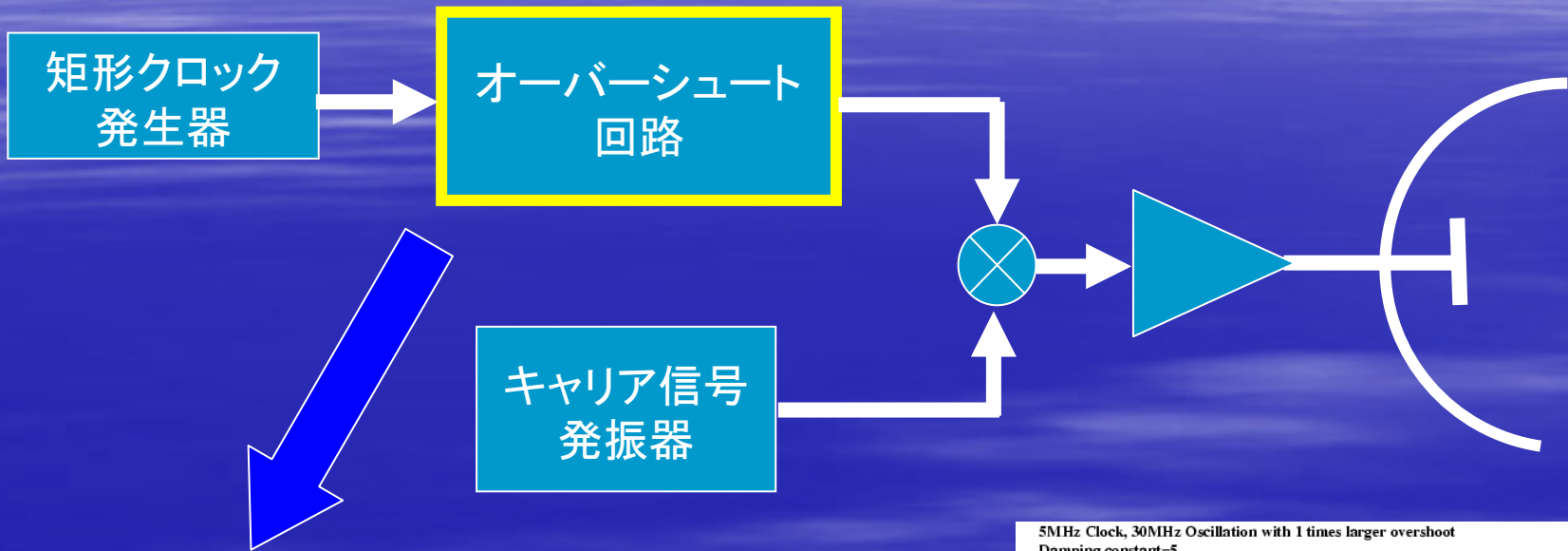
- ステップリカバリーダイオード
- トンネルダイオード



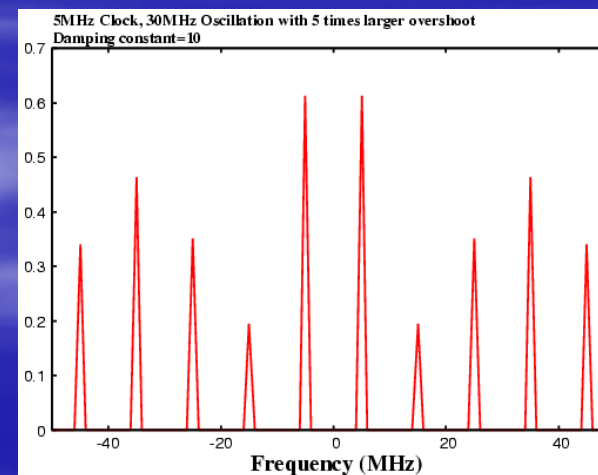
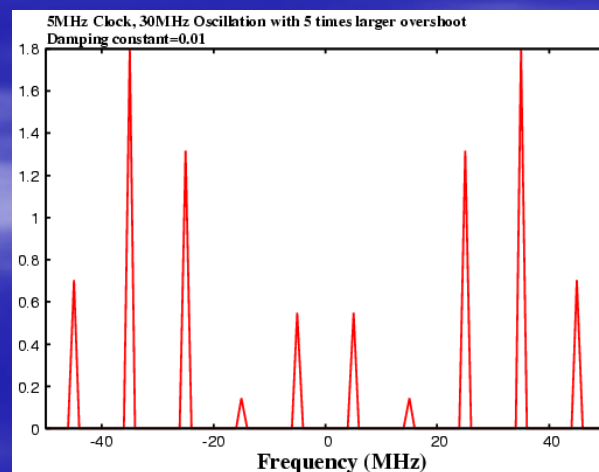
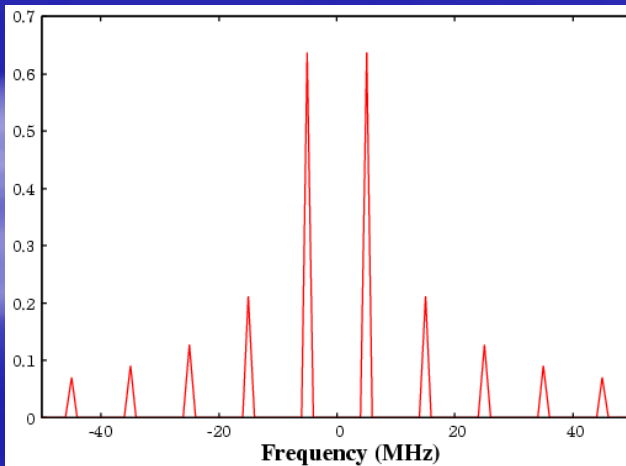
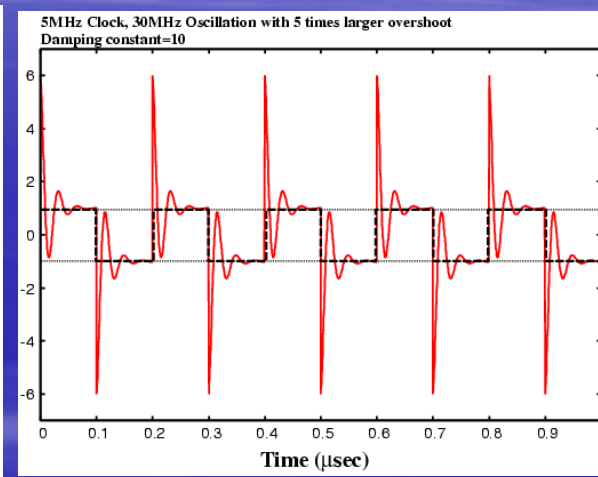
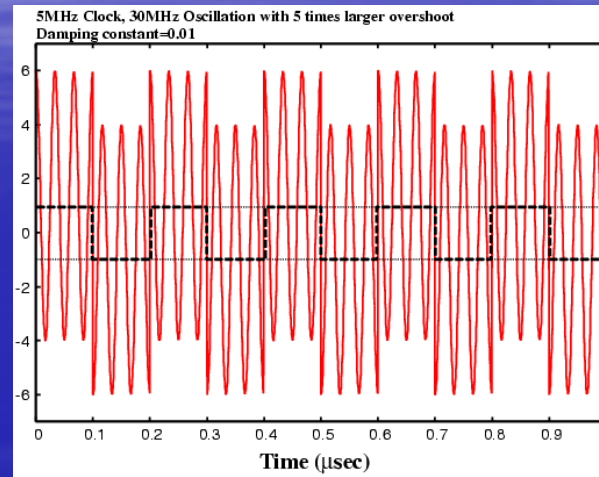
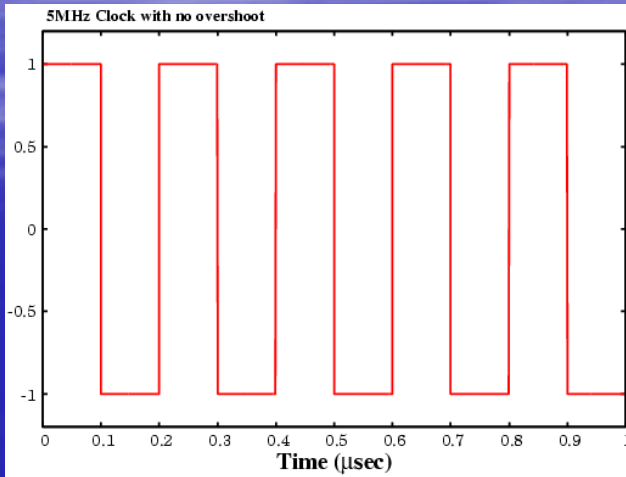
## 2. 矩形波のオーバーシュート

- デジタル信号でよく見かける
- LCRの単純な回路で構成可

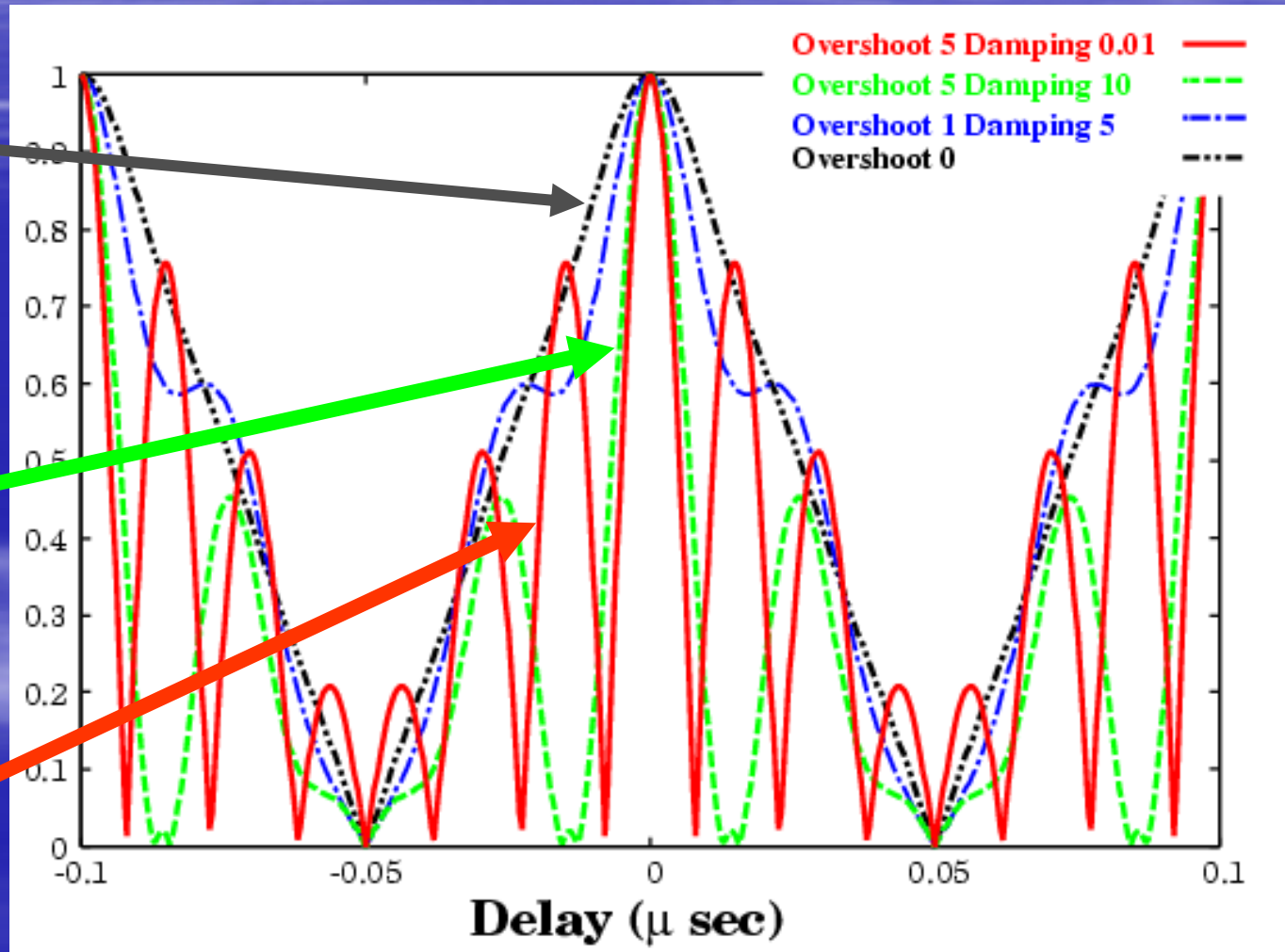
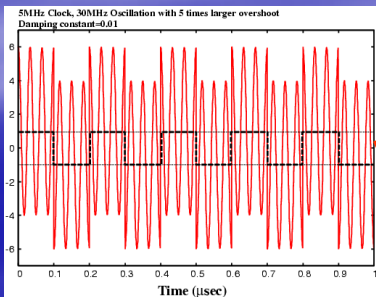
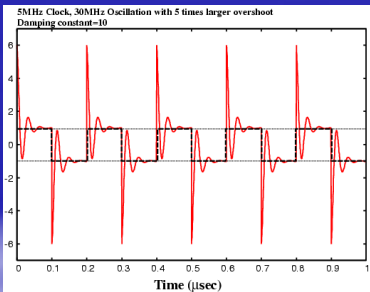
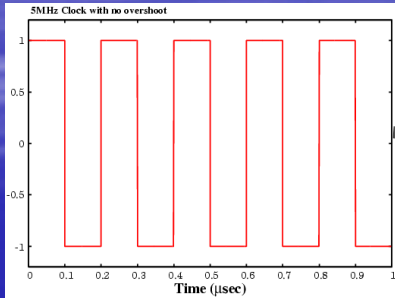
# オーバーシュートの回路例



# オーバーシュートクロックのスペクトル



# オーバーシュートクロックの相関関数



# まとめ

- 相対VLBIによる飛翔体のVLBI観測
- 群遅延量を利用する試み～絶対遅延量を得やすい
  - 問題点: 遅延精度の不足  $\leq$  帯域幅とSNR
- 将来のミッションでVLBIの精度向上にむけて
  - 信号形態の検討
  - 簡便なマルチトーン発生法の一つとしてオーバーシュートの積極利用について検討