An XF-type Software Correlator Developed by NICT

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Contents

- Software correlators at Kashima
- History of the processing speed of XF-type software correlators
- Details of an XF-type software correlator for geodetic use
- Distributed processing
- Conclusions

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Software Correlators at NICT

for K5/VSSP (geodetic use)

- XF-Type Correlator (for 1bit AD data) (K5-cor)
- FX-Type Correlator (for multi-bit AD data) (K5-fx_cor)

K5/VSSP

for K5/VSI (gigabit VLBI system)
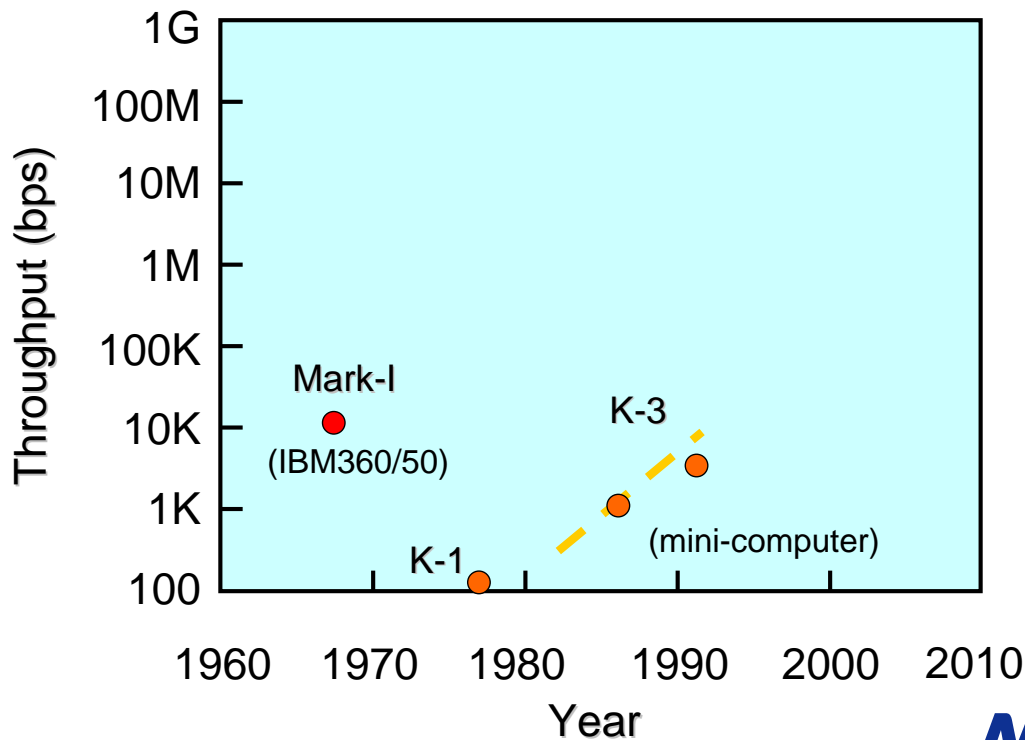
- FX-Type Correlator

  (developed by Kimura-san)*

  *This software correlator is very fast, but not for geodetic use right now
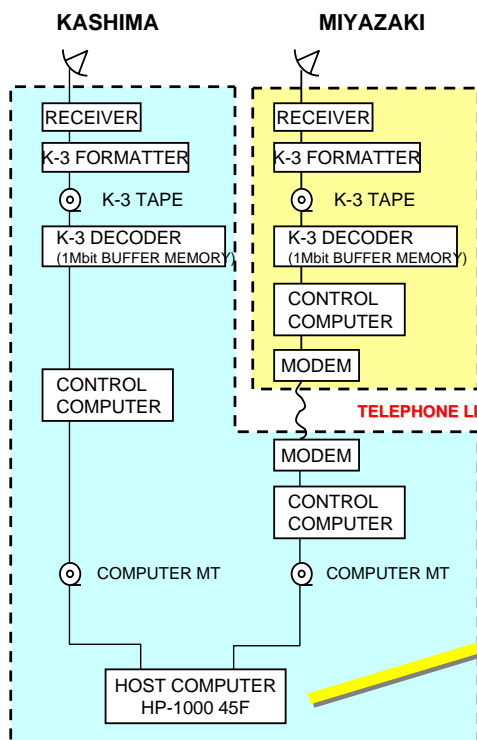
K5/VSI

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History of the processing speed of XF-type software correlators

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History of Processing Speed (XF-type)
(converted to 32-lag complex correlation)

Historical e-VLBI Experiment using Software Correlator in JAPAN (1986)

It took about 10 hours to get fringes!
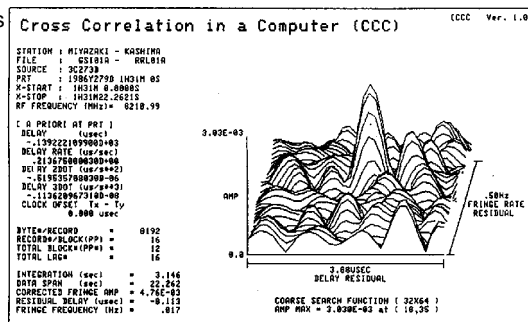
History of Processing Speed (XF-type)
(converted to 32-lag complex correlation)

Throughput (bps)

1G
100M
10M
1M
100K
10K
1K
100

K-5
(PC)
Moore's Law

Mark-I
(IBM360/50)

K-3

K-1

(mini-computer)

1960 1970 1980 1990 2000 2010

Year
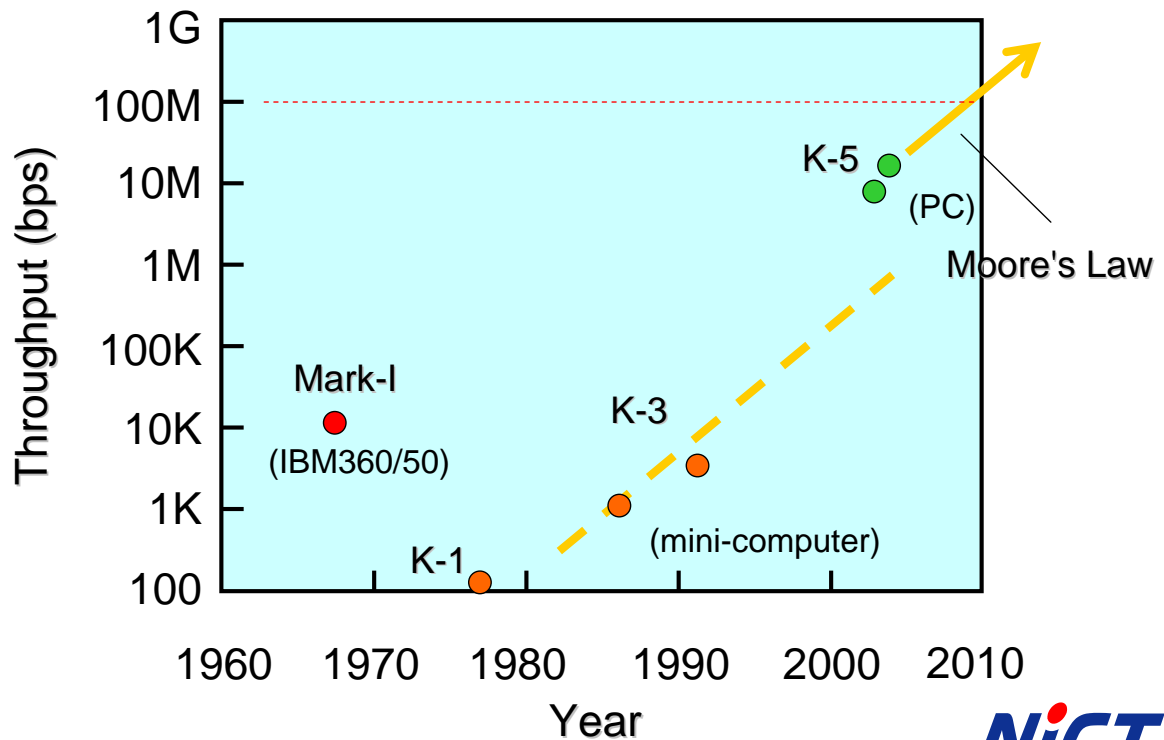
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Details of an
XF-type software correlator
for geodetic use

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Requirements for a Software Correlator for Geodetic Use

- Compatible with conventional hardware correlators, such as K3, KSP correlators
  - Consistent definitions in delay, clock parameters, etc.
  - PCAL signal detection
  - Checking bit slip or make
- Both K5 and Mark-5 data processing capability

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Architecture of K5-cor Correlator

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How to get 8-lag cross-correlation

refer look-up table as a function of
1byte-integer(X) and 2byte-integer(Y)

1Byte 8bits) data

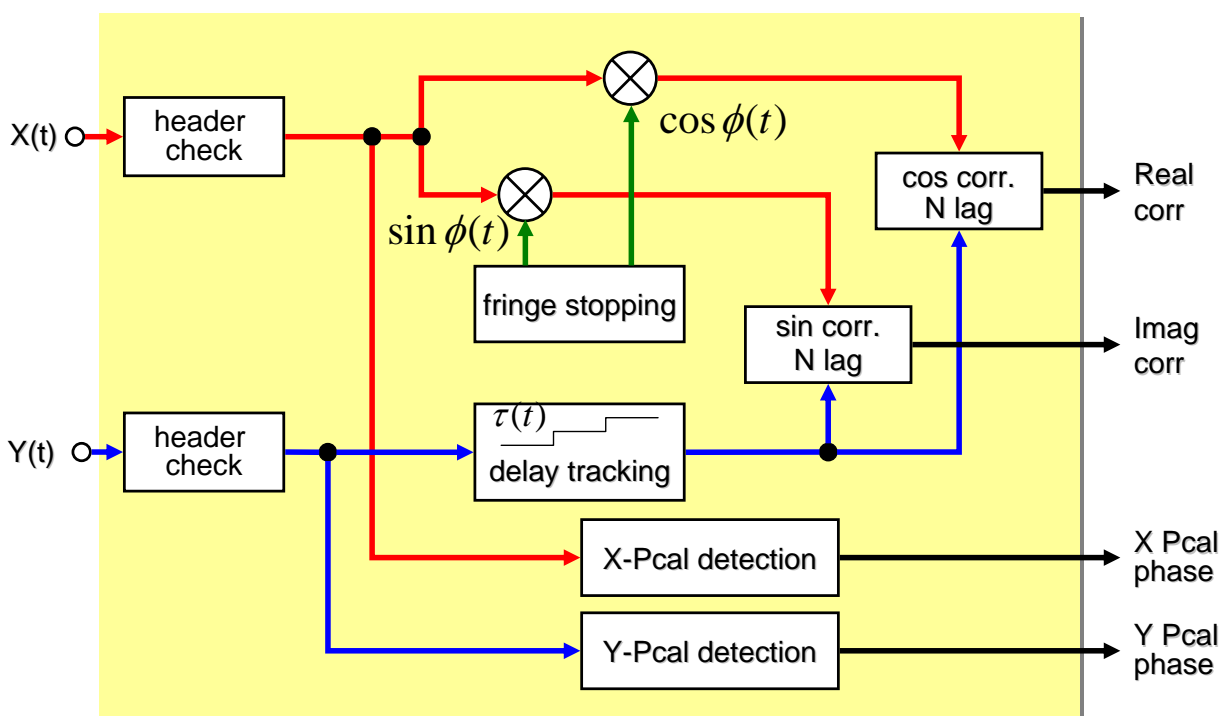X | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | = 128+32+8+1= (169)

LSB   MSB

LSB   MSB

Y | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 |

16bits data = 32768+8192+4096+1024+128+64+16+4+1= (46293)

correlation counts for 0 lag = cortable0(169,46293) =6

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How to get 8-lag cross-correlation

refer look-up table as a function of
1byte-integer(X) and 2byte-integer(Y)

1Byte 8bits) data

X | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | = 128+32+8+1= (169)

LSB   MSB

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16bits data = 32768+8192+4096+1024+128+64+16+4+1= (46293)

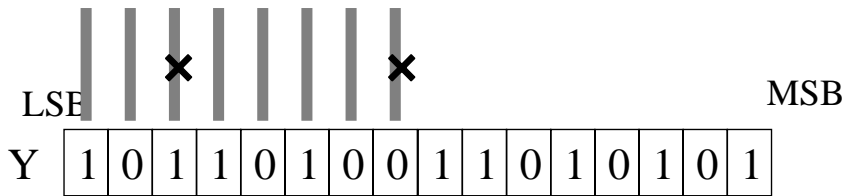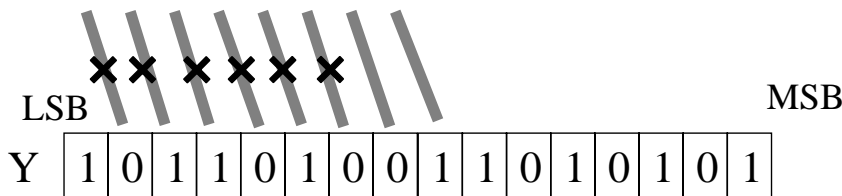correlation counts for 0 lag = cortable0(169,46293) =6
1 lag = cortable1(169,46293) =2

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How to get 8-lag cross-correlation

refer look-up table as a function of
1byte-integer(X) and 2byte-integer(Y)

1Byte 8bits) data

X | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | = 128+32+8+1= 169

LSB   MSB

× × × × × × × ×

LSB   MSB

Y | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 |

16bits data = 32768+8192+4096+1024+128+64+16+4+1= 46293

correlation counts for 0 lag = cortable0(169,46293) =6
1 lag = cortable1(169,46293) =2
…………………….
7 lag = cortable7(169,46293)=0

Actual look-up table is

cortable(169,46293)=

32-bit integer

0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 0 | 0 | 0 | 0

lag 0   lag 1   lag 2   lag 3   lag 4   lag 5   lag 6   lag 7

table size (8lags) =$2^8 \times 2^{16} \times 4$ bytes =67Mbytes

table size (16lags) =$2^8 \times 2^{32} \times 8$ bytes =8.8Gbytes

too large

Mark5 to K5 converter (m5tok5)

VEX File → Get AD bits, fanout, track#, CH# information

Mark5 File → Analyze bit length, bit position vs track#

→ CIF Conversion Information File

information file creation mode

conversion mode

CIF

Mark5 File → Mark5 → K5 conversion → K5 File

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Mark5 Data File Format

t_0 t_1 t_2 t_3 t_4

MSB bit#31

bit #n   Trk #k

LSB bit#0
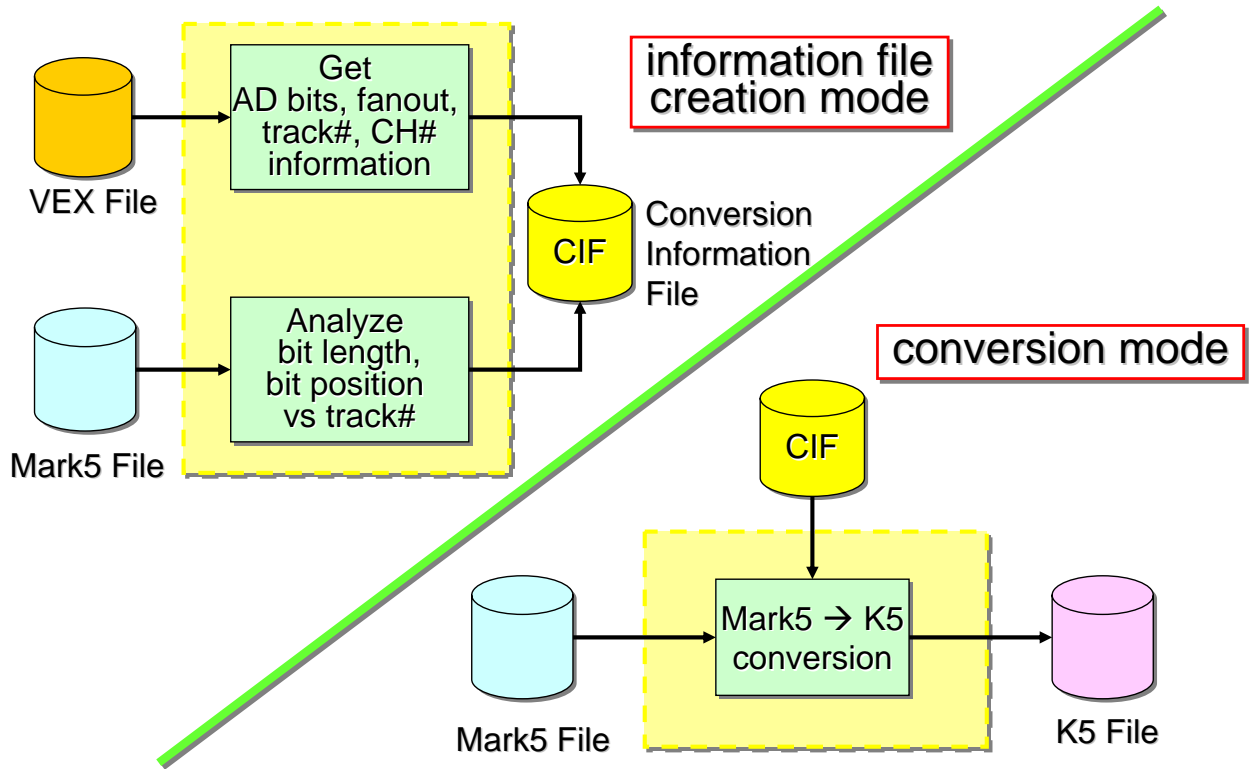
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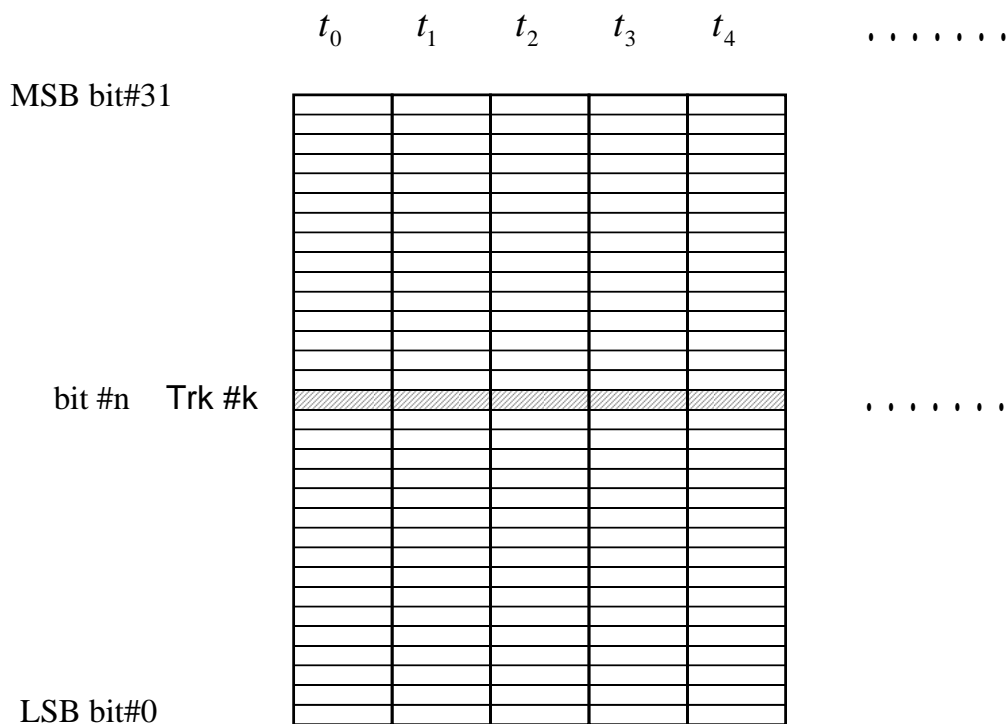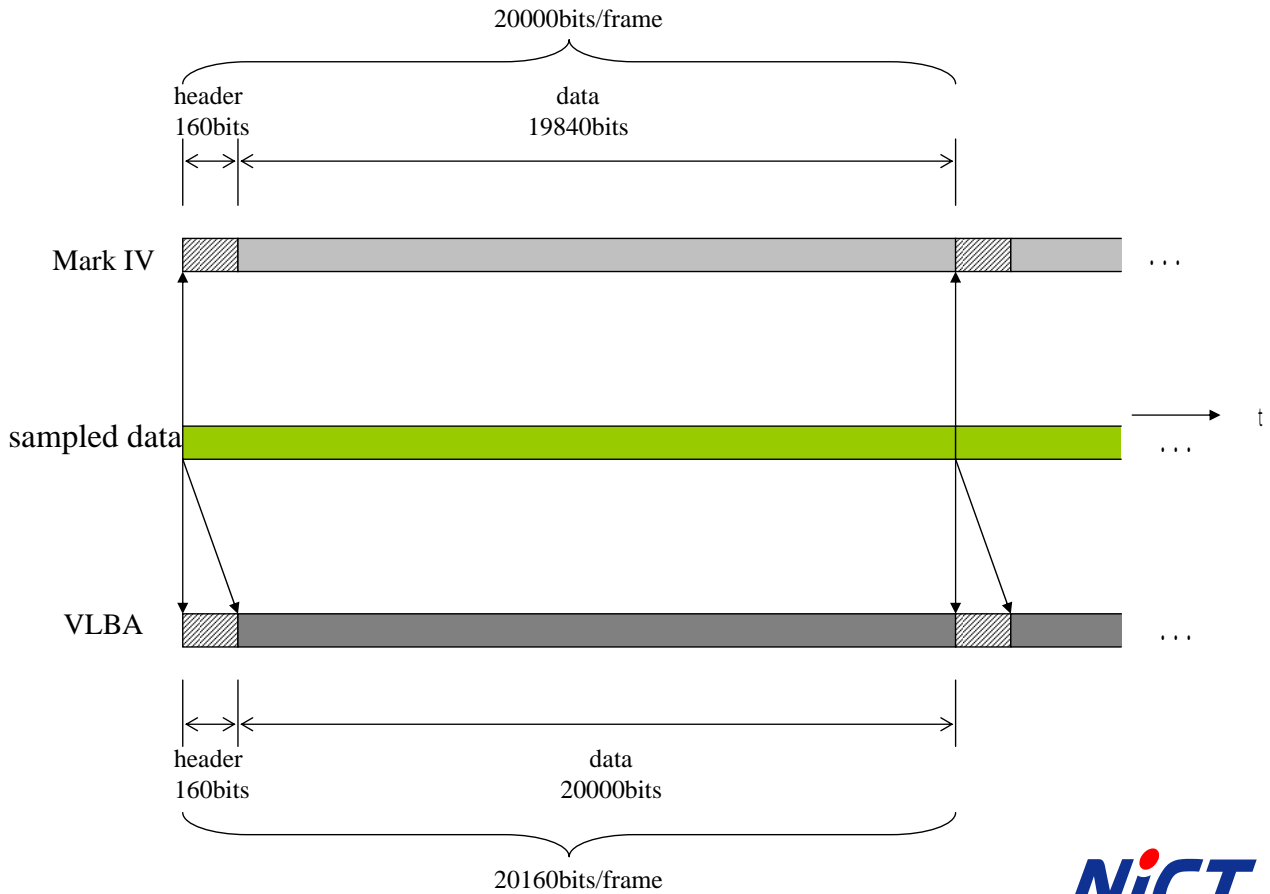
Mark IV Header block format

20000bits/frame

header 160bits — data 19840bits

Mark IV

sampled data

VLBA

header 160bits — data 20000bits

20160bits/frame

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block#																					2	
word#	1				2				3				4				5				1	5
byte#	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4		
bit# 1–8	Auxiliary Data (16 hexa)				Sync word (all "1")								Y / 100D	10D / D	10H / H	10M / M	10S / S	0.1S / 0.01S	0.001S / CRC-12 code		Sampled data (20byte)	
P	odd parity				even ("0")				odd parity												odd	

Auxiliary field — Sync word — Time field

Header block — Data block

FRAME BORDER

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VLBA Header block format

block#	1																				2		
word#	1				2				3				4				5				1	5	
byte#	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4			
bit# 1–8	Auxiliary Data (16 hexa)								Sync word (all "1")				100MJD / 10MJD, MJD / 10000S, 1000S / 100S, 10S / S, 0.1S / 0.01S, 0.001S / 0.0001S				CRC -16 code				Sampled data (20byte)		
P	odd parity								even ("0")				odd parity								odd		

Auxiliary field — Sync word — Time field

Header block — Data block

FRAME BORDER

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K5/VSSP Data File Format
(in case of 4ch data)

word#	1				2				3				4				
byte#	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	
bit# 1	Sync word (all "1")				time of day (sec)(17bit)		ch / sample freq / ADbits	sync byte ("8Bh")	ch1	ch1	ch1	ch1	ch1	ch1	ch1	ch1	
2									ch2	ch2	ch2	ch2	ch2	ch2	ch2	ch2	
3									ch3	ch3	ch3	ch3	ch3	ch3	ch3	ch3	
4									ch4	ch4	ch4	ch4	ch4	ch4	ch4	ch4	
5									ch1	ch1	ch1	ch1	ch1	ch1	ch1	ch1	
6									ch2	ch2	ch2	ch2	ch2	ch2	ch2	ch2	
7									ch3	ch3	ch3	ch3	ch3	ch3	ch3	ch3	
8									ch4	ch4	ch4	ch4	ch4	ch4	ch4	ch4	

header data   sampled data

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K5/VSSP Data File Format

(in case of 1ch data)

word#	1				2				3				4			
byte#	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
bit# 1									ch1	ch1	ch1	ch1	ch1	ch1	ch1	ch1
2							ch		ch1	ch1	ch1	ch1	ch1	ch1	ch1	ch1
3									ch1	ch1	ch1	ch1	ch1	ch1	ch1	ch1
4		Sync word (all "1")			time of day (sec)(17bit)		sample freq	sync byte ("8Bh")	ch1	ch1	ch1	ch1	ch1	ch1	ch1	ch1
5									ch1	ch1	ch1	ch1	ch1	ch1	ch1	ch1
6									ch1	ch1	ch1	ch1	ch1	ch1	ch1	ch1
7							ADbits		ch1	ch1	ch1	ch1	ch1	ch1	ch1	ch1
8									ch1	ch1	ch1	ch1	ch1	ch1	ch1	ch1

header data   sampled data

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K5   Mark5 Fringes

Oct. 15, 2002

Kashima - Westford

X band

COARSE SEARCH FUNCTION (64×128)

KASHIM34 – WESTFORD
Source : 4C39.25
PRT : 2002Y288D 18:06:30
VBW(MHz) : 2.00

Ref Freq(MHz) = 8210.99
Integration (sec) =100.0
Peak Position (32, 67)
Amplitude =7.091e−004
$\Delta\tau$ (μsec) = −0.0113
Δf_r (Hz) = 0.0224
$\Delta\dot\tau$ (s/s) = 2.725e−012

S band

COARSE SEARCH FUNCTION (256×128)

KASHIM34 – WESTFORD
Source : 4C39.25
PRT : 2002Y288D 18:06:30
VBW(MHz) : 2.00

Ref Freq(MHz) = 2237.99
Integration (sec) =100.0
Peak Position (128, 54)
Amplitude =2.451e−003
$\Delta\tau$ (μsec) = −0.0299
Δf_r (Hz) = 0.0022
$\Delta\dot\tau$ (s/s) = 9.880e−013

4C39.25

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Distributed processing

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VLBI@home

Distributed Correlation Processing

huge VLBI data
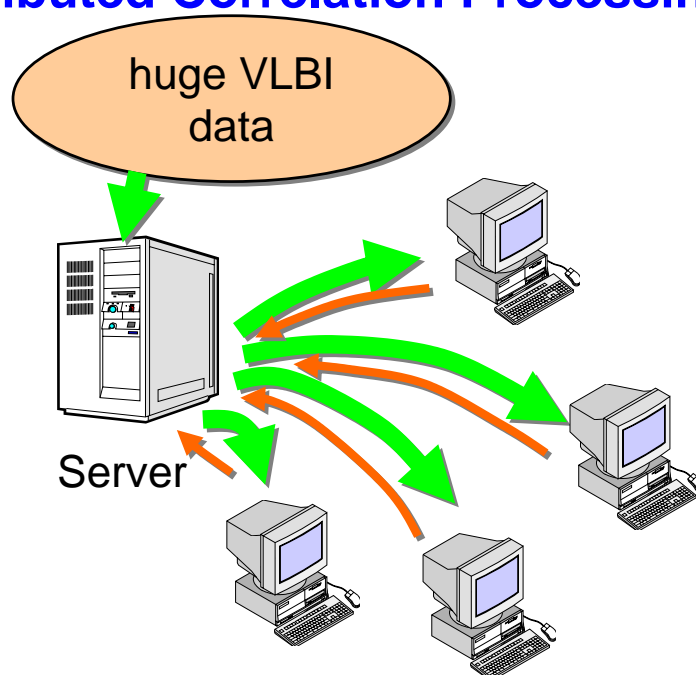
Server

developed by
Takeuchi-san

GSI has developed similar distributed system **NiCT**

Improvement Factor α

$$\alpha = \frac{\text{Total Processing Speed using N PCs}}{\text{Total Processing Speed using one PC}}$$

- Assumptions
  - Data are transferred from a server
  - Data transfer does not affect the speed of correlation processing
  - Correlation processing is possible with a data transfer for a different scan
  - Speed of data transfer reduces to 1/N in case of N parallel data transfers

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Improvement Factor α

$$\alpha = \frac{\text{Total Processing Speed using N PCs}}{\text{Total Processing Speed using one PC}}$$

10 scans

CT
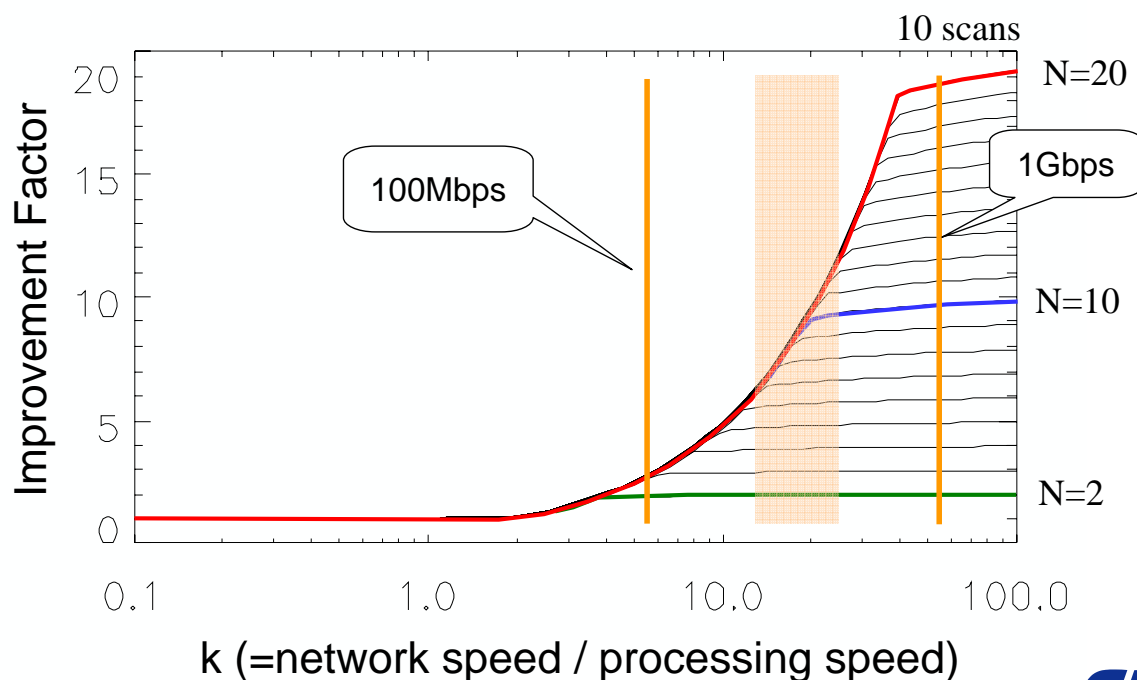
Total Processing Speed in case of the use of N PCs

Network Speed >> Processing Speed

1   2   3   4   . . .   N

N times faster
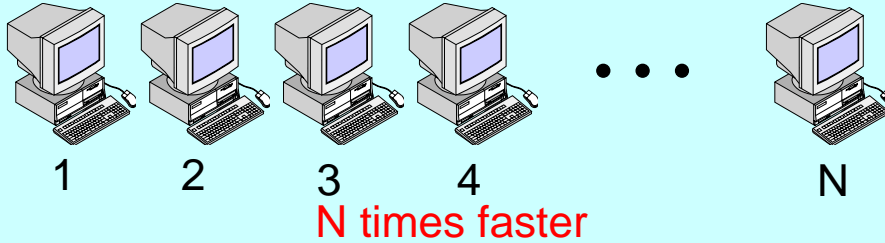
Network Speed ~ Processing Speed
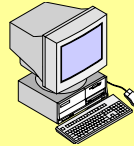
same as one PC

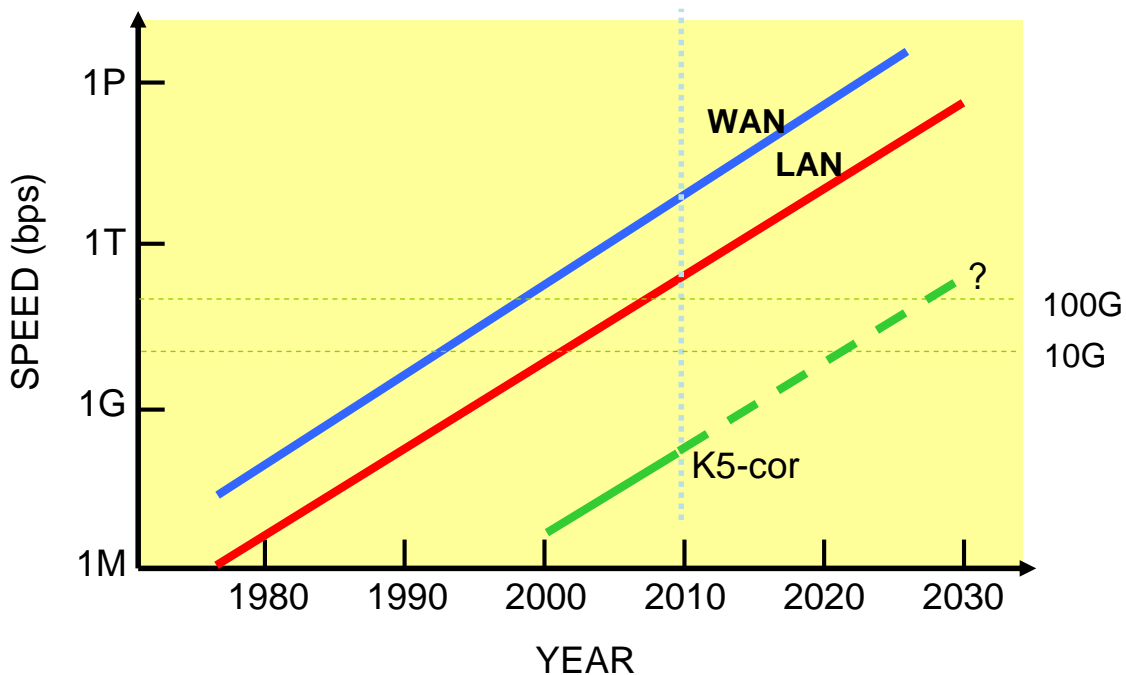# Current Status of XF Software Correlator

- Correlation processing speed of K5-cor
  - **17Mbps** for 32-lag complex correlation
  - 34Mbps for 16-lag* complex correlation
- Network speed for distributed processing
  - 100Mbps ~ 1Gbps (at office), **10Gbps** (available)
- Total processing speed of distributed processing can be
  - ~**170Mbps** (32-lag, use of 10 PCs)
  - ~**340Mbps** (32-lag, use of 20 PCs)   } more realistic
  - ~**1.7Gbps** (32-lag, use of 100 PCs)
  - ~**3.4Gbps** (32-lag, use of 200 PCs)

* 16-lag is good enough for geodetic VLBI

Road Map of Network Speed and K5-cor Processing Speed

WAN & LAN from
http://www8.cao.go.jp/cstp/project/super/haihu02/siryo3-sanko.pdf **NiCT**

Expectation at 2010

- Correlation processing speed of K5-cor
  - ~100Mbps for 32-lag complex correlation
- Network speed for distributed processing
  - ~100Gbps
- Total processing speed of distributed processing
  - ~ **1Gbps** (32-lag, use of 10 PCs) ⎤
  - ~ **2Gbps** (32-lag, use of 20 PCs) ⎦ more realistic
  - ~ **10Gbps** (32-lag, use of 100 PCs)
  - ~ **20Gbps** (32-lag, use of 200 PCs)

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Conclusions

- Processing speed of software correlator (K5-cor : XF type) for geodetic use is **17Mbps** for 32-lag complex correlation

- **170Mbps~340Mbps** for distributed processing with 10~20 PCs will be available soon

- About **10~20Gbps** for distributed processing with 100~200 PCs will be expected by **2010,** if we don't care about "costs" and "save-energy".

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