Subj: Usuda Time Correction File Tests: Phase detection delays

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Summary

This document describes two sets of measurements of the internal delays in the phase detector system in the Usuda tracking station. The purpose of these tests was to measure the Usuda residual phase detector delay. The phase detector delay measurement is a component of the *time tag* correction that must be applied to correct for the delay of the downlink signal from the tracking station reference until time when the downlink phase residuals are measured.

The first set of tests were performed by Kenta Fujisawa and myself on 98 November 17. After discussions with Nori Kawaguchi, a new set of tests was planned. The second set were performed by Yasuhiro Murata and Kazumasa Suzuki on 99 February 10.

The first tests showed that the phase detector functioned in the manner intended and the internal (or averaging time) delay in the phase detector is very low, less than 0.001 seconds. The tests also showed that there is *no* 1 second time tag error in the phase residual data. This is inconsistent with assumptions made in earlier versions of the Usuda TCF program. The second set of tests measured the internal delay of the Usuda phase detector to be approximately $22 \pm 7\mu$ sec. The TCF values are weakly dependent on the phase detector delay. The phase detector value is measured accurately enough to produce very accurate TCF values.

Background

Unknown problems existed in the Usuda TCFs, which resulted in large residual offsets ($\sim \pm 10\mu\ sec$) and rates ($\sim \pm 500 \times 10^{-12}\ sec/sec$) at correlation. Since some experiments using the the Usuda station were successful, I assumed that some station parameters were not accurately measured and different satellite orientation and range configurations were causing the variable correlation results.

I started by studying aspects of the Usuda station which were most different from the Green Bank configuration. The differences I considered were:

A. Long delay between NCO producing the up-link frequency and up-link antenna reference point ($\sim 3\mu sec$).

B. Very short phase detector time constant assumed ($< 1\mu sec$) compared with 2.6 seconds in the Green Bank implementation

C. Relatively large phase residuals measured ($> 20Hz$) at Usuda, indicating errors in the satellite prediction

First, using rough estimates of the satellite orbit properties, the effect of time tag errors on delays and rates were calculated. Assuming a typical satellite velocity of 3 km/sec and a 6.25 hour orbital period, the average range rate is $3/3 \times 10^5 = 10^{-5} sec/sec$, and the average range acceleration is $2 \times 10^{-5}/3.125 * 3600\ sec\ =\sim 2 \times 10^{-9}\ sec^{-1}$.

Time	*Delay*	*Rate*	*Delay*	*Rate*
hhmmss	nano-sec	pico-sec/sec	nano-sec	pico-sec/sec
	(TCF .a)	(TCF .a)	(TCF .c)	(TCF .c)
22h33m34	-7510.4	56.1	-810	-1.6
22h40m22	-7471.1	52.3	-815	-2.0
22h50m29	-7450.4	45.4	-818	-2.0
22h57m17	-7437.3	39.1	-820	-1.9
23h07m56	-7416.6	28.5	-820	-2.0
23h13m40	-7404.5	20.3	-821	-1.9
23h20m20	-7405.0	9.5	-822	-2.2
23h30m28	-7400.1	-9.2	-825	-2.2
23h44m04	-7416.0	-42.1	-829	-2.1
23h50m44	-7439.0	-62.0	-828	-2.6
00h04m20	-7525.0	-123.4	-830	-3.5
00h17m48	-7653.5	-200.9	-835	-9.7
00h31m16	-7852.2	-275.4	-849	-11.2

Table 1: Table of residual delays and delay rates for Usuda tracking pass on 98 July 26., after application of the Usuda TCF 9807262221.kcu.a and after application of my TCF 9807262221.kcu.c

It was suggested by Dave Del Rizzo at Penticton that I try producing a TCF for the 98 July 26 Usuda tracking pass, because strong fringes were detected; but large residual delay offsets and delays were found at the correlator. The magnitude of these errors (see Table 1) indicitated the type of problem which must be generating them. Table 1 also shows the correlation results after application of a new TCF created by correcting the satellite orbit prediction after the tracking pass.

Based on the order of magnitude calculations, a 7.4×10^{-6} time error requires a station time error of $7.4 \times 10^{-6}/10^{-5} = .74\ sec$. Also based on order of magnitude calculations, to get a $4 \times 10^{-11}\ sec/sec$ range rate error requires a $4 \times 10^{-11} sec/sec\ /\ 2 \times 10^{-9} sec^{-1} \sim 0.02\ sec$ time tag error. I considered these values close enough to be able to explain the observed problems, and started to look for effects causing additional delays of a few milliseconds.

The large time tag offset required to explain the observed rates ruled out the $2.5\mu sec$ delay due to the fiber optic link (option A above) between the NCO and antenna as a cause of the excess delays and rates found at the correlators.

Tests

We performed a test at Usuda similar to one that was performed in Green Bank. The test is relatively straight forward and allows use of the station hardware to measure the internal phase processing delay in the system.

During the first tests on 98 November 17 (The evening of the Leonid meteor shower) Kenta Fujisawa modified the Usuda station hardware by disconnecting the up-link 15.3 GHz output to the fiber optic modem and connecting it to the ISAS HALCA satellite simulator. The Simulator was configured to transpond the normal 128 MBits/sec downlink data stream with a clock locked to the up-link signal generated by the Usuda station. The 14.3 GHz simulator downlink was routed through some attenuators and input into the station input normally connected to the output of the downlink fiber optic modem. The delay through the extra cabling and the simulator was not measured but was probably less than 100 nano-sec. This test did not use the Usuda fiber optic link or any equipment at the 10m antenna site.

The test is achieved by creation of a special satellite prediction. A one minute interval of the prediction is shown in Figure 1. The up-link prediction frequency offset oscillated between ± 10.77 Hz every 32 seconds. The Usuda up-link and downlink prediction file is in ASCII and contains a file header describing the satellite prediction and a table of entries. The table contains one entry for each second of the Usuda tracking pass. The table contains a date and time tag up-link range (km), downlink range (km), up-link range rate (km/sec), downlink range rate (km/sec), up-link IF frequency (Hz) and downlink IF frequency (Hz). There is a simple relationship between the range rate and IF frequency columns. At zero satellite velocity, a 15.3 GHz tone is transmitted by the station if the IF frequency is 65 MHz. If exactly a 14.2 GHz downlink frequency is expected, the downlink IF frequency is 65 MHz.

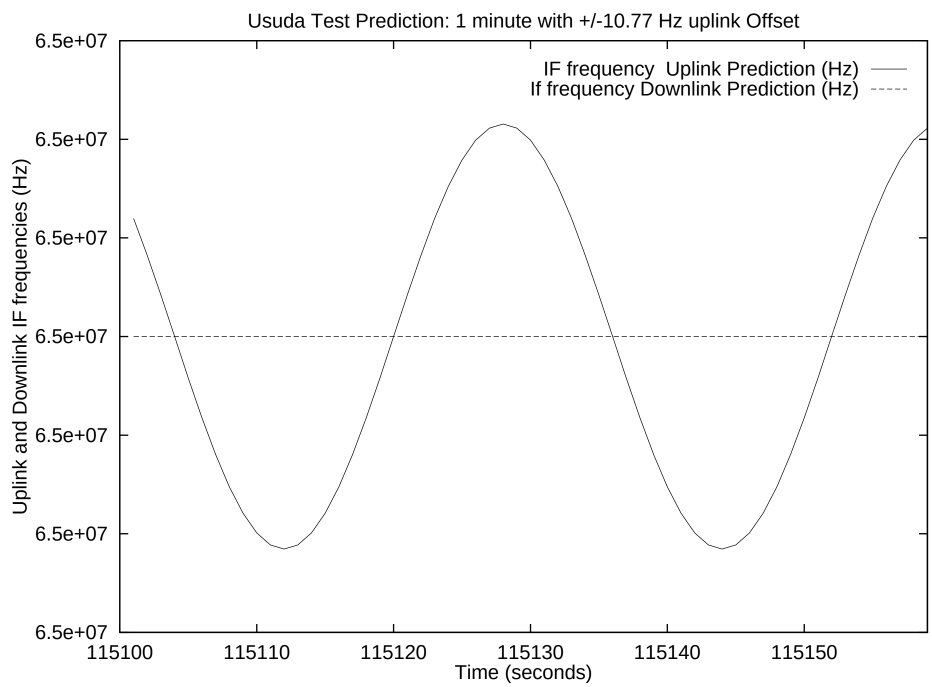


Figure 1: One minute section of Usuda Test prediction

In all tests, the station software was run in the usual manner and the phase residuals were collected at the 10 Hz rate. A number of Usuda tests were made, but one proved most useful. This Usuda test lasted 15 minutes and from the phase residuals collected, a Usuda TCF was generated. The frequency residual crossed from positive to negative or negative to positive 24 times during the test.

After the test, I wrote a special program to fit 1.7 seconds of data on either side of the frequency residual zero crossing point. This allowed the delay in the zero crossing time to be measured every 32 seconds. A total of 24 measurements were made and yielded an average value of 0.0003 seconds.

As a check of the internal consistency of the data, I divided the data into two halves. The first have had average delay of 0.0002 seconds and the second half had average delay of 0.0004 seconds.

Assuming the difference in these two values to be approximately equal to the noise in the time offset measurement, a reasonable delay estimate is 0.0003 ± 0.0002 seconds. The offsets values for the tests are shown in figure 2.

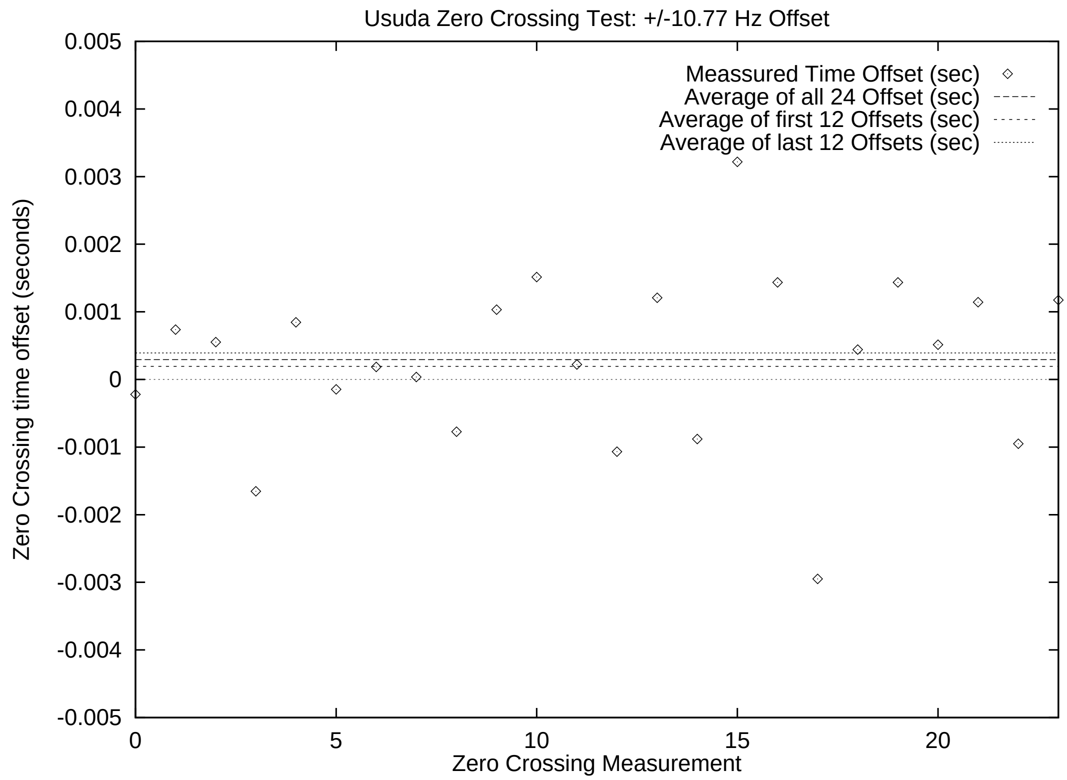


Figure 2: Delay offset measurements based on phase residual data. Note that large scatter is due to coarse phase residual sampling (every .1 seconds).

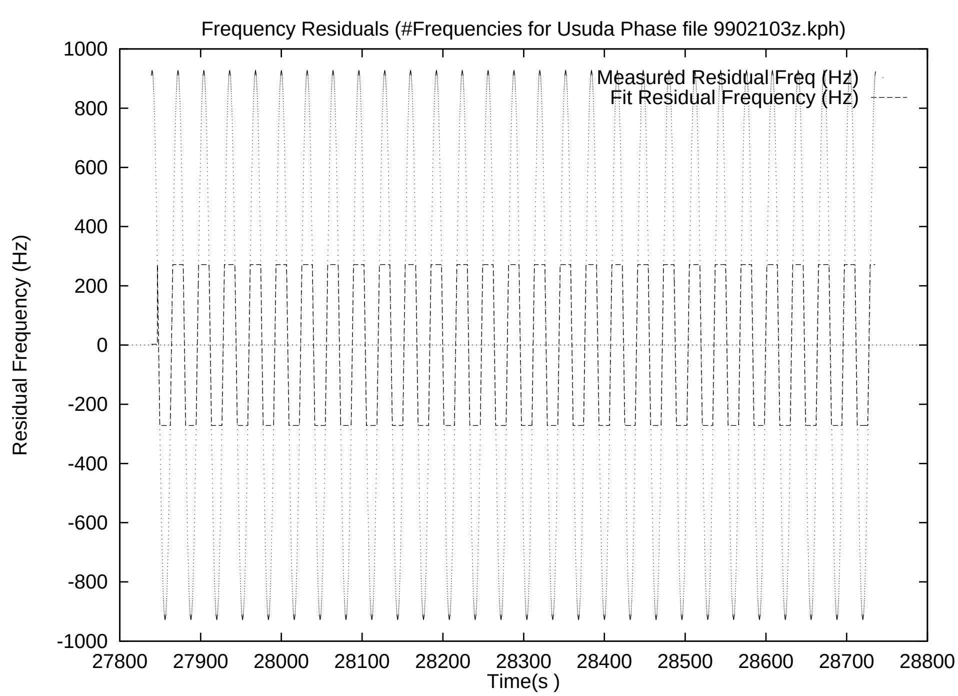


Figure 3: 99 February 10 residual frequency measurements (dots) and linear fit to data at the times the frequency offset changes sign.

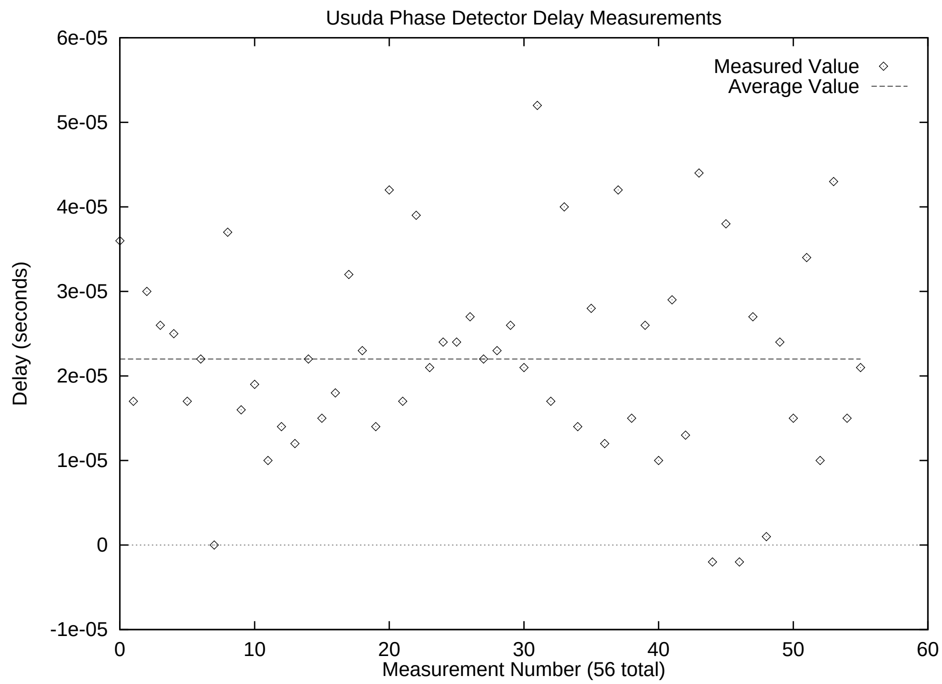


Figure 4: Delay offsets measured for 99 February 10 tests. The data show 56 fits to the time of frequency residual changing from negative to positive, relative to predicted time. On average the time of zero frequency was delayed 22 μ seconds compared to the predicted time.

After the tests, Kawaguchi-san suggested that using larger frequency variations would allow more accurate measurement of the phase detector delays. On 99 February 10, Murata-san and Suzuki-san ran a longer zero crossing test, with a greater frequency offset. The hardware configuration was the same as during the earlier test. The frequency offset changed sign 56 times during the tests. The average offset for the first 23 tests was 22μ seconds and for the second 23 tests was 23μ seconds. The measurement accuracy is significantly improved over the first tests.

Conclusions

The internal delay in the Usuda station for measurement of the phase residuals was shown to be small, approximately $22 \pm 7\mu$ sec.

The phase detector delay is measured accurately enough to be certain that it is *not* the cause of the high residual delays and rates found at the correlators. Excess hardware delays in the station NCO-s, IF electronics and phase detectors could not explain the large residual delays and rates observed at the correlators. Future tests could improve the hardware delay measurement by increasing the averaging time and also increasing the variation in the up-link frequency. There was no one-second error in the Usuda phase residual time tag.

Appendix A

Numerous tests of the Usuda station were made by the NEC Contractors during the development phase. Most of these documents are in Japanese. I found one short document particularly useful and it is included as Appendix A. The contents are summarized below.

The document title has two lines. The first line is approximately "Muses-B Ku band facilities station delay". The second is "Muses-B Ku band facilities block diagrams". The memo starts with a one page summary of 4 separate tests which were performed to measure the total internal delay in transmitting data from the 10m antenna to the VLBA tape recorder. The test was concerned only with the total *data path* delay through the tracking station and did *not* measure the phase detector delay, which was the subject of my tests.

This delay is the sum of 4 components:

A: (2.4399 μ *sec*) Link from tracking antenna to QPSK demodulator, via fiber optic cables. One way delay was estimated to be half the total round trip delay measured in their tests.

B: (0.162 μ *sec*) Delay internal to QPSK demodulator. Assumed to be half the total delay in both QPSK modulator and demodulator pair.

C: (0.4329 μ *sec*) Digital Delay in telemetry frame synchronizer. Two digital devices were used in the test: *1)* The frame synchronizer delays the data by 37 bits and *2)* the PCM generator delays the data by 33 bits. The delay in the frame synchronizer is 58 % of the total delay 0.736 μ *sec*.

D: (0.230 μ *sec*) Delay in hardware buffer to the VLBA data recorders

The total delay from the 10m antenna to the VLBA tape recorder was 3.2648 μ *sec*.

The next page of memo contains a sketch of the entire set of tests. The delay between the 10m az-el reference point and the fiber optic modem was not described in this memo. The remainder of the document contains figures describing the individual tests.

Note that of the 4 components described above, only component B is included in my phase detector tests. The 4 components above all directly are added (subtracted) to the TCF values. In contrast, the phase detector delay effects the TCF values only indirectly, by changing *which* residual phase value is included in the TCF table. Since the residual link frequency changes slowly with time, the phase detector delay does not strongly effect the TCF data.

MUSES-B Ku帯設備 局内群遅延時間

MUSES-B Ku帯設備局内 DELAY 系統図 1 より
(BLOCK DIAGRAMS)

A ポイント (U/C 〜 D/C RF 折り返し)

B ポイント (QPSK MODEM)

C ポイント (PCM 復調装置)
※ GEN部とフレーム同期部のDELAY比
1 : 1.7

D ポイント (PCM フレーム同期部 〜 VLBAインターフェース盤)

☆ 受信系 DELAY

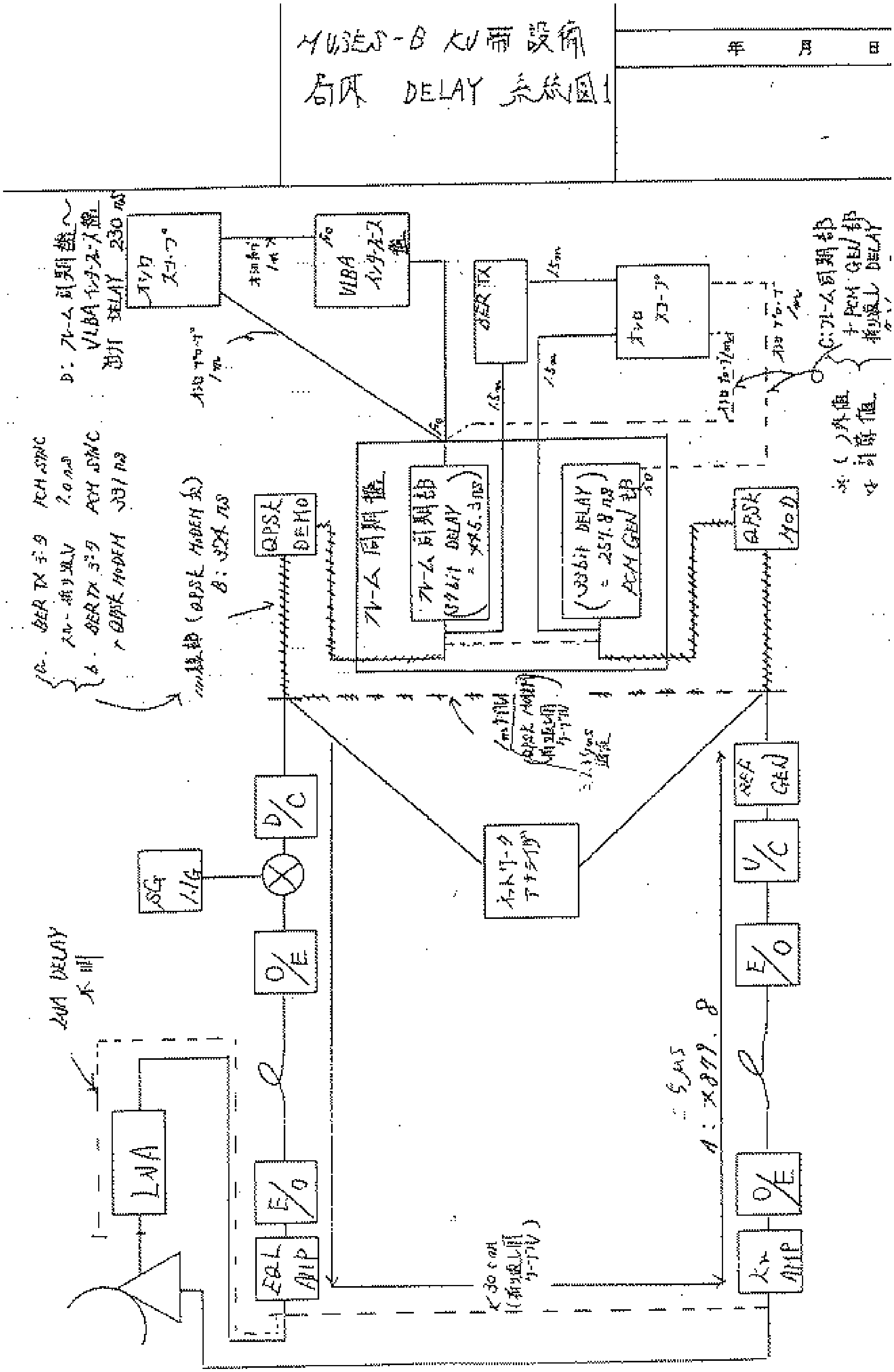
A : $\frac{4879.87}{2}$ = 2439.9 ns (a)

B : $\frac{324\ \text{ns}}{2}$ = 162 ns (b)

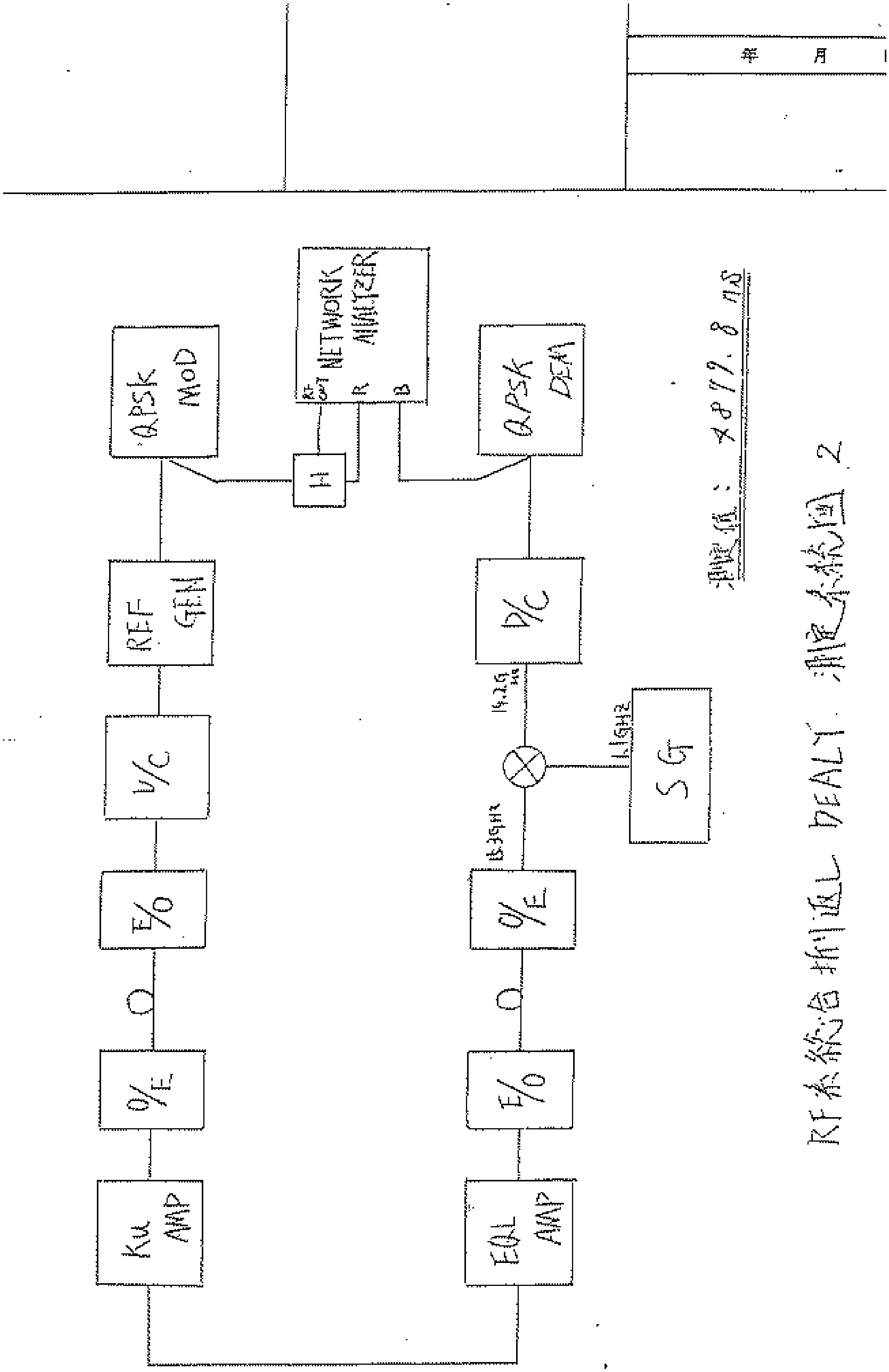
C : $\frac{736\ \text{ns}}{1.7}$ = 432.9 ns (c)

D : 230 ns (d)

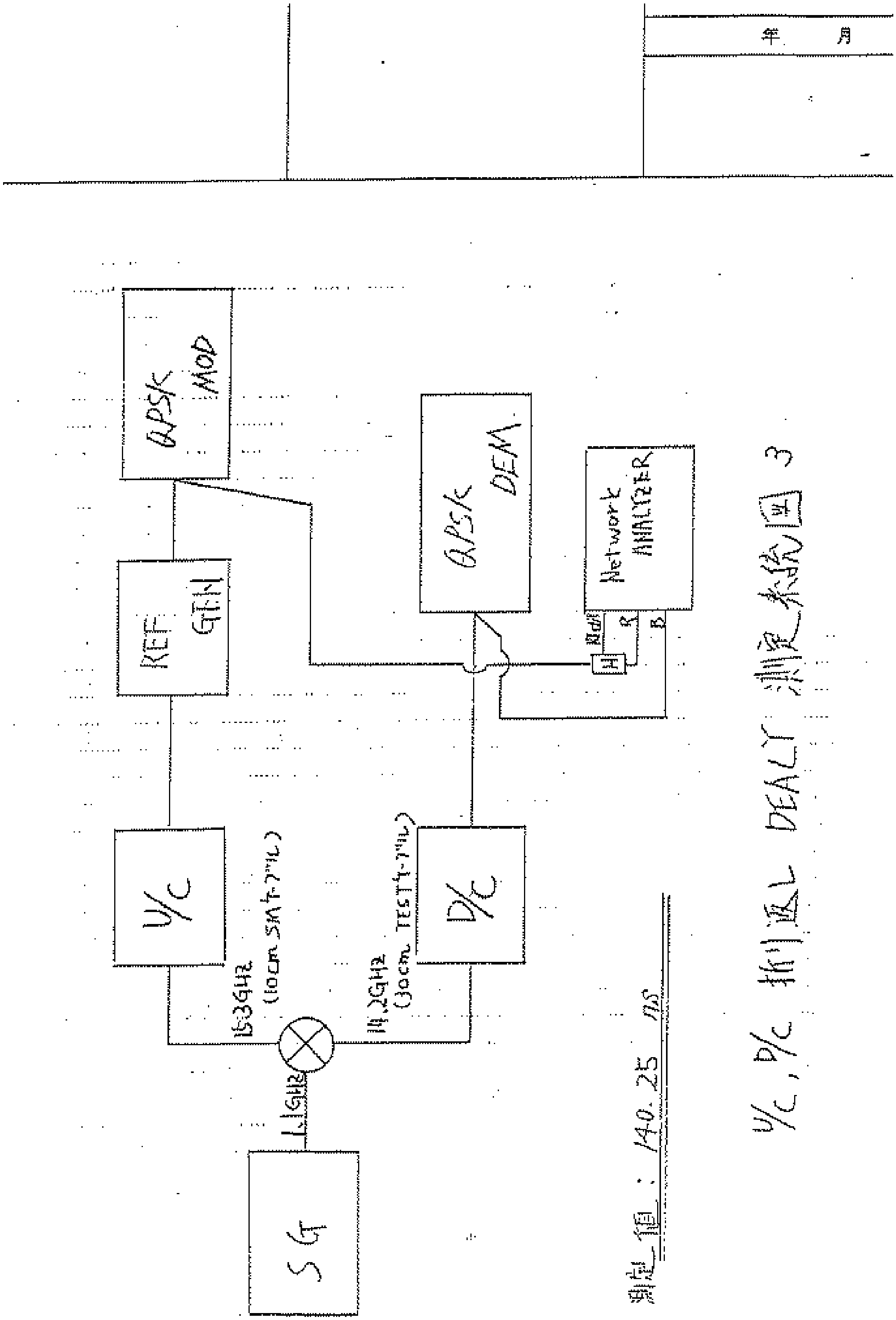
※ 受信系 DELAY
(a) + (b) + (c) + (d)
= 2439.9 ns + 162 ns + 432.9 ns + 230 ns
= 3264.8 ns



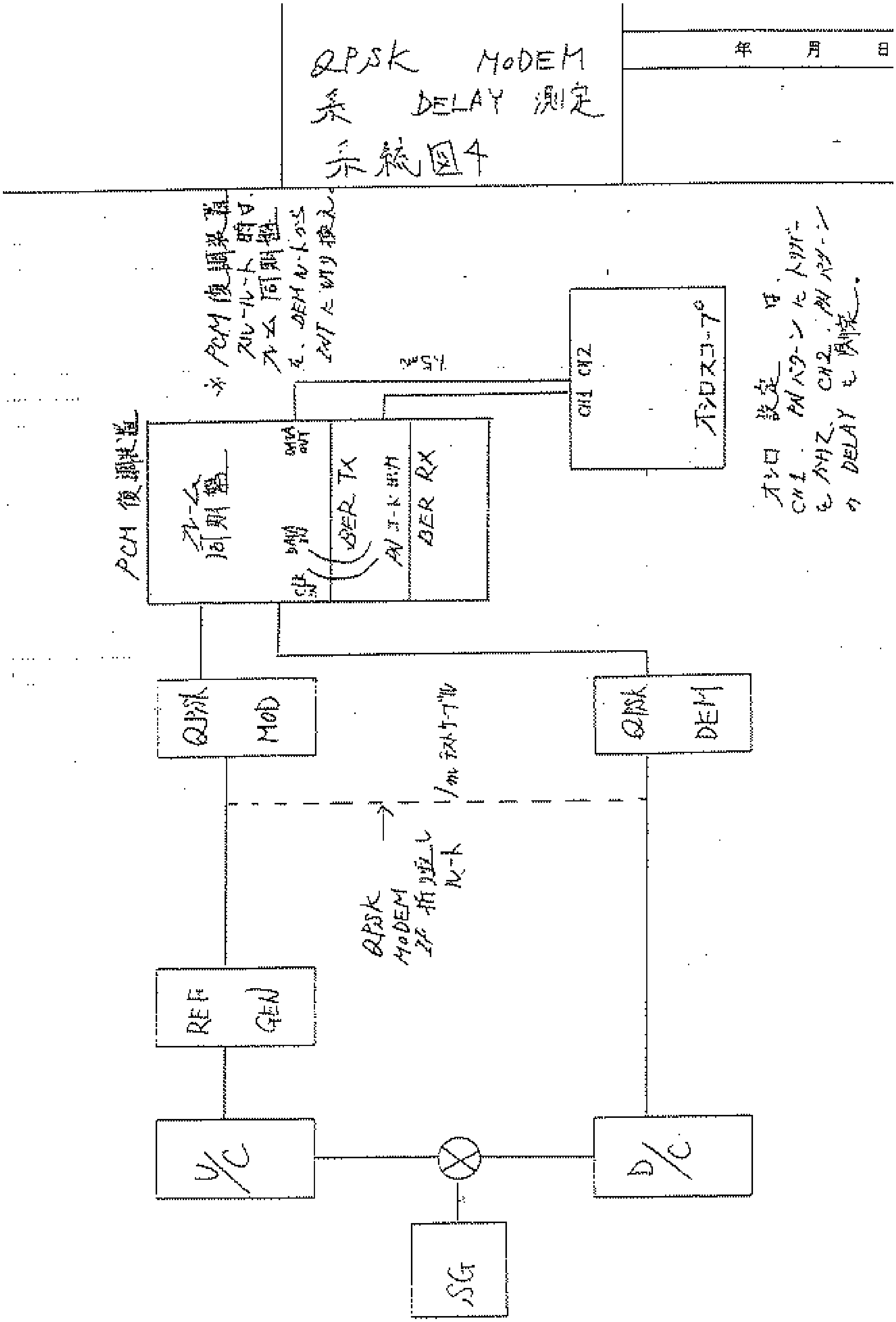
Muses-B Ku Band Facilities Station Delay Measurements 2/7.



Muses-B Ku Band Facilities Station Delay Measurements 3/7.

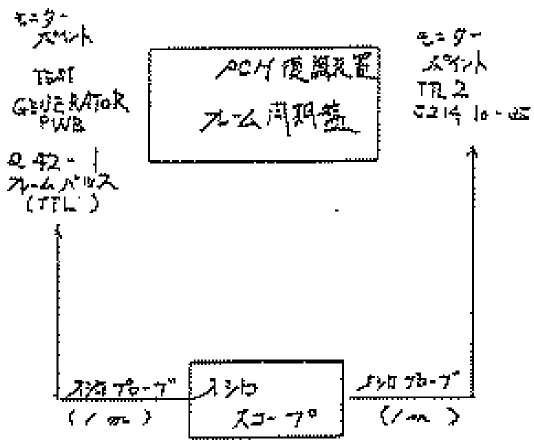


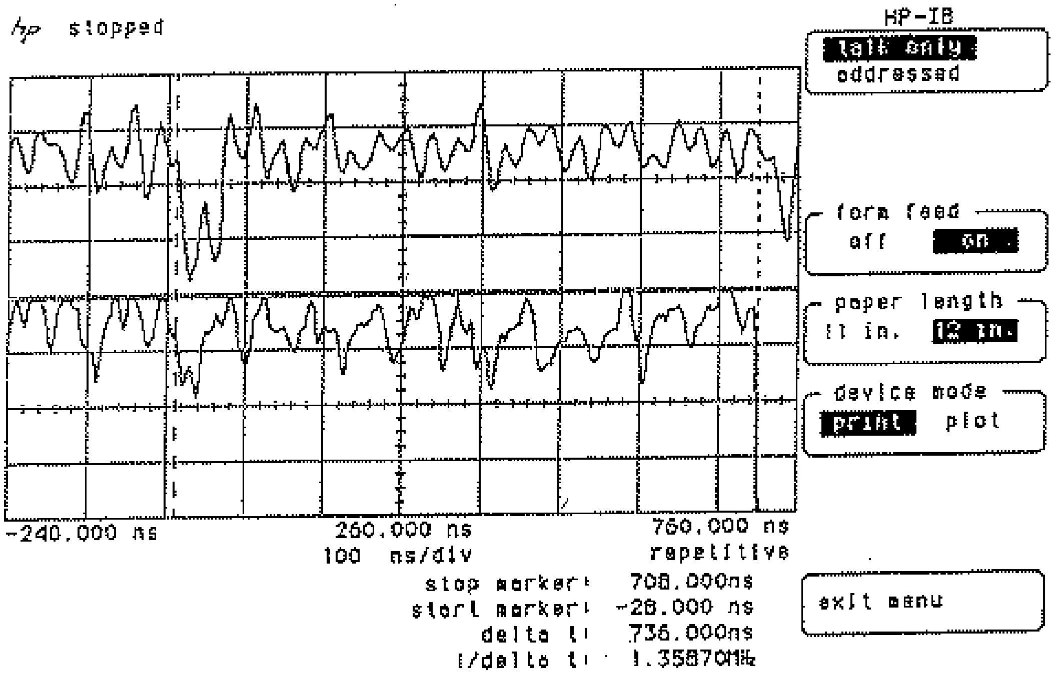
Muses-B Ku Band Facilities Station Delay Measurements 4/7.



Muses-B Ku Band Facilities Station Delay Measurements 5/7.

PCM復調装置 内 折り返し DELAY





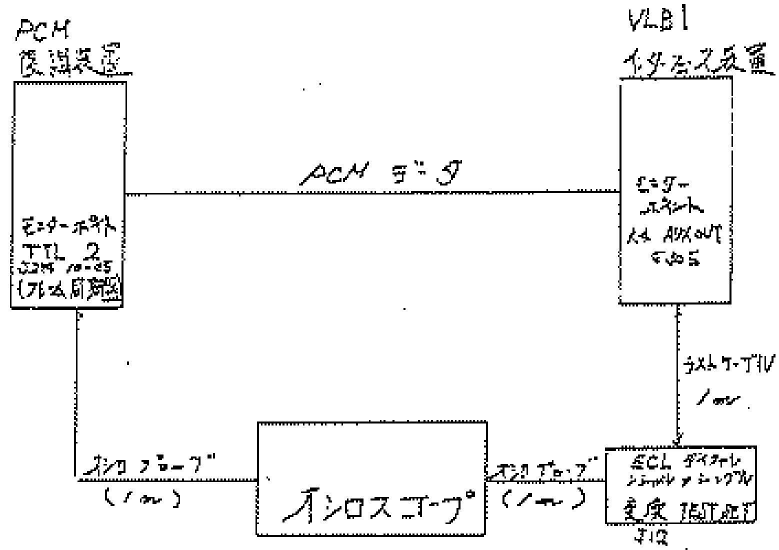
	Sensitivity	Offset	Probe	Coupling	Impedance
Channel 1	3.00 V/div	2.50000 V	10:1	dc	1M ohm
Channel 2	3.00 V/div	2.50000 V	10:1	dc	1M ohm

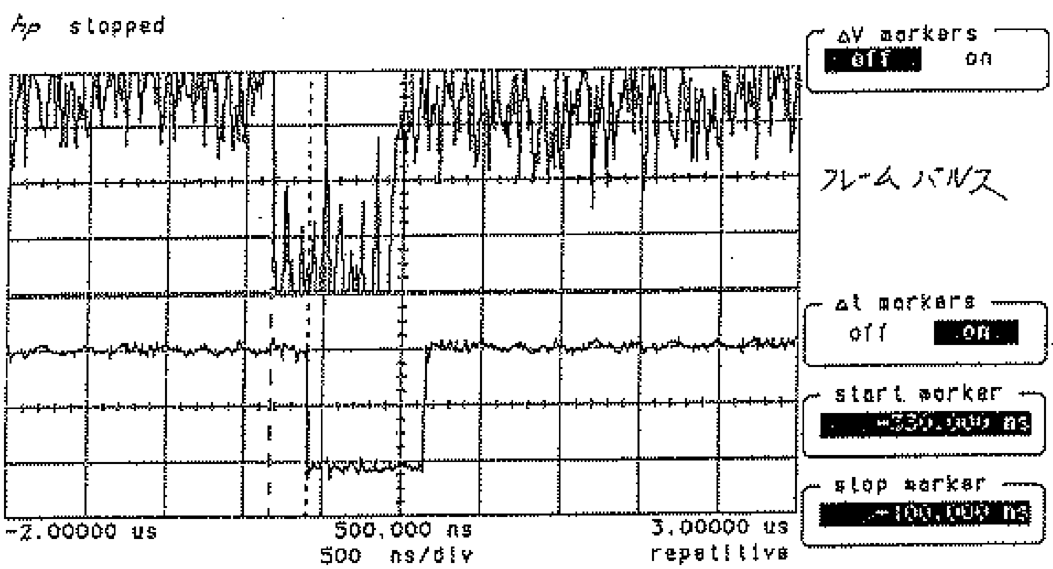
Trigger Mode: Edge
On the Positive Edge of Channel1
Trigger Level(s)
Channel1 = -1.12500 V (noise reject OFF)
HoldOff = 652 Edge(s)

Muses-B Ku Band Facilities' Station Delay Measurements 6/7.

PCM 復調装置～VLBIインターフェース盤

までの DELAY





stop marker: -100.000ns
start marker: -330.000ns
delta t: 230.000ns
1/delta t: 4.34783MHz

	Sensitivity	Offset	Probe	Coupling	Impedance
Channel 1	2.00 V/div	2.50000 V	10:1	dc	1M ohm
Channel 2	400 mV/div	-1.30000 V	10:1	dc	1M ohm

Trigger Mode: Edge
On the Positive Edge of Channel1
Trigger Level(s)
Channel1 = 1.40000 V (noise reject ON)
HoldOff = 652 Edge(s)

Muses-B Ku Band Facilities Station Delay Measurements 7/7.