NBSIR 73-332

DELAY LINE MEASUREMENTS

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Electromagnetics Division
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Boulder, Colorado 80302

August 3, 1973

Prepared for
Jet Propulsion Laboratory
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U.S. DEPARTMENT OF COMMERCE, **Frederick B. Dent, Secretary**
NATIONAL BUREAU OF STANDARDS, **Richard W. Roberts, Director**

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DELAY LINE MEASUREMENTS

This report describes the techniques and results of time delay measurements made by NBS on delay lines for JPL.

Methods of measurement include frequency variational, pulse delay, and RF impedance bridge techniques.

Key words: Bandwidth; dispersion; group delay; phase shift; pulse burst, time delay.

1. Background

A problem in calibrating a ranging system for the Mariner project generated several discussions between the staffs of JPL and NBS. A project was formed wherein NBS was to measure the group delay characteristics of three lengths of delay line cable at 500 kHz, 2.113 GHz, 2.295 GHz, and 8.415 GHz. The cables were supplied by JPL and had nominal delay times of 15, 30, and 60 nanoseconds. The proposed maximum measurement uncertainties were ± 1.5 percent.

2. Summary of Measurement Techniques

The evaluation of time delay at 500 kHz was done by calculating the time delay characteristics from bridge measurements of open and short circuit impedances of the lines.

At each of the higher frequencies (2.113 GHz, 2.295 GHz, and 8.415 GHz), two independent measurement techniques were used. One was a "frequency variational" technique using phase measurements; the other was a "pulse delay" technique, which was a time domain determination using particular waveforms and sampling oscillography.

A brief description of all three of these measurement techniques and the associated errors follows.

3. Bridge Technique

This measurement technique utilizes the relationship of the complex propagation constant to the ratio of the short and open circuit impedances of the line. This relationship can be calculated from the Telegraphers Equations, and is given by:

$$\tanh \gamma \ell = \sqrt{Z_s Y_o}, \tag{1}$$

where: γ is the complex propagation constant

ℓ is the line length

Z_s is the short circuit input impedance

Y_o is the open circuit input admittance.

The time delay was computed by dividing $\beta\ell$ (where $\beta\ell$ is the imaginary part of γ) by the angular frequency.

The uncertainty statement includes systematic error limits derived from the impedance and admittance measurements and a random error component based on three times the estimated standard deviation of the impedance and admittance determinations.

4. Frequency Variational Technique

The expression for group delay time, τ_{gd}, is:

$$\tau_{gd} = \frac{1}{360} \frac{d\phi}{df}$$

and can be calculated, approximately, using finite differences from:

$$\tau_{gd} \cong \frac{1}{360} \frac{\Delta\phi}{\Delta f}. \qquad (2)$$

The frequency variational technique involves a phase shift ($\Delta\phi$) measurement with a simultaneous frequency shift (Δf) measurement.

The group delay time for each delay line was determined from the difference between a measurement with the delay line in the system and a system reference measurement.

The uncertainties for this type of measurement are limited almost entirely by the phase shift measurement error, as frequency measurement errors are several orders of magnitude smaller than phase measurement errors. From eq. (2) the error in time delay (ε_d) can be expressed:

$$\varepsilon_d = \frac{1}{360}\left\{\frac{\Delta f \; d(\Delta\phi) - \Delta\phi \; d(\Delta f)}{(\Delta f)^2}\right\}. \qquad (3)$$

The error in a phase shift measurement, $d(\Delta\phi)$, is the arithmetic sum of the mismatch phase error and the phase meter error. For each measurement the system insertion point VSWR was tuned to $\leq$ 1.005 at the measurement frequency and was found to be

$\leq$ 1.007 over the range through which the frequency was varied. In addition, the VSWR of the delay lines was $\leq$ 1.050. The limit of phase error resulting from mismatch [1]* is ± 0.035 degrees. The maximum error from the phase meter reading is ± 0.060 degrees and the resultant maximum phase error is ± 0.095 degrees. Substituting this value into eq. (3), the maximum phase error for a 1 MHz frequency variation (Δf) is ± 0.26 nanoseconds and is ± 0.13 nanoseconds for a 2 MHz frequency variation. It would appear that a large variation of the frequency, such as 100 MHz, would result in a very accurate determination of group delay; however, only a perfectly nondispersive line could be measured in this manner [2].

5. Pulse Delay Technique

The pulse delay technique requires recording the pulse position of an rf pulse burst with respect to a sync trigger with the delay line both in and out of the system.

The pulse is obtained using a diode switch to gate the output from a microwave oscillator. The gating signal is obtained from a countdown circuit using the microwave signal so that the output pulse has an envelope coherent with its microwave oscillations. In addition, the countdown circuit

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*Figures in brackets refer to references.

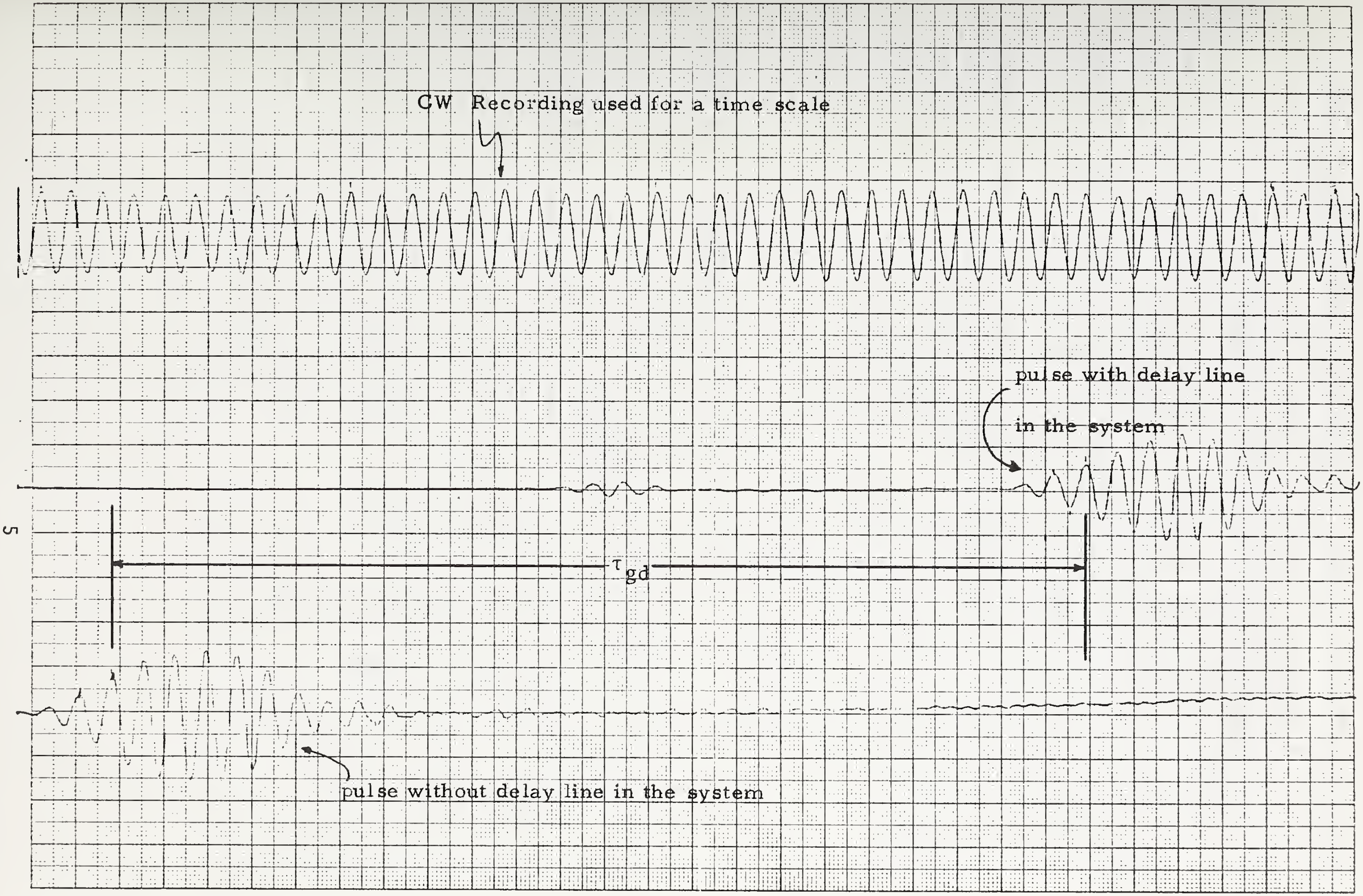

Figure 1. An X-Y Recording Used in a Pulse Delay Measurement

produces the sync trigger to a sampling oscilloscope coupled to an X-Y recorder so that the scope trace and recording are also coherent with the microwave oscillations.

Figure 1 shows a reduction of one of the X-Y recordings used for these measurements. The CW trace (diode switch on) is recorded to obtain a time scale for the most precise measurement of time difference.

The errors in pulse delay result from time scale resolution, pulse distortion, and countdown circuit jitter. The estimated limits are:

time scale resolution	$= \pm\ 0.001\ \tau_{gd}$
pulse distortion	$= \pm\ 0.001\ \tau_{gd}$
countdown circuit	$= \pm$ 0.020 nanoseconds
Total	$= \pm\ [0.020+0.002\ \tau_{gd}]$ nanoseconds.

6. Results

The results from each of the measurements previously described are shown in tables 1, 2, and 3. Because of dispersion, the group delay times are affected by the frequency components contained in the delayed signals; therefore, the approximate bandwidths for each measurement are included with the results.

TABLE 1. Time Delay Measurement Results for the 15 Nanosecond Line.

Frequency	Measurement Technique	Approximate Bandwidth	Delay Time Nanoseconds	Uncertainty Nanoseconds
500 kHz	Bridge	0	15.65	±(0.05+0.01)
2.113 GHz	Freq Variation	1 MHz	14.95	± 0.26
2.113 GHz	Freq Variation	2 MHz	15.09	± 0.13
2.113 GHz	Pulse Delay	400 MHz	14.95	± 0.05
2.295 GHz	Freq Variation	1 MHz	14.97	± 0.26
2.295 GHz	Freq Variation	2 MHz	15.09	± 0.13
2.295 GHz	Pulse Delay	400 MHz	15.04	± 0.05
8.415 GHz	Freq Variation	1 MHz	15.17	± 0.26
8.415 GHz	Freq Variation	2 MHz	15.10	± 0.13
8.415 GHz	Pulse Delay	1.3 GHz	15.03	± 0.05

TABLE 2. Time Delay Measurement Results for the 30 Nanosecond Line.

Frequency	Measurement Technique	Approximate Bandwidth	Delay Time Nanoseconds	Uncertainty Nanoseconds
500 kHz	Bridge	0	31.03	±(0.08+0.02)
2.113 GHz	Freq Variation	1 MHz	29.99	± 0.26
2.113 GHz	Freq Variation	2 MHz	30.03	± 0.13
2.113 GHz	Pulse Delay	400 MHz	30.18	± 0.08
2.295 GHz	Freq Variation	1 MHz	29.91	± 0.26
2.295 GHz	Freq Variation	2 MHz	30.02	± 0.13
2.295 GHz	Pulse Delay	400 MHz	30.21	± 0.08
8.415 GHz	Freq Variation	1 MHz	30.19	± 0.26
8.415 GHz	Freq Variation	2 MHz	30.06	± 0.13
8.415 GHz	Pulse Delay	1.3 GHz	29.90	± 0.13

TABLE 3. Time Delay Measurement Results for the 60 Nanosecond Line.

Frequency	Measurement Technique	Approximate Bandwidth	Delay Time Nanoseconds	Uncertainty Nanoseconds
500 kHz	Bridge	0	61.73	±(0.15+0.02)
2.113 GHz	Freq Variation	1 MHz	59.86	± 0.26
2.113 GHz	Freq Variation	2 MHz	59.94	± 0.13
2.113 GHz	Pulse Delay	400 MHz	60.07	± 0.14
2.295 GHz	Freq Variation	1 MHz	59.92	± 0.26
2.295 GHz	Freq Variation	2 MHz	59.98	± 0.13
2.295 GHz	Pulse Delay	400 MHz	59.82	± 0.14
8.415 GHz	Freq Variation	1 MHz	59.96	± 0.26
8.415 GHz	Freq Variation	2 MHz	60.03	± 0.13
8.415 GHz	Pulse Delay	1.3 GHz	59.91	± 0.27

7. Acknowledgments

The major portion of this measurements project was accomplished through the efforts of the individuals named below.

Raymond Jones -- bridge techniques

Philip Simpson -- pulse techniques.

In addition, background information was provided by Mr. Doyle Ellerbruch and Dr. Robert Beatty.

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[1] G.E. Schafer, Mismatch Errors in Microwave Phase Shift Measurements, IRE Transactions on Microwave Theory and Techniques, November 1960, 617-622.

[2] R.W. Beatty, D.A. Ellerbruch, D.H. Russell, G.E. Schafer, R.S. Turgill, J.P. Wakefield, and T.L. Zapf, Lecture Notes for the Phase Shift Measurements Seminar, unpublished NBS Report, 10-1 to 10-11, June 1967.

FORM NBS-114A (1-71)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET	1. PUBLICATION OR REPORT NO. NBSIR 73-332	2. Gov't Accession No.	3. Recipient's Accession No.

4. TITLE AND SUBTITLE

Delay Line Measurements

5. Publication Date

August 1973

6. Performing Organization Code

7. AUTHOR(S)

Keith C. Roe

8. Performing Organization

9. PERFORMING ORGANIZATION NAME AND ADDRESS

NATIONAL BUREAU OF STANDARDS, Boulder Labs.
DEPARTMENT OF COMMERCE
Boulder, Colorado 80302

10. Project/Task/Work Unit No.

2724630

11. Contract/Grant No.

12. Sponsoring Organization Name and Address

Same as item 9.

13. Type of Report & Period Covered

14. Sponsoring Agency Code

15. SUPPLEMENTARY NOTES

16. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)

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Methods of measurement include frequency variational, pulse delay, and RF impedance bridge techniques.

17. KEY WORDS (Alphabetical order, separated by semicolons) Bandwidth; dispersion; group delay; phase shift; pulse burst; time delay.

18. AVAILABILITY STATEMENT

☐ UNLIMITED.

☒ FOR OFFICIAL DISTRIBUTION. DO NOT RELEASE TO NTIS.

19. SECURITY CLASS (THIS REPORT)

UNCLASSIFIED

20. SECURITY CLASS (THIS PAGE)

UNCLASSIFIED

21. NO. OF PAGES

22. Price

USCOMM-DC 66244-P71

USCOMM - ERL