DELAY LINE LENGTH MEASUREMENT FOR THE X-BAND DLDS

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Abstract

In order to control the driving RF phase at the input of the accelerating structure of X-band linear collider main linacs that is driven by the DLDS, it is necessary to measure the length of the long TE01 mode Delay lines of 40-80m. A new measurement scheme by using the low frequency resonant mode of the delay line was tested. With 70mm diameter, 14m long circular guides, by monitoring the reflected phase of 3GHz resonant mode of this line, the delay line electric length was measured within 0.05 degree of 11.424GHz.

1 INTRODUCTION

DLDS (Delay Line Distribution System)[1] is a high efficiency RF pulse compression equivalent system for main linac of X-band linear collider. DLDS has long circular wave guides as delay lines. The longest delay lines are about 80m in 4/3 DLDS and about 120m in 4/4 DLDS.

In X-band main linac, RF phase deviation must be less than 1 degree to keep energy spread of a single bunch under 0.2%[2]. This limit is determined by the energy acceptance of the final focus system and requirement of physics experiment. In case of 80m long 118mm diameter delay line of 4/3 DLDS, allowable length change of delay line is about 100μm. This limit corresponds to 0.08 degree Celsius of acceptable temperature change if delay lines are made by cupper ($\alpha = 1.6 \times 10^{-5}$). It is very difficult to control temperature of long delay lines within this limit. If delay lines are made from Invar which is low thermal expansion alloy ($\alpha = 10^{-6}$), temperature limit is relaxed to 1 degree Celsius. Considering the size of delay lines and scale of main linac, it is desirable that some measurement of delay line electric length and some phase control system are necessary.

Because X-band RF pulses running through the delay lines are very short pulse (about 250ns), it is difficult to measure phase of X-band RF pulse directly. We developed and tested a new measurement scheme which measure electric length indirectly by using characteristics of delay lines as resonator for lower frequency.

2 MEASUREMENT PRINCIPLE

In single mode 4/3 DLDS design, delay lines have tapered circular guide that are connected TE_{10}-TE_{01} mode converters. And this type of delay lines act as resonant cavities for lower frequency RF than the cut off of these tapered guide. Delay line dimension change effects resonance properties.

By one port resonator theory, for incident wave which frequency is different δf from resonant frequency, reflection coefficient is given as

$$S = \frac{\beta - 1 - 2Q_0 \dfrac{\delta f}{f_0} i}{\beta + 1 + 2Q_0 \dfrac{\delta f}{f_0} i}, \qquad (1)$$

where β is coupling coefficient and Q_0 is unloaded Q value.

Resonant frequency changes caused by thermal expansion can be measured by measuring phase of reflected wave from test port by using (1), and assuming that thermal expansion is uniform, electric length change of delay lines for X-band RF can be calculated resonant frequency change.

Calculation result of correlation between electric length change for X-band RF ($\delta\phi_x$) and phase of reflected wave of fixed frequency from test port for various coupling coefficient is shown in figure 1,2.

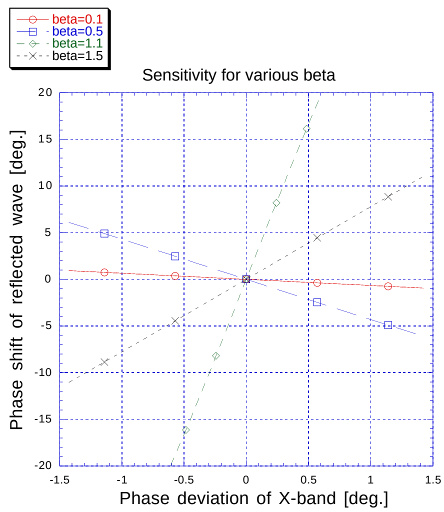

Figure 1: 80m, ϕ118mm, $TE_{11,400}$, Q = 35000)

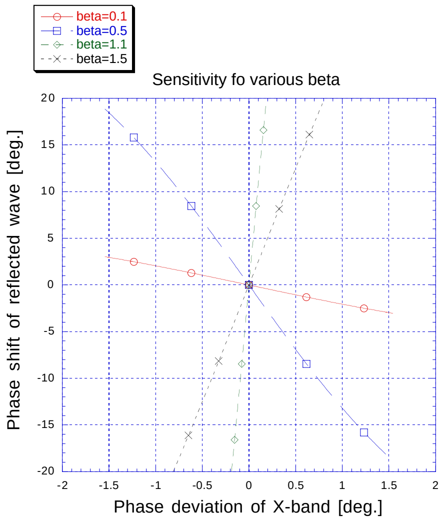

Figure 2: 14m, ϕ70mm, $TE_{11,150}$, Q = 25000

From this result, it is clear that:

- it is possible to determine desirable sensitivity by determine coupling coefficient,
- near critical coupling, measurement might be difficult because power of reflected wave from test port is very small.

For this experiment, we designed and made the test port coupler that have coupling coefficient $\beta = 0.2 \sim 0.5$.

3 TESTS

3.1 *Test setup and procedure*

Schematic diagram of this experiment is illustrated in figure3. To avoid effects of long RF cable, two delay lines were set parallel making round trip way, and were connected by rectangular guide (WRJ-10). For monitoring temperature, thermoelectric pairs were used. Electric length for X-band RF was measured by network analyzer (HP8720), and phase of reflected wave from test port couplers was measured also by network analyzer (HP8753). Control and data taking processed by PC-AT compatible.

Recorded data are

1. Temperature on wave guides (10 point) and air temperature,
2. Average temperature of wave guides,
3. X-band transmission phase (ϕ_x),
4. Phase of reflected wave from test ports (ϕ_1, ϕ_2).

Measurement procedure is described below. First, as preparation of data taking was that:

1. Calibration of network analyzers,
2. searching for resonant points for each guide and setting markers,
3. measurement of Q value and β at resonant points.

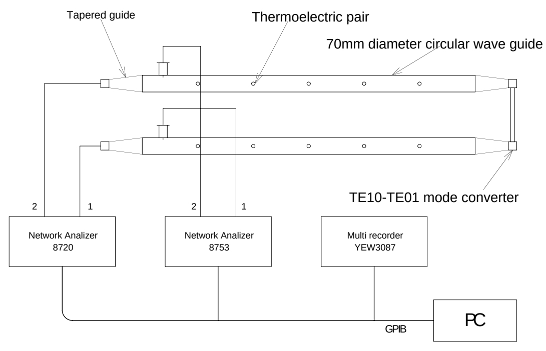

Figure 3: Test setup

And data taking was executed each 30 seconds, such as

1. Reflected phase on markers measurement,
2. X-band transmission phase measurement,
3. Temperature measurement on each point.

3.2 *Results*

$f_1 = 2.962183$ GHz (WG1) and $f_2 = 2.962345$ GHz were chosen as operation frequency. These are near $TE_{11,150}$ resonant mode. Q value and coupling coefficient($beta$) are measured such as

$$Q_0 = 21517, \qquad \beta = 0.315$$

for WG1 and

$$Q_0 = 22869, \qquad \beta = 0.298$$

for WG2.

This experiment was operated for about 2 days. During this measurement, air temperature changed within ± 1 degree very slowly (1 degree per 5 hours maximum). And temperature of waveguides was very close to air temperature.

Correlation between change od electric length for X-band RF ($\Delta\phi_x$) and phase changes of reflected wave from test port ($\Delta\phi_1$, $\Delta\phi_2$) is shown in figure 4. Dots correspond to measurement data, solid and dotted line correspond estimation which is calculated from measured Q value and β.

Thus, this system can measure electric length change for X-band RF within 0.05 degree when 0.25 degree phase change of reflected wave can be measured.

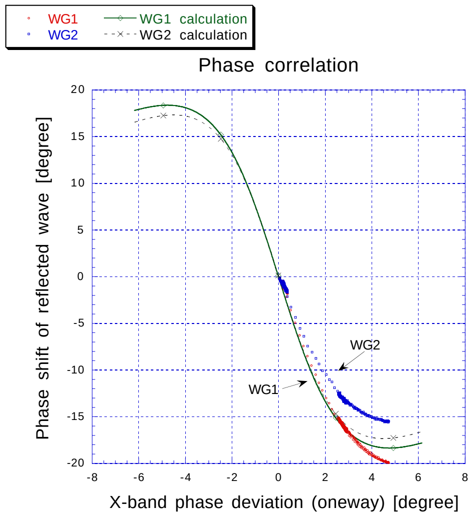

Figure 4: $\Delta\phi_x$ vs $\Delta\phi_s$

4 DISCUSSIONS

Merits of this measurement scheme when comparing with measuring directly X-band RF pulses are described below.

- This scheme do not needs long reference line, and needs only one test port on each delay line for electric length change measurement. Thus, it is possible to avoid unstableness caused by electric length change of reference line.
- It is easier to measure phase of continuous wave than short pulse.

Because sensitivity limit of this measurement scheme is determined only by measuring devices, we expect that this scheme will perform for 80m class delay lines of real-size DLDS with needed sensitivity by proper coupling coefficient.

For application to real DLDS of linear colliders, there are some problems to be considered.

- In this experiment, there is difference between calculation and measured data about 10 %. We think that using round trip style with two delay lines made some unknown factor. We might be able to make more precise measurement with good reference line which has very stable electric length.
- Considering high power X-band pulse (about several hundred mega watt) running through delay lines of DLDS, leakage of X-band RF into test port will be cause interference to measurement using resonance of delay line. Very careful designing and analysis of test port coupler are very important to suppress the leakage of X-band RF.

5 ACKNOWLEDGMENTS

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6 REFERENCES

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