The RF breakdown phase measurement at Nextef

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Abstract

We applied the IQ demodulator to measure the breakdown RF phase at Nextef. The IQ demodulators were evaluated with Network Analyzer first. The deviation of the output phase is less than 8 degree without any correction, meaning that we can use it to measure and identify the breakdown reflected RF phase different by 120 degree at the next cell. We established the RF phase measurement system and measured the reflected RF phase with IQ demodulators during the high power testing of T24_dis_#3 at Nextef.

Introduction

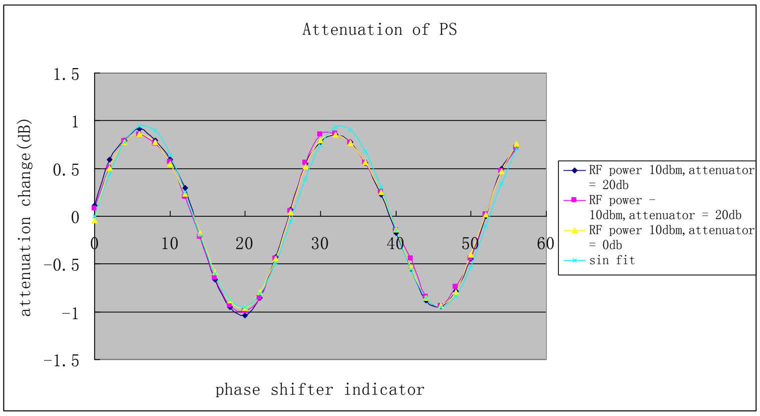
At present, the high gradient testing aiming at the evaluating CLIC prototype structures is ongoing at Nextef at KEK [1]. It is helpful for understanding why the RF breakdown happens if we can identify the position of the breakdown in the accelerator structure. In KEK, people measured the time delays of the forward, reflected and transmitted RF pulse with crystal detectors, and estimated the position of the breakdown with the time delays. Since the difference of the delay for two adjacent cavities is small and comparable to the noise of the signals, it is not easy to identify the position clearly only with the time delay information. For quite a while, NLCTA team has been used the reflected RF phase to get a better identification of the position[2], because the CLIC accelerator structure is traveling wave structure with 120degree phase advance per cell, and the reflected phase from a certain cell differs in phase by 240 degree from that of the adjacent cells. The IQ demodulators for phase measurements were bought and evaluated [3].

During the high power testing of the T24_disk_#3 at Nextef, we established the phase measurements system with the IQ demodulators and measured the reflected RF phase. We also evaluated the output characterizations of the IQ demodulators with Network Analyzer. These results are presented in this report.

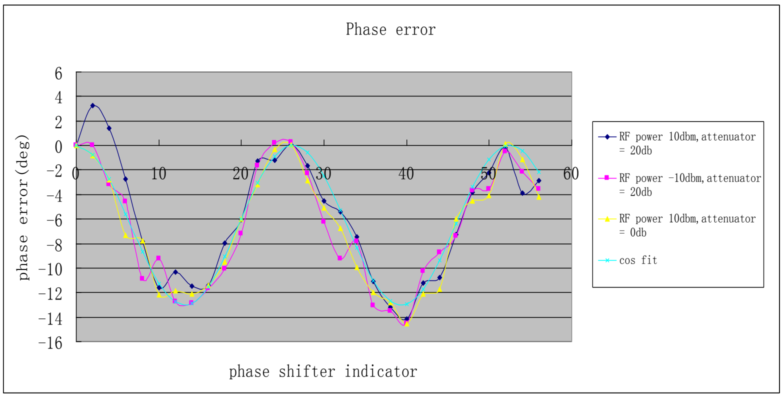
The characterization of the IQ demodulators

In Jingru Zhang's previous works [3], the phase errors from the IQ demodulators were about 60 degree, which were much worse than that we expected. We tested all the elements in the phase measurement system with Network analyzer and found that the large errors came from the phase shifters used in the experiments. We found that the attenuation of the phase shifter was changed when we change the RF pulse phase with it, and this influence was not considered in previous works. The output characterizations of the phase shifters are shown in figure 1.

We evaluated the IQ demodulators with Network Analyzer. The schematic of the setup is shown in figure 2. The RF from the port 1 of the Network Analyzer is split with a 3dB divider first, one is connected to IQ demodulator LO IN port as the reference RF signal, the other is connected to the isolator, the step variable attenuator, the phase shifter and the continuous variable attenuator one by one, then split to two part by a 3dB divider and connected to the IQ demodulator RF IN port and the port 2 of the Network Analyzer, respectively. The step variable attenuator is used to change the input RF power, the phase shifter is used to change the RF phase, and the continuous variable attenuator is used to compensate the attenuation shift of the phase shifter. The amplitude and the phase of the RF to IQ demodulator RF IN port are monitored with the Network Analyzer.



(a)



(b)

Figure1: the output characterizations of the phase shifters as a function of the indicators. (a), the attenuation and (b) the output phase error.

The output phase of the IQ demodulator, defined as Arctan(Q/I), was measured as function of the input phase difference of LO IN and RF IN. The power level of the LO IN was 8dBm, and the power of the RF IN is -3dBm, -5dBm and -14dBm, respectively. Figure 3 shows the measured output phase versus the input phase monitored with Network Analyzer for different input powers. Figure 4 shows the deviations of the output phase to the input phase for different input phase. The deviations are less than 8 degree.

Some parameters of the IQ demodulator, such as the unbalance power of each channel, skew angle and DC offset [4], can result in the deviations. We try to correct the errors by fitting the data using the ellipse shape in the complex (I, Q) plane. Figure 5 shows the fitting results of various input power level. In the figure, the blue asterisks are the initial measurement data, the red curve are the ellipse fitting and the green circle are the corrected data point. The phase error after correction is also shown in figure 4. The value is less than 2 degree, which is much more less than the results from Jingru zhang's report. This means that this device can be used for the reflected RF phase measurement with good resolution.

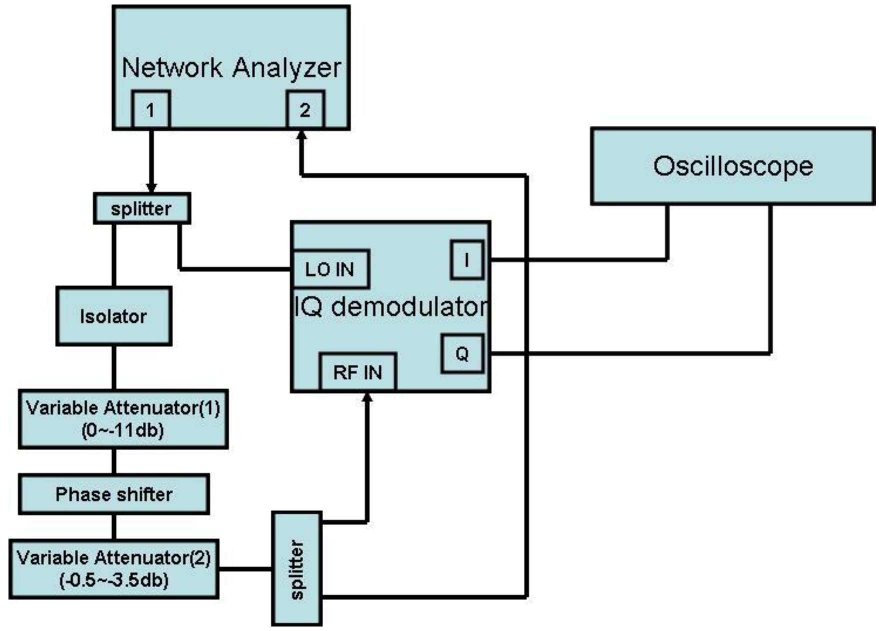


Figure 2: the schematic of the calibration system for IQ demodulators.

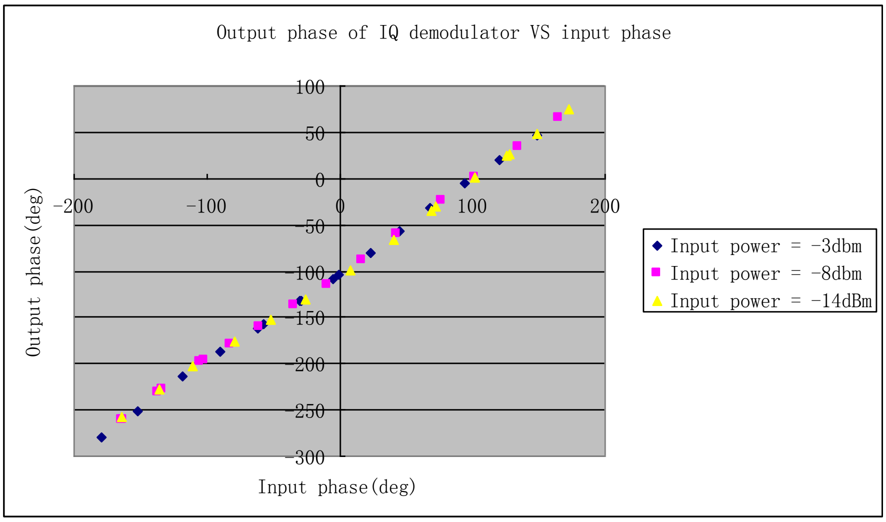


Figure 3: the output phase of IQ demodulator versus the input phase with different input RF power.

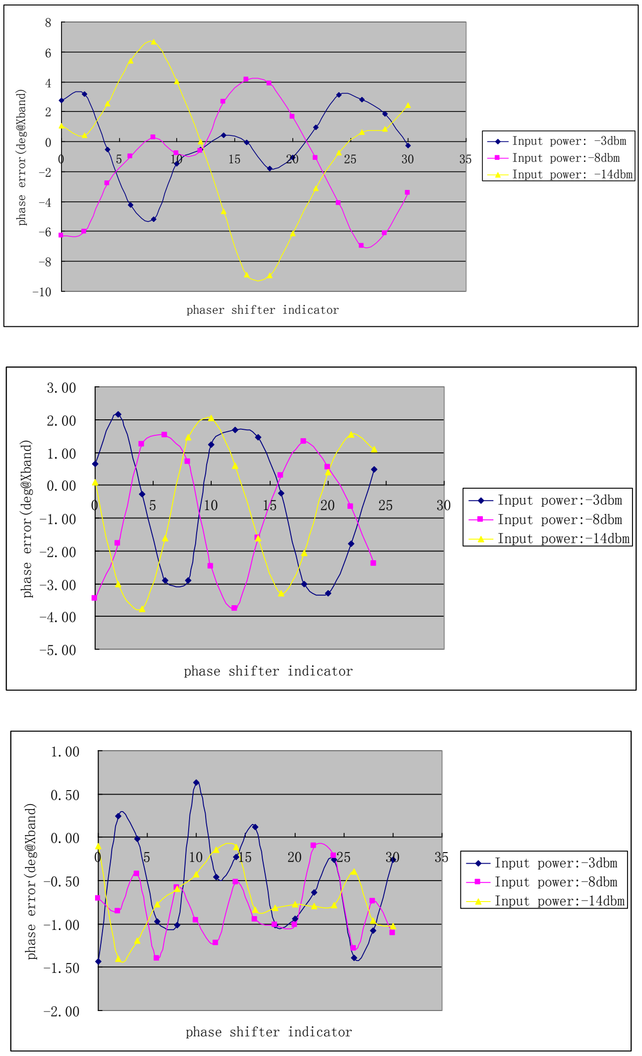


Figure 4: the deviations of the output phase to the input phase. From top to bottom: without calibration; With incomplete calibration (only DC offset is subtracted); fully calibration.

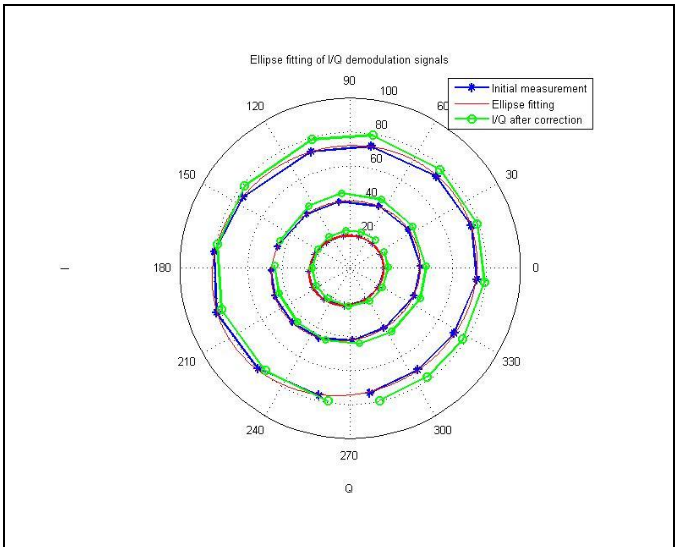


Figure 5: IQ diagram in complex plane.

Reflected RF phase measurement and analysis at Nextef

We set up the preliminary phase measurement system with the IQ demodulators for Nextef, as shown in figure 6. The forward RF phase is measured as a reference. The power level is about 10dBm for LO IN and about -10dbm for RF IN. The typical waveforms for the normal RF pulse and the breakdown pulse are shown in figure 7. The measured phase of the forward and reflected RF for the breakdown case is also shown in figure 7.

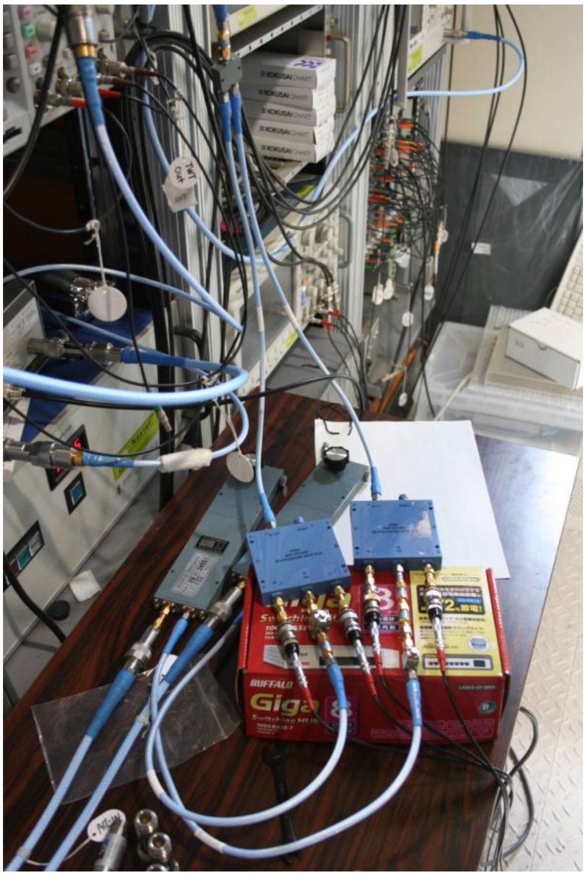


Figure 6: preliminary setup for T24 reflected RF phase measurement.

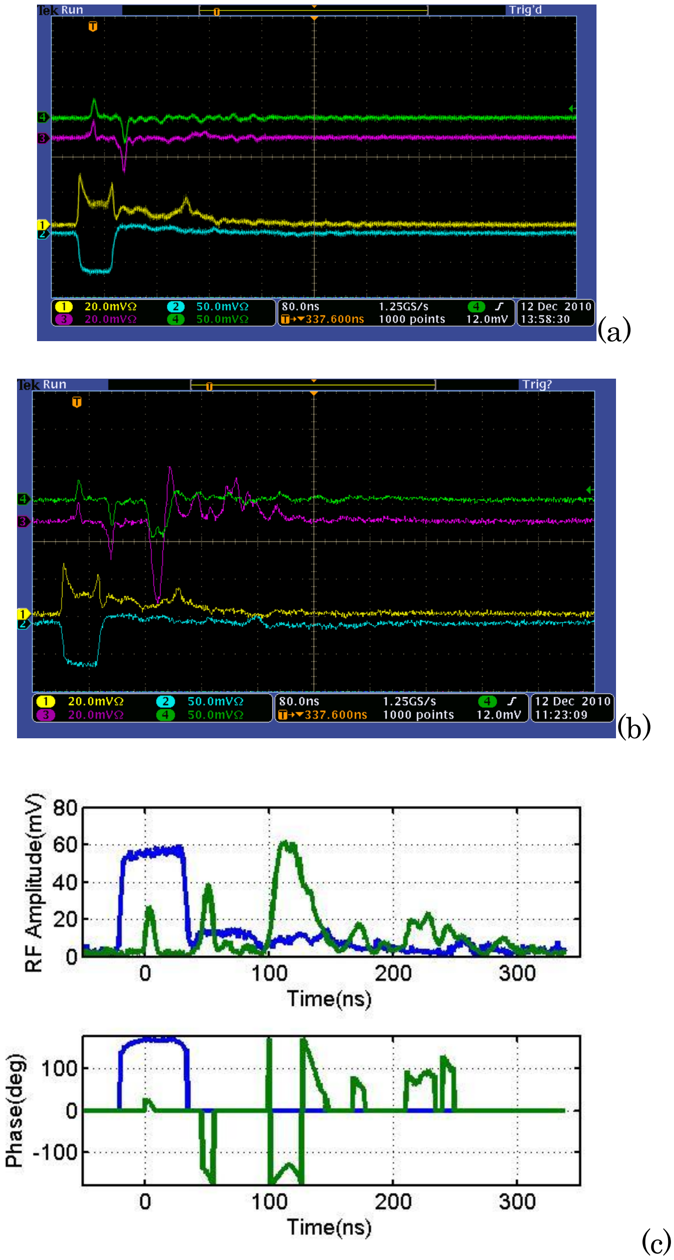


Figure 7: the typical I and Q waveforms for the normal pulse (a) and breakdown pulse (b). The ch1 and ch2 are connected to the Q and I output of the forward pulse. The ch3 and ch4 are connected to the Q and I output of the reflected pulse. The amplitude and phase of the breakdown pulse are shown in (c), the blue is forward pulse and the green is reflected pulse.

Because the reflected phase is related to the forward RF phase, it is necessary that the forward RF phase is stable otherwise we should subtract it as a reference phase. The forward RF phase and the reflected RF phase at the first peak during the T24_disk_#3 RUN2 are shown in figure 8. The deviations are within 20 degree and much less than the system requirements.

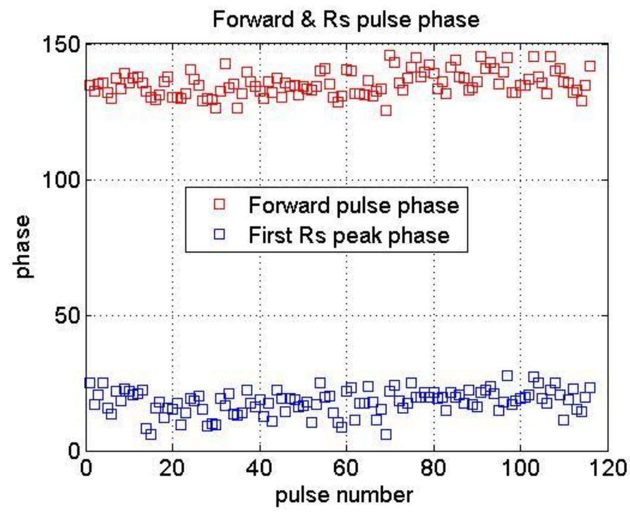
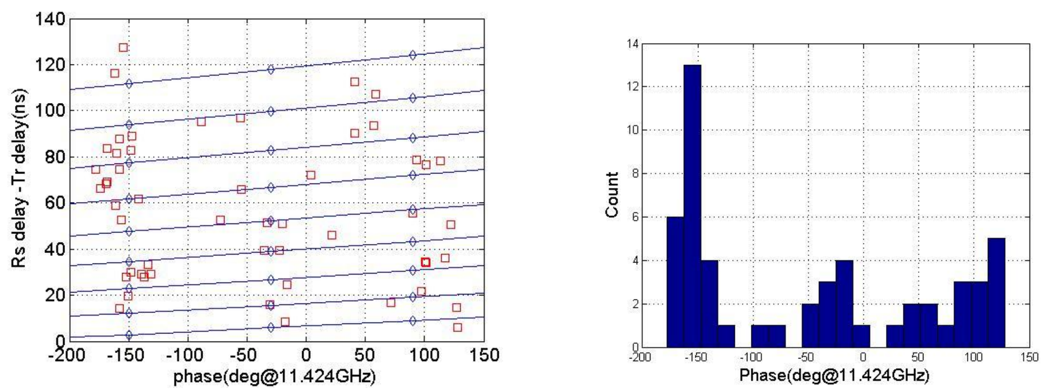


Figure 8: The forward RF phase(red) and the reflected RF phase at the first peak(blue) for normal pulse during the T24_disk_#3 RUN2.



(a) (b)

Figure 9: The typical reflected RF phase distribution for breakdown pulse. The phase versus Rs-Tr delay time which corresponds to the RF breakdown position (a), and the histogram plot (b).

Figure 9 shows the reflected RF phase for breakdown during T24_disk_#3 Run 2. It is clear from the figure that the phase is separated into three parts with interval about 100~120 degree as we expected before. With the time delay and phase information, we can get a better identification of the breakdown position.

Although we get the reflected phase information, the phase for the case that the breakdown happens at the first cell is still dubious. This phase is related to the forward RF phase, the waveguide length, the cable length from the directional coupler to IQ demodulator, the reference RF phase, and so on, and it is not easy to estimate the value. We estimate intuitively it should be close to the value that the phase at the first peak minus 120 degree. This value should be confirmed by measuring or simulating in the future works.

During the running of T24_disk_#3, we notice the phase advance of the accelerator structure is increased from the measured reflected RF phase. Figure 10 shows the measured reflected RF phase as a function of the Rs-Tr time delay from 20110108~20110117. The time delay corresponds to the breakdown position in the structure, and the position is closer to the end of the structure with higher Rs-Tr time delay. We can clearly find the phase advance of the structure is increased about 35 degree from the plot.

The reasons caused the phase advance increasing are not clear yet. The temperature of structure during the testing is about 1 degree Celsius higher than the design value, this will contribute about 5 degree to phase advance of the total structure. The most likely reason is the frequency of the structure increase about 1MHz during the testing. We will confirm it by low power level measurement after the high power testing.

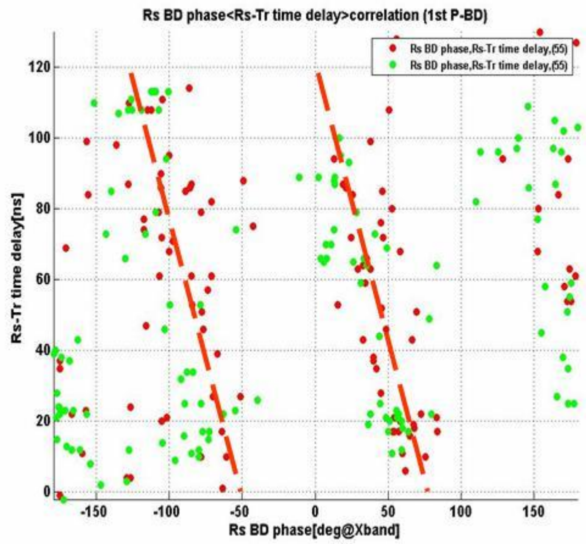


Figure 10: The breakdown phase distribution as a function of the Rs-Tr time delay. The red is ACC-breakdown type, and the green is the 1st pulse breakdown. The forward RF pulse width is 252ns.

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Reference

[1] T. Higo et al., “Advances In X-Band TW Accelerator Structures Operating in the 100 MV/m Regime”, IPAC10, THPEA013, Kyoto, Japan, May 2010.
[2] C. Adolphsen, “Report from NLCTA”, International Workshop on Linear Colliders 2010, ILCWS, Geneve, Switzerland, https://espace.cern.ch/LC2010/default.aspx.
[3] Jingru Zhang, T.Matsumoto and T.Higo, “Evaluation of an IQ demodulator”, Nextef – Technical - Note 2009-01;
[4] T.Schilcher, “Diginal signal processing to RF applications” CAS, Sigtuna, Sweden, June,2007.