LOW RF CONTROL FEEDBACK AND IQ VECTOR MODULATOR COMPENSATION FUNCTIONS.

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Abstract

I-Q vector modulator is key element of the gun and linac RF control circuits at Accelerator Test Facility at Brookhaven National Laboratory. I-Q modulator calibration procedure was developed to find proper compensation functions in the conversion algorithm to minimize phase-amplitude coupling and setting-reading errors: rms(A_{set} - A_{read})= 0.03dB, rms(ϕ_{set} - ϕ_{read}) = 0.3 deg. Since stabilization of the RF phase and amplitude is become critical for many experiments the slow feedback was developed and applied as well to significantly compensate drifts in RF system.

I-Q VECTOR MODULATOR

BNL ATF use digital I-Q vector modulator (7122 series of General Microwave [1]) in low RF gun and linac control circuits. Power and phase set points cover operational range of 20 dB and 360 degree with well known accuracy. The goal of this work was upgrade I-Q modulator software control to minimize set-read error by new compensation functions. Accuracy of new control is mostly defined by temperature during calibration technique at switching power points and environmental conditions.

CALIBRATION

I and Q modulator functions can be expressed as:

$$\mathrm{InPhase}(A,\phi,A_0,\phi_0) := 10^{\frac{A+A_0}{20}} \cdot \cos(\phi-\phi_0)$$

$$\mathrm{QuPhase}(A,\phi,A_0,\phi_0) := 10^{\frac{A+A_0}{20}} \cdot \sin(\phi-\phi_0),$$

where A and φ are power and phase set points, while A_0 and φ_0 are correction power and phase values. Those correction values depend from power level and phase range as well, so can be presented as functions $A_0(A,\varphi)$ and $\varphi_0(A,\varphi)$.

Before install I-Q modulators in operational circuit good part of work was done to calibrate them. In other words – to find those $A_0(A,\varphi)$ and $\varphi_0(A,\varphi)$ dependences in operational power and phase ranges. When range and steps were chosen, iteration scan cycles was performed at each power and phase set points, so correction A_0 and φ_0 values form table to cover all operational range. If operational set points lie between found table knots, correction values are calculated by simple linear two dimensional interpolation algorithm. It turns out that to use I-Q vector modulator with some defined accuracy, control system computer need to follow each set point

Figure 1: Digital I-Q vector modulator.

value, calculate both compensation values for power and phase and then apply corrected values. The whole interpolation-correction cycle takes not more than millisecond and that is enough to operate machine.

ACCURACY

Measurements and calibrations setup was done by network analyzer in the temperature controlled area to minimize an environmental temperature drifts. If expected errors were minimized they still exists and some effort was done to find and estimate it impact.

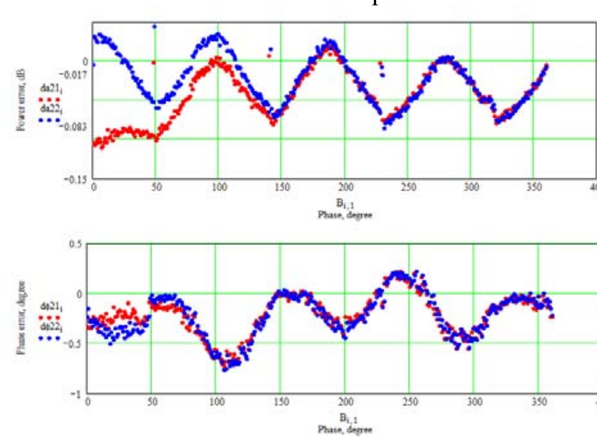

Figure 2: Difference between set points and measured power and phase. Two scans (1st is red, 2nd is blue) on the constant power. Top picture shows power difference, bottom is phase difference. Temperature stabilization takes about 5 min (150° in this scan) .

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Systematic Errors

At start of calibration procedure accuracy of measurements was estimated by measure only cables without I-Q modulator. That is defining threshold of iterations cycles and bottom line of the systematic error. For power it was found as $\delta A \leq 0.005$ *dB*, for phase $\delta\varphi \leq 0.07$ *deg*. After that I-Q modulator was connected and whole measurement cycle of 360 points at constant power (20dB) and phase (100deg) settings was repeated. This is define accuracy of I-Q modulator itself and was found as $\Delta A \leq 0.03$ *dB*, for phase $\Delta\varphi \leq 0.2$ *deg*.

After calibration was done, compensation tables for power and phase were built and applied for operation. Accuracy of new control circuit measured in whole operational range. It was found that most error value comes at switching power level while temperature is stabilizing in the system. This transition time takes about 5 minutes and gives error in power less than *0.1 dB* and in phase less than *0.2 deg*. During calibration this error was neglected by iteration cycles and overlapped by environmental temperature changes (day-night).

In the Table 1 is shown power and phase errors during scan of the most usable operational region of 0-10 dB power and 0-360 degree phase. Errors represented in rms and max values. Since I and Q are coupled in digital 12-bit range, during scan depending on power-phase settings it could make jumps switching values from 4095 to 0 (and vice versa) that will covered by max error.

Table 1: Comparison of old and new control accuracy

	Used control	**New control**
LINAC		
Power error over all scan	rms =0.15 dB max=0.43 dB	rms=0.02 dB max= 0.07 dB
Phase error over all scan	rms = 0.7^0 max = 2.7^0	rms = 0.13^0 max = 0.57^0
GUN		
Power error over all scan	rms =0.14 dB max=0.48 dB	rms = 0.03 dB max= 0.10 dB
Phase error over all scan	rms = 0.85^0 max = 2.73^0	rms = 0.31^0 max = 1.22^0

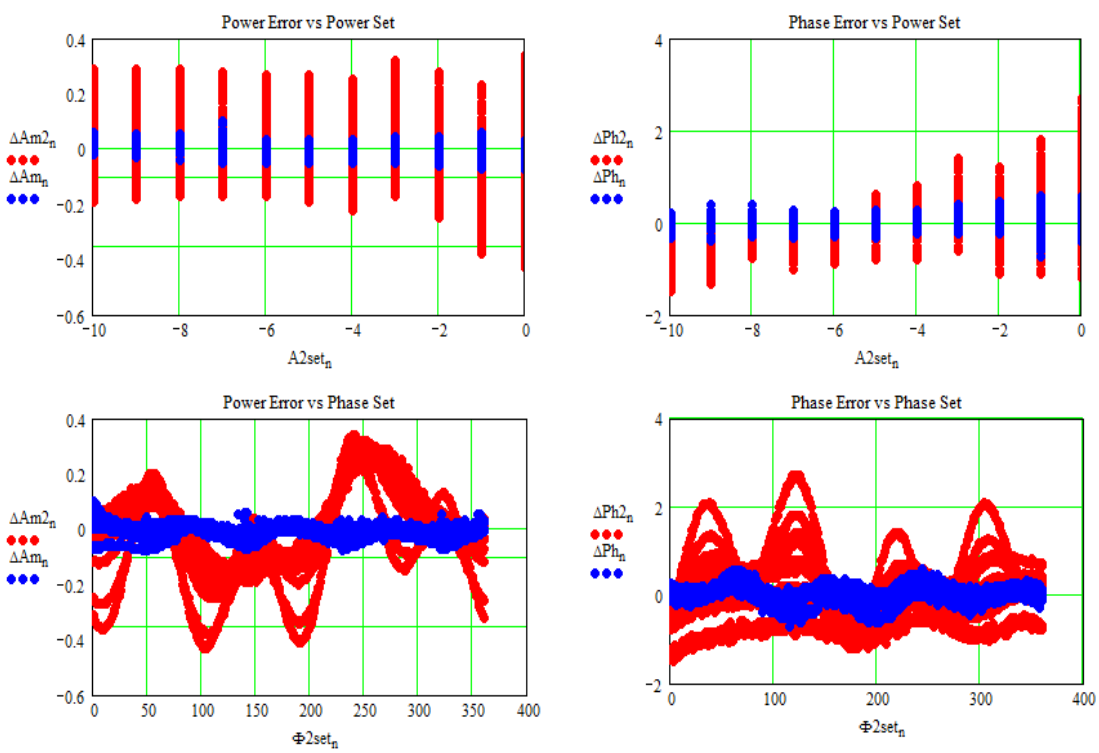

Figure 3: Old (red) and new (blue) control errors. Top pictures shows power and phase differences versus power. Bottom pictures shows difference versus phase. Scan ranges: power 0-10 dB, 1dB step; phase 0-360^o with 1^o step.

SLOW FEEDBACK

When new I-Q modulator control was commissioned and put in operation, gun and linac RF control was modified for slow feedback feature. Phase meter was installed to measure phase difference between Master Oscillator input and klystrons output in both gun and linac RF circuits. It measured phase difference then use it to readjust phase set points to hold phase output close to constant. Measure - adjust cycle is going with frequency about 0.3 - 0.5 Hz and compensate all temperature dependent drifts in the system. With success of this work it become possible to carry out experiments with fine tuning beam parameters [2].

CONCLUSION

New I-Q modulator software control was developed and commissioned at BNL ATF with operational rms errors less than 0.03dB of power and 0.3^{o} of phase.

Slow feedback for gun and linac RF were built to compensate slow drifts that mostly have an environment temperature changes.

REFERENCES

[1] www.herley.com

[2] V. Yakimenko, M. Fedurin, V. Litvinenko, A. Fedotov, D. Kayran, “CSR shielding experiment”, PAC11, WEP107.