DEVELOPMENT OF COMPONENTS FOR AN S-BAND ELECTRON LINAC RF FEEDBACK CONTROL

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Abstract

A feedback control of the RF phase and amplitude for an S-band electron linac is an effective method to cure phase and amplitude instabilities that directly affect the beam energy and its emittance. Low-power RF components for this feedback should respond faster than the pulse repetition(50pps) of a linac RF. This paper describes the development of four solid-state devices with "intelligent" control circuits: a) phase detector, b) amplitude detector, c) phase modulator, and d) amplitude modulator (phase/amplitude detectors and phase/amplitude modulators). The most important point of the mentioned circuits is that they must be able to change the phase and/or amplitude in a linear way, but independently from one another. For example, linearization of the output signal of a diode used in the amplitude detector is achieved by the control circuit. The components have been evaluated and improved with satisfaction for our requirements.

Introduction

Recent S-band linear accelerators applied to FELs (free electron laser) and linear colliders, such as the SLC, should produce the ability to generate beams having high brightness, a narrow energy spread and stable energy. This characteristic is generally achieved by refining elements, such as the klystrons and magnets. However, there are other helpful methods involving the RF phase and amplitude feedback control to obtain such beams. The PID(proportional, integral, differential) method is commonly employed for this purpose, but it can only control a linear-response system. If the phase and amplitude control from the feedback system to the elements changes in a dependent way and non-linearly, the non-linearities must be considered in the feedback loop while preventing the employment of these characteristics.

In our case, the low-power RF components of the feedback control are required to respond within a time of several ten milli-seconds which corresponds to three RF pulses operated at 50pps. Therefore, solid-state devices are suitable in spite of their non-linearity and dependence(as an above-mentioned), but compensation is needed. In order to realize these objectives, the intelligent control circuits for them are satisfactory. The mathematical method applied to the circuit can easily convert the original characteristic of the solid-state devices into linear and independent characteristics. We have developed low-power RF components with an intelligent control circuit for the PID feedback control: modulators called IΦA(isolator, phase shifter, attenuator) and two-detectors.

IΦA

The IΦA shown in Fig. 1 comprises 2 parts: one is a phase/amplitude modulation module; the other is a control module based on a microprocessor.

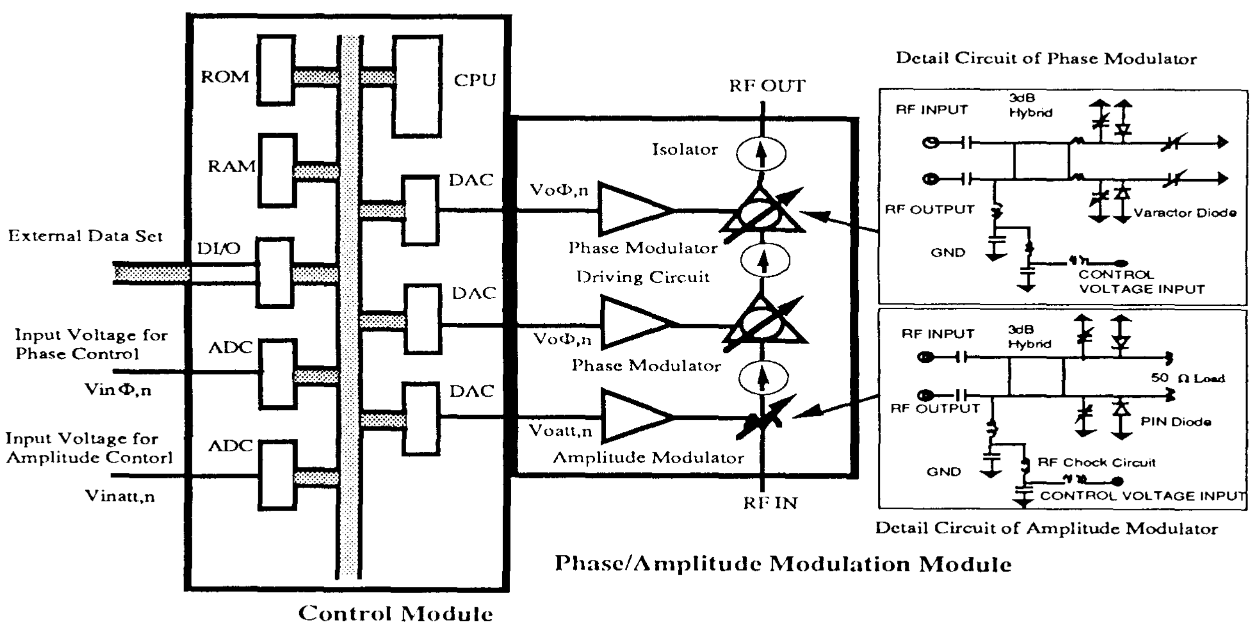


Fig. 1 Block diagram of IΦA modules.

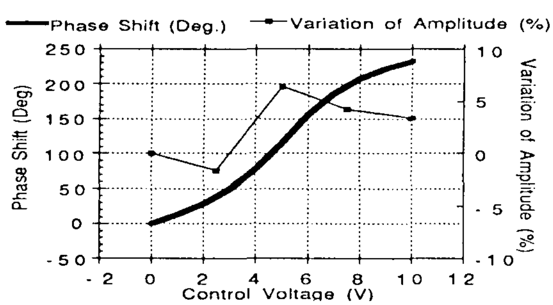
Phase/amplitude modulation module. The module comprises modulators as well as an isolator and driving circuits. The phase modulator[1][2] employs varactor-diodes. The amplitude modulator[3] applies PIN-diodes. The two were specially designed to obtain a quasi-linear control characteristic and a small insertion-loss variation(Fig. 2a). However there are still residual non-linearities and some cross-effects between the phase and the amplitude.

Compensation method of the control module. The compensation of the non-linearities and the cross-effects by the control module can be expressed by the matrix equation

$$\begin{pmatrix} Vo_{\phi,n} \\ Vo_{att,n} \end{pmatrix} = (F, \quad G) \begin{pmatrix} Vin_{\phi,n} \\ Vin_{att,n} \end{pmatrix} \qquad (1),$$

where $Vin_{\phi,n}$ and $Vin_{att,n}$ are the input voltages to the control module; $Vo_{\phi,n}$ and $Vo_{att,n}$ are the output voltages from the control module for the phase/amplitude modulators; F and G are calibration matrices to obtain linear and independent characteristics and the index n stands for the measurement point of the calibration data.

Correction method to obtain a calibration Matrix. In order to obtain a calibration matrix, an RF network analyzer controlled from a computer with a ROM writer(Calibration System) is used. Changing the control voltages($Vo_{\phi,n}$ and $Vo_{att,n}$) as parameters, the phase($Y_{ph,n}$) and amplitude($X_{att,n}$) variations of the complex of the modulators are measured as shown in Fig. 2a. Here, we assume that a polygonal line interpolation can be used to express the variation of $Y_{ph,n}$ and $X_{att,n}$ as a function of the two control-voltages in a simple way, because the measured data do not vary drastically. Then, the two obtained functions are represented as data points on a 32×32 grid mesh. Each grid mesh can also be defined as an interpolated linear-plane.



a) Phase shift with the amplitude variation by the control voltage of the phase modulator.

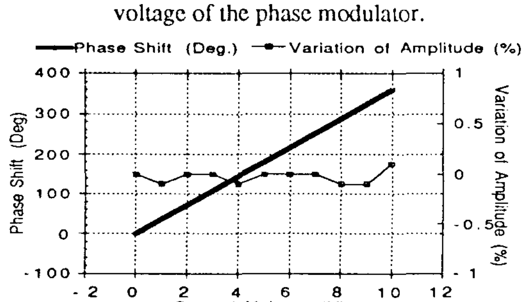


Fig. 2 b) Compensated phase shift with amplitude variation by a control voltage of IΦA.

In the individual plane, we solve linear-equation systems of the reverse-functions,

$$V_{o\phi,n} = a_{0n} + a_{1n} \times X_{att,n} + a_{2n} \times Y_{ph,n} \qquad (2)$$

$$V_{oatt,n} = b_{0n} + b_{1n} \times X_{att,n} + b_{2n} \times Y_{ph,n} \qquad (3),$$

to obtain the a and b-coefficents that give F and G. For use in the control circuit, $Vo_{\phi,n}$ and $Vo_{att,n}$ are calculated from $Vin_{\phi,n}$ and $Vin_{att,n}$, which correspond to the values of $Y_{ph,n}$ and $X_{att,n}$ normalized to the maximum input voltages.

Control-module configuration and its function. The configuration of the control-module using a Z80 CPU is shown in Fig. 1. The calculated control voltages($Vo_{\phi,n}$ and $Vo_{att,n}$) are written on the ROM as a 2-dimensional matrix. Each matrix address, indicating one data set of $Vo_{\phi,n}$ and $Vo_{att,n}$, corresponds to the digitized input voltage of $Vin_{\phi,n}$ and $Vin_{att,n}$. By giving the ROM address, the control-voltage data of the modulators are quickly withdrawn and converted into analog voltages.

Results. The response time of the IΦA is less than 10ms. The performance of its phase variation at a room temperature is shown in Fig. 2b. The amplitude variation is ± 1% for a phase shift from 0 to 360 deg; the phase variation is ±1 deg over an amplitude range from 30 to 100%.

Amplitude Detector

Linearization method. Linearization of a non-linear diode detection-characteristic(Fig. 4a) is made using

$$Pout,n = H\,(Vin,n) \qquad (4),$$

where Pout,n is a linearized RF power, H(Vin,n) is a linearization function and Vin,n is the diode output voltage. To obtain H(Vin,n), a curve of Vin,n versus the input RF powers to the diode is made by a computer-control calibration system with a CW-RF power meter and a ROM writer. The curve is fitted with a 3rd-order spline-function. Then, the function H(Vin,n) can be obtained as a reverse function of the fitted curve.

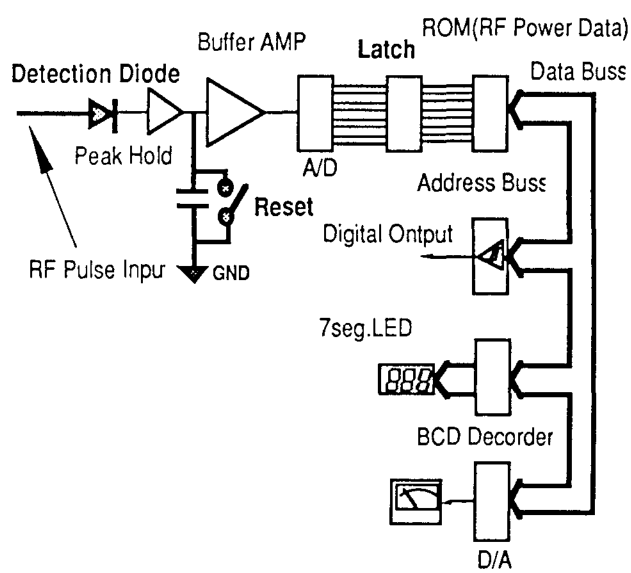


Fig. 3 Block diagram of the amplitude detector.

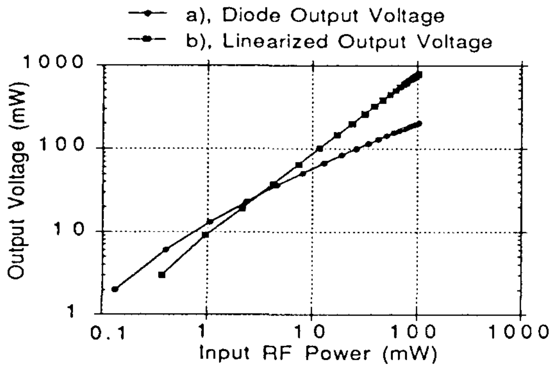


Fig. 4 Line-a: Original characteristic of the RF diode.
Line-b: Characteristic of the amplitude detector.

Module configuration and its function. The amplitude detector of Fig. 3 comprises a) an RF detector diode, b) a fast peak-hold circuit that can respond up to a pulse width of 50ns and c) a digital circuit for linearization. The linearized data of Pout are stored in the ROM of the circuit by the calibration system. The role of the data is to convert the diode output voltage to the RF power. As in the case of the IΦA, the addresses of the ROM are assigned to the detected voltage of the diode. The analog and digital output are also yielded from the RF power dataa.
Results. Lines a) and b) of Fig. 4 show the behavior before and after the linearization. Good linearity with ±2% is shown over the range of the diode detection power from 1 to 90mW. The amplitude detector is able to work until a pulse-repetition period of a couple of ten micro-seconds.

Phase Detector

Module Configuration. The configuration of the phase detector is shown in Fig. 5. The detector comprises a) two-frequency converters from 2856MHz to 200MHz using DBMs[4], b) limiter amplifiers, c) an phase detector[5] and d) a differential integrator connected to the phase detector outputs of U and $\overline{U}$, which are anti-phase square-waveforms. The detector principally has a linear detection characteristic from 180 to -180 deg at 200MHz with the use of a differential integrator.
Results. In the actual phase detector, the performance of the limiter amplifier and the differential integrator mainly limits the output linearity. For example, we improved it by increasing the number of amplifiers. Fig. 6 shows the temporary result of the phase-detection characteristic of the detector using a single-ended integrator connected to the U output. The detector can detect a proper phase value with about ± 2% linearity in the range of input phases from 50 to 150 deg. The pulse response time of the detector is about 30ns when the input phases varies. The detector is still under development. The differential integrator just replaced a single-ended type in order to obtain a wider phase detection range(about 360 deg). The detector will be tested.

Conclusion

We have almost successfully completed the development of low-power RF components of the feedback control. They have been tested in a noisy environment like that near to klystron modulators for a short period, and worked without any problem. In the next step, they will be tested regarding long-term stability. Also, a differential RF diode-detector, which we have already developed, will be employed as an amplitude detector to reject any common-mode noise, instead of the present single-ended diode.

Acknowledgment

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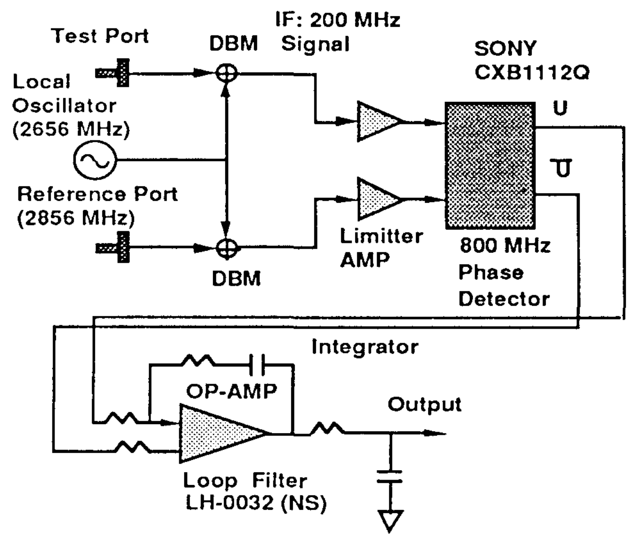

Fig. 5 Block diagram of the phase detector.

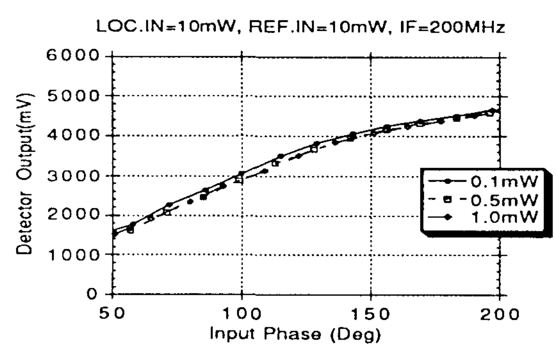

Fig. 6 Characteristic of the phase detector.