A Technique for Improving the Accuracy and Dynamic Range of Beam Position-Detection Equipment*

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Abstract

Beam position detection equipment often employs circuits that convert amplitude-modulated position signals to phase modulation. These signals are limited to remove amplitude variations and phase detected to obtain analog position information. The phase-modulated signals are clipped by limiters that must be closely phase matched in pairs over the signal intensity range of interest. Accuracy and dynamic range are determined principally by the phase match between the limiters. When the time duration of the beam is a few microseconds or more, significant improvements can be obtained by down-converting the RF signals to an intermediate frequency near 10 MHz. Limiter circuits are available that can be closely matched in pairs at 10 MHz over a 60-dB signal amplitude range. For example, the peak phase deviation measured among 30 matched pairs was <0.4°, corresponding to a phase tracking error of <0.1 dB. This exceptional matching enabled beam position measurements over a 50-dB dynamic range of signal intensity. A description of the detection technique and the limiter is given by this paper.

Introduction

Beam-position detection equipment frequently employs circuits that convert amplitude-modulated (AM) position signals to phase modulation (PM) using an AM/PM converter. The phase-modulated signals are clipped by limiters to remove amplitude variations and are phase detected to obtain analog position information. Papers by Higgins,[1,2] Jachim,[3] Shafer,[4,5] and Webber[6] describe equipment employing these circuits. When the time duration of the beam is a few microseconds or more, significant improvements in accuracy and dynamic range can be obtained by down-converting the RF signals to an intermediate frequency near 10 MHz. Limiter circuits are available that can be closely matched in pairs at 10 MHz over a 60-dB signal intensity range. A description of these circuits is given below.

Down Conversion Equipment

Figure 1 is a block diagram of a typical circuit for detecting the X and Y positions of a beam. For this case, a proton beam is modulated at 200 MHz and induces 200-MHz in-phase RF signals into stripline pickups. These signals, designated A_x, B_x, A_y, and B_y are applied to low pass filters having a cutoff frequency of about 300 MHz. The filtered signals are amplified and fed to the RF ports of four double-balanced mixers. Applied to the local oscillator (LO) ports is a LO frequency of 210 MHz. The difference frequency of 10 MHz is extracted by four bandpass filters as shown. Notice that the LO frequency applied to the B_x and B_y mixers is phase shifted 90° relative to that applied to the A_x and A_y mixers.

The output from the A-channel mixer can be expressed as

$$E_A \approx \frac{A}{2} \cos\left[(\omega_{LO} - \omega_{RF})t\right] \quad , \qquad (1)$$

while the output from the B-channel mixer is

$$E_B \approx \frac{B}{2} \cos\left[(\omega_{LO} - \omega_{RF})t - 90°\right] \qquad (2)$$

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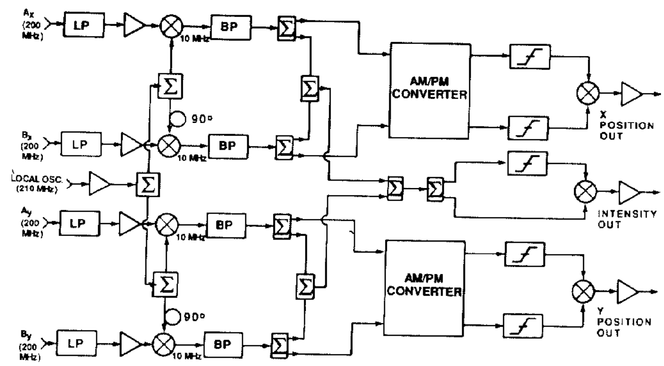

Fig. 1. Block diagram of the beam position-detection equipment.

Thus, the amplitude factors A and B are maintained in the difference frequencies, and the 10-MHz component from the B-channel lags the component from the A-channel by 90°. It is of interest to note that a local oscillator frequency of 190 MHz will produce a 90° phase lead in the B-channel component.

AM/PM Converter

The four 10-MHz signal components are power-divided to provide signals for position detection and intensity measurement. The X and Y position channels are processed by AM/PM conversion circuits that transform the amplitude-modulated position information to phase modulation. Figure 2 illustrates the operation of this converter, which employs three 0° power dividers and one 0°/180° divider. The interconnection of these components, along with the 90° phase lag produced by the down converter in the B channel produces two signals, r_1 and r_2, having the phase relationship $\psi_d = 2\tan^{-1}|B/A|$. Thus, the amplitude ratio B/A is converted to a phase angle. The conversion gain is about 6.6° per decibel of input signal imbalance for in-phase RF signals.

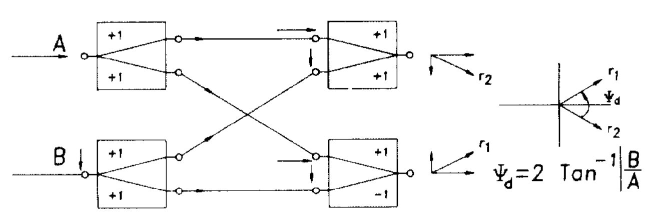

Fig. 2. Operation of the AM/PM converter.

A plot of this quantity is shown in Fig. 3. For beam positions near the center of the channel, the curve is relatively linear. Because this technique employs ratio detection, the phase angle is independent of the beam intensity over several decades of beam current.

Limiters

The phase-modulated signals are clipped by limiters that must be closely phase-matched in pairs over the signal intensity range of interest. Accuracy and dynamic range are determined principally by the phase match between the limiters. If the position detection circuits are operated near 10 MHz, comparators are available to serve as limiters that can be closely phase matched over a 60-dB dynamic range.

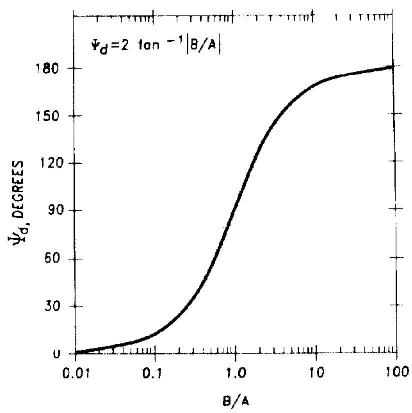

Fig. 3. Plot of the AM/PM converter phase relationship.

In particular, the SP9685 comparator is an excellent choice for this application. Figure 4 shows a limiter circuit that uses this comparator.

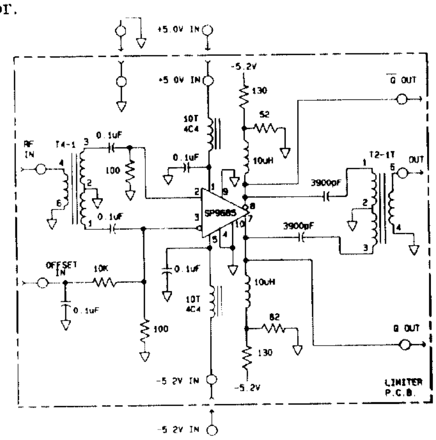

Fig. 4. Schematic diagram of a limiter employing the SP9685 comparator.

In Fig. 5, the peak phase deviation for 30 matched pairs of SP9685 limiters is shown. The worst case match was 1.6° and the majority were within 0.4° over the 60-dB dynamic range.

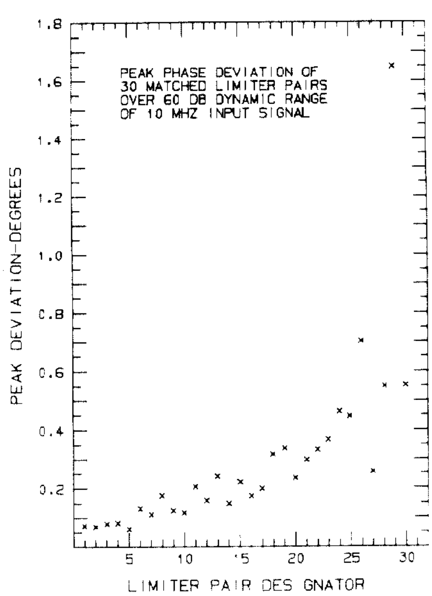

Fig. 5. Peak phase deviation of 30 type SP9685 limiter pairs matched over a 60-dB dynamic range of 10-MHz input signal.

A differential change of 1 dB in signal intensity produces 6.6° of phase change in the AM/PM converter output. Thus, the limiter phase-tracking error was less than 0.1 dB.

Referring to Fig. 1 again, the two output signals from the limiters are applied to a double-balanced mixer that functions as a phase detector. An exclusive OR-circuit could also perform this function. The output is filtered and amplified to produce the analog position signal.

Figure 6 shows oscilloscope traces that illustrate the dynamic characteristics of the equipment. The horizontal scale represents beam current variations ranging from about 10 μA on the left to about 10 mA on the right. The corresponding signal power to each input ranges from -64 dBm to -4 dBm. The family of horizontal lines represents 21 position values corresponding to differential signal intensity changes of 1 dB/step to the two inputs of the AM/PM converter. The beam-centered trace results when the two signals are equal ($A = B$). The upper traces correspond to $A > B$, while the lower traces result when $A < B$. The position measurements are quite uniform from about -54 dBm to -4 dBm. Below -54 dBm the limiter operation deteriorates, finally ceasing to operate below -64 dBm. The position measurement uniformity is due, primarily, to the excellent phase-matched characteristics of the limiters over the 50-dB dynamic range of signal intensity.

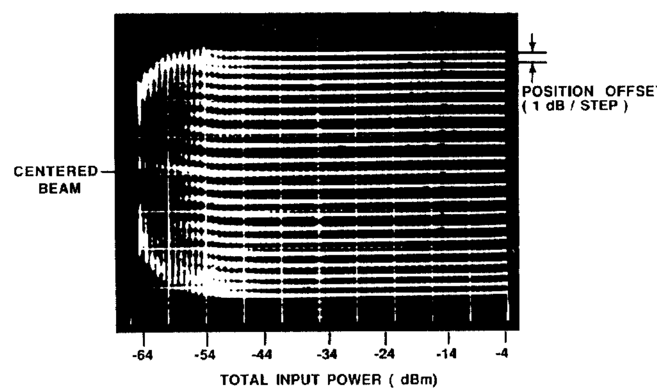

Fig. 6. Oscilloscope traces illustrating the dynamic characteristics of the position-detection equipment.

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References

1. E. F. Higgins, "High Speed Beam Position Electronics for Accelerator Control and Diagnostics," IEEE Trans. Nucl. Sci. **22** (3), 1574-1577, June 1975.
2. E. F. Higgins and F. D. Wells, "A Beam Position Monitor System for the Proton Storage Ring at LAMPF," IEEE Trans. Nucl. Sci. **28** (3), 2308-2310, June 1981.
3. S. P. Jachim, R. C. Webber, and R. E. Shafer, "An RF Beam Position Measurement Module for the Fermilab Energy Doubler," IEEE Trans. Nucl. Sci. **28** (3), 2323-2325, June 1981.
4. R. E. Shafer, R. E. Gerig, A. E. Baumbaugh, and C. R. Wegner, "The Tevatron Beam Position and Beam Loss Monitoring Systems," Proc. 12th International Conference on High Energy Accelerators, Fermi National Accelerator Laboratory, Batavia, Illinois, 1983, pp. 609-615.
5. R. E. Shafer, "A Large Dynamic Range Amplitude Comparator," R.F. Design, September 1986, Vol. 9, pp. 74-75.
6. R. C. Webber, J. Fritz, S. Holmes, W. Marsh, and J. Zagel, "A Beam Position Monitoring System for the Fermilab Booster," Proc. 1987 IEEE Particle Accelerator Conference, IEEE Catalog no. 87CH2387-9, vol. 1, pp. 541-543.