LOG-RATIO CIRCUIT FOR BEAM POSITION MONITORING

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Abstract

The logarithmic ratio of the signal amplitudes from beam-position probe-electrodes provides a normalized real-time analog signal that is more linear in beam displacement than other signal-processing techniques for circular cross-section, beam-position monitors. This paper describes work being done to develop a log-ratio circuit using an inexpensive, commercially available, logarithmic-response, integrated-circuit rf-amplifier. The circuit uses two amplifiers in a log(A) - log(B) = log(A/B) configuration to provide the logarithmic ratio of the two rf input signals from the probe. The output is a real-time analog signal proportional to beam displacement.

I. SIGNAL-PROCESSING TECHNIQUES

Three commonly available methods for deriving normalized beam-position signals are amplitude-modulation-to-phase-modulation conversion (AM/PM), difference-over-sum, and log-ratio processing [1]. Figure 1 shows the amplitude response of the three processing techniques for 45° electrodes in a 60 mm circular beam pipe. Notice that log-ratio processing provides the most linear response across the probe aperture.

![Response curves of the log-ratio, difference-over-sum, and AM/PM processing techniques.](image)

Figure 1. Response curves of the log-ratio, difference-over-sum, and AM/PM processing techniques.

Until recently, the log-ratio technique has not been a viable candidate because of amplifier cost and accuracy constraints. In 1989 Analog Devices Corporation announced the AD640 Logarithmic Amplifier, a monolithic device that provides a dynamic range of up to 50 dB for frequencies from dc to 120 MHz. Comprising the circuit are five cascaded, decoupled, amplifier/limiter stages, each having a small signal voltage gain of 10 dB with a -3-dB bandwidth of 350 MHz, and five full-wave detectors. These circuits implement a successive detection technique that approximates the logarithmic response characteristic. The five detected signals are summed to provide an output current proportional to the logarithm of the input voltage. The response is absolutely calibrated to within ±1 dB for dc or square-wave inputs. The linearity for sinusoidal inputs ranges from 0.75 to 1.5-dB [2]. Availability of this device was the impetus for an investigation of the log-ratio beam-position processing technique.

II. LOG-RATIO IMPLEMENTATION

For a pair of microstrip probe electrodes in a circular beam pipe, the ratio of the two currents produced by an rf-modulated beam current traveling in the z-direction past the electrodes can be expressed as [3]

\[
\frac{I_A}{I_B} = \frac{1 + 4 \sum_{n=1}^{\infty} \frac{1}{n^n} \frac{r_0^n}{R^n} \cos(n\theta_0) \sin\left(\frac{n\Phi_0}{2}\right)}{1 + 4 \sum_{n=1}^{\infty} \frac{1}{n^n} \frac{r_0^n}{R^n} \cos(n\theta_0) \sin\left(\frac{n\Phi_0}{2}\right)}
\]

where \(\Phi_0\) is the angle in radians subtended by the probe electrodes,
\(R\) is the radius of the probe aperture,
\(r_0\) and \(\theta_0\) are the coordinates of the beam bunch,
\(r_0\cos \theta_0 = x\) is the beam displacement from the center.

By expanding and simplifying this equation, a solution for the beam displacement can be obtained as

\[
x = \frac{\ln(10)}{160} \left(\frac{R\Phi_0}{\sin(\Phi_0/2)}\right) 20 \log\left(\frac{I_A}{I_B}\right)
\]

Thus, the displacement is expressed as a function of the logarithm of the ratio of the two currents.

Figure 2 shows a block diagram of the complete log-ratio circuit. Each logarithmic amplifier has two AD640 devices in cascade and an operational amplifier that sums and converts the currents to a voltage that is filtered to provide an envelope proportional in amplitude to the logarithm of the input signal. The filtered outputs are applied to a differencing amplifier to produce a beam-position signal proportional to log(A/B).
In Figure 3 the transfer curve for one of the logarithmic amplifiers operating at 60 MHz is shown with an error plot giving the deviation from a straight line fit. Over the range from −50-dBm to −5-dBm the amplifier deviation is less than ±0.1-dB from the straight line fit. Amplifiers 1 and 2 have transfer slopes that differ by less than 1% and their zero crossing points are nearly identical.

III. CIRCUIT PROCESSING ERRORS

Ideally, the traces of Figure 4 should be straight horizontal lines. In reality the lines have non-zero slopes and they deviate from straight lines, indicating that the processed beam position output is a function of the rf-signal power level.

Some of the errors inherent in log-ratio processing are illustrated in Figures 5 and 6 where the 0-dB and 6-dB lines are normalized to the transfer factor. In each figure the lower curve is the output divided by the transfer factor, giving the normalized response in dB. The upper error curve is the same normalized curve with the straight line fit values subtracted. This curve shows the positional variation in the transfer function.

For example, in Figure 6, the variation of ±0.14-dB compares to a variation of about ±0.05 dB for an AM/PM processor. If a typical 45-mm aperture microstrip probe having a sensitivity of 1.2 dB/mm is considered, the log-ratio positional error is ±0.12 mm. This compares to ±0.04 mm for the AM/PM processor, a factor of three smaller. The sinusoidal variation is a characteristic of the log-ratio circuit and is related to the successive approximation logarithmic amplification technique. It is described by the manufacturer's performance specifications.
V. CONCLUSIONS

The log-ratio circuit technique gives a more linear response characteristic for circular cross section beam position probes than other types of processors. The output is a real-time normalized position signal with good bandwidth and the dynamic range is equivalent to that of the AM/PM processor. Potentially, the log-ratio processor will be less expensive to manufacture and its operating power will be lower. A major advantage over AM/PM processing is that cables connecting the pickup electrodes to the processor do not need to be closely phase matched because the log-ratio circuit responds to amplitude differences and is not sensitive to phase differences.

At this stage of development the positional error of the log-ratio circuit is substantially greater than that of the AM/PM processor. If a logarithmic-response, integrated-circuit rf-amplifier can be designed to be absolutely calibrated within ±0.1 dB, then the log-ratio circuit will become a more viable beam position processor.

VI. REFERENCES


