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TITLE: # LOG-RATIO CIRCUIT FOR BEAM POSITION MONITORING

AUTHOR(S): F. D. Wells AT-3
J. D. Gilpatrick AT-3
R. E. Shafer AT-3
R. B. Shurter AT-3

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LOG-RATIO CIRCUIT FOR BEAM POSITION MONITORING*

F. D. Wells, J. D. Gilpatrick, R. E. Shafer and R. B. Shurter
Los Alamos National Laboratory, MS: H808
Los Alamos, NM 87545

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.

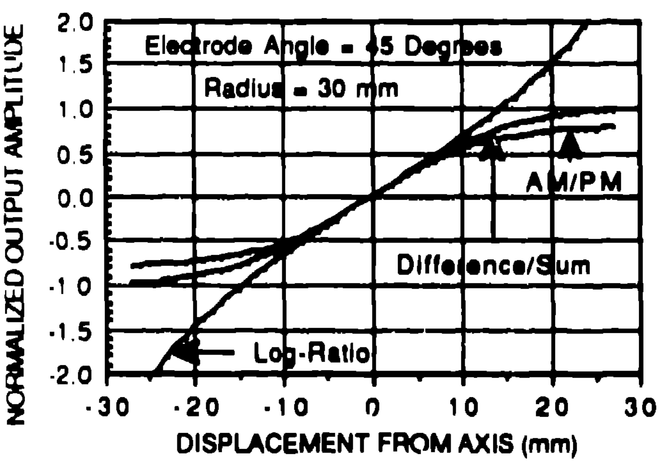

Figure 1. Response curves of the log-ratio, difference-over-sum, and AM/PM processing techniques.

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, dc-coupled, 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.

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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]

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

where Φ_0 is the angle in radians subtended by the probe electrodes,
R is the radius of the probe aperture,
r_0 and θ_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

$$X \cong \frac{\ln 10}{160}\left(\frac{R\Phi_0}{\sin(\Phi_0/2)}\right) 20\log\left(\frac{I_A}{I_B}\right) \qquad (2)$$

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).

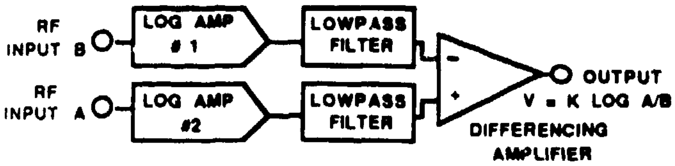

Figure 2. The log-ratio circuit block diagram.

In Figure 3 the transfer curve for one of the logarithmic amplifiers 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.

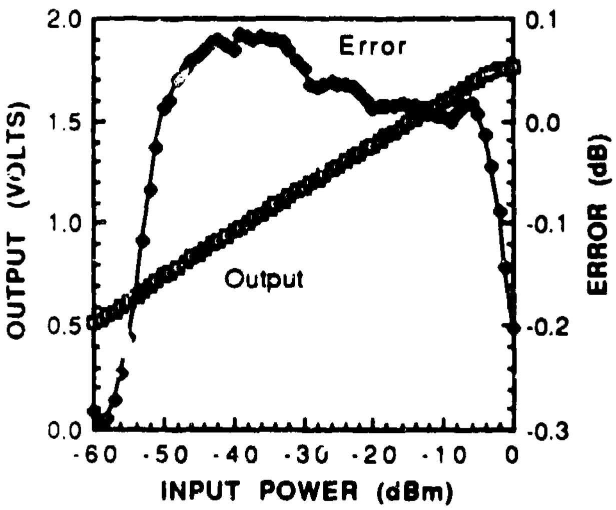

Figure 3. Transfer and error curves for a typical AD640 dual stage logarithmic amplifier.

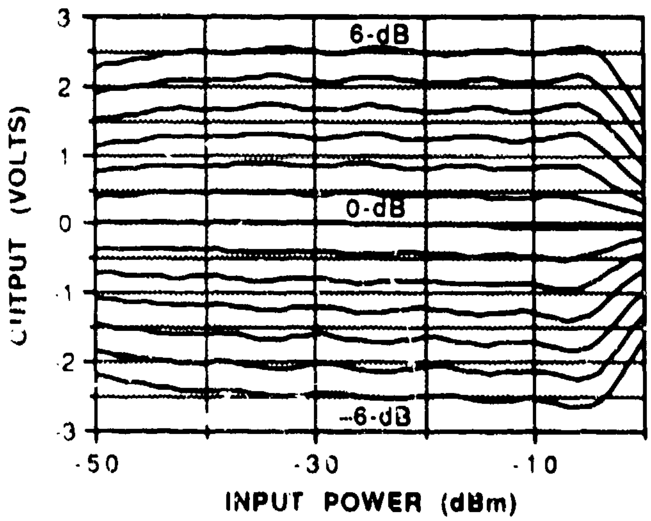

Figure 4. Log-ratio circuit transfer function curves for 60 MHz rf input signals.

The response of this circuit to 60-MHz rf input signals is shown in Figure 4. On the horizontal axis, the rf input power to the A and B channels is plotted, ranging from -50-dBm to 0 dBm. The family of curves represents 13 position values corresponding to signal input ratio changes from -6-dB to +6-dB in 1 dB steps. The center 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. Best operation occurs in the range of -45-dBm to -5-dBm, corresponding to a dynamic range of 100:1 in beam current. The transfer factor for the circuit is about 0.42 volts per dB.

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.

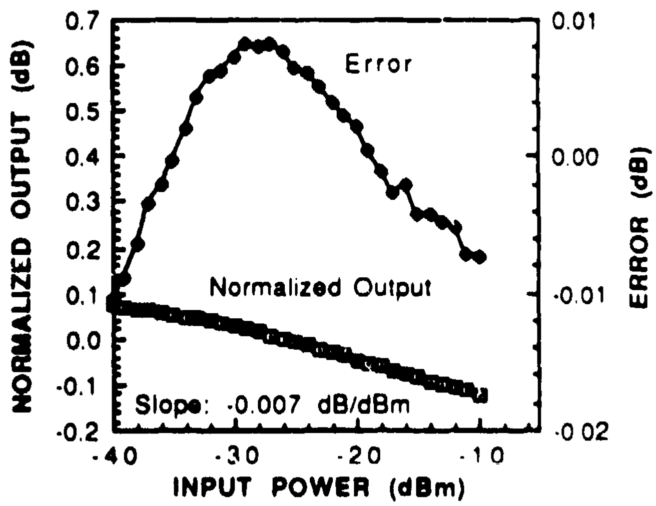

Figure 5. Error and normalized output curves for the 0-dB line of Figure 3.

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.

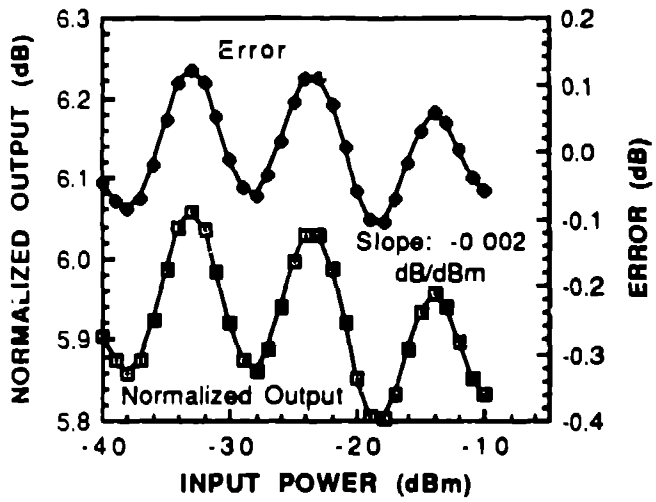

Figure 6. Error and normalized output curves for the 6-dB line of Figure 3.

IV. NOISE CONSIDERATIONS

Figure 7 compares the effective input noise of the log-ratio circuit operating at 60 MHz to that of an AM/PM circuit operating at 20 MHz and to the theoretical minimum noise. These plots are obtained by normalizing the measured RMS noise values at the circuit outputs by the transfer factor. The model for the theoretical noise plot assumes kTB noise at each back terminated probe electrode. A nominal bandwidth of 2 MHz for each plot is assumed. In the -40-dBm to -10-dBm input power range, the AM/PM circuit has a substantially lower noise level [4].

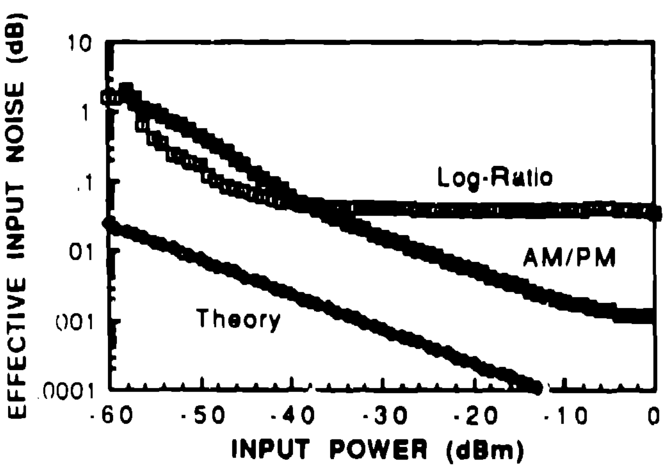

Figure 7. Noise comparisons of the log-ratio and AM/PM processors versus the theoretical minimum noise.

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

[1] R. E. Shafer, "Beam Position Monitoring," AIP Conference Proceedings 212, Accelerator Instrumentation, p. 47, 1989.

[2] "Monolithic DC-to-120 MHz Log-Amp is Stable and Accurate," Analog Dialogue, Vol. 23, No. 3, p. 3, 1989, (Analog Devices, Inc., Norwood, MA 02062-9106).

[3] R. E. Shafer, "Characteristics of Directional Coupler Beam Position Monitors," IEEE Transactions on Nuclear Science, Vol. NS-32, No. 5, pp. 1933-1937, Oct. 1985.

[4] J. D. Gilpatrick, "Noise Measurements for Three Port Beam Position Circuits," AT-3:Technical Note, Los Alamos National Laboratory, 1991.