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TITLE: **LOG-RATIO CIRCUIT FOR BEAM POSITION MONITORING**

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

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Los Alamos

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

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LOG-RATIO CIRCUIT FOR BEAM POSITION MONITORING*

F. D. Wells, R. E. Shafer, J. D. Gilpatrick and R. B. Shurter
MS: H808, Los Alamos National Laboratory
Los Alamos, NM 87544

Abstract

A synopsis is given of work in progress on a new signal processing technique for obtaining real-time normalized beam position information from sensing electrodes in accelerator beam pipes. The circuit employs wideband logarithmic amplifiers in a configuration that converts pickup electrode signals to position signals that are substantially independent of beam current. The circuit functions as a ratio detector that computes the logarithm of (A/B) as (Log A - Log B), and presents the result in a video (real-time analog) format representing beam position. It has potential benefits of greater dynamic range and better linearity than other techniques currently used and it may be able to operate at substantially higher frequencies.

The Log-Ratio Signal Processing Algorithm

Consider a pair of microstrip pickups in a circular beam pipe as shown in Fig. 1. When a short beam bunch, $I(r_o, \theta_o)$ travels past the electrodes in the z-direction, image currents are induced into the microstrips. The ratio of these currents can be expressed as[1],

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

where, ϕ_o is the angle subtended by the pickup elements,
R is the radius of the pickup aperture,
r_o and θ_o are the coordinates of the beam bunch,
$r_o \cos\theta_o = X$ is the beam displacement from the center.

Taking the first term of the series,

$$\frac{I_A}{I_B} \cong \frac{1+\frac{4}{\phi_o}\left(\frac{X}{R}\right)\sin\left(\frac{\phi_o}{2}\right)}{1-\frac{4}{\phi_o}\left(\frac{X}{R}\right)\sin\left(\frac{\phi_o}{2}\right)} = \frac{1+\varepsilon}{1-\varepsilon} \qquad (2)$$

Converting this ratio to decibels gives,

$$20\log\frac{I_A}{I_B} \cong 20\log\frac{1+\varepsilon}{1-\varepsilon} = \frac{20}{\text{Ln }10}\text{Ln}\frac{1+\varepsilon}{1-\varepsilon} \qquad (3)$$

$$\cong \frac{40}{\text{Ln }10}\left[\varepsilon+\frac{\varepsilon^3}{3}+\frac{\varepsilon^5}{5}+\ldots\right] \qquad (4)$$

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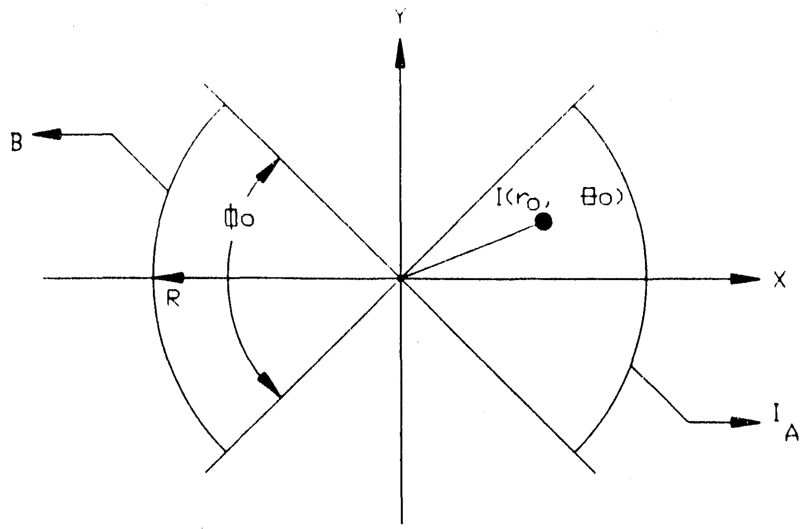

Fig. 1. Cross section of a pair of microstrip electrodes in a circular beam pipe.

Taking the first term of this expression gives,

$$20\log\frac{I_A}{I_B} \cong \frac{40}{\text{Ln } 10}\left[\frac{4}{\phi_o}\left(\frac{X}{R}\right)\sin\frac{\phi_o}{2}\right] \qquad (5)$$

Solving for X gives,

$$X \cong \frac{\text{Ln } 10}{160}\left(\frac{R\phi_o}{\sin\frac{\phi_o}{2}}\right)20\log\frac{I_A}{I_B} \qquad (6)$$

Thus, the logarithmic ratio of the signal amplitudes provides a reasonably linear measurement proportional to beam position.

Fig. 2 compares the response of log-ratio processing to the two most commonly used processing techniques: difference-over-sum and amplitude-modulation to phase-modulation (AM/PM) conversion. Notice that log-ratio processing combined with the microstrip electrode beam position response theoretically provides the most linear response over the full aperture of the pickup[2].

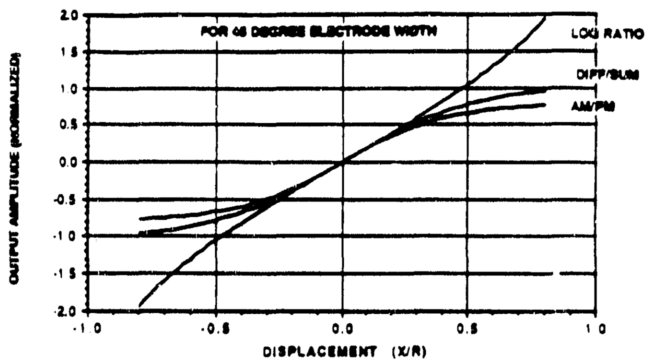

Fig. 2. Response curves of the log-ratio, difference-over-sum and AM/PM processing techniques.

Implementation

Detector-logarithmic video amplifiers are used extensively in radar and electronic warfare applications, and are available from a number of manufacturers. Input frequencies range from DC to tens of GHz and the input dynamic range can exceed 60 dB (typically -45 dBm to 15 dBm)[3].

In 1989 the model AD640 Logarithmic Amplifier became available from Analog Devices Corporation[4]. It is a monolithic logarithmic amplifier containing five cascaded dc-coupled amplifier/limiter stages, each having a small signal voltage gain of 10 dB and a -3 dB bandwidth of 350 MHz. Each stage has an associated fullwave detector that produces an output current that is proportional to the absolute value of the input voltage applied to the amplifier. The detector outputs are summed to produce a composite current that approximates a logarithmic transfer function. To complete the circuit, the current is converted to a voltage and filtered to provide a video envelope representing the input signal.

For the log-ratio application two AD640 chips have been cascaded as shown in Fig. 3. The current outputs are summed and converted to voltage by an amplifier and the video output is extracted from a 2 MHz low-pass filter.

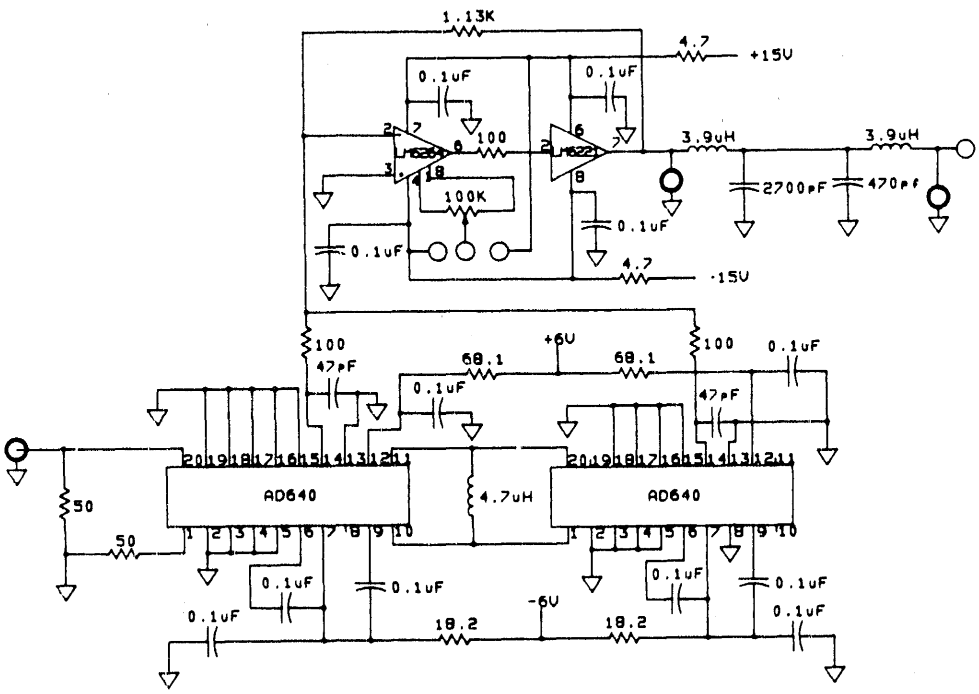

Fig. 3. Circuit diagram of a 70 dB dynamic range logarithmic amplifier for 50 MHz to 150 MHz operation.

Figs. 4 and 5 show the transfer and error curves for two of these amplifier circuits responding to 60 MHz RF input signals. Superimposed on the transfer curves are straight line fit curves. The slopes of the two amplifiers differ by less than 1% and the zero crossing points are nearly identical. Over the range from -10 dBm to -60 dBm the amplifier deviations are less than 1 dB from the straight line, as shown by the error curves.

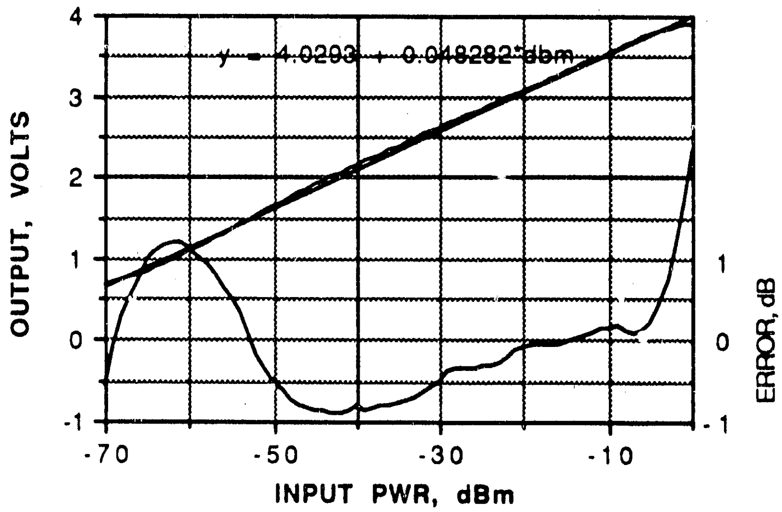

Fig. 4. Transfer curve, straight line fit and error curves for logarithmic amplifier number one.

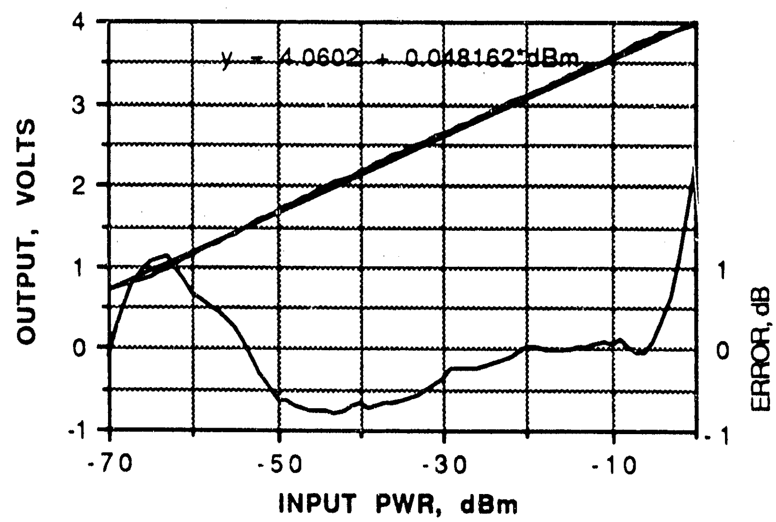

Fig. 5. Transfer curve, straight line fit and error curves for logarithmic amplifier number two.

The complete log-ratio circuit is shown in Fig. 6. Two logarithmic amplifiers are connected to a differencing amplifier to produce a video output proportional to Log (A/B).

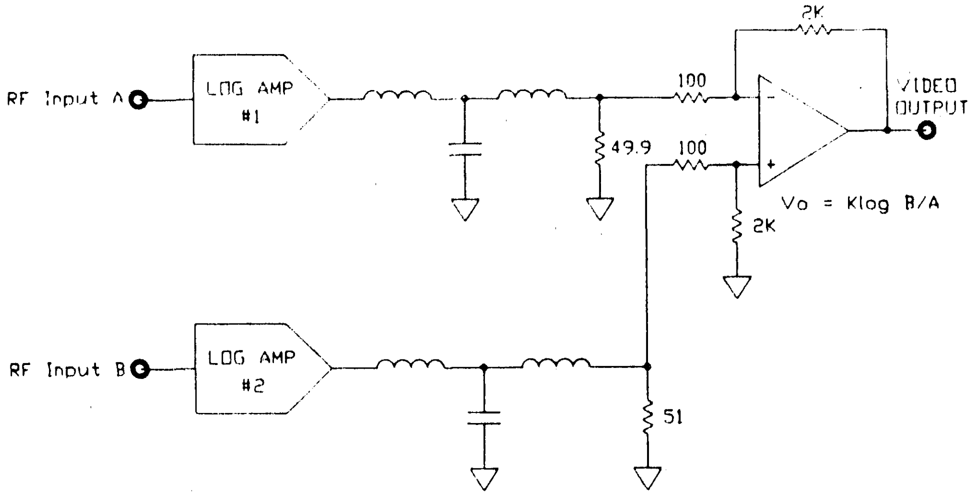

Fig. 6. The log-ratio circuit showing the two logarithmic amplifiers, the lowpass filters and the differencing amplifier.

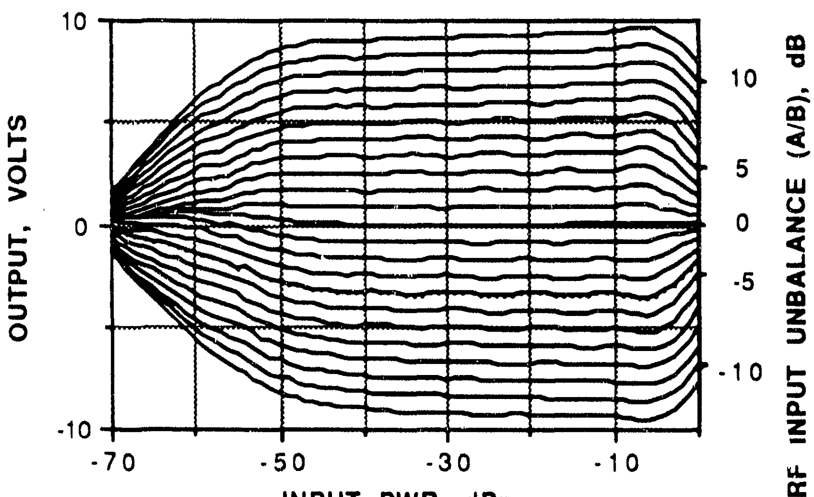

Fig. 7. Log-ratio circuit response curves to 60 MHz RF input signals.

The circuit response is shown by the curves of Fig. 7. On the horizontal axis the RF input power to the A and B inputs is plotted, ranging from 0 dBm to -70 dBm. This family of curves represents 23 position values corresponding to differential signal intensity changes of 1 dB/step to the two inputs. 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 -10 dBm to -50 dBm. Ideally the traces should be straight horizontal lines. The variations from straightness are due to the deviation of the amplifier transfer curves from the straight line fit.

Fig. 8 is a plot of the output voltage versus the offset from center for an input power of -15 dBm. This illustrates the linearity characteristic of the log-ratio processing technique.

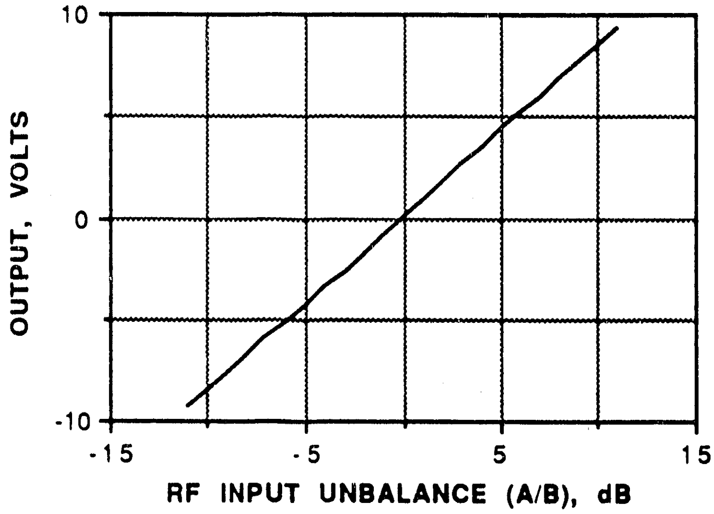

Fig. 8. Transfer curve of the log-ratio circuit at -15 dBm input power.

For the amplifier gains used in this investigation the average calibration factor over the input power range of -10 to -45 dBm is 0.853 volts/dB with individual factors differing by a maximum of ± 4.3%. If the circuit was connected to a microstrip pickup having a sensitivity of 6 mm/dB the overall calibration factor would be 7.03 ± 0.3 mm/volt.

Conclusions

1. The log-ratio circuit technique provides a more linear response characteristic than other types of position detection such as difference-over-sum and AM/PM processing.

2. The deviation of the logarithmic amplifier transfer curves from a straight line fit has, thus far, limited the accuracy and dynamic range.

3. The output is a real-time normalized position signal with good bandwidth.

4. 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.

5. The availability of commercially manufactured quasi-logarithmic response chips with wide dynamic range, high bandwidth and reasonable cost make log-ratio processing a technique that deserves continued investigation.

6. More work is planned to determine if the log-ratio process is a viable alternative to the difference-over-sum and AM/PM processing techniques. Improvements in the circuit response may be effected by close matching of the logarithmic amplifier chips. Other topics to pursue include noise considerations, drift sensitivity and cost effectiveness.

References

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