# A S-BAND HIGH POWER FEEDBACK AMPLIFIER

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## Abstract

A 2.0 GHz high power feedback amplifier has been designed and fabricated, which has an RF gain of 34 dB and delivers an output power of 2W with third order IM distortion products down 40 dB from the carrier level. A 10 dB reduction in third order IM distortion products is achieved by applying negative feedback to the power amplifier.

## Theoretical Considerations

Application of negative feedback to a microwave amplifier requires special treatment of the time delays and bandwidth involved. Since a typical amplifier will have several cycles delay from input to input, a simple means of applying feedback is to include a single-tuned, band-limiting cavity in the feedback loop.[1] Such a configuration is shown in Fig. 1. The amplifier A, feedback loss B, and cavity C are chosen so that the loop transmission is greater than one only between two frequencies of 180° phase shift. Consider the response of each block:

$$A = ae^{-j\tau_a\Delta\omega} \tag{1}$$

$$B = be^{-j\tau_b\Delta\omega} \tag{2}$$

$$C = \frac{c}{1 + j\Delta\omega T} \tag{3}$$

where a, b, and c are the midband gains of each block, $\tau_a$ and $\tau_b$ are the time delays through the amplifier and feedback path, T is the cavity time constant $T = \frac{1}{\pi BW}$, and $\Delta\omega$ is the frequency difference from the center frequency. (B includes input and output couplers.) Then:

$$e_o = \frac{AC}{1 + ABC} e_i + \frac{1}{1 + ABC} e_{im} \tag{4}$$

where $e_{im}$ is the intermodulation products introduced by the amplifier. Thus the intermodulation products are reduced by 1/(1 + ABC) and the amplifier gain was reduced by C/(1 + ABC). Note that this gain can be replaced relatively easy at low power level.

The factor (1 + ABC) determines the tradeoffs which must be made between loop gain, bandwidth and phase margin. The loop transmission[2] is defined as:

$$ABC = \frac{abce^{-j\tau\Delta\omega}}{1 + Tj\Delta\omega} \tag{5}$$

where $\tau = \tau_a + \tau_b$. When $|ABC| = 1$,

$$\omega_c T = a^2b^2c^2 - 1 \tag{6}$$

where $\omega_c$ is the unity gain frequency.

Let $\Theta(\Delta\omega) = \angle(ABC)$: then

$$\Theta(\omega_c) = -\omega_c\tau - \tan^{-1}(\omega_c T) \tag{7}$$

The phase margin, $\Theta$, is:

$$\Theta = 180° - |\Theta(\omega_c)| \tag{8}$$

Figure 2 shows the tradeoff of cavity bandwidth and midband return difference, $|1 + ABC|$, for various phase margins.

The gain margin is the solution of a transcendental equation, but this can be easily found numerically. For the loops constructed, about one dB of gain margin results for each 10 degrees of phase margin.

The cavity bandwidth, BW, is only a rough indication of the useful bandwidth of the feedback amplifier. The amount of IMD reduction, $|1 + ABC|$, falls off with frequency due to the cavity frequency response and degrades the amplifier linearity when $|1 + ABC| < 1$. The degradation is worst when $\Theta(\Delta\omega) = 180°$ and the closed-loop gain also peaks near this frequency to an extent dependent on the gain margin. Figure 3 shows the linearity improvement and closed-loop gain vs. frequency of a loop with 14 nsec total delay, a cavity 3 MHz wide, and abc = 18 dB. (Loss in the output coupler is neglected.) To achieve a wider bandwidth, the total delay of the loop, the midband linearity improvement, or the phase margin must be decreased, and a cavity with wider bandwidth can be used.

## Component Selection and System Assembly

Time delay, gain and phase stability are important in every block of the loop, since time delay or phase margin can be traded for bandwidth or loop gain.

The cavity must be a single tuned resonator, so that the phase shift introduced will be less than 90°. Asymmetries in its frequency response, or a gain slope elsewhere in the loop will cause unequal gain margin and phase margin at the ends of the passband. Its bandwidth must be determined in conjunction with loop gain and phase margin, as discussed above. In the loop constructed a bandwidth of 5 MHz was used.

The amplifier used in the loop provided 50 dB gain at 2.0 GHz and +33 dBm output with third-order IM products 30 dB down from the carrier level. The loss in the output coupler should be as low as possible, since the IMD will be degraded by about twice that loss at equal output power. The total time delay around the loop was about 16 nsec. To minimize the delay the closest possible proximity and shortest cables were used. The complete feedback amplifier assembly is shown in Figure 4. To further minimize the delay, couplers and attenuators could be fabricated as part of the MIC power amplifier.

## Performance Measurements

Measurements on the 2 watt feedback amplifier showed good agreement with the theoretical calculations. A loop transmission of 13.2 dB was used, so the gain of the closed loop system was about 34 dB. Allowing for loss in the output coupler, the midband IMD reduction should be 13.7 dB; a graph of the calculated and measured result is given in Figure 5. 0 dB on the ordinate refers to the third-order IMD level of the amplifier without feedback, which was 30 dB down at +33 dBm output. Photographs of the output spectra of the amplifier without and with feedback are shown in Figures 6 and 7. The phase margin and gain margin of the feedback system should be determined and adjusted before turning on the closed loop system to avoid oscillations which may seriously damage the main amplifier. A network analyzer is a convenient instrument to measure the phase and gain margin. Figure 8 is a display of the loop transmission response, from which the phase margin can be read at points A and B, and the gain margin is the magnitude difference between points C and D. Figure 9 shows the AM-PM conversion of the amplifier with and without feedback, at the center of the passband. Optimum performance can occur only when the phase and gain margins are nearly equal on the sides of the passband.

## Concluding Remarks

Negative feedback technique has been successfully applied to a MIC power amplifier which greatly reduces the IM distortion products. The main advantage of this technique is its simplicity as compared to the feedforward technique[3] which proved to be a low cost technique to linearize a microwave amplifier. The D.C. efficiency is improved by more than 40% over an amplifier using the brute-force approach.

As indicated in the analysis given, the limitation of a microwave feedback amplifier is its relatively narrow bandwidth as compared to a brute-force or a feedforward amplifier. However, for a narrow band application the negative feedback technique could be the most practical way to achieve linearity at microwave frequencies.

## References


1. H. A. Rosen and A. T. Owens, "Power Amplifier Linearity Studies for SSB Transmissions", IEEE Transactions on Communications Systems, pp. 150-159, June, 1964.

2. M. S. Ghausi, Principles and Design of Linear Active Circuits, McGraw Hill, New York, 1965.

3. C. C. Hsieh and S. P. Chan, "A Feedforward S-Band MIC Amplifier System", IEEE Journal of Solid-State Circuits, Vol. SC-11, No. 2, pp. 271-278, Apri, 1976.


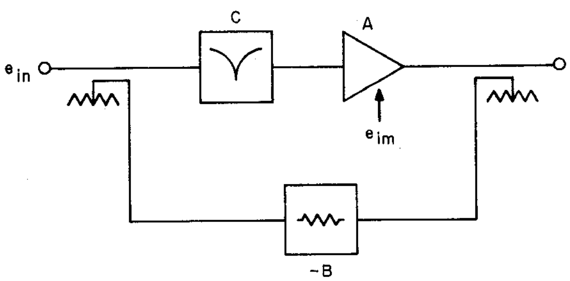


FIGURE 1: BLOCK DIAGRAM OF A MICROWAVE FEEDBACK AMPLIFIER

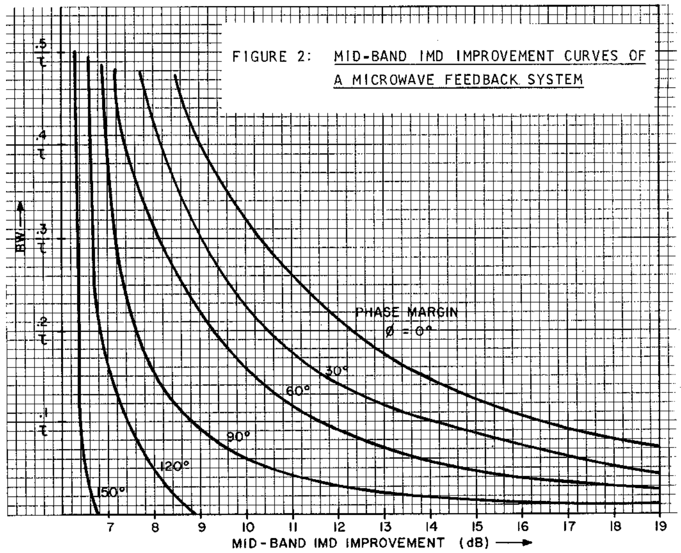


FIGURE 2: MID-BAND IMD IMPROVEMENT CURVES OF A MICROWAVE FEEDBACK SYSTEM

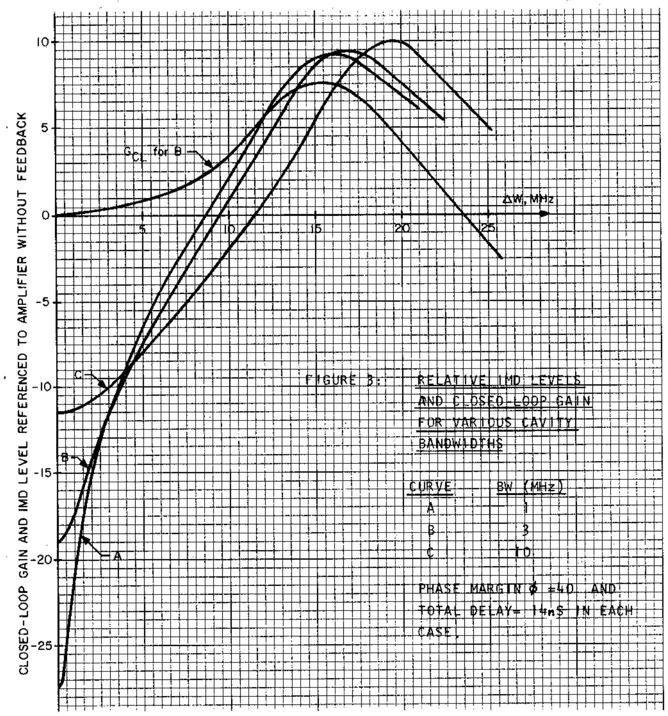


FIGURE 3: RELATIVE IMD LEVELS AND CLOSED-LOOP GAIN FOR VARIOUS CAVITY BANDWIDTHS

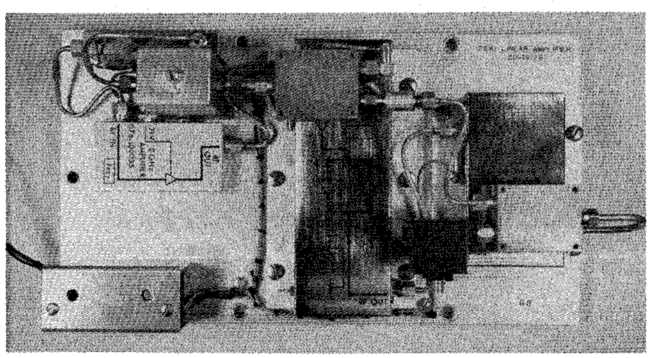

Figure 4 Feedback Amplifier Assembly

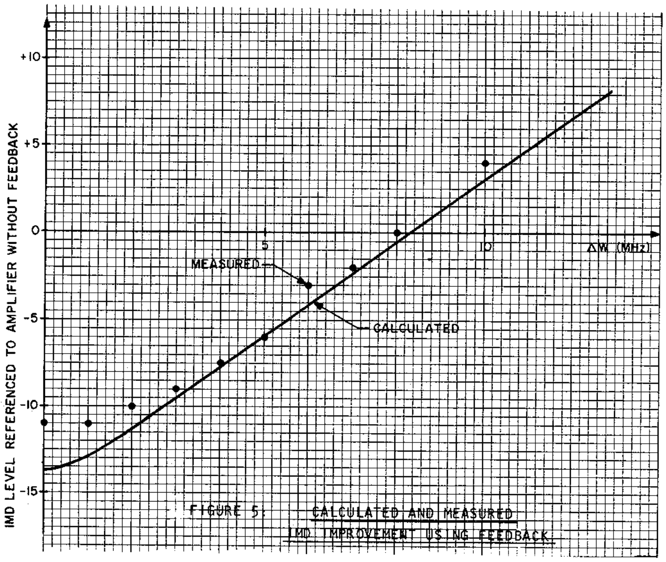


FIGURE 5: CALCULATED AND MEASURED IMD IMPROVEMENT USING FEEDBACK

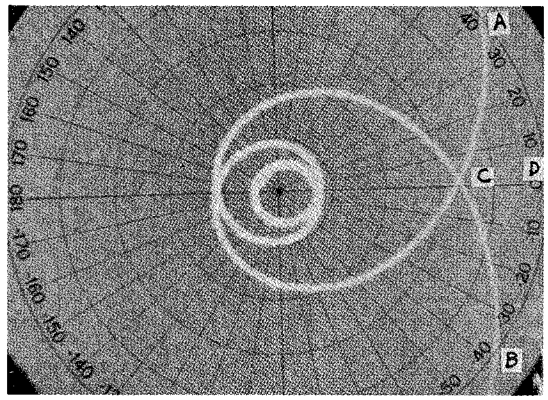


Figure 8. Network Analyser display of loop transmission, showing phase margin and gain margin.

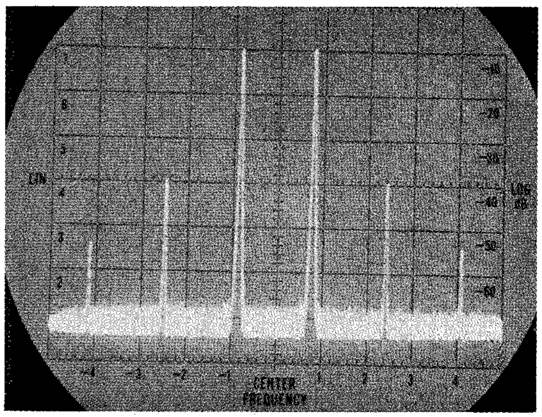


Figure 6 Two-tone Spectrum of Amplifier Without Feedback $P_o$=+33 dBm

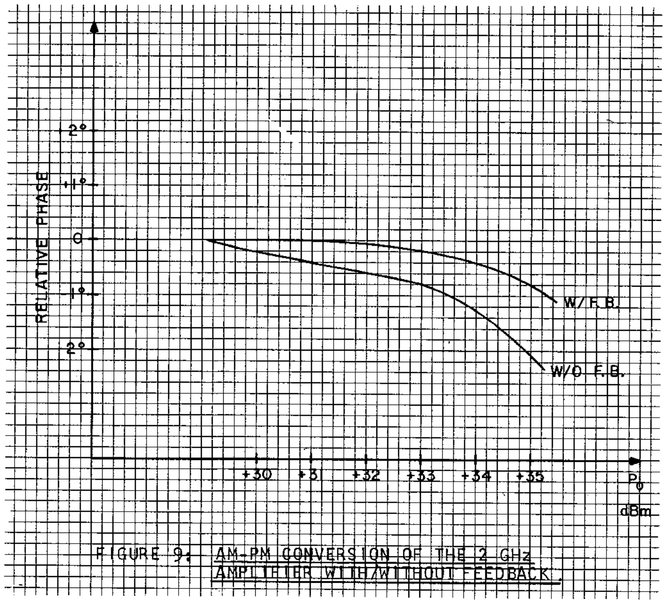


FIGURE 9: AM-PM CONVERSION OF THE 2 GHz AMPLIFIER WITH/WITHOUT FEEDBACK

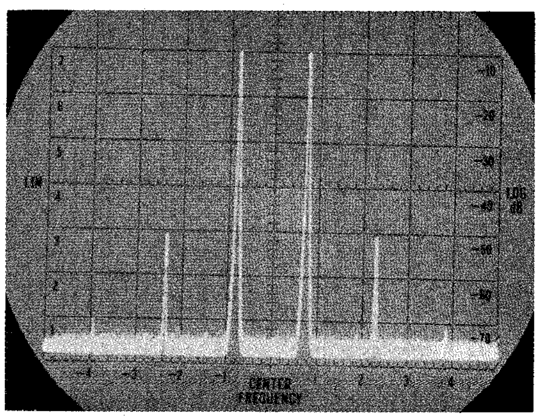


Figure 7 Two-tone Spectrum of Amplifier with Feedback $P_o$=+33 dBm