Measurement of Klystron Phase Modulation Due to AC-Powered Filaments

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This article shows the experiment that was conducted in order to determine the intermodulation components in the RF spectrum of the S-band radar transmitter generated by having the klystron filaments heated by 400-Hz AC power.

I. Introduction

The klystron manufacturer recommended changing the filament power of the klystron on the high-powered transmitter from DC to AC to increase the filament/cathode life. Before proceeding it had to be decided if the AC filament excitation would be reflected in the RF output as incidental phase modulation (IPM), and, if so, would it degrade the RF spectrum.

II. Conclusion

When the klystron is being operated with 400-Hz (AC) on the filament, the IPM is buried in the 400-Hz equipment interference noise. The modulation sidebands were separated and identified and found to be −67 dB below the main carrier. This is well below the transmitter specifications, and operating the filaments on AC would not degrade the spectrum to where it would be detrimental to the radiated RF.

III. Measurement Technique

The technique used for measuring the phase modulation sideband was to use a double balanced mixer as a phase comparator to cancel out the IPM from the exciter. A sample of the drive (using a directional coupler) to the klystron was connected to the LO port of the mixer and a sample of the klystron output was connected to the RF port. A double balanced mixer (DBM) was used in order to increase the isolation between the LO and RF inputs. An inherent characteristic of a DBM is that the IF point is DC-coupled to the diodes. This means that the frequency response is from DC to some very high frequency, which lends itself to be used as a phase detector needed to detect the (400-Hz) filament frequency.

This phase-modulated frequency spectrum was then measured and displayed on a frequency analyzer that is capable of determining both the frequency and amplitude of the modulation. It was very difficult to detect the phase modulation of the filaments because it was buried in the noise caused by the 400-Hz rotating machinery. The solution for this was to excite the filaments with a variable frequency source; this separated and identified the phase modulation generated by the filament power.

The second problem was that the frequency source used to drive the klystron did not have the frequency stability needed. It was found in earlier experiments that the generator used was too unstable to be detected by the spectrum analyzer. That is, after the frequencies were beat together, the difference frequency was moving too fast for the analyzer to capture and present on the scope. A frequency synthesizer, which has a high degree of stability, was used in order to stabilize the difference frequency. When these two problems were resolved, the experiment progressed smoothly.

IV. Equipment Setup

The equipment was arranged as shown in Figs. 1 and 2 with the frequency source being stabilized by a synthesizer. The RF mixer was connected as shown in Fig. 2 and the phase shifter was adjusted for zero volts DC. This configuration canceled all IPM frequencies except those generated from within the klystron itself. The variable frequency source was connected to the klystron filaments and set to approximately 380 Hz and 430 Hz in order to verify that the modulation observed with the spectrum analyzer was indeed generated by the filament. Shifting the frequency proved the modulation in the RF output was caused by the AC on the filaments. The filament IPM was 3.5 dB lower than the system 400-Hz noise. Figures 3 and 4 show the filament frequency at 426 Hz and 386 Hz, respectively. These recordings are graphs plotted from the spectrum analyzer.

V. Calculations and Results

Figures 1 and 2 show the equipment set up as the experiment was performed at DSS 13. Figures 3, 4, and 5 show the frequency spectrum as indicated by the spectrum analyzer. The bandwidth on Figs. 3 and 4 is 0 to 500 Hz and 0 to 1000 Hz in Fig. 5. As indicated above, Figs. 3 and 4 show the phase modulation from the filaments; Fig. 3 is with the filament power at 426 Hz and Fig. 4 at 386 Hz. Figure 5 expands the scale to 1000 Hz; as can be seen, the second harmonic (855 Hz) due to the filament excitation is present. It may be noted that when the filaments are excited by 400 Hz (as is normal in operation) the phase modulation would be buried in the system noise and therefore not obvious.

The equipment was adjusted in the following manner. The phase shifter was adjusted through 180 degrees and the DC shift was ±0.3 volts DC; it was then adjusted for zero volts. The spectrum analyzer was adjusted so that the indication presented on the scope recorded modulation below 0.1 volt. For instance, Fig. 3 shows the phase modulation due to the filaments to be −57.7 dB. This would be 57.7 dB below 0.1 volt. Therefore, if the maximum excursion on the S-curve is 0.3 volt, the phase modulation due to the filaments would be

$$dB_t = 20 \log \frac{0.3}{0.1} + (57.7) = 67.24 \text{ dB}$$

below the carrier. The second harmonic generated by the filament power would be 75.1 dB.

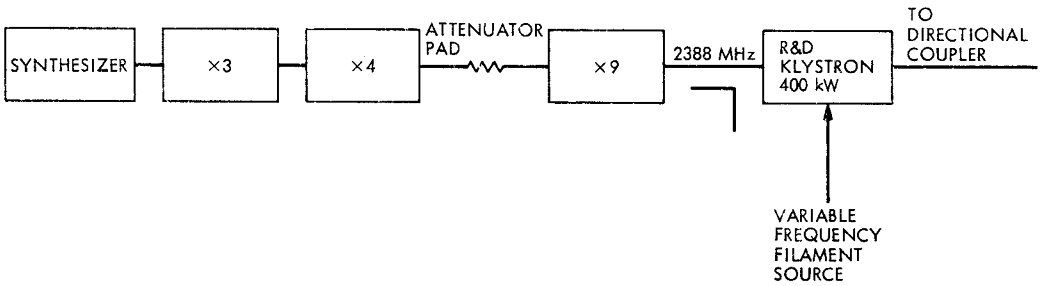

Fig. 1. RF drive chain

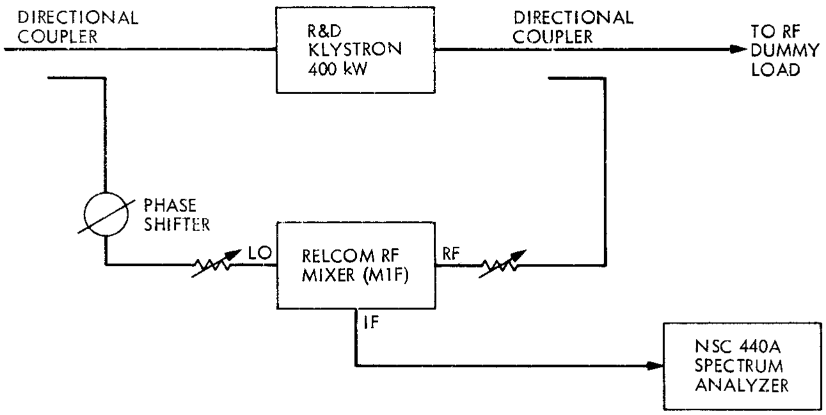

Fig. 2. Intermodulation setup

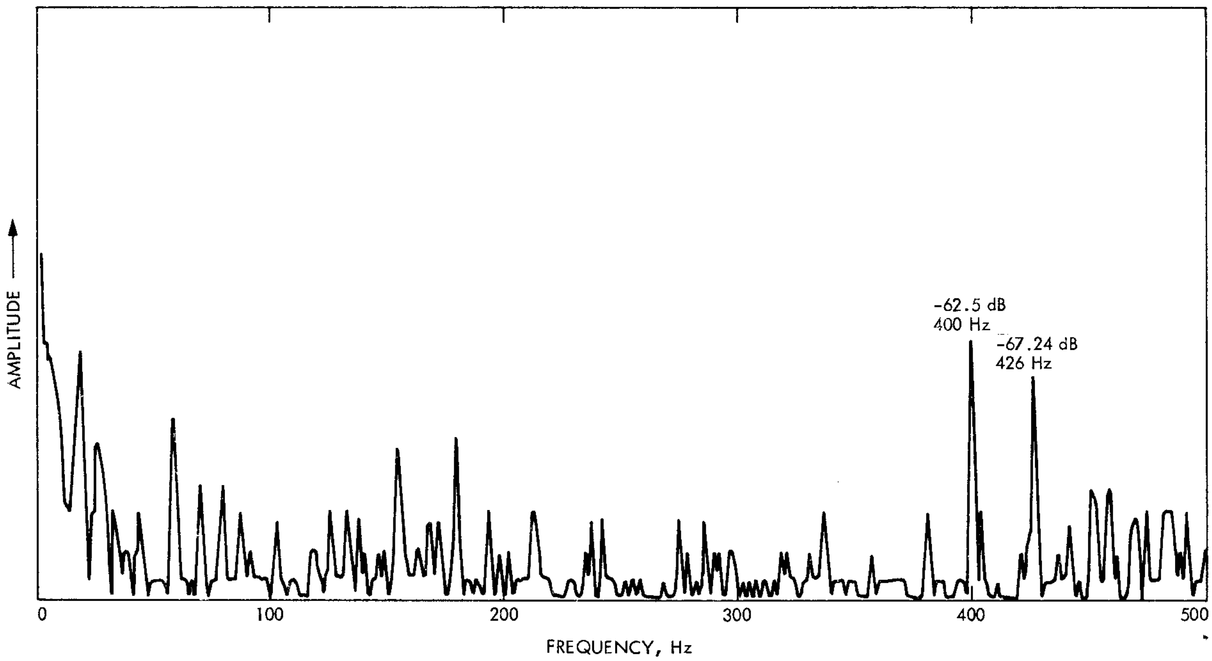

Fig. 3. Modulation due to AC filaments at 426 Hz

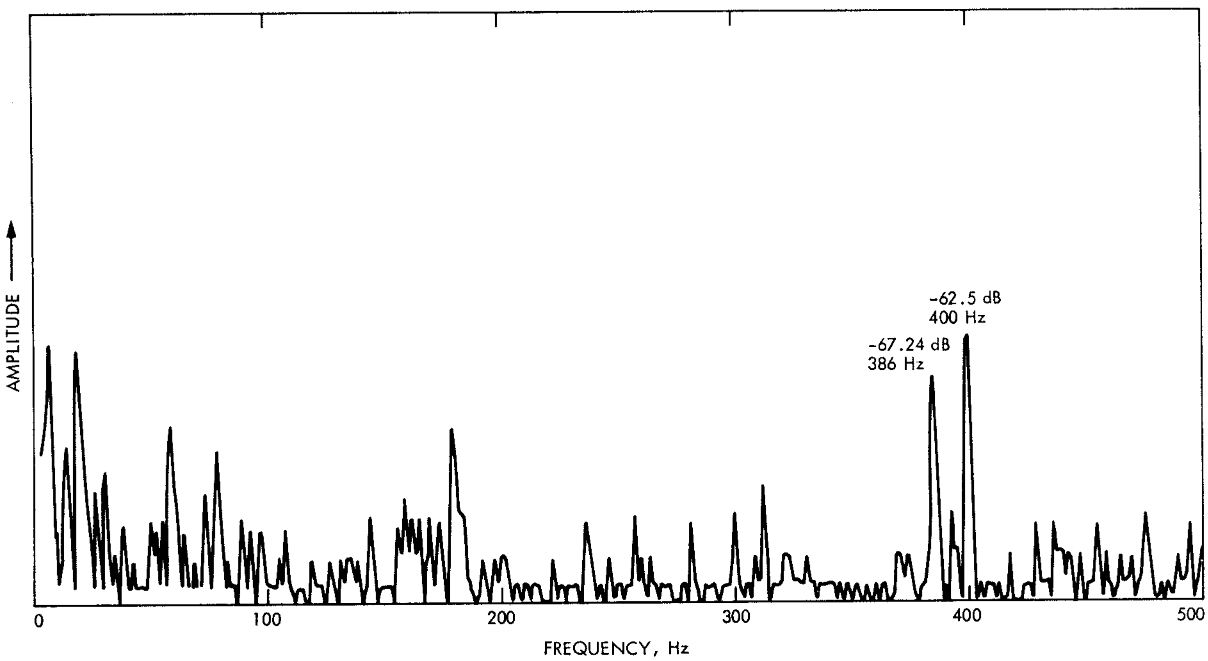

Fig. 4. Modulation due to AC filaments at 380 Hz

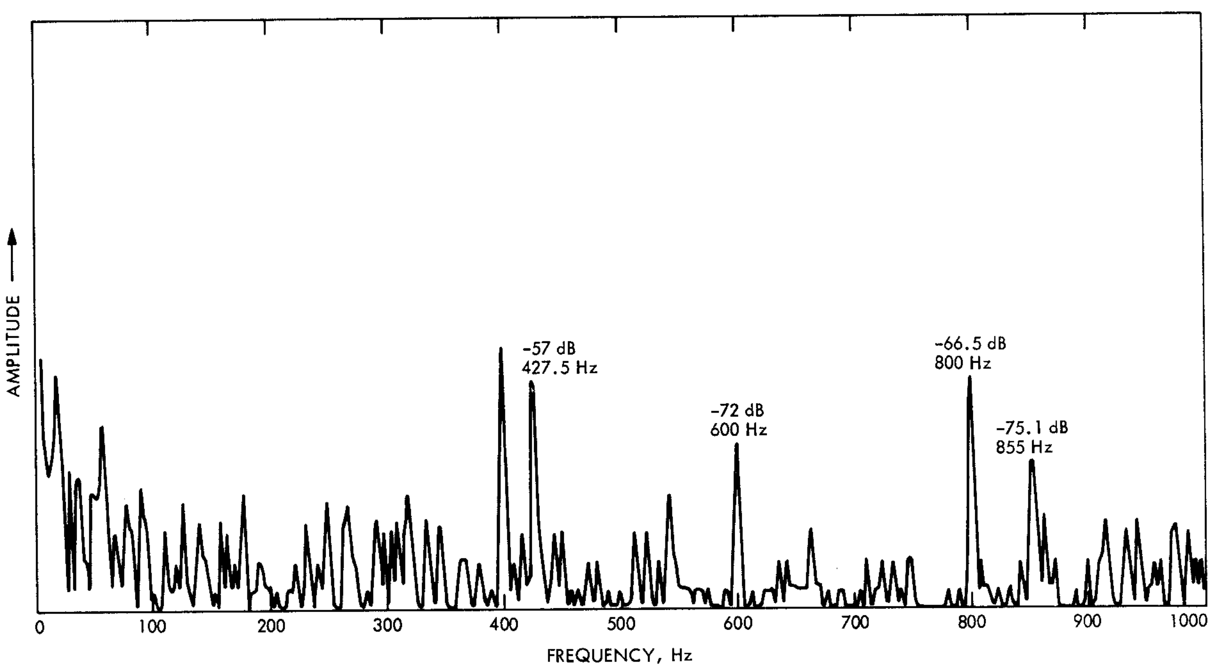

Fig. 5. Second harmonic modulation due to AC filaments (855 Hz)