III-7. AN ELECTRICALLY-TUNED PARAMETRIC AMPLIFIER

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A parametric amplifier is a device which normally can be tuned only over relatively restricted frequency ranges. One of the basic reasons for this tuning difficulty is the fact that more than one frequency range is of importance: In addition to the signal frequency, a pump frequency and one or more sum or difference frequencies must be considered. For example, one could construct a tunable parametric amplifier by using a fixed-tuned broadband signal circuit, a tunable pump source, and a fixed-tuned difference or sum frequency circuit. Or, one could use a fixed-tuned broadband signal circuit, a fixed-tuned pump source, and a tunable difference or sum frequency circuit. A third approach would be to use tunable signal and sum or difference frequency circuits, together with a fixed-frequency pump source.

In this paper a tunable parametric amplifier using the last of these approaches is described. This amplifier is unique in two respects. One is that the amplifier is electrically tuned through the use of yttrium iron garnet (YIG) resonators. Secondly, useful low-noise performance has been achieved over a tuning range of almost one octave. This amplifier thus successfully demonstrates that the technique of magnetic tuning with YIG resonators can be applied to a device as complex as a parametric amplifier in much the same manner as it has been applied in the past to microwave bandpass and bandstop filters.

The amplifier is of the negative-resistance, non-degenerate type, using a varactor diode for the nonlinear reactance. In many respects the amplifier is of conventional design. The signal circuit operates in S-band with a fixed-tuned pump at 17 gc. Two YIG resonators are coupled to the diode to form the tunable resonant circuits at the signal frequency and the idler frequency. Separate magnetic bias circuits are used to tune the signal and idler resonators with proper tracking of the two achieved electronically by means of the associated tuning control circuitry.

A schematic representation of the amplifier is shown in Figure 1. The signal and idler circuits are of coaxial construction. Between the signal input and the varactor is a conventional low-pass filter structure which is cutoff at the pump and idler frequencies. On the opposite side of the varactor a length of shorted coaxial line is used to couple to two appropriately placed YIG resonators, one for the signal circuit and one for the idler circuit. Pump power is coupled to the diode through a simple single-tuned waveguide bandpass filter.

There are two major design considerations involved in the placement of the YIG resonators: The position of the resonators with respect to the varactor, and the degree of coupling of the resonators to the varactor. These parameters can best be understood by considering the equivalent circuit of a YIG resonator coupled to a TEM mode transmission line. Such an equivalent circuit is shown in Figure 2. On the basis of this equivalent circuit, it can be determined that the proper spacing of the signal circuit YIG resonator is at the end of a shorted transmission line, approximately a quarter wavelength from the varactor. Under this condition the equivalent circuit of the varactor and the YIG resonator at the signal frequency is as shown in Figure 3. The resonant frequency is given by

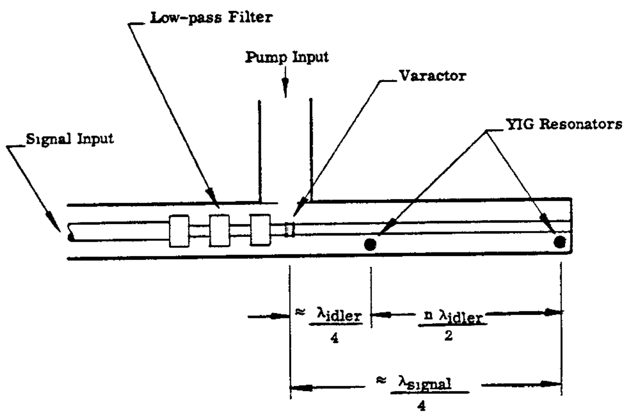

Figure 1. Schematic Representation of the Electrically-Tuned Parametric Amplifier

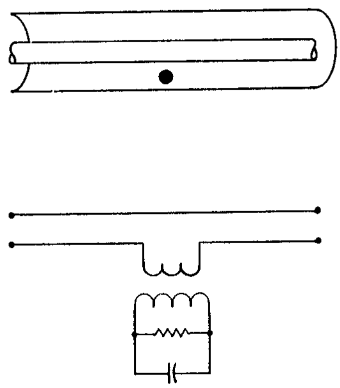

Figure 2. Equivalent Circuit of a YIG Resonator Coupled to a TEM Mode Transmission Line

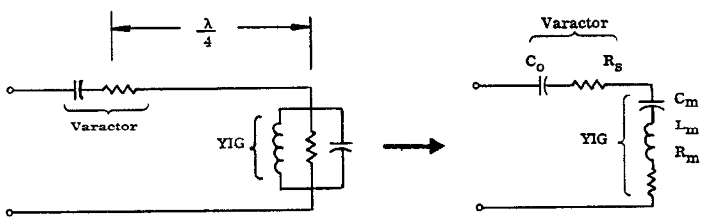

Figure 3. Equivalent Circuit of the Varactor-YIG Combination

$$\omega = \left[\frac{C_o C_m L_m}{C_o + C_m}\right]^{-\frac{1}{2}}$$

$$\simeq (C_m L_m)^{-\frac{1}{2}}$$

$$\text{when } C_m << C_o .$$

We thus see that the resonant frequency of the signal circuit is completely determined by the YIG resonator if sufficient coupling to the YIG resonator is achieved.

A further condition on YIG resonator coupling is obtained by considering the effect of YIG loss on the amplifier noise figure. This consideration leads to the following relation:

$$\frac{f_c}{f} \frac{C_o}{C_m} \frac{1}{Q_{YIG}} << 1 ,$$

where f_c is the varactor cutoff frequency and Q_{YIG} is the unloaded Q of the YIG resonator. For proper operation of the amplifier, the following conditions must therefore be satisfied:

$$1 << \frac{C_o}{C_m} << \frac{f}{f_c} Q_{YIG} .$$

The idler circuit is of almost identical configuration. Again, a quarter wavelength spacing between varactor and YIG resonator is used. In this case it is not possible to have a short circuit in the transmission line immediately after the resonator. Proper operation can be achieved, however, if the distance between the YIG resonator and the shorted line is approximately an integral number of half-wavelengths at the idler frequency.

A photograph of the experimental amplifier, complete with pump source, circulator, and magnetic tuning assembly is shown in Figure 4. Test results indicated that the best performance was obtained over the frequency range 2.2 gc to 3.3 gc, with useful performance extending to 4 gc. Thus it was possible to achieve operation over almost an octave in frequency. Over the range 2.2 gc to 3.3 gc, "single-knob" electrical tuning was employed, with no adjustment of pump power. Gain and noise figure for this mode of operation are as indicated in Figure 5. By separately tuning the signal and idler circuits and trimming the pump level, operation at about 25 db gain was achieved over the frequency as shown in Figure 6. The 3 db bandwidth for the "single-knob" tuning case varied between 5 mc and 14 mc, while in the optimized mode the bandwidth varied between 8 mc and 17 mc.

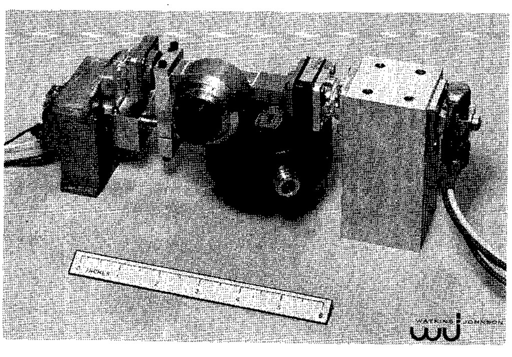

Figure 4. Photograph of the Experimental Parametric Amplifier

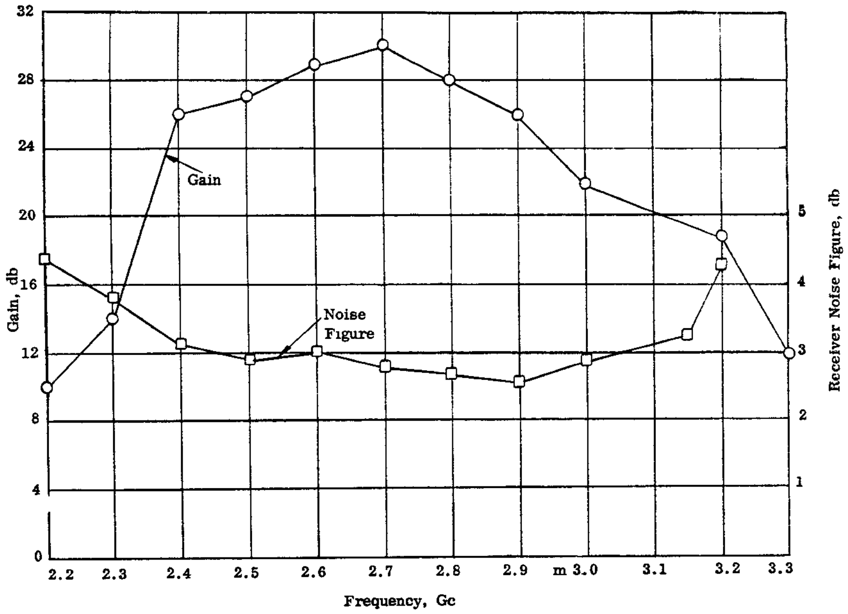

Figure 5. Gain and Noise Figure Performance of the Electrically-Tuned Parametric Amplifier. "Single-Knob" Tuning, Fixed Pump Level, 14 db Noise Figure Second Stage

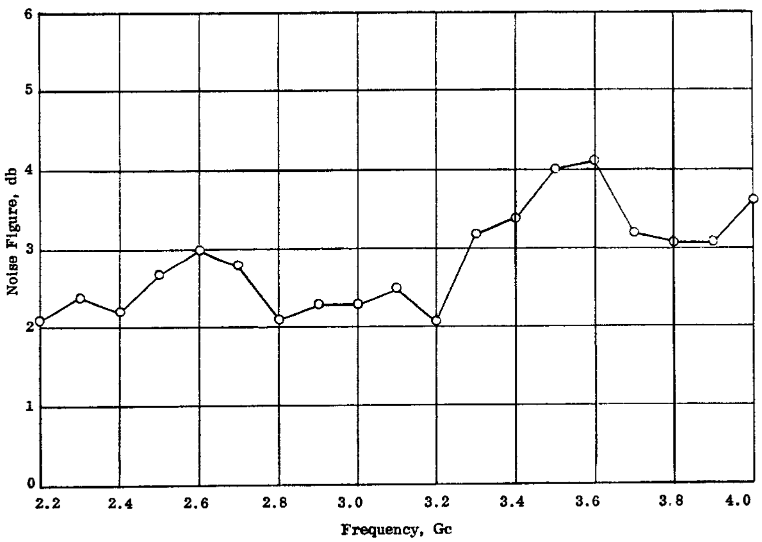

Figure 6. Noise Figure Performance of the Electrically-Tuned Parametric Amplifier. Optimized Tuning, with Pump Level Adjusted to Give 25 db Gain, 9 db Noise Figure Second Stage