2.3 A NOVEL TRAVELING-WAVE PARAMETRIC AMPLIFIER

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The traveling-wave parametric amplifier to be described in this paper consists of a TEM line-over-plane transmission line periodically shunted by eight varactor diodes to propagate the signal and idler frequencies and a waveguide paralleling this transmission line to propagate the pump frequency. The pump power is lightly coupled to each diode by means of probes, the sign of the coupling alternating from diode to diode. This effectively introduces an additional 180-degrees phase shift per section along the pump line, producing several interesting features of this simple configuration.

A cross-section through the experimental amplifier is shown in Fig. 1. The width of the pump waveguide is variable in order to vary the pump phase velocity. This amplifier exhibited several regions of amplifications. One is a broadband region around the degenerate frequency when pumped at 3100 Mc. Gains of over 20 db are obtained in the forward direction over 15 percent bandwidths, as shown in Fig. 2. At the same time, the amplifier exhibited very high losses in the reverse direction, also shown in Fig. 2. It has been possible to find regions in which the reverse loss is everywhere greater than the forward gain, meaning that the amplifier remains unconditionally stable, and cannot oscillate even with short circuits at each port. Figure 2 which shows the responses of the amplifier with different pump powers also illustrates the fact that this mode of operation is remarkably insensitive to changes in the pump power. The actual pump power used by the diodes is only a small fraction of the total indicated in the figure, since most of the applied power is dissipated in the load terminating the pump waveguide.

A second interesting mode of operation occurs when same amplifier is pumped at much higher frequencies as shown in Fig. 3. In this case, a relatively narrow-band response is obtained that can be tuned from about 950 to 1350 Mc as the pump frequency is varied from about 3700 to 4100 Mc. In this case the amplification is more nearly bilateral and the idler frequency remains nearly constant within the stop band of the periodically loaded line.

The graphical analysis of traveling-wave amplifiers using the familiar ω-β diagrams will be briefly reviewed and a novel method of comparing various designs will be described. Figure 4 illustrates the solutions to the traveling-wave parametric amplifier equations for a particular design, the normalized signal and idler frequencies, $\omega_1 \ell / c$, and $\omega_2 \ell / c$, plotted vs. the normalized pump frequency, $\omega_3 \ell / c$, where ℓ is the length of line between diodes and c the velocity of light in the medium. Both forward- and backward-wave solutions are included, as well as solutions for uniform coupling from each diode to the pump line and solutions for the alternating coupling mentioned above. An auxiliary grid shows the best noise figure that can be obtained at each place in the band. The $\beta_3 \ell$ scale along the top of the figure, found from the ω-β diagram of the pump waveguide, indicates the degree of unilateral or bilateral amplification at each place in the band (bilateral at $\beta_3 \ell = 0, \pi, 2\pi, \ldots$ and nearly unilateral at $\beta_3 \ell = \pi/2, 3\pi/2, \ldots$).

The research reported in this paper was supported by Wright Air Development Division under contract AF 33(616)-5803.

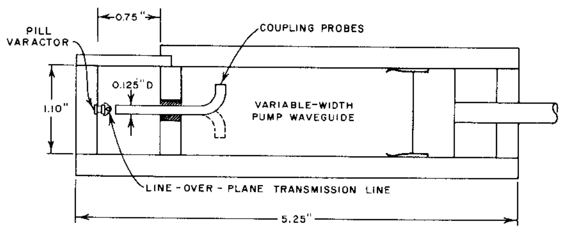

Figure 1 - Cross-Section of Traveling-Wave Parametric Amplifier.

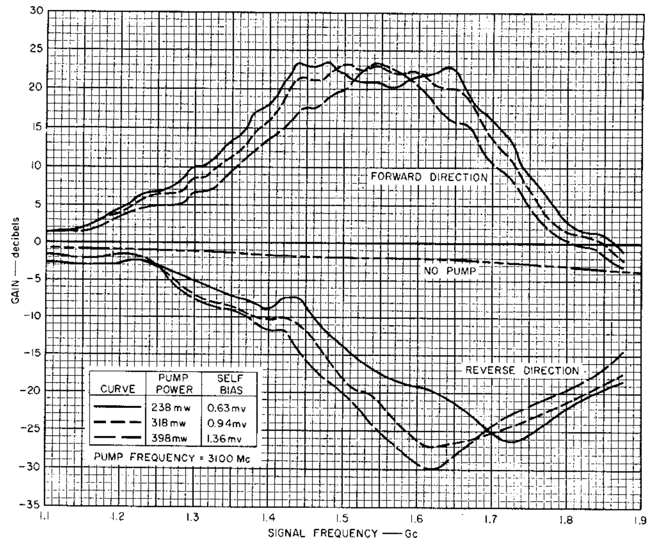

Figure 2 - Frequency Response of Amplifier for 3100-Mc Pump.

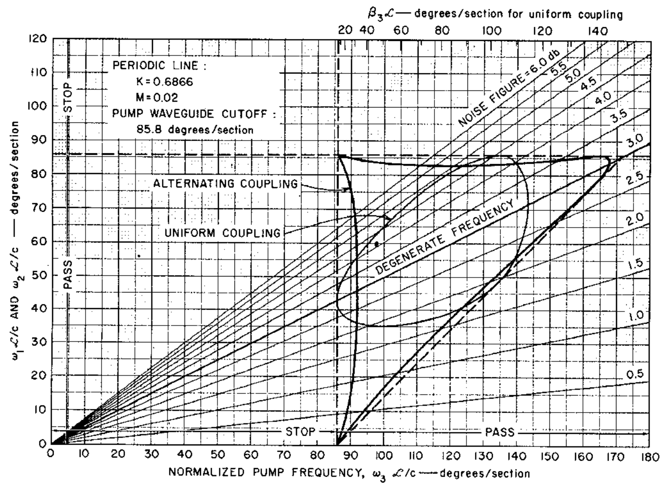

Figure 3 - Frequency Response of Amplifier for Several High Pump Frequencies.

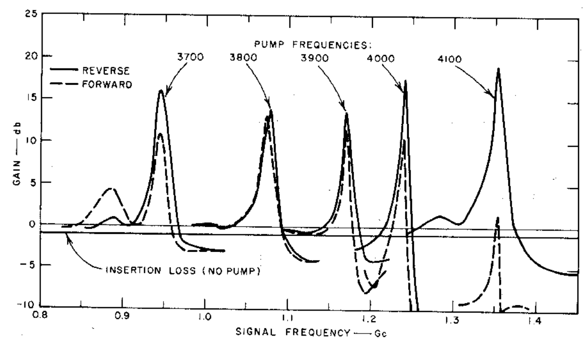

Figure 4 - Parametric Amplifier Solutions.