9.1: MULTIPLE PUMPED PARAMETRIC AMPLIFIERS

GEORGE C. SPACEK

General Motors Corporation, Defense Research Laboratories
Santa Barbara, California

A new concept in the field of parametric amplifiers has been evolved which provides significant increase in the gain-bandwidth product and stability of such devices. The concept involves the use of two independent pump sources of different frequencies. In this paper, the basic idea of multiple pumping is described and the analysis of double pumped parametric amplifiers is given. The experimental results obtained with such devices at VHF and microwave frequencies are reported.

The basic bandwidth limitation of the varactor parametric amplifier is the presence of the parasitic reactances (i. e., static capacitance and lead inductance) of a practical varactor. Because the varactor is used as coupling element between the signal and idler circuits, these parasitic reactances effect the bandwidth of both these circuits. There is, however, an essential difference between the maximum obtainable signal bandwidth and the maximum obtainable idler bandwidth:

Firstly, in the case of single tuned circuits, the Q of the signal tank is always lower than the Q of the idler circuit because the former is loaded by the signal generator (and/or load) conductance and varactor loss conductance, while the idler tank is loaded by the varactor loss conductance only. This results, of course, in larger fractional bandwidth and in almost all cases, also in larger absolute bandwidth of the signal tank, because the optimum idler frequency is not much higher than the signal frequency for presently available varactors and frequencies at or above S band.

Secondly, the bandwidth of the signal circuit can be made wider by a bandfilter structure as shown by Matthaei[1], and by Seidel and Herrmann[2], while a bandfilter structure for the idler circuit is not permissible. The reason is that a bandfilter structure requires resistive terminations, which are available for the signal circuits, i. e., positive conductances of the signal generator and load on one side and negative conductance of the varactor on the other side, while a bandfilter in the idler structure calls for an external resistive termination which would increase substantially the noise figure of the amplifier, especially if the idler termination is at room temperature. Even if one is willing to accept liquid helium or nitrogen cooling of the idler termination, such an amplifier requires considerably more pump power than an amplifier with singly tuned idler tank. In addition to it, it is more difficult to design a satisfactory idler bandfilter than a signal bandfilter, because the requirements for the flatness of the bandfilter are more strict for the idler circuit.

Thirdly, it is possible to design a parametric amplifier with no signal resonant structure at all, as suggested by S. T. Fisher[3].

From the above, it follows that if the most attractive characteristic of the parametric amplifier, i. e. low noise figure, is to be conserved, one has to use a singly tuned idler circuit only, while either multiply tuned circuit or no resonant structure at all for the signal circuit can be used. Or, in other words, the overall bandwidth of a single pump parametric amplifier is always limited by its idler, rather than signal bandwidth and no conventional broadbanding technique can increase the amplifier bandwidth behind the bandwidth of the singly tuned idler tank, as determined by the Q of the varactor at the idler frequency. The overall bandwidth of the amplifier can be increased considerably, however, if two pumps at different frequencies are used. In this case the one pump frequency will produce with some signal frequency an idler frequency which is equal to the self resonant frequency of the idler tank, and the other pump frequency will produce with some other signal frequency an idler frequency which is also equal to the self resonant frequency of the idler tank. Intuitively, one would expect that the bandwidth will increase in this case by a factor of two. Actually, experiments and analysis showed that double pumping of a parametric amplifier improves its performance in many other ways:

Firstly, the bandwidth increases more than twice, because the spectrum of a double pumped varactor has many sidebands on each side of the two pump frequencies, all of them contributing to the amplification process. In addition to this, the filling ratio of a double pumped varactor is about 40 per cent bigger than for the same varactor driven by one pump.

Secondly, the gain stability increases considerably, because the slope of the pump-power versus gain function is smaller in the neighborhood of the most practical gains and because the gain depends on two independent pump powers, introducing a "redundancy" effect.

Thirdly, the total pump power required is reduced, provided that filters are used to prevent interchange of pump power between the sources.

Finally, in many cases, the idler frequency can be chosen with respect to minimum noise figure only, thus avoiding the necessity of compromising between the optimum design in terms of noise figure and bandwidth.

In this paper, the Manley-Rowe equations for a double pumped parametric amplifier are derived and expressions for its gain and input admittance are given. The analysis indicates that a double pumped parametric amplifier is electrically equivalent to a series of cascaded, staggered tuned parametric amplifiers where each stage amplifies over a different frequency range as determined by the frequency and amplitude of the particular component of the double pumped varactor spectrum and where the bandwidth of each stage is equal to the effective bandwidth of the idler structure. The pump power and stability of a single pumped and double pumped parametric amplifier is analyzed and compared.

The results of experiments with double pumped parametric amplifiers at VHF and 7 kMc/s are reported. The experiments showed that the bandwidth of a double pumped parametric amplifier is typically 8 times as big as the bandwidth of a single pumped parametric amplifier. Stable power gains of 30 db were achieved, about 5 to 10 db more than the maximum stable gain of the same parametric amplifier driven by one pump only.

It appears to us that a double pumped parametric amplifier solves very radically the bandwidth problem so far encountered with a conventional single pumped parametric amplifier. Theoretically, bandwidths almost equal to the bandwidth of positive resistance parametric amplifiers (upper-sideband upconverters) could be obtained if even more than two pumps were used. The multiple pumped parametric amplifier is especially important at frequencies above S band, where wide, extremely flat bandfilters are difficult to achieve and strong pump sources are not available.

---

1. G. L. Matthaei, "A Study of the Optimum Design of Wide-Band Parametric Amplifiers and Up-Converters," Trans. IRE MTT-9, 23-38 (1961)

2. H. Seidel and G. F. Herrmann, "Circuit Aspects of Parametric Amplifiers," 1959 WESCON Convention Record, Pt. 2, 83-90.

3. S. T. Fisher, "Theory of Single-Resonance Parametric Amplifiers," Proc. IRE 48, 1227-1232 (1960).