AN ACTIVELY BROADBANDED MIC PARAMETRIC AMPLIFIER

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ABSTRACT

The design, construction and performance of an actively broadbanded MIC parametric amplifier is described. The broadbanding technique is simple with no multiple tuned circuits; the result is a 500 MHz bandwidth amplifier at 7.5 GHz that is five times less susceptive to pump instability than one of conventional design.

Introduction

Satellite communication systems continue to demand wide-band low noise amplifiers and the exploitation of the higher frequency bands will retain interest in non-degenerate parametric amplifiers. This paper describes the design, construction and performance of a parametric amplifier for the 7.25-7.75 GHz frequency range; the circuit can be readily scaled to operate through X-band. The novel features of the design are the broadbanding technique and the MIC realisation. The broadbanding is by an active technique which permits a simple realisation for a significant increase in bandwidth without involving multiple tuned circuits; the result is a broadband paramp that is also at least five times less susceptible to pump instability than an amplifier of conventional design. This broadbanding technique requires no critical adjustment of stub lengths and has enabled the circuit to be designed in microstrip. A passively compensated design has also been made and characterised and this offers a direct comparison between the two techniques.

A further major problem in the design of a microstrip paramp concerns the requirement for a high frequency, low loss filter to confine idler currents to a well defined circuit. For this purpose a novel circuit utilising a spur line filter has been developed. The paper describes the broadbanding technique and the MIC design which includes a Gunn oscillator specifically designed for use with this broadband technique and summarises the performance achieved with practical amplifiers.

Principle of Operation

Active broadbanding uses two single tuned amplifiers which are separately pumped from a single source. The principle of active broadbanding has been studied analytically, numerically and experimentally. As originally envisaged[1,2] the principle of active broadbanding was an extension of the passive broadbanding approach[3] in which a parallel resonant circuit shunt connected across a series resonant input to a single tuned amplifier compensates the reactance versus frequency slope resulting in increased bandwidth. In active broadbanding the shunt parallel resonance is provided by transforming the series resonance of a second amplifier through a quarter wavelength transmission line.

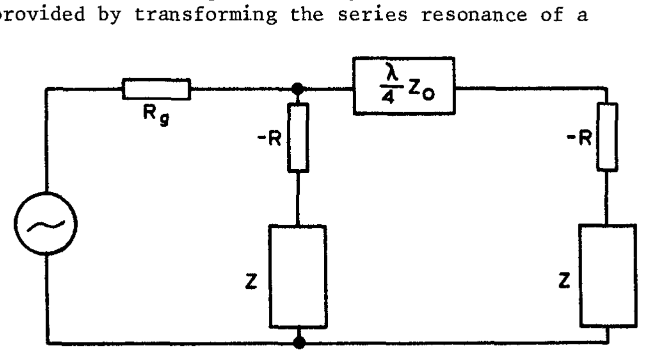

Fig.1 Schematic of active broadband amplifier

If analysed for the 'reactance-compensation' condition a single solution of $Z_o = |R|$ is obtained; as mentioned by Watson[4] this is a high ripple condition. However, it is shown later that by analysing this condition for stability, although a stable operating point it is found not to be physically realised in a parametric amplifier. It is considered that the equivalent negative resistance of a paramp builds up from a small magnitude when the pump power is supplied; the above circuit goes into oscillation at the band edges for $|R| < Z_o$.

In order to achieve a maximally flat bandwidth in the general case, two degrees of freedom are required. For convenience in setting up an active broadband amplifier it is usual to combine two single amplifiers which have been previously aligned. The two most readily varied parameters to achieve the required degrees of freedom are the impedance of the coupling line and the generated equivalent negative resistance due to the pumping of the varactor diodes. This precludes each of the single tuned amplifiers from using impedance transformers of an odd number of quarter-wavelengths; the susceptance slope across the band is then a function of transformer impedance and this is not generally compatible with the required source impedance of the diode.

An analysis based on a low pass prototype, figure 1, with Z replaced by an inductance and a frequency invariant impedance inverter in place of the $\lambda/4$ line, gives values for Z_o and the negative resistance (R) for both maximally flat and double humped gain responses. It is assumed that the plot of admittance loops in the G, B plane and the double humped condition chosen is that which gives equal gains at the three frequencies at which the susceptance is zero (band centre and two others).

For the double humped design

$$R = \frac{2Q}{2-Q^2} \quad \text{and} \quad Z_o^2 = \frac{4}{2-Q^2} = \frac{2R}{Q}$$

where $Q = \dfrac{\sqrt{G_{no}} - 1}{\sqrt{G_{no}} + 1}$ and G_{no} is band centre gain.

and R and Z_o are normalised with respect to the source impedance R_s.

For G_{no} = 10 dB this yields a gain ripple of 2.25 dB (the ripple varies with G_{no}).

For the maximally flat design.

$$R = \frac{Q}{2}\left|(5 - Q^2) - \sqrt{(9 - Q^2)(1 - Q^2)}\right|$$

and $$Z_o^{\,2} = \frac{1}{2}\left| 3 + 6Q^2 - Q^4 + (1-Q^2)\sqrt{(9-Q^2)(1-Q^2)}\right|$$

$$= 4 - \frac{(1-Q^2)R}{Q}$$

Since $0 < Q^2 < 1$ we find that for the maximally flat condition.

$0 < R < 2$ and $\sqrt{3} < Z < 2$.

For values of $Z < \sqrt{3}$ the amplifier goes unstable at the band edge for small values of R.

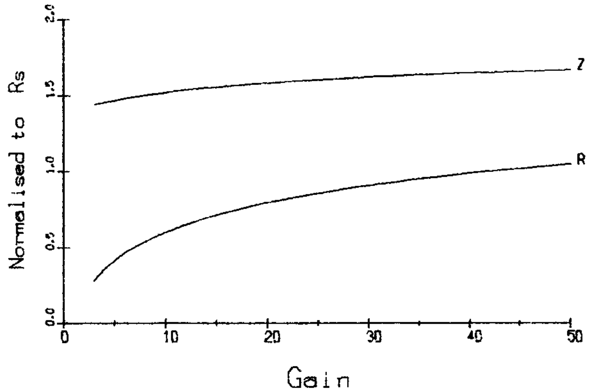

Fig.2 Double humped design

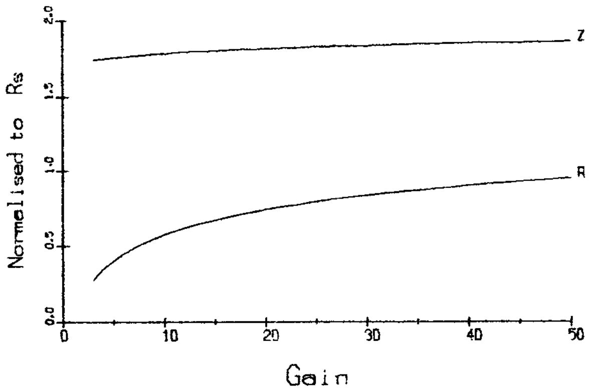

Fig.3 Maximally flat design

Figure 2 shows normalised R and Z_o values against Gain (ratio) for double humped design and Figure 3 the values for maximally flat design.

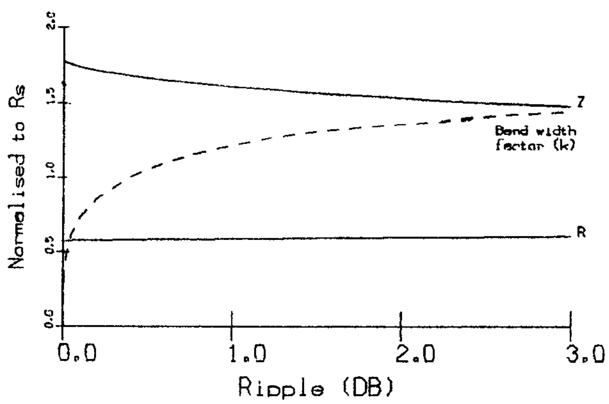

Fig.4 R & Z for various ripple values. Gain = 10.

Using a simple computer program to solve non-linear simultaneous equations it is possible to find R and Z_o values to give a response with any desired ripple and band centre gain using the above values for R and Z as starting estimates.

Figure 4 shows Z_o and R values against ripple for a band centre gain of 10 and it is seen that Z_o is the controlling variable, R being nearly constant over the ripple range plotted.

The bandwidth factor k is also plotted.

To transform this prototype to a bandpass design the following apply:

$$L = \frac{R_s k}{\Delta\omega} \qquad C = \frac{\Delta\omega}{k R_s \omega_o^{\,2}}$$

where ω_o is centre frequency $\Delta\omega$ = bandwidth and k is the bandwidth factor (Figure 4). In practice it may not be possible to vary L and C at will in which case one can predict the likely bandwidth from :

$$\frac{\Delta\omega}{\omega_o} = \frac{k R_s}{\sqrt{L/C}}$$

Final gain ripple and bandwidth prediction was computed from a more complete circuit model with lossy transmission lines and circuit discontinuities in the signal circuit together with idler circuit and diode parameters.

Computer modelling indicated that the active broadband amplifier is more than ten times less sensitive to pump instability at the centre band and about five times less sensitive at the band edges when compared to a single tuned amplifier at the same (15 dB) gain.

The microstrip amplifier circuit

Both passive and active broadbanding techniques have been applied to the basic single tuned MIC amplifier circuit.

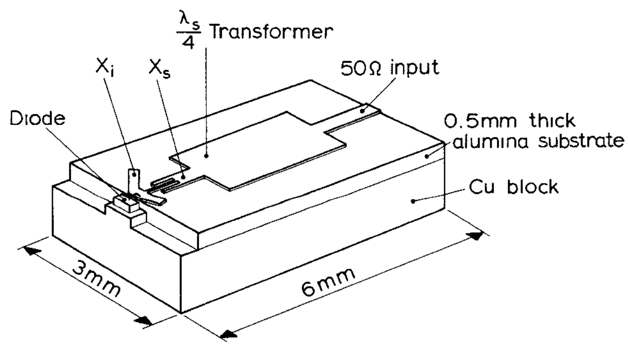

Fig.5 The MIC single tuned parametric amplifier

Single tuned amplifier circuit design

A diagram of the amplifier circuit is shown in Figure 5. The signal circuit consists of a transformer to present the required source resistance to the diode and an inductive length of high impedance line. Signal circuit resonance is achieved by etching the mesa to resonate with this line. As this etching process is done with the diode in its operational position, precise control of resonant frequency can be achieved. (Typically better than 50 MHz). The high impedance transmission line forms part of a spur line filter structure that was developed for this application. This band stop filter supports the odd microstrip mode and operates satisfactorily up to 40 GHz. Idler energy is confined to the immediate vicinity of the diode, the diode capacitance and bond wire inductance form part of the idler circuit which is completed by an open circuit stub. To avoid the shunting effect of this stub at the pump frequency an additional stub is added. The transformer nearest the diode has a narrow slot down the centre line to prevent transverse modes being excited in the microstrip which can form resonant circuits at, or near the idler frequency.

The diode is in chip form to minimise stray reactances and is mounted off the substrate on the substrate support. Pump power is matched to the diode direct from the pump waveguide by a waveguide transformer and inductive iris. The guide is cut off below 30 GHz to confine further the idler energy to the vicinity of the diode. The single tuned paramp circuit 1 dB bandwidth is 70 MHz at 15 dB gain. The noise figure is 1.9 dB including a microstrip circulator.

Passive double tuned amplifier

The practical realisation of a passive double tuned microstrip circuit will be briefly described and the problems highlighted to indicate the benefits of the preferred active broadband solution. A 1 dB bandwidth of 300 MHz has been achieved, the noise degradation was 0.3 dB.

The active compensated amplifier

Active broadbanding uses two single tuned amplifiers which are separately pumped from a single source. The pump oscillator is described; it is an extension of a single diode post coupled design[7]. In the configuration used the resonant cavity is formed in a waveguide transmission line thereby providing two output ports and the power from each port can be equalized (Figure 6).

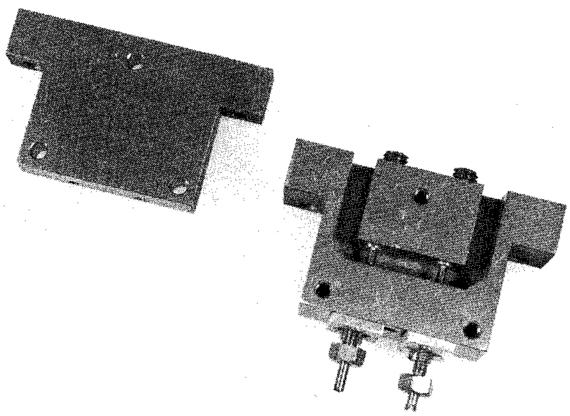

Fig. 6 Photograph of double Gunn oscillator

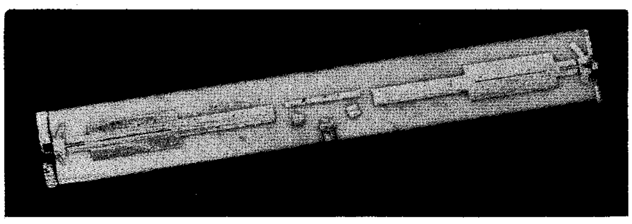

Fig. 7 Photograph of the active broadband amplifier circuit

A photograph of the amplifier circuits is shown in Figure 7. The input and coupling lines are finally joined after setting up each half of the amplifier. Provided the halves are closely similar only adjustment of the coupling line impedance is necessary for optimum bandwidth. The insensitivity to pump instability is close to the computed prediction, pump amplitude changes of up to 1 dB being tolerable. A photograph of the gain frequency response is shown in Figure 8. The 1 dB bandwidth is in excess of 550 MHz with 0.25 dB ripple. The noise figure is 1.9 dB, including a circulator.

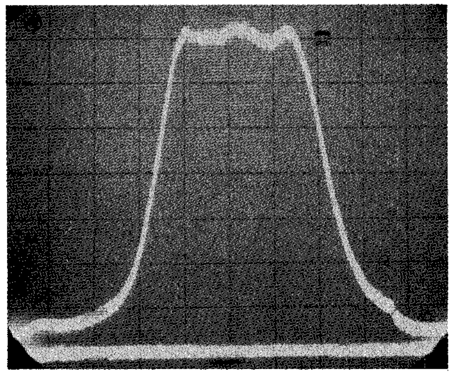

Fig. 8 Photograph of gain frequency characteristic of the active broadband amplifier

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The valuable contribution to the work by R Davies, and the development of the pump oscillator by I D Higgins and A P Tod is gratefully acknowledged.

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