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On the use of a solid-state maser as a non-reciprocal amplifier

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Résumé. — Nous avons construit un maser pour amplifier la fréquence de 1420 MHz. La fréquence à saturer est 4000 MHz. La plus grande difficulté dans l'ensemble générateur-maser-détecteur est d'éviter l'amplification du bruit du détecteur arrivant à la cavité du maser

Afin d'obtenir ce résultat, il nous faut un élément non réciproque dont la construction est délicate pour des longueurs d'onde élevées.

Nous nous proposons d'utiliser les propriétés non réciproques du maser lui-même quand la polarisation de la magnétisation est circulaire.

Un système non réciproque est étudié.

The solid-state maser [1] offers the possibility of amplification at U.H.F. and microwave frequencies with a very low noise figure. A number of regenerative amplifiers have been constructed [2, 3, 4, 5, 6, 7] using a paramagnetic salt at liquid helium temperatures, and for these the noise introduced in the amplifying process is expected to correspond to a temperature of about 2° K. It has not been possible so far to construct a low noise maser amplifier without adding non-reciprocal elements, since otherwise the maser would amplify the large amount of noise arriving from the mixer crystal in its output line. At centimetre wavelengths a circulator has been used [8] to shield a reflection-cavity maser from the mixer; noise is introduced by the forward loss in the circulator, and the experiments of Mc Whorter and Arams [8] show that it is desirable to cool the circulator as well as the input line. Alternatively one can use a transmission cavity maser with an isolator in its output line. The isolator has to be cooled to very low temperatures to reduce the thermal noise which it radiates toward the maser.

At longer wavelengths no circulators or efficient isolators have yet been developed, and the attainment of low-noise amplification has been thought to await the development of such non-reciprocal devices. We wish to point out that in solid-state masers there is a sense of polarisation associated with the precession of the spins of the paramagnetic ions about the static magnetic field which can be used to develop a non-reciprocal amplifier with a low excess noise.

Consider the case in which the transverse magnetisation between the " amplifying " levels of the paramagnetic ion is circularly polarised. Then if the crystal is in a cavity which contains circularly polarised radio frequency fields, only one polarisation will be amplified, the other not being affected.

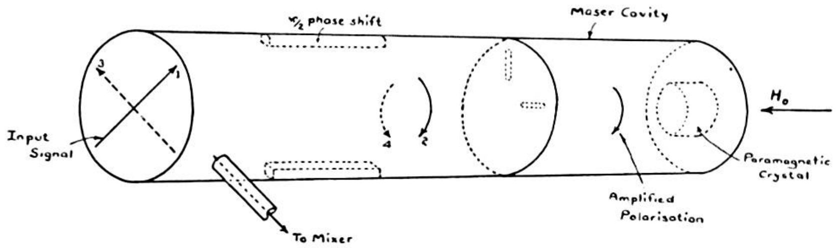

Fig. 1.

(This is simply the inverse of the process occurring in an isolator in a travelling wave system). It is possible to design the coupling to the output line of the maser so that the receiver noise will excite in the cavity only the non-amplified polarisation. One could use the arrangement which Marie [9] has described for a resonant isolator, but with a maser crystal in place of the ferrite. However at longer wavelengths this design would become rather difficult to fit into a cryostat.

We propose to use the system shown in figure 1. A cylindrical waveguide carrying the TE_{11} mode is fed by the generator with linear polarisation in direction 1. A quarter wave plate then converts this to a circularly polarised wave, say with a clockwise rotation, which is coupled into a cavity (TE_{111} mode) by suitable irises. We can choose the direction of the static magnetic field so that this polarisation is amplified by the maser. The amplified wave returning along the waveguide is converted into linear polarisation in direction 2 perpendicular to 1 and picked up by the line to the mixer. Noise emitted by the mixer (which in practice has a noise temperature of about 2000° K) is converted by the $\lambda/4$ plate to anticlockwise circular polarisation, and is therefore not amplified but mainly reflected. If now the generator (antenna) is matched to the guide with a V.S.W.R. better than 1.04, the mixer will contribute less than 1° K to the noise of the maser. This arrangement has the same noise temperature as that reached by a reflection maser with a cooled circulator, while for a given volume of paramagnetic salt the gain is 3 db greater because all the signal energy is coupled to the circularly polarized transverse magnetisation.

The same principle can be used to achieve non-reciprocal amplification for a transmission cavity maser, a quarter wave plate being placed in the output line. The gain will then be lower, and the noise temperature greater.

In general the magnetisation between the amplifying levels is elliptically polarized, and then the maser will amplify both circular polarisations. Thus the mixer noise will undergo some amplification. In practice the excentricity of the polarisation ellipse will be the most serious limitation to the overall performance.

A maser is now being designed to operate at 1420 MHz (pumped on 4000 MHz) which will use the principle described here in an attempt to obtain low-noise amplification for observation of the emission from interstellar atomic hydrogen.

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