MASER AMPLIFIERS

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When the lowest possible noise is required the maser amplifier remains the unquestionable amplifier choice for moderate bandwidth microwave and long wavelength millimeterwave receivers. The reason for the outstanding low noise properties of the maser is partly that it is cooled to a few degrees K ($\lesssim$ 4 K) but also that the amplification process is the most fundamental one, i.e. amplification takes place when quanta (photons) are added directly to the signal field by stimulated emission of radiation from energetically excited particles.

As practically useful devices masers are today used between 1 GHz and 40 GHz at various places around the globe. In Table 1 data are given for a few typical masers in use in radio astronomy.

Table 1. Typical Maser Data

Tunable freq. range GHz	Inst. bandw. MHz	Receiver Noise temp. K	Active material	Operated by
3.2 - 3.5	17	< 10	rutile	Onsala
18 - 26	240	< 15	ruby	NRAO
29 - 35	60	$\simeq 35$	rutile	Onsala

The noise temperature of a maser measured at the input port of the interaction circuit is typically only a few degrees K. It is therefore very important to design the waveguide section between the horn-antenna and the amplifier for minimum loss i.e. minimum noise contribution.

Masers operating up to about 50 GHz should be possible with existing techniques and materials. In the longer time perspective there are a number of possible and very challenging questions in maser development.

B. H. Andrew (ed.), Interstellar Molecules, 615–617.

- Can rutile masers be made to work properly for frequencies between 50 - 150 GHz? An 80 - 90 GHz rutile maser is near completion at Univ. of Massachusetts.

- Are there other paramagnetic materials that can be used in masers for frequencies above 50 GHz, maybe up to a couple of hundred GHz? There are a great number of materials that are not available as large synthetic crystals today, which, however, may be more efficient than ruby or rutile, not only for millimeter waves but also for microwaves.

- Are there other types of materials where phenomena other than paramagnetism can be utilized for maser amplification of microwaves and millimeter waves?

It should be emphasized that the amount of research done on maser materials and also on the design of maser interaction circuits is not very large, so there is certainly room for surprises in the future.

Parametric amplifiers cooled to 4 K are the only type of amplifier that can compete with the maser where low noise is concerned. Such an amplifier has been proposed for 22 GHz with a bandwidth of about 2 GHz and with a noise temperature which is about 30 K at the room temperature input flange. Cooled FET amplifiers with an input noise temperature below 40 K can be built for a few GHz. However, the noise properties for frequencies above 10 GHz become an order of magnitude worse than for masers. Parametric amplifiers also become less competitive for increasing frequencies.

For frequencies above 50 GHz the predominant receiver type today is the Schottky barrier diode mixer. In Table 2 are listed data for existing cooled mixer receivers for about 100 GHz and for room-temperature mixer receivers for 230 GHz. The figures within parentheses indicate what might be obtainable within one or two years using improved Schottky-barrier diodes recently developed at Bell Laboratories and the University of Virginia.

Two different types of superconducting mixers are worked on, the Josephson mixer and the quasiparticle mixer. The latter type particularly is receiving a lot of attention and there is hope that this mixer represents a breakthrough for low noise receivers for short millimeter and sub-millimeter waves. Experiments carried out at Bell Laboratories and University of California indicate noise properties around 100 GHz superior to those of Schottky mixers, and in Table 2 are given probable single sideband data that may be obtained within a year or so. It should be pointed out that the superconducting mixer is operated with a very low pump power, which is a great advantage at very high frequencies. The bandwidths are limited by the if-amplifier used, which is a parametric amplifier for the Schottky mixer and a FET amplifier for the superconducting mixers. To obtain the system noise temperature one has to add the atmospheric and antenna noise, which add 50 - 100 K around 100 GHz.

Table 2.

Mixer type	Freq. GHz	Bandwidth MHz	Rec. Noise K SSB
Cooled Schottky	$\sim$ 100	$\sim$ 500	$\sim$ 300 ($\sim$ 200)
Room Temp. Schottky	$\sim$ 240	$\sim$ 500	$\sim$ 2000
Josephson	$\sim$ 100	($\gtrsim$ 200)	($\sim$ 100 - 150)
Quasi part.	$\sim$ 100	($\gtrsim$ 200)	($\sim$ 150 - 200)

DISCUSSION FOLLOWING KOLLBERG

Morimoto: What limits the bandwidth of the various types of front ends?

Kollberg: The bandwidth of the maser is limited by the natural linewidth of the paramagnetic transition used. It is possible to increase the maser bandwidth by broadening the paramagnetic resonance line using a tuning magnetic field which is inhomogeneous (staggertuned) over the maser crystal, as is done with the maser in the 18-26 GHz band listed in Table 1. The bandwidth of the various mixers is mainly limited by the if-amplifiers used. For the Schottky diode mixers one usually uses a parametric amplifier with about 500 MHz bandwidth. The superconducting mixers are easily saturated by the pump power of a parametric amplifier and therefore for these mixers one uses FET amplifiers with about 100 MHz bandwidth (which might be improved in the future).

Thaddeus: I would like to ask Dr. Phillips at what level the quasiparticle mixer is expected to saturate as compared to the Josephson-junction mixer.

Phillips: It should be noted that the InSb mixer operates to 500 GHz with noise temperatures of 200-500 K, but with a bandwidth of only $\sim$2 MHz. Josephson-junction mixers require a prefilter of about 2-5 GHz to prevent saturation. They saturate at a power about 10^5 lower than the quasiparticle photon-assisted tunneling diodes.