Extremely Low-Noise Cryogenic Amplifiers for Radio Astronomy: Past, Present and Future

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Improvements in the noise temperature of field-effect transistors (FET's) and, later, heterostructure field-effect transistors (HFET's) over the last several decades have been quite dramatic. In 1970, a noise temperature of 120 K was reported at 1 GHz and physical temperature of 77 K. By 2010, noise temperatures of 3, 10 and 25 K were reported at 10, 40 and 100 GHz, respectively, for physical temperatures of about 15 K. These values of minimum noise temperatures in respective bands are typical of cryogenic low noise amplifiers currently being built for NRAO EVLA and GBT receivers and are to be built for ALMA band 1 and 2 receivers.

In the first part of the presentation, the developments in this field are briefly traced and an attempt is made to identify important milestones. Examples of experimental results obtained with different generations of FET's (HFET's) are compared with the model predictions. The current state-of-the-art in cryogenic low noise InP HFET amplifiers is presented and some gaps in our understanding of experimental results are emphasized. Random gain fluctuations of these amplifiers, important for applications in broadband continuum radiometers for radio astronomy, are also shortly discussed.

The second part addresses the question of possible future progress in amplifier noise performance. For that purpose, noise models of unipolar and bipolar transistors are reviewed with emphasis on certain properties of noise parameters which are common to all microwave low noise transistors. The limits on allowable values of noise parameters of microwave transistors are reviewed. Specifically, the influence of further progress in gate length reduction of FET's and technology of artificially structured III-V semiconductors on achievable minimum noise temperatures (noise figures) are discussed. In that light, the question of limits on noise performance of cryogenic microwave field effect transistors is discussed and compared with rapidly advancing technology of SiGe heterostucture bipolar transistors (HBT's).