FUTURE PERFORMANCE LIMITATIONS FOR GROUND AND SPACEBORNE MILLIMETER WAVE RECEIVER SYSTEMS

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ABSTRACT

Recent developments in the technology for millimeter wave receiving equipment make a much more promising case for increased utilization of millimeter waves in telecommunication links. Low system noise figure coupled with large achievable antenna gain in small earth terminals make a good case for millimeter direct satellite broadcast links. Future technology trends indicate that use of the 80-100 GHz region of the spectrum will be beneficial and useful in the 1985-1990 timeframe.

INTRODUCTION

For many years, millimeter wave receiver technology remained for the most part within the jurisdiction of University laboratories and a few government research institutes. This is no longer the case, with major emphasis on millimeter wave receiver and component technology becoming a major factor in both commercial and DOD planning for the next decade and beyond. Coupled with this new interest, is a series of major advances in Solid State component design, particularity in the area of IMPATT, GUNN and GaAs Schottky Mixer performance at millimeter wavelengths. Although transmitter sources at millimeter wavelengths tend to be somewhat lower power than what is commonly used in microwave links, the additional antenna gain resulting from modest aperature area at the shorter millimeter wavelengths makes systems both practical and cost effective. Receiver technology in the near term up through 100 GHz is comparable to that which can be attained at X band and below, and promises to be much better from the standpoint of instantaneous bandwidth in the 1985-1990 timeframe.

NEAR TERM LOW NOISE RECEIVER LIMITATIONS

Unlike previous receiver technology, which centered around the use of whisker-contacted diodes mounted in sections of reduced-height waveguide to enable low conversion loss mixing and downconverting from millimeter wavelengths, new designs currently in production utilize beam-lead Schottky Barrier devices. (1) Use of advanced beam lead diode technology has allowed room temperature downconverters at 94 GHz to be designed and manufactured with less than 8 dB Single Sideband Noise Figure including the IF and back-end contribution. Such performance is typically attained using a low-noise GUNN effect local oscillator and a FET IF amplifier. Bandwidths of greater than 2 GHz can be obtained at frequencies above 75 GHz. Similar performance and a high degree of reliablility can be obtained to at least 140 GHz in near term production-capable designs.

Present beam lead Schottky technology allows for conversion loss in ruggedized commercial mixers which is perhaps 0.5 to 1.5 dB greater than the minimum which can be obtained over the 40 - 140 GHz frequency range. Results very near the theoretical limit for room temperature devices can now be achieved routinely at 35 GHz. Advances in room temperature FET IF amplifiers allow the IF bandwidth to reach several GHz in practical mixer designs making millimeter wavelength receivers even more attractive from the standpoint of spectrum-available bandwidth.

A performance summary of many units developed by the TRG Division of Alpha Industries, appearing in Figure One, points to the general slope of the mixer family over the millimeter frequency range. These are among the lowest noise figures ever achieved in practical production mixers at these frequencies. As is evident, no real performance difference exists for either fundamentally pumped, or subharmonically pumped balanced mixers. All noise measurements have been accomplished without the use of Local Oscillator injection filters and have been independently verified by outside contractors in the systems-industry. The measured response of one such 94 GHz mixer, illustrated in Figure 2, where a broadband 94 GHz noise source with a 12.7 dB ENR, produced a 8 to 9 dB Y factor over the entire 100-1000 MHz IF bandpass used in that design clearly illustrates the broad bandwidths over which low-noise performance can be realized. Less than 5 dB total system noise figure can be attained in room temperature mixers made using these technologies at a cost of less than $2000.00 in 1979 dollars for the entire mixer/ preamplifier when considered in large quantities (1000 pieces or more).

At 35 GHz several other technologies are catching up with resistive mixers such that over the near term it will be practical to field cooled mixers, cooled FET preamplifiers and parametric amplifiers with noise figures all less than 3.0 dB SSB. As is always the case various tradeoff's between the technologies will result in the most practical and cost effective approach being accepted for telecommunications applications. These different approaches are summarized in Table 1, where it may be evident that in the near term the cooled mixer preamplifier is the most practical and highest performance approach to millimeter receiver implementation.

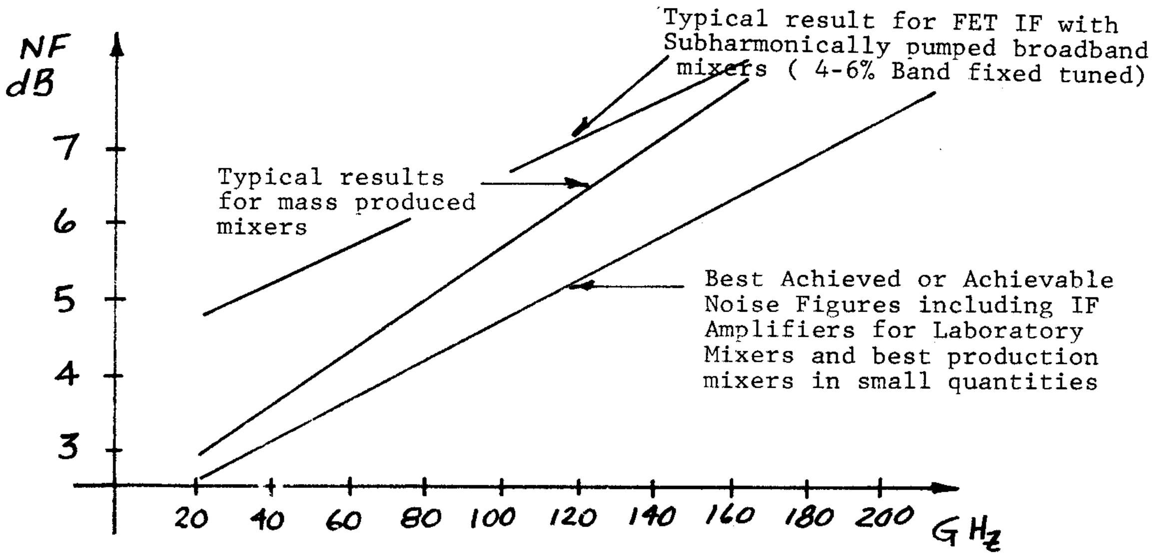


FIGURE ONE -- PRESENT BEAM LEAD MIXER STATE OF THE ART

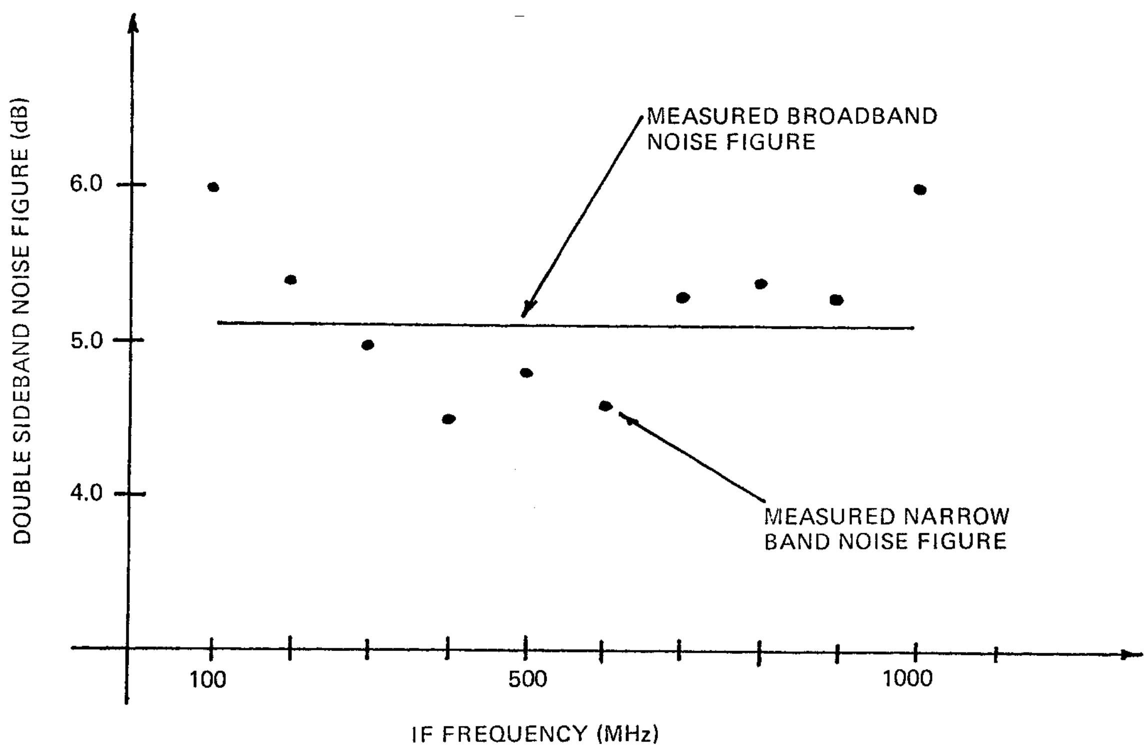


FIGURE TWO -- TYPICAL NOISE FIGURE FOR PRODUCTION MILLIMETER MIXER AT 94 GHz

TABLE ONE
MILLIMETER--NEAR TERM RECEIVER TECHNOLOGY FOR MAJOR GROUND TERMINALS

RF FREQUENCY	RECEIVER TYPE	NF(SSB)	BW(GHz)
35 GHz	Room Temperature Mixer	5.5 dB	1 GHz BW
	Cryogenically Cooled Mixer	3.0 dB	1 Ghz
	Room Temperature FET	5.0 dB	5 Ghz
	Parametric Amplifier	3.0 dB	0.5 GHz
84-86 GHz	Room Temperature Mixer	7.5 dB	2 Ghz
	Cryogenically Cooled Mixer	4.5 dB	2 GHz

Such cooled mixer preamplifiers will utilize cooled FET IF amplifiers in the 4 to 8 GHz range for optimum overall noise performance when cooled. Typical Local Oscillator requirements for 35 GHz mixers are in the range of 1-2 mW at the LO port of the mixer, or closer to 5 mW when coupled into a cryogenically cooled mixer through appropriate waveguide circuits.

Cooling may be accomplished through the use of closed cycle refrigeration systems or through the use of multi-stage thermoelectric coolers. One such configuration for use at millimeter wavelengths is outlined in Figure Three, where the feedhorn is also cryogenically cooled to reduce the system noise figure to the lowest practical limit.

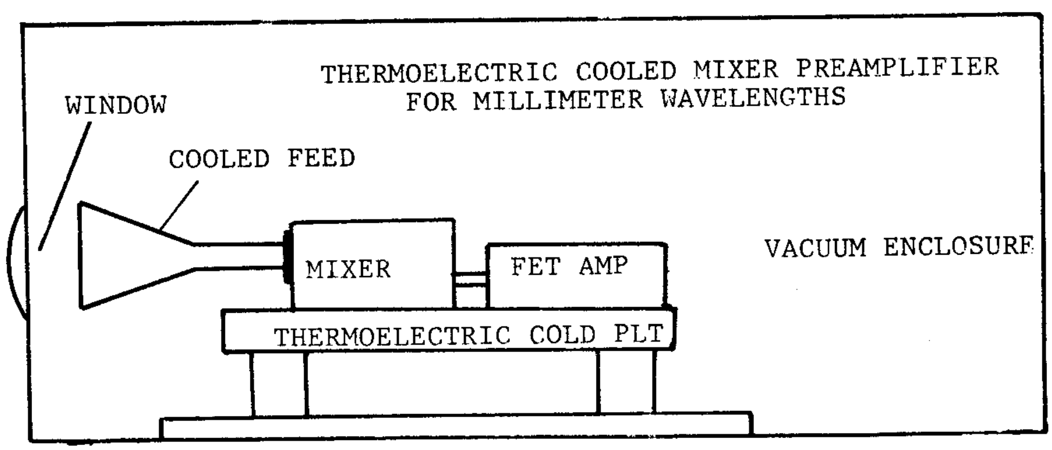


FIGURE THREE

In the latter part of the next decade, several technologies now being investigated in various research establishments, may alter the most cost effective approach for telecommunications receiver implementation. As is evident in Table 2, Cooled FET preamplifiers at 35 GHz will be low noise, and probably broader in bandwidth than comparable cooled mixers. Additionally, the RF gain provided by the FET preamplifier is advantageous from many standpoints in overall system design. Cooling of the FET device somewhere in the range of 60-100K is probably required for optimum operation at long millimeter wavelengths.

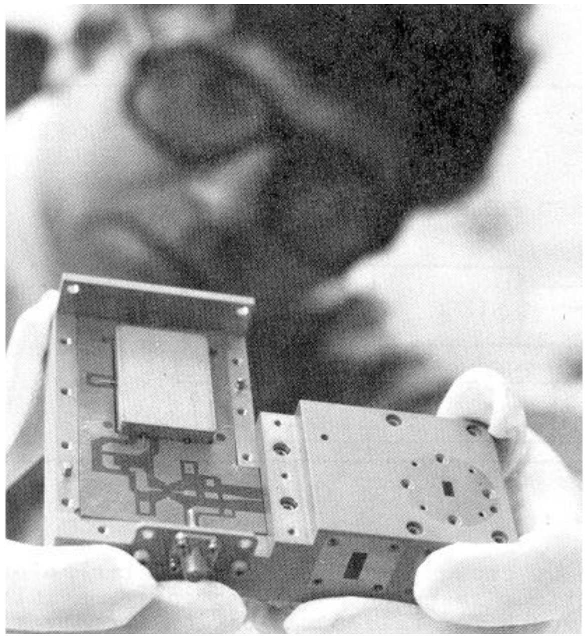
TABLE 2
PROJECTED RECEIVER TECHNOLOGY -- 1985-1990 Timeframe

FREQUENCY	RECEIVER TYPE	NOISE FIGURE	BANDWIDTH
3 5 GHz	Cooled FET	2.5-1.5 dB SSB	4-6 GHz
	Cooled Mixer	3.0-2.0 dB SSB	2-4 GHz
84-46	Cooled Mixer	5.0-3.5 dB SSB	2-4 GHz
GHz	Josephson Mixer **	1.0-0.5 dB SSB	4-6 GHz
	Cooled 3 Terminal Amplifier	3 dB SSB	??

** requires more complicated cooling system with cold temperatures near to 4K while all other cooled systems utilize easy to attain cooling at 60-100K.

It is also possible that the use of a cooled beam-lead varactor in conjunction with a FET preamplifier as a reactive downconverter may offer some hope of reducing the attainable noise figure well below 3 dB at 86 GHz at some point in the next decade.

As is evident from the photograph below, work is already well along on integrated millimeter mixer/ FET preamplifers for space communciations at millimeter wavelengths. The present results indicate a bright future for millimeter communciations with a large payoff in increased channel capacity, and most importantly making possible the development of a high volume consumer direct broadcast system for use by the average citizen in the late part of the next decade.



A 40-50 GHz subharmonically pumped mixer with integrated FET IF amplifier is shown prior to final assembly. This device is a prototype for next-decade telecommunications systems at millimeter wavelengths.

1. Cardiasmenos, A. G. “Planar Devices make Production Practical” Microwave Systems News May 1979, Vol 9 No. 5