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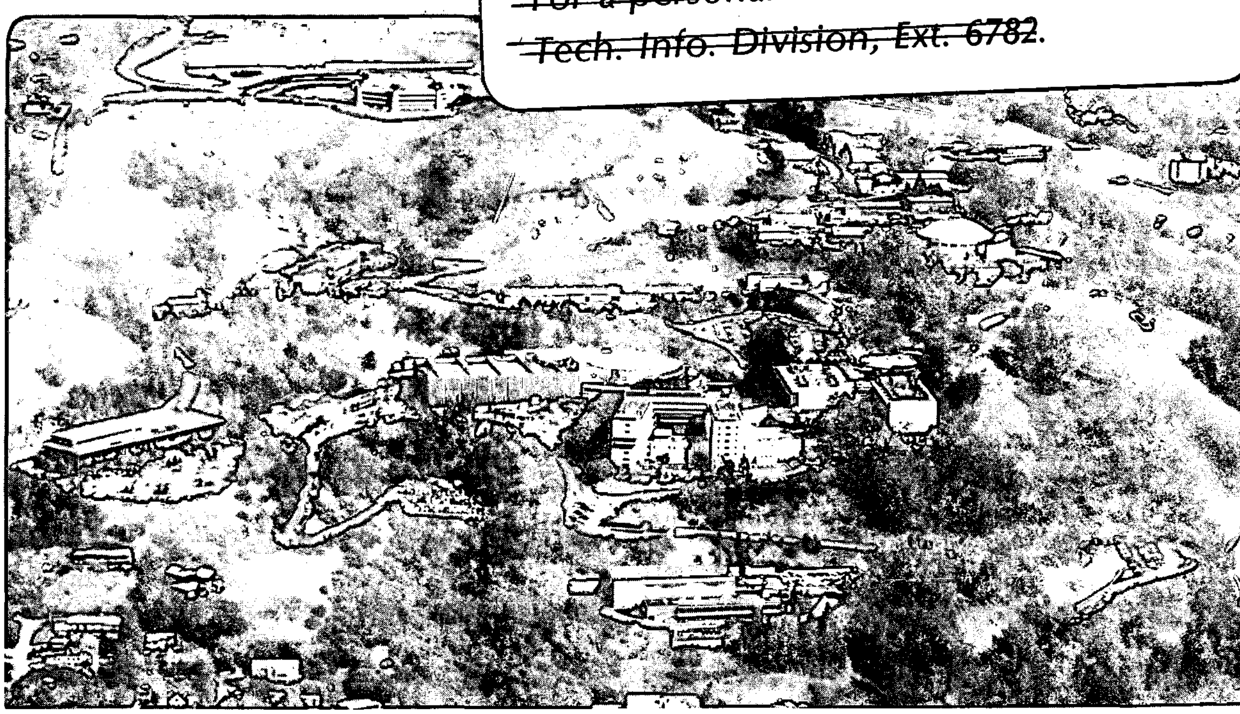

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DISCLAIMER

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Summary

A low-noise preamplifier has been developed for use in stochastic beam cooling experiments. Over the passband of 2 to 4 GHz the preamplifier exhibits a minimum noise figure of 0.6 dB and 1.3 dB at ambient temperatures of 80K and 300K respectively. The associated gain is 39±1 dB at 80K, and 34±1 dB at 300K. Over the passband the relative phase-shift is ±20°, and the input and output voltage standing-wave ratios are both <2.0. These latter characteristics are relatively uneffected by temperature. The preamplifier is unconditionally stable with an open-circuited or short-circuited sliding line at the input or output.

The preamplifier noise figure, gain, phase-shift, and input and output voltage standing-wave ratios have been measured as a function of frequency over the range of 1.8 to 4.2 GHz, and at ambient temperatures of 300K, 80K, and 20K. Also, the output power and intermodulation product content as a function of the input power and versus frequency have been measured.

The preamplifier consists of a cascade of four GaAs field-effect transistors, and is made with lumped components. Two prototype preamplifiers have been constructed that show very similar performance characteristics.

Introduction

The characteristics of an amplifier for stochastic beam cooling experiments at the Fermi National Accelerator Laboratory, Batavia, Il., have been described[1-3]. An essential component of such a system is a low-noise wide-band preamplifier. A low-noise 1-2 GHz preamplifier has been proposed for the system to stochastically cool the antiprotons in the Accumulator Ring, and has been reported[4]. The low-noise 2-4 GHz preamplifier described here is proposed for the system to reduce the antiproton betatron oscillations in the Debuncher Ring, and is a further development of the previous work.

Similar to the previous work Mitsubishi type MGF 1412 and MGF 1402 GaAs field-effect transistors were used. Four stages of gain were required to develop a minimum power gain of 30 dB with less than 1 dB of ripple in the passband. As in the previous work, the transistor source leads were mounted on 2.5 mm high, 2.5 mm diameter copper studs that were soldered directly to the gold-plated copper enclosure. This provides good thermal conductivity to the GaAs chip, and good RF grounding.

Ceramic chip capacitors were used extensively for RF by-passing and coupling. One chip resistor is also used. Discrete metal-film resistors were used in the bias networks of each transistor. The inductors used consist of either straight lengths of 0.25 mm diameter gold-plated phosphor-bronze wire ($L \approx 0.5$ nH/mm), or the wire is wound, using a 1 mm diameter wire as a coil form, with a pitch of about 1.5 turns/mm ($L \approx 5$ nH/turn). The transistors are essentially mounted in air, but the basic substrate for the preamplifier is Rogers RT/duroid 5880 (relative dielectric constant, $\varepsilon_r = 2.2$). To minimize its physical length the $\lambda/4$ matching line at the input of the preamplifier is on RT/duroid 6010 material ($\varepsilon_r = 10.5$). A photograph of the preamplifier is shown in Fig. 1.

Preamplifier Design

The circuit schematic of the preamplifier is shown in Fig. 2. MGF 1412 transistors were used in the first two stages of the amplifier because of their superior noise figure. Cheaper MGF 1402 transistors were adequate in the last two stages. To optimize the gain and low noise performance of the preamplifier separate gate and drain bias supplies were provided for each transistor. However, as designed, the amplifier exhibits a broad optimum bias point around I_D = 10 mA and V_{DS} = 4.0 V. Unfortunately, with the grounded source connection used and because of production tolerances of these devices, common gate and drain supplies for all four transistors were not possible.

At the bias point these transistors are potentially unstable at frequencies below ~3 GHz. The stability factor was increased by including low-loss series feedback due to the self-inductance of the source leads of the devices. The series feedback also serves to increase the input impedance of the gain stage. This is especially useful at the input stage, where each of the two source leads are ≈3 mm long. Broadband input matching can then readily be obtained using a $\lambda/4$ transmission line (T1), with a characteristic impedance Z_t that is the geometric mean of the source impedance (Z_s = 50 Ω) and the real part of the input impedance of the first gain stage. For this preamplifier Z_t is nominally 37 Ω. An additional control of the input VSWR is provided by the inductor L1. The tap point is moved along the microstrip transmission line to obtain the best VSWR over the passband.

With the amplifier providing more than sufficient gain, a simple method of obtaining a good output matching characteristic and improved stability factor, was to insert a 6 dB attenuator pad in the output transmission line (T2). The nominal impedance of the output microstrip line is 50 Ω.

Both series and shunt peaking were used in each interstage, to yield essentially a low Q narrowband amplifier at each gain stage. The self-inductance of the transistor gate and drain leads provide the series peaking, while the inductors made with the phosphor-bronze wire form the shunt peaking. The transistors were spaced on 7 mm centre-to-centre spacing, providing a total lead length of about 5 mm (~3 nH) between transistors. The low channel, gate, and source resistance of these devices (total <10 Ω) contributes to the low Q of the interstage networks. The interstage networks were stagger-tuned for an overall broadband response. Additionally, the components C15 and L6 at the drain of Q2, and C32 and R9 at the drain of Q3 were included to flatten the gain response over the passband. The optimum value of C32 differed in the two amplifiers.

The ferrite beads around Q1 and Q2 were included to suppress any parasitic oscillations.

Preamplifier Characteristics

The systems used to characterize the performance of the preamplifier made extensive use of the S-parameter test set, and were similar to that described in the previous report[4].

The gain characteristics are obtained directly from measurements of $|S_{21}|$, and are shown in Fig. 3. Over the passband of 2-4 GHz and at an ambient temperature of 300K the gain was 34.4±0.6 dB. At 80K the gain has increased to 38.8±0.7 dB, and at 20K the gain has decreased to 37.4±0.7 dB. This decrease in gain was not observed in the second preamplifier. It showed an increase in gain of about 0.5 dB when the temperature was decreased from 80K to 20K.

The phase angle of S_{21} as a function of frequency and temperature are shown in Fig. 4. The maximum phase variation over the passband was ±21° at 300K, ±18° at 80K, and ±20° at 20K.

The input VSWR was obtained from measurements of S_{11}, while the output VSWR was calculated from measurements of S_{22}. From Fig. 5, the input VSWR is seen to be <2.0 over the passband of 2-4 GHz at 300K and 80K, but does rise above 2.0 at 20K. The output VSWR, also included in Fig. 5, is <2.0 over the passband of 2-4 GHz at all three ambient temperatures. Indeed, over most of the passband it is <1.5.

The output power as a function of the input power, with frequency as a parameter, was only measured at 300K. The results are shown in Fig. 6. The power output for 1 dB gain compression around the middle of the passband was -6 dBm. The third order intermodulation distortion was measured using fundamental frequencies of 3.0 and 3.2 GHz. A straight line extrapolation of the fundamental, and the third order responses yield the third order intercept point of +5 dBm.

The noise figure measurements, made using a hot-cold source, are presented in Fig. 7. At 300K, the noise figure over the passband averages 1.3 dB, but rises to 1.8 dB at 2 GHz and 1.5dB at 4 GHz. At 80K, the average noise figure has been reduced to 0.65 dB, and at 20K this figure is further reduced to 0.55 dB.

Stability measurements, similar to those previously reported[4], were also performed with this preamplifier. The preamplifier was found to be stable with any phase of a shorted and open line at either the input or output connectors.

Conclusions

The performance of a cryogenically cooled low-noise 2-4 GHz preamplifier has been presented. Over the passband the minimum noise figure is 0.6dB at an ambient temperature of 80K, and 1.3 dB at 300K. The associated gain is 39±1 dB at 80K, and 34±1 dB at 300K. The increase in the noise figure at the band edges is attributed to the increase in the input VSWR at these frequencies.

Although made with lumped components and packaged devices the two prototype models exhibited very similar characteristics. However, this required very careful control of the physical layout and construction.

The question might be asked, why was the preamplifier not fabricated with distributed microstrip lines? This is a good question; but it was our conclusion that the optimizing of the circuit, especially the gain and frequency response, was better facilitated with the lumped components. Though certainly, any further increase in the centre frequency of an octave bandwidth amplifier, say a 4-8 GHz preamplifier, would require a totally distributed approach, and probably the use of chip transistors.

Acknowledgements

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The authors wish to thank Branko Leskovar and C. C. Lo for many helpful discussions and generous assistance during the development of this preamplifier.

Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U. S. Department of Energy to the exclusion of others that may be suitable.

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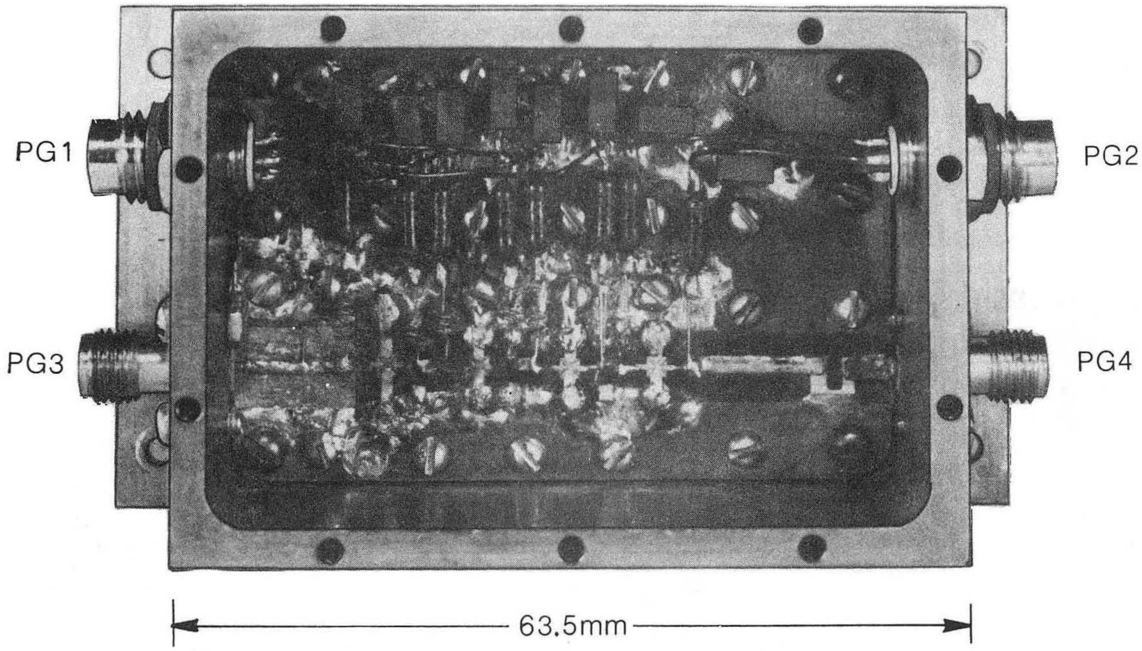

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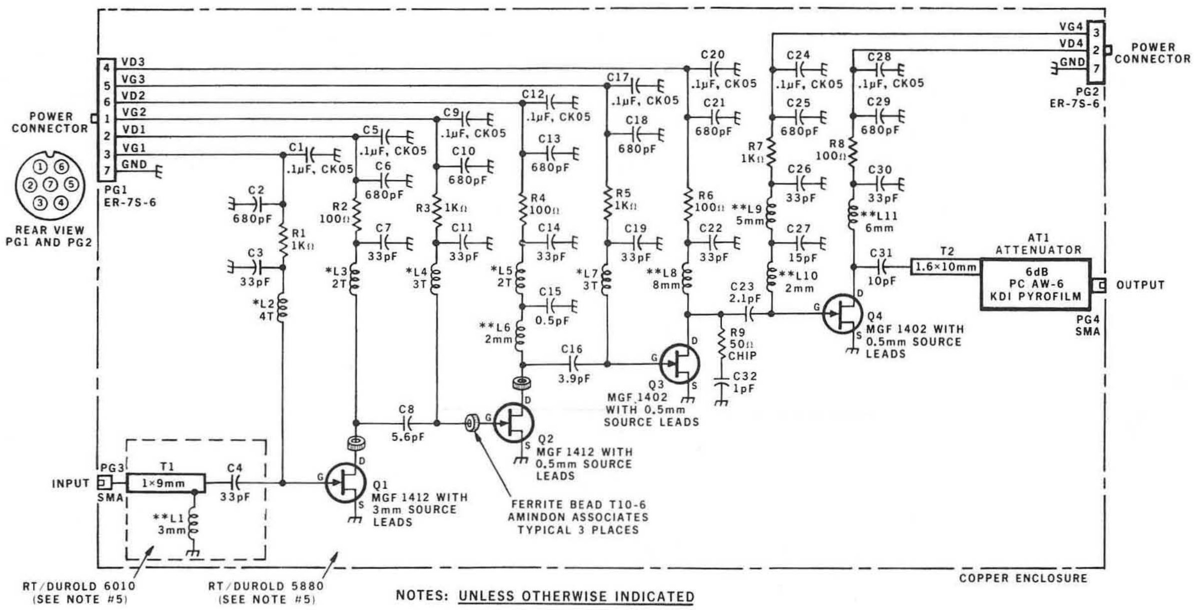
Fig. 1 A photograph of the preamplifier.



NOTES: UNLESS OTHERWISE INDICATED

1. CAPACITORS CHIP TYPE.
2. RESISTORS 1/8W 1% METAL FILM.

*3. COILS MADE OUT OF 0.25mm DIA. GOLD PLATED PHOSPHOR BRONZE WIRE USING 1mm DIA. WIRE AS A COIL FORM.

**4. STRAIGHT LENGTH OF 0.25mm DIA. GOLD PLATED PHOSPHOR BRONZE WIRE.

5. SUBSTRATE MATERIAL: RT/DUROLD 5880 EXCEPT T1, L1 AND C4 ON RT/DUROLD 6010 AS SHOWN ON SCHEMATIC.

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Fig. 2 Circuit schematic of the preamplifier.

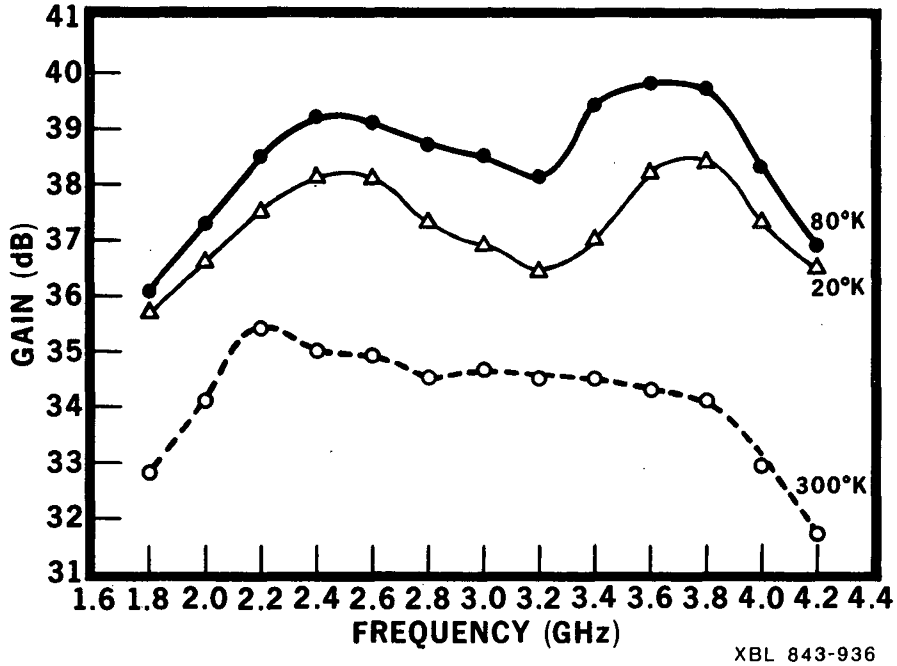

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Fig. 3 Preamplifier gain as a function of frequency measured at an ambient temperature of 300K, 80K, and 20K.

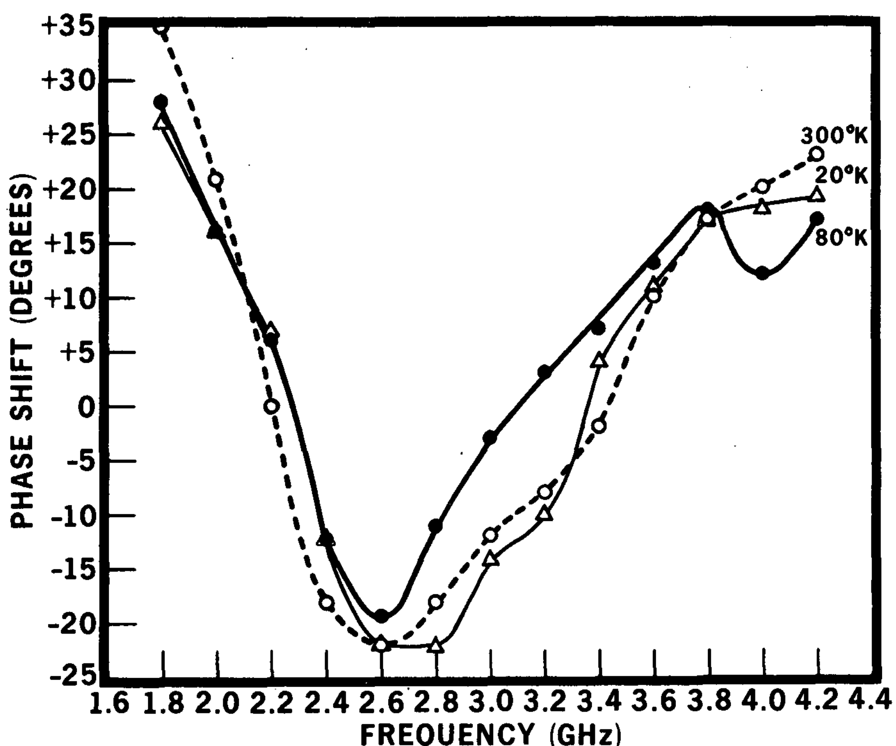

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Fig. 4 Preamplifier phase-shift as a function of frequency at an ambient temperature of 300K, 80K, and 20K.

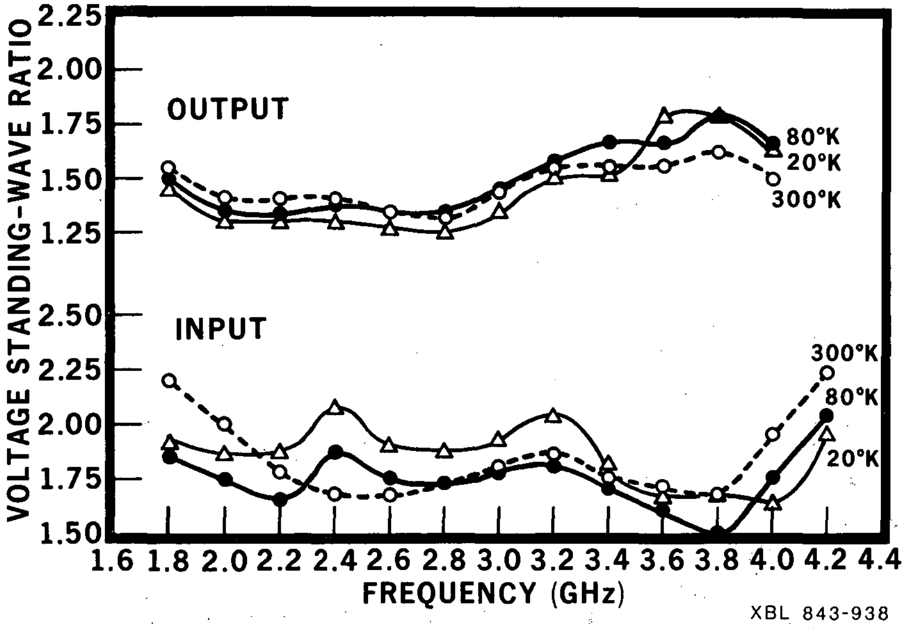

Fig. 5 Preamplifier input and output voltage standing wave ratio as a function of frequency measured at an ambient temperature of 300K, 80K, and 20K.

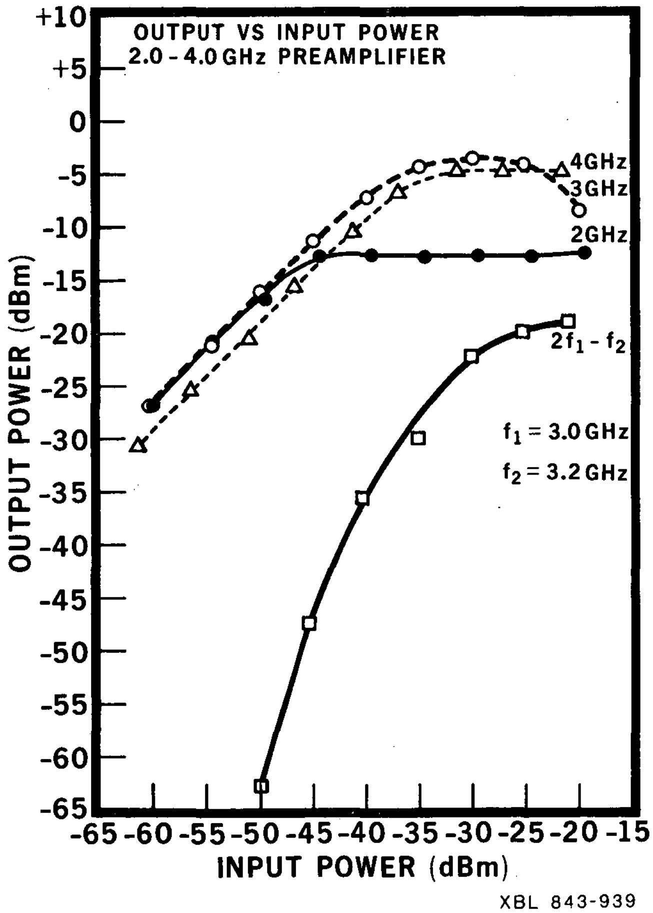

Fig. 6 Power transfer characteristics of the preamplifier.

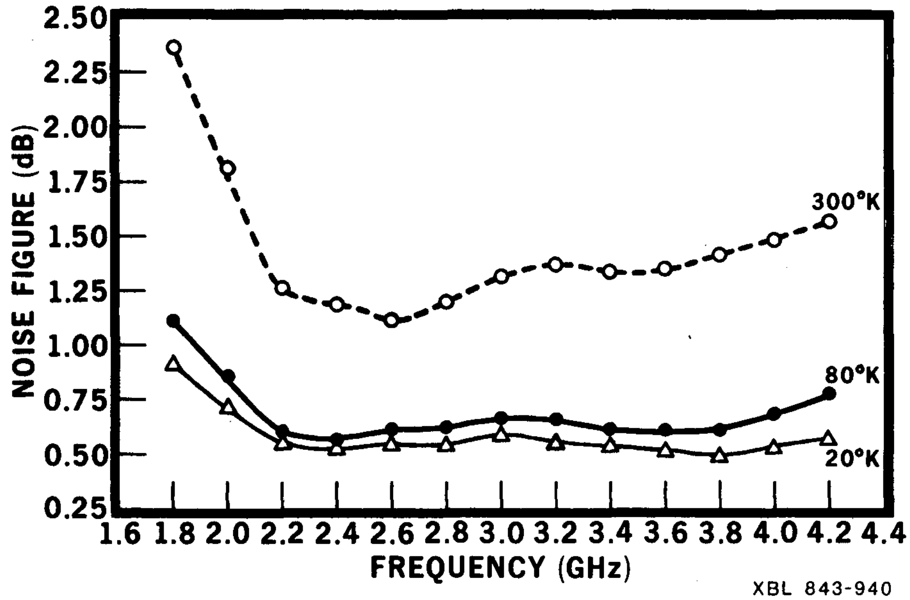

Fig. 7 Preamplifier noise figure as a function of frequency measured at an ambient temperature of 300K, 80K, and 20K.

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