18 GHz PARAMPS WITH BOTH LIQUID HELIUM AND ROOM TEMPERATURE OPERATIONS AND WITH TRIPLE-TUNED GAIN CHARACTERISTICS

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Summary

18 GHz low noise and wide band paramps designed considering skin effects of varactor diodes with both liquid helium and room temperature operations and with triple-tuned gain characteristics by a double-tuned signal circuit, for the experimental domestic satellite communication earth station, are described.

Introduction

A basic design consideration on K-band paramps has been the same one on paramps below X-band. But, in K-band paramps a design considering a skin effect of a varactor diode is considered to be reasonable. Gain characteristics of paramps with double-tuned signal circuit have been considered to be maximally flat or double-tuned, but from the equation representing the gain characteristics of this paramps triple-tuned gain chaacteristics may be possible. Cryogenically cooled paramps have been usually first adjusted at a room temperature by room temperature circulator, and second, adjusted at a cryogenically cooled temperature exchanging the circulator for a cryogenically cooled one. But, a circulator for both room and cryogenically cooled temperature without any adjustment may have many merits.

This paper describes the discussions on the above three problems and some characteristics of 18 GHz low noise amplifier system for the experimental domestic satellite communication earth station of NTT applying these results.

Skin Effect of Varactor Diodes

Dynamic Q_2 of varactor diodes at an idler frequency f_2 has been represented by dynamic Q_1 of varactor diode at signal frequency f_1 as follows: $\tilde{Q}_2=(f_1/f_2)\tilde{Q}_1$. But, if

$$\tilde{Q}_2 \doteq (f_1/f_2)^{3/2}\,\tilde{Q}_1 \qquad (1)$$

considering the skin effect of varactor diodes, noise figure of paramps can be represented by

$$F = 1 + \frac{\tilde{Q}_1^{\,2}(f_1/f_2)^{5/2}+1}{\tilde{Q}_1^{\,2}(f_1/f_2)^{3/2}-1}\,. \qquad (2)$$

When the skin effect is not considered and $\tilde{Q}_1=4$, an optimum idler frequency to minimize noise figure is calculated to $f_2/f_1=3$, but considering the skin effect the optimum idler frequency becomes $f_2/f_1=2$ and it is desired to choose the idler frequency lower. Actually, an index of (f_1/f_2) in Eq. (1) may not simple be 3/2 but will be larger than 1 at least. From the viewpoint of widebanding frequency characteristics of gain and noise figure it is preferable that the Q of the idler resonator become lower depending on the skin effect.

Triple-tuned Gain Characteristics with Double Tuned Signal Circuit

Frequency characteristic of gain of paramps with double-tuned signal circuit is given by

$$G_0/G \doteq 1 + A\alpha^2 + B\alpha^4 + C\alpha^6 \qquad (3)$$

with high gain at the center frequency[1]. Where, A, B, and C are constants decided by follows: gain of the center frequency, G_0, signal frequency, f_1, idler frequency, f_2, loaded Q of signal resonant circuit, Q_{L1}, unloaded Q of idler resonant circuit, Q_{u2}, and loaded Q of second signal resonant circuit, Q_3. And, $\alpha \propto 2\Delta f_1/f_1$. Because $C>0$, it can be verified from Eq. (3) that gain characteristics can be made triple-tuned under condition.

$$B<0\;,\quad B^2/3C > A > 0 \qquad (4)$$

are satisfied.

From given G_0 and $q=\sqrt{(f_1/f_2)(Q_{u2}/Q_{L1})}$, Q_3 for Chebyshev gain characteristics can be decided, but the gain ripple can not be chosen at will. Calculated results on gain characteristics are shown in FIG. 1. For example, if G_0=10dB, Chebyshev gain characteristics are obtained for $q>1.05$ and when q=2.0, the gain ripple becomes 0.7dB. Obtained gain characteristic of 18 GHz paramps satisfying this condition were triple-tuned as shown in FIG. 2 and triple-tuned gain characteristics with double-tuned signal circuit were verified experimentally, too.

In paramps with single-tuned signal circuit, the coefficient C in Eq. (3) becomes zero, and A and B are positive. So, in this case maximally flat or double-tuned gain characteristics can never be realized.

Paramps with Both Cryogenically Cooled and Room Temperature Operations

Circulators with both cryogenically cooled and room temperature operations with different d.c. magnetic field have been attempted. But, circulators with both cryogenically cooled and room temperature operations without any adjustment make it easy to adjust cryogenically cooled paramps because only bias voltage and pump power adjustment are required.

Using Li ferrite with good temperature characteristics of magnetization and operating under optimum d.c. magnetic field, 18 GHz coaxial circulators with cryogenically

cooled and room temperature operations without any adjustment were realized. These circulators have good electrical characteristics from room to liquid helium (LHe) temperature. FIG. 3 shows VSWR characteristics at LHe and room temperature measured through a low thermal conductivity waveguide and a waveguide to coaxial transition.
Measured insersion loss was 0.3 ~ 0.4 dB per 1 path.

Gain characteristics of an 18 GHz paramp using above mentioned circulator at room and LHe temperature are shown in FIG. 4 as an example. Bias voltage and pumping power were -0.5V and 71mW respectively. Being cryogenically cooled with LHe, gain characteristics similar to ones at room temperature were obtained only with bias voltage and pumping power adjustment to -0.1V and 44mW respectively for compensation of characteristic variation of the varactor diode by LHe refrigeration. Pumping frequency was 52.7 GHz. Pumping powers of 4 paramps using different diodes at LHe refrigeration varied by +0.9~ -2.2dB compared with those at room temperature.

Construction of Paramps

Inner construction of paramps is shown in FIG. 5. A miniature pill prong packaged varactor diode with fc(-6V) of 430 GHz in X-band was installed in this mount of which losses were avoided as possible. Measured impedance loci of the mounted varactor at signal and pump frequency, 18.5 GHz and 52.7 GHz respectively, are shown in FIG. 6 as its bias voltage is varied. Measured fc(-6V) at these frequencies are 410 GHz and 280 GHz, respectively. From this results, it is reasonable that the index of Eq. (1) is made larger than 1.

18 GHz Low Noise Amplifier System

A block diagram of 18 GHz low noise amplifier system constructed applying above results is shown in FIG. 7. The experimental earth station has two receiving frequency bands, 4 GHz and 18 GHz, and 1 stage of 18 GHz paramp and 3 stages of 4 GHz paramp are cryogenically cooled with one liquid helium refrigenerator to make the overall low noise amplifier system simple, small sized and economical. FIG. 8 shows the outer view of 4/18 GHz low noise amplifier system.

Overall characteristics including input waveguide switch through 18.1~18.8 GHz were gain of 30dB, gain flatness of ±0.5dB, noise temperature of 88~100°K, and relative delay time of 1.5 nsec. FIG. 9 shows relative delay time characteristics.

When the first stage of paramp was at room temperature, overall noise temperature was 500~660°K. Calculated noise temperatures of liquid helium cooled paramp at cryogenically cooled temperature and room temperature are 23°K and 394°K, respectively, and noise temperatures near these values are considered to be obtained from measured overall noise temperature.

Conclusion

Considering skin effect of a varactor diode, it is desired to choose an idler frequency lower than that obtained when the skin effect is not considered.

Triple-tuned gain characteristics of paramps with a double tuned signal circuit were shown theoretically and verified experimentally. An 18 GHz coaxial circulator with cryogenically cooled and room temperature operations without any adjustment was realized using Li ferrite. Adjustment procedure on liquid helium cooled paramps with this circulator was able to be made very simple. Applying above results, a wide band and low noise 18 GHz low noise amplifier system including 1 stage of a liquid helium cooled paramp and 2 stages of a room temperature paramp was constructed for the experimental satellite communication earth station, and required characteristics could be achieved.

18 GHz paramps with a bandwidth of 1,200 MHz at the gain of 10dB and a solid state pump source will be realized in near future.

Achnowledgement

Thanks are due to Dr. Hikaru Shioya, Nippon Electric Co., Ltd., for his useful discussions through the co-operative research project, and Nobutake Orime, Mitsubishi Electric Corporation, for development of 18 GHz circulators for both liquid helium and room temperature operations.

Reference

1. W. P. Conners: "Maximally flat bandwidth of a non-degenerate parametric amplifier with double tuned signal circuit and single tuned idler circuit", IEEE Trans., MTT-13, p.251 (May 1965).

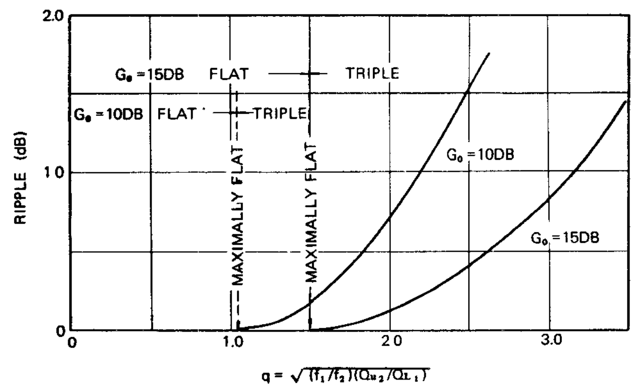

FIG. 1 Conditions for gain characteristics and gain ripple of triple-tuned gain characteristics.

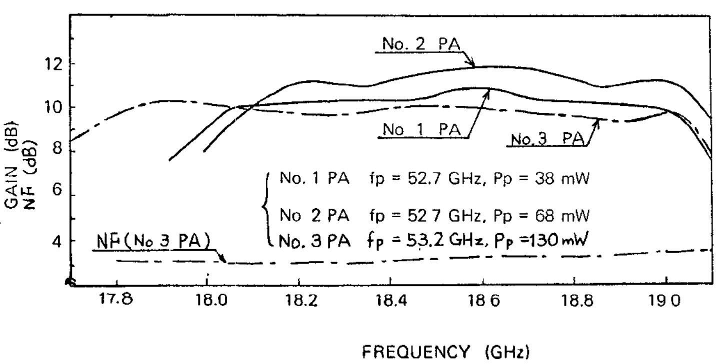

FIG. 2 Triple-tuned gain characteristics of room temperature paramps with a double -tuned signal circuit.

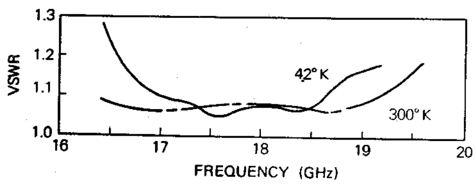

FIG. 3 VSWR characteristics of 18 GHz coaxial circulator for both liquid helium and room temperature operations.

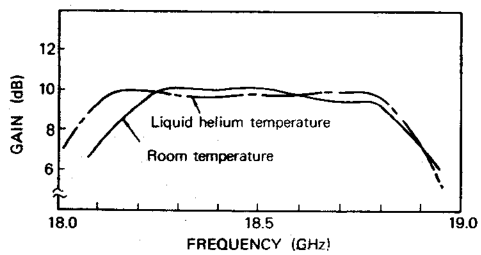

FIG. 4 Gain characteristics of paramps with both liquid helium and room temperature operations.

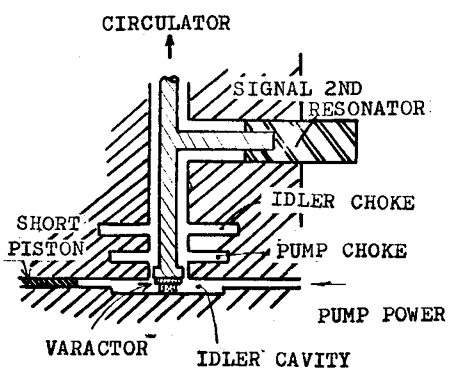

FIG. 5 Construction of paramp.

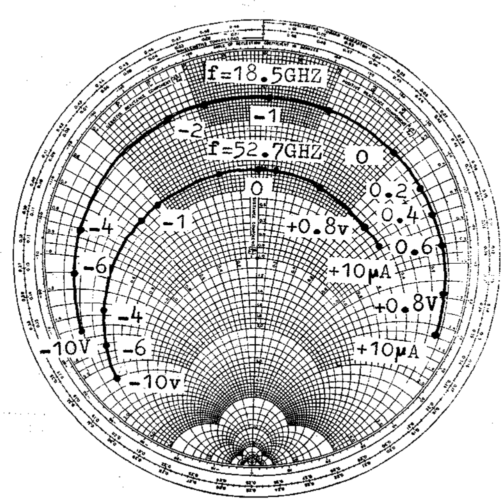

FIG. 6 Measured impedance loci of the mounted varactor as its bias voltage is varied at 18.5 GHz and 52.7 GHz.

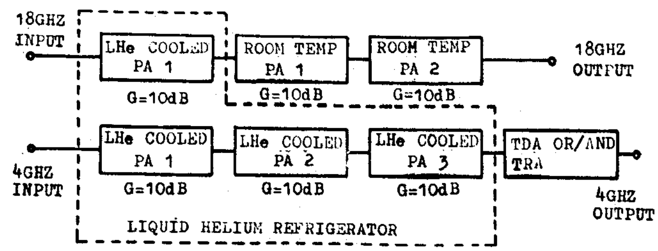

FIG. 7 Block diagram of LNA system

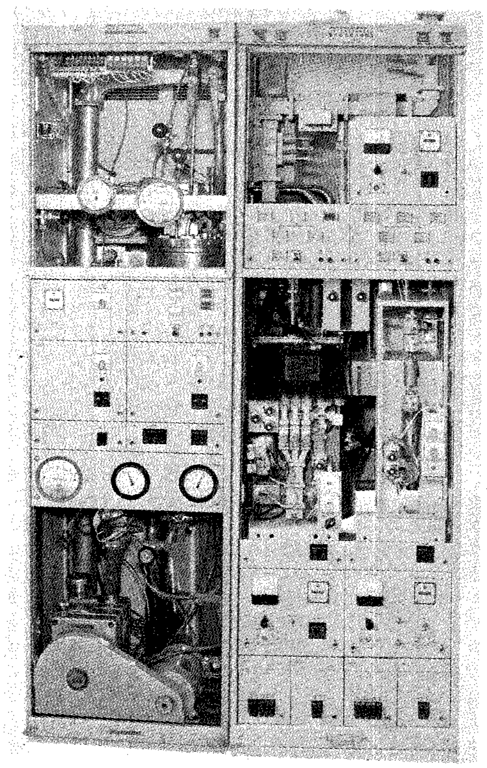

FIG. 8 Outer view of LNA system. (left rack: liquid helium refrigenerator, right rack: 4/18 GHz low noise amplifiers)

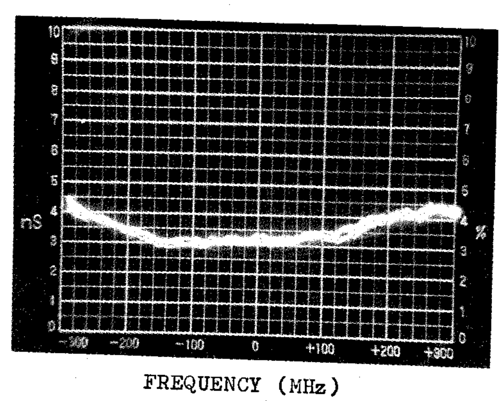

FIG. 9 Relative delay time of 18 GHz LNA.