Maser Development

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Operational X-band masers are being developed for use in the DSIF. Mathematical models have been formulated that provide useful information about the amplitude and phase performance of the proposed X-band maser as well as the existing S-band masers. These models, described in this article, provide X-Y plots of frequency vs amplitude response, carrier phase shift, or time delay.

I. Introduction

Development of operational, X-band, DSIF masers is currently in process. The work is based upon previous masers developed at JPL, but the specific performance desired has not been obtained. Some of the previous masers will operate in the frequency range required for the current effort, but none meet the performance requirements set forth as design goals for future operational masers. Since it takes many months to fabricate a "breadboard" maser, careful attention must be given to the design details at the outset of the program in order to complete the development in a timely manner. With respect to the X-band maser, questions exist about the maser length, the pump and magnet stability, and the capability of a double-tuned (single-step) amplifier to meet the bandwidth requirements. To obtain the answers to these and other questions, mathematical models were formulated that provide information about both the proposed X-band maser and the existing S-band masers. The models, programmed in PDP-11 Basic, provide X-Y plots of frequency vs amplitude response, carrier phase shift, or time delay.

II. Amplitude Response

The amplitude model utilizes the usual equation which assumes a Lorentzian magnetic resonance line shape (Ref. 1). For i sections, the electronic power gain at frequency f is

$$G(f) = \sum_i Gei \left\{ \frac{1}{1 + [2(f - foi)/\Delta f_L]^2} \right\} \tag{1}$$

where

G_{ei} = electronic power gain of the ith section in decibels (a controllable parameter determined by the microwave structure design)

f_{oi} = magnetic resonance frequency of the maser material for the ith section

Δf_L = maser material magnetic resonance line width

Although there may be minor variations in the value of Δf_L, it is a reasonable approximation to treat it as a constant. The proposed X-band maser uses a two-section design, and Eq. (1) can be used to calculate an amplitude response curve. However, the curve predicts electronic gain. Since net gain is the desired function when describing performance for the purpose of interfacing with other equipment, a loss term should be included. The loss term includes microwave structure losses and losses caused by the isolators that are internal parts of the DSIF masers. The loss term is a function of frequency.

In addition, if stability factors are to be evaluated, provisions should be made for altering Eq. (1) with terms that are of interest. One term of interest is a pump detuning effect. It is not usually possible to pump a stagger-tuned maser at the optimum pump frequency of each section when only one pump frequency is used. Because of practical limitations on the pump power which may be applied to the maser, it is not generally possible to overcome, with increased pump power, the gain loss due to pump frequency detuning. Therefore, the electronic gain of the ith section will not be the maximum available for its geometry. The model includes a pump detuning term to correct for this and to allow evaluation of the correlation between pump frequency stability and maser gain stability. The pump detuning term is a function of the applied magnetic field.

Magnetic field stability is the other term that is of interest. It appears in Eq. (2) as a term which affects the magnetic resonance frequency of the maser material.

Now, the model takes on the form

$$G'(f) = \sum (G_{ei} - P)$$

$$\times \left\{ \frac{1}{1 + \{2[f - f_{oi} - (m)(\Delta H)]/\Delta f_L\}^2} \right\} - L$$

(2)

where

$G'(f)$ = net power gain in decibels

P = pump detuning term

ΔH = magnetic field change from field of f_{oi}

m = maser signal frequency magnetic tuning rate

L = loss term

S-band maser amplitude response curves from Eq. (2) have been compared with experimental data taken during S-band maser fabrication, and the agreement is very good. Fig. 1 presents a computer-drawn amplitude plot of an S-band maser with experimental test data superimposed. This lends confidence to the predictions for the X-band maser. Fig. 2 presents a computer-drawn amplitude plot of the proposed X-band design. The requirements are a net gain of 45 dB and a 1-dB bandwidth of 30 MHz. The plot shows that the proposed design will meet the requirements.

III. Phase and Time Delay

At low signal levels, the presence of the maser material in the microwave structure causes a phase and time delay distortion. The phase distortion and its derivative, the time delay distortion, as functions of frequency are calculated from

$$\phi = 6.56 \sum_i (G_{ei} - P)$$

$$\times \left\{ \frac{2[f - f_{oi} - (m)(\Delta H)]/\Delta f_L}{1 + \{2[f - f_{oi} - (m)(\Delta H)]/\Delta f_L\}^2} \right\}$$

(3)

where

ϕ = phase distortion in degrees

The results of applying Eq. (3) to S- and X-band designs indicate that carrier phase stability will easily meet present requirements. Tests performed on S-band masers confirm this result. Time delay stability is another matter.

The design goal, and hence the measurement accuracy requirement, for time delay stability is in the sub-nanosecond region. Because of the difficulty of measuring time delay with sufficient accuracy, there are no valid

data with which the computed delays may be compared. The next phase in the maser development project is to develop a test technique to verify the computed results through a direct measurement of delay in an S-band maser. This technique requires a measurement of the time that a modulated signal actually takes to traverse the maser.

It is expected that this method will avoid the difficulties encountered when a two-signal-carrier phase measurement is made and the time delay is calculated from the apparent slope between the points. A time delay plot is not presented here because verification of its accuracy is still lacking. However, the computed curves indicate that

sub-nanosecond stability can be achieved through careful design. Further reports will be given as progress is made.

IV. Conclusion

The mathematical models indicate that the proposed double-tuned maser will meet the gain and bandwidth requirements, and that it is possible to meet the time delay stability requirements even though it will be difficult. Also, it has become evident that the models will provide a useful means for obtaining quantitative explanations of maser performance after the units are placed in field service.

Reference

1. Siegman, A. E., *Microwave Solid-State Masers*, p. 315. McGraw-Hill Book Company, Inc., New York, N.Y., 1964.
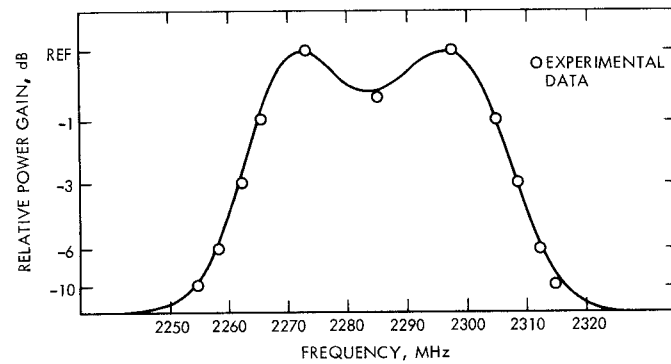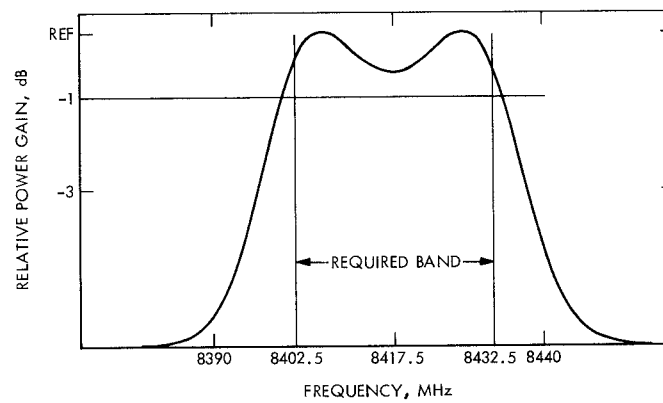
Fig. 1. Computer plot of S-band maser model

Fig. 2. Mathematical model amplitude response
for X-band maser