VII. Low Noise Amplifier for Radar

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1. Introduction

The major problems in extending the range of radar signals are: increasing antenna gain; development of a communication system which is noise-immune; larger power output transmitter tubes and reduction of noise in the receiver.

The minimum acceptable signal level in a receiver system is often so weak that noise generated within the receiver itself interferes with the reception. In a case where detection and measurement of a target near the horizon is concerned, the noise received at the antenna is so close to the thermal noise at normal temperature that the reduction of radar range due to it is minor. However when the noise at the antenna is much smaller than the thermal noise at normal temperature, the range of the radar can be increased by reducing the amount of noise to the same degree.

Figure 1 expresses the noise level at an antenna for a single fre-

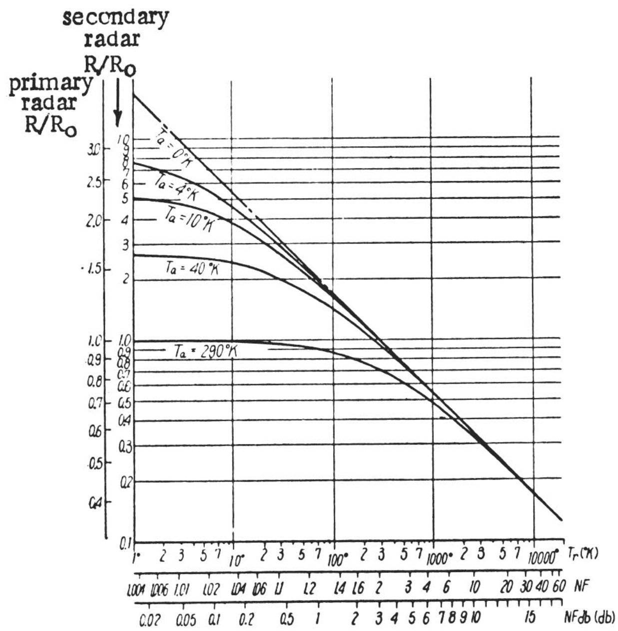


Figure 1. Relationship between sound numbers and range.

quency, the relationship between the noise level ($N_r = KT_r$) generated by the receiver system and the relative range (R/R_0). Here K - 1.38×10^{-23} Joules/°K. T is the equivalent noise temperature, R_0 is the range when T_a = 290°K, T_r = 0°K. T_r is expressed in the following manner by noise number NF determined with 290°K as base.

$$T_r = (NF - 1) \times 290°K. \tag{1}$$

The relative range R/R_0 for primary radar using scatter waves is read on the left scale and the secondary radar using a transponder, is read on the right scale. As can be seen from the graph when NF is great, the effect of T_a is negligible and when NF becomes smaller, the range is expanded considerably as the value of T_a decreases. For example, when substituting a receiver with NF = 12db for NF = 2db the range of the secondary radar is extended 3.1 times when T_a = 290°K, and 4.5 times when T_a = 40°K. As NF decreases this difference becomes more noticeable.

The noise factor NF of the receiver system is expressed by the following formula:

$$NF = L_a \left\{ (NF)_1 + \frac{(NF)_2 - 1}{G_1} \right\} \tag{2}$$

where L_a (>1); $(NF)_1$ is the noise factor of the first stage amplifier of the receiver; G_1 is its power gain and $(NF)_2$ is the noise factor of the remainder of the amplifier. Therefore, we need wiring with a small L_a in order to decrease NF, and we must use an excellent primary amplifier in which G_1 is great and $(NF)_1$ is small. In this article I will discuss the new low noise parametric amplifier in use at the Akita Proving Grounds, which was developed at this Institute as a first stage amplifier for rocket tracking radar. (1)

2. Operating Principles

In a parametric amplifier using reactances which oscillate at high frequencies, since noise is not included in the amplifier mechanism a low noise amplifier can be constructed if a suitable variable reactance is used. (2) Figure 2 is a block diagram showing the principle of the new type of parametric amplifier. As shown in Figure 2, this amplifier has a form in which an up converter having regenerated gain is linked to a down converter by unidirectional tubes. The input signal of frequency f_1 entering the left terminal is converted by the up converter into frequency $f_2 = f_p - f_1$ and is amplified at the same time. f_p is the fluctuating frequency of the reactance and is called a pump or drive frequency. After the amplified f_2 signal passes through the unidirectional tubes, it enters the down converter having a fluctuating reactance at the same pump frequency f_p, and at the same time as it is reconverted to $f_1 = f_p - f_2$ it is somewhat amplified and sent from the terminal on the right to the secondary amplifier. Since the variable reactance of this converter is excited by the same pump power source, it is again returned to the same frequency f_1 as the input by the down converter, even if f_2 is changed due to the fluctuation of f_p. Consequently, in this amplifier the stability of f_p is not required to the same degree as when a single up converter is used. Also, this amplifier does not use a circulator, but because it is possible to apply all input signals to the up converter, it is possible to obtain a suitable noise factor equivalent to the case when a circulator is used. The isolator for frequency f_2 is used to prevent the occurrence of oscillation due to reflection between the two converters.

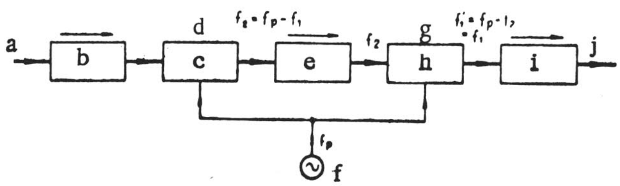


Figure 2. Diagram of the principle of the new type parametric amplifier.

Legend: a. input f_1
b. unidirectional tube f_1
c. up converter $f_1 \rightarrow f_2$
d. amplifier
e. unidirectional tube f_2
f. pump source
g. amplifier
h. down converter $f_2 \rightarrow f_1$
i. unidirectional tube f_1
j. output f_1

Now when a pump is not added, the normalized conductance of the up converter, measured from the terminals of I_1 and f_2 are g_{1U}, G_{2U}, and assuming that the gain is sufficiently large, the noise factor $(NF)_U$ when a pump is added is:

$$(NF)_U = (1 + g_{1U}) \ (1 + \frac{f_1}{f_2}) \tag{3}$$

Also assuming the same normalized conductances for the down converter to be g_{1D} and g_{2D}, its noise factor $(NF)_D$ is:

$$(NF)_D = (1 + g_{2D}) \ (1 + \frac{f_2}{f_1}) \tag{4}$$

If the power gains of the up converter and down converter are G_U and G_D

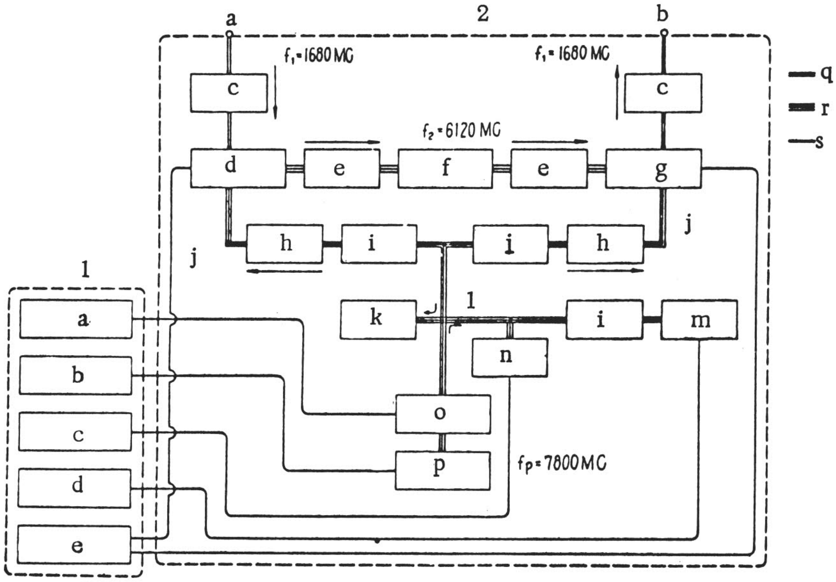


Figure 3. Block Diagram of Trial Manufactured Amplifier.

Legend:

1) Power Section
   a. power control circuit
   b. Klystron power source
   c. tuner control circuit
   d. pump power indicator
   e. bias circuit
2) Main amplifier section
   a. input
   b. output
   c. unidirectional tube f_3
   d. up-converter $f_1 \rightarrow f_2$
   e. unidirectional tube f_2
   f. band pass filter f_2
   g. down-converter $f_2 \rightarrow f_1$
   h. unidirectional tube f_p
   i. Semifixed attenuator
   j. Waveguide at breaking area for $f_1 f_2$
   k. no-reflection terminal
   l. directionalccoupling
   m. detector
   n. cavity resonator f_p
   o. Ferrite f_p variable attenuator
   p. Klystron f_p
   q. same axis line
   r. waveguide
   s. others

and the sequential direction insertion loss of the unidirectional tubes joining both converters is $L_2(>1)$, the reverse direction insertion loss is sufficiently greater than $G_U G_D$ and the sequence direction insertion losses of frequency f_1 in the unidirectional tubes joining the input and output in order to guard against reflections from the antenna and the secondary amplifier are L_1 and L_1' respectively, the noise number $(NF)_1$ for the entire amplifier in Figure 2 and power gain G_1 are obtained in the following manner:

$$(NF)_1 = L_1 \left\{ (NF)_U + \frac{(NF)_D \times L_2 - 1}{G_U} \right\} \tag{5}$$

$$G_1 = G_U G_D / L_1 L_1' L_2 \tag{6}$$

Consequently, in order to improve the noise factor, it is necessary to reduce L_1 and $(NF)_U$ and increase G_U. Also, in order to reduce $(NF)_U$, it is necessary to use a small circuit g_{1U}, to select an f_p sufficiently greater than f_1, and to reduce sufficiently f_1/f_2 in comparison with 1 [See Note].

3. Construction of Amplifier

The input-output frequency f_1 of the experimental amplifier was designed to equal the 1680 MC transmission frequency of the rocket-borne transponder. This amplifier is used as a head amplifier of the radar receiver already constructed. The details of the construction of the amplifier are given in the block diagram in Figure 3. The unidirectional tubes with frequency f_p are used to stabilize the klystron for the pump power source, and the power applied to both converters is regulated by a ferrite variable attenuator. The pump frequency is selected to be 7800 Mc, and consequently the f_2 = 612OMc radio waves are transmitted between both converters. Variable capacity diodes are used for the variable reactances which fluctuate periodically at frequency f_p within both converters. The power of the DC bias voltage f_p applied to this, as well as the frequency are regulated and observed at the power source section. The band pass filter placed between the f_2 unidirectional tubes joining both converters is used for the purpose of preventing the f_p powers applied to both converters from passing along this path, and interfering with one another.

NOTE: When improving to the maximum the pump frequency and circuit, the minimum value of the noise number is expressed by the following relationship:

$$NF\,min = 1 + \frac{f_1}{f_c}$$

f_1: Signal frequency
f_c: the highest oscillation frequency when operating close to degeneration (a constant indicating the quality of the diode).

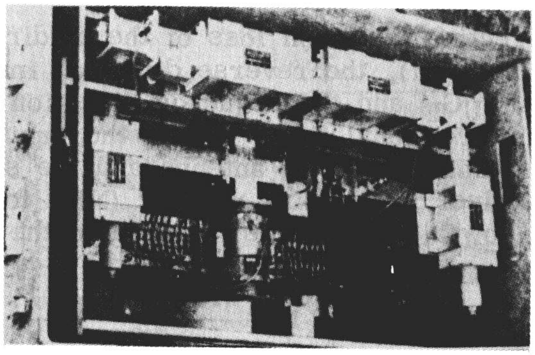
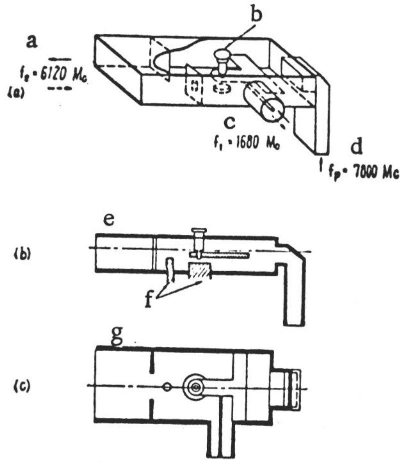


Figure 4. Composition of Parametric Amplifier (Main Amplifier Section)



a) image signal power
b) variable capacity diode
c) signal power
d) pump power
e) lateral view
f) screws for regulating frequency
g) plan

Figure 5. Construction of Converter.

Figure 4 is a photograph of the construction of the head amplifier. The head amplifier is placed near the antenna in order to reduce loss in the antenna system. The construction of the converter is shown in Figure 5. The resonance circuits for f_1 and f_2 are formed by shielded strip resonators and a cavity resonator respectively. Variable capacity diodes are placed in a position which strongly couples both resonance circuits (Microwave Associate MA 460F, the estimated value for maximum resonance frequency when operating close to degeneration is approximately 20,000Mc). The resonance frequencies of both resonators are regulated by a screw [sic] and by the bias voltage of the diodes. The pump power as shown in the illustration, for both frequencies f_1 and f_2 is applied by a waveguide acting as a shielded area. The signal for f_1 is guided outside by the same axis path and the f_2 signal is guided outside by a 6Gc band standard waveguide. When it is especially necessary to expand the bandwidth, it is effective to make the f_2 cavity resonator a double tuner.

4. Experiment Results

The gain of the experimental amplifier and the noise factor frequency characteristics are shown in Figure 6. The gain characteristics are measured at an input signal level of 65-80dbm and have not been effected by saturation. The noise numbers are the values measured for the overall

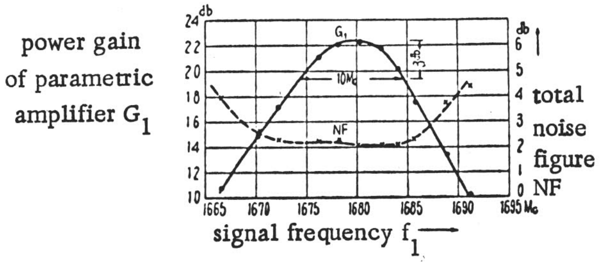


Figure 6. Frequency characteristics of power gain and noise.

circuit, including the parametric amplifier, frequency transducer, center frequency amplifier (bandwidth approximately 3Mc, noise number including frequency transducer approximately 12db).

The noise generated by the fluorescent lamps is the standard. (Assuming that the noise is 15.8db higher than thermal noise at room temperature.) As in the graph, the half value for the gain at 22db is 10Mc, and an overall noise number of approximately 2db is obtained.

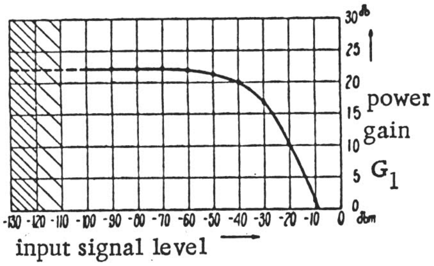


Figure 7. Saturation characteristics.

Figure 7 shows the saturation characteristics of this amplifier. When the input signal level reaches 40dbm, saturation phenomena appear, and when reaching -10dbm it is completely saturated. When the input is decreased to -110dbm, a considerable amount of noise appears, but below 120dbm, it becomes possible to discriminate the input.

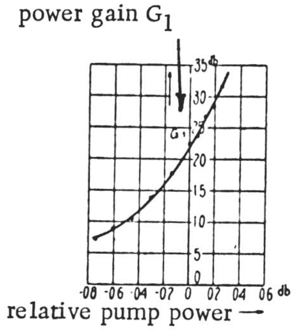


Figure 8. Relationship between power gain and pump power.

Figure 8 shows the relationship between pump power and power gain. With a gain of 22db, when the pump power changes 0.1db it is discovered that the gain changes about 3db. This amplifier does not have any pump power or frequency stabilizer other than that belonging to the klystron powe source, but it is not especially inconvenient for determining the rocket tracks. Figure 9 shows the relationship between the power gain and the amplifier bandwidth.

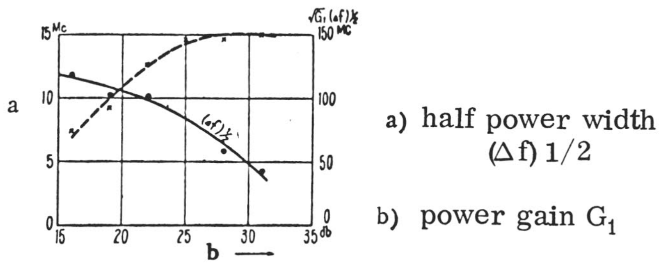


Figure 9. Relationship between power gain and amplified bandwidth.

5. Conclusion

I have treated the low noise parametric amplifier trial-manufactured for the purpose of low noise in a rocket tracking radar receiver. This amplifier is now being used at the Akita Proving Grounds and with it we have been able to increase the transponder signal range 3-4 times. I wish to express my thanks to Mr. Shuho Kurashige, head of the Meguro (Tokyo) Laboratory of the Meisei Electric Company, who rendered much assistance in the manufacture and testing of the amplifier.

(November 12, 1960)

References

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