9.4: DESIGN OF A WIDEBAND TUNNEL DIODE PREAMPLIFIER FOR PHASED ARRAY RADARS*

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The development of the phased array radar has generated the requirement for a simple, inexpensive low noise preamplifier which will have at least a 12 per cent 1 db bandwidth, less than a 4 db noise figure and which will phase and amplitude track over the pass-band.

A L-band tunnel diode preamplifier has been developed at Bendix Radio which will meet all of the above requirements. This preamplifier is a circulator coupled shunt mode, reflection type tunnel diode amplifier which is built as one integral unit (see Figure 1). The use of this unique

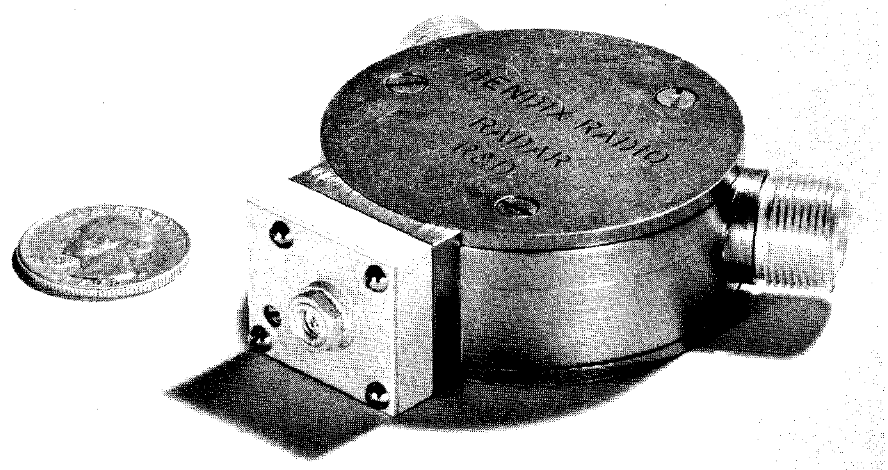

Fig. 1. Three port circulator coupled tunnel diode amplifier.

mounting technique resulted in a preamplifier which is extremely stable and which exhibited a 200 Mc/s bandwidth as is shown in Figure 2. The overall preamplifier performance is tabulated below:

Center frequency	1250 Mc/s
1 db bandwidth	200 Mc/s
Gain	15 db
Noise figure	3.5 db
1 db Saturation level	-35 dbm
Type tunnel diode	STD 023 (Bendix Spec)
Peak RF power capability	10 watts

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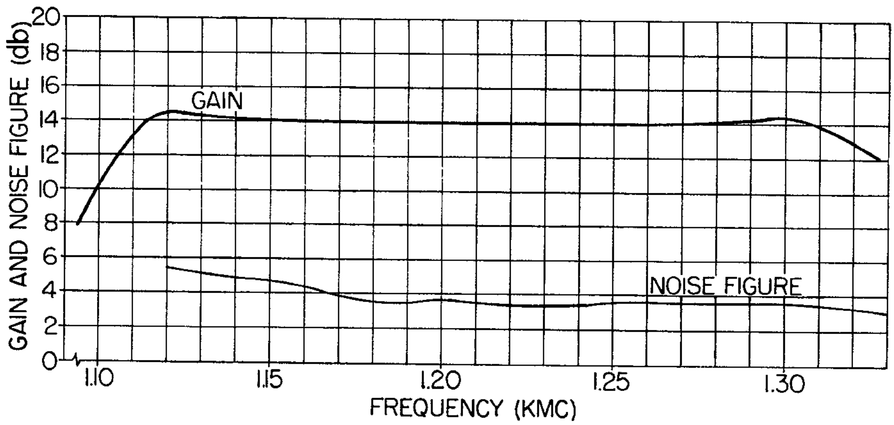

Fig. 2. Tunnel diode amplifier gain and noise bandwidth.

The successful design of a tunnel diode amplifier must consider not only the gain, bandwidth, and noise figure of the preamplifier, but related system parameters also. The following points are considered primary in any tunnel diode receiver design.

The gain of the tunnel diode reflection type amplifier can be expressed by

$$W_p = \frac{(1 + a)^2 + B^2}{(1 - a)^2 + B^2}$$

where W_p is power gain

a is $\frac{G'_d + G'_s}{G_c}$

G'_d is transformed negative conductance

B is total circuit susceptance.

Since the negative resistance of most tunnel diodes vary considerably from unit to unit, it is often necessary to use a matching device which will set the impedance levels to give the desired gain. While quarter wave transformers are commonly used, they are only about 10 per cent wide and cause stability problems due to the added line length. A better scheme is to use a series-parallel reactance arrangement. The series reactance in effect alters the terminal negative resistance sufficiently to change the amplifier gain by 3-4 db. This technique is particularly attractive since it does not require a change in bias voltage and hence a degradation in noise figure (changing the bias also alters the terminal negative resistance, hence gain, but with a sacrifice in noise figure).

The predominate factor controlling the tunnel diode noise figure is shot noise, generally expressed in terms of the I/G ratio. The noise figure equation for the tunnel diode is

$$F = \frac{1 + \alpha 20 \frac{I_o}{|G_d|}}{\left(1 - \frac{R_s(f)}{R_d}\right)\left(1 - \frac{f^2}{f_{co}^2}\right)}$$

where

α is the gain factor

I_o bias current

G_d negative conductance

$R_s(f)$ AC Series resistance

f operating frequency

f_{co} resistive cutoff frequency at the I/G point.

Although the $\frac{I_o}{|G_d|}$ ratio is the predominate noise contributing factor, the series resistance to negative resistance ratio and operating frequency to resistive cutoff frequency ratio will degrade the diode noise figure drastically if allowed to become excessive.

For any tunnel diode there is only one bias point which will give the lowest I/G ratio or diode noise figure; therefore, changing the bias point to alter gain noticeably degrades the diode noise figure.

The single tuned bandwidth can be expressed by

$$BW = \frac{1}{2\pi R_d C_d}\left(\frac{1 - \alpha}{\alpha}\right)\left(1 - \frac{R_s}{R_d'}\right)$$

R_d is negative resistance

C_d is diode terminal capacitance

R_s diode series resistance

R_d' transformed negative resistance

α gain factor

While the single tuned response is 180 Mc/s, this is a 3 db bandwidth and therefore is not adequate. It is necessary then to use a double tuned response. The integral mating of circulator and preamplifier again proved advantageous since their individual parameters can be controlled such that together they form an equivalent two resonator bandpass filter circuit. The resultant response is shown in Figure 2.

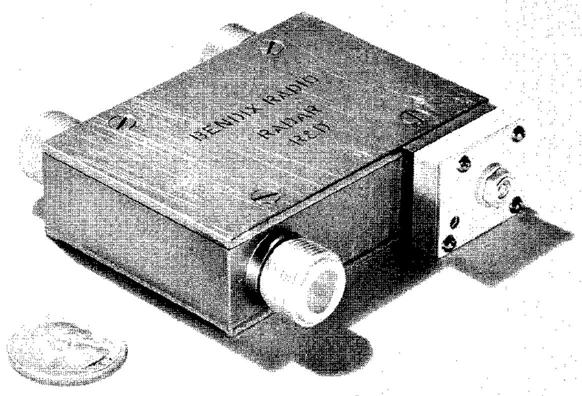

Fig. 3. Four port circulator coupled tunnel diode amplifier.

The stability of the tunnel diode preamplifier is largely controlled by the circulator and for that reason extreme care must be exercised in its design. The VSWR of the amplifier port must be kept low at the center frequency, but must be tapered toward the band edge so that its impedance compliments that of the amplifier. The integral mating of circulator and amplifier eliminates undesired line length thus reducing impedance variations across the band.

The normal stability inequality

$$\frac{L_T}{|R_d| C_T} < R_T < |R_d|$$

where L_T is total circuit inductance
R_d is negative resistance
R_T is total positive resistance
C_T is total circuit capacity

must of course be satisfied not only for the signal frequencies, but also for very low frequencies. This then requires special care in the bias network design.

Although the three-port circulator provides adequate isolation for most cases, a poor design in the succeeding stages can cause instability via the antenna VSWR. Three methods which will correct this situation are:

1) A four-port circulator
2) A three-port circulator and an isolator
3) A directional filter.

The four-port circulator offers the best solution and can be realized by combining two three-port circulators under one set of magnets. A preamplifier using this method is shown in Figure 3. This preamplifier exhibited the same characteristics as its three-port counterpart except that the stability was improved. In the latter cases (2 and 3), caution must be used since the VSWR of the isolator or filter may become excessive at the edge of the band, thereby creating an unstable condition.

One of the system requirements is that of local oscillator rejection. The tunnel diode will not operate properly if LO leakage from the mixer is greater than -30 dbm, therefore mixer design becomes important.

While the tunnel diode is basically a low power device, tests have shown that it will continue to operate when subjected to RF peak powers of 10 watts. This becomes attractive since the monoplexer requirements (or duplexer) can be reduced thus saving monoplexer insertion loss (additional monoplexing may be necessary to protect the mixer diodes, but its loss appears after the preamplifier gain).

The final requirements for the phased array configuration is that the preamplifiers, which includes the circulator, phase and amplitude track over the desired bandpass within ± 10 degrees and ± 1 db, respectively. Again the succeeding mixer stage must be well matched so that reflections will not alter the tracking characteristics. Two preamplifiers checked against each other were found to track within ±5 degrees and ± 1 db, respectively. Figure 4 shows typical phase and amplitude tracking curves for these preamplifiers.

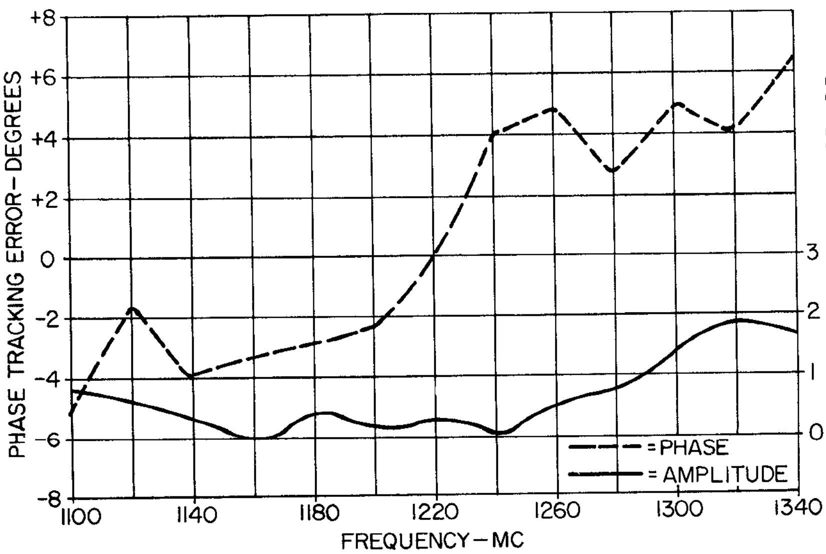

Fig. 4. Tunnel diode amplifier phase and amplitude tracking curves.