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FOURTH QUARTERLY REPORT

FOR

DEVELOPMENT OF MICROWAVE INTEGRATED

CIRCUIT NOISE SOURCE

This report covers the period of 17 January 1970 to 16 May 1970.

Prepared By:

J.C. Collinet

DEPARTMENT OF THE NAVY
WASHINGTON, D.C.

Contract No. N00039-69-C-1573

MICROWAVE ASSOCIATES, INCORPORATED
BURLINGTON, MASSACHUSETTS

DEVELOPMENT OF MICROWAVE INTEGRATED CIRCUIT NOISE SOURCE

FOURTH QUARTERLY REPORT
17 JANUARY 1970 TO 16 MAY 1970
DEPARTMENT OF THE NAVY
NAVAL ELECTRONIC SYSTEMS COMMAND
WASHINGTON, D.C. 20360
Code-05143A.

Contract No. N00039-69-C-1573

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ABSTRACT

Six Microwave integrated circuit, solid state noise sources have been built and tested between the frequency of 8 to 12.4 GHz. Results of the output spectrum noise measurements are presented.

I INTRODUCTION

This program is concerned with the development of a solid state noise source suitable for testing microwave receivers for noise figure and sensitivity. The objective is to produce a noise power density of 20 dB above 300°K thermal noise with a minimum instantaneous bandwidth of 100 MHz, flat to within ± 0.2 dB at any center frequency across the band of 2 to 12.4 GHz.

A single diode type noise source was intended to be used across the all frequency band as defined above. Therefore, a diode mount and its associated noise diode was investigated, designed, built and tested and results were presented in the first two quarterly reports (1,2). At this point, the program was re-oriented to a different goal for the following reasons.

Most of the systems in need of a solid state noise source are usually not as broadband as the bandwidth first suggested of 2 to 12.4 GHz, but divided in sub-bandwidths very similar to the bandwidths associated with standard waveguides such as: 2 to 4 GHz, 4 to 6, or 4 to 8 GHz and 8 to 12.4 GHz.

Cost of such devices are of prime considerations and must be competitive with actual noise sources such as gas discharge noise tubes, (dis-association is made here with the size and power supplies of such devices).

The cost of a broadband unit is directly proportional to the bandwidth specified and, in the present case, more than two octaves have to be covered. Two factors only determine mainly the cost involved. The circuit and the testing of the packages unit.

The circuit must have an extremely flat characteristic, small VSWR and insertion loss. These musts are fulfilled by the use of sophisticated components not readily available and of high costs.

Testing of the diode and the circuit is very lengthy because it requires switching test set-up as apparatus covering 2 to 12.4 GHz are not available, but covers only frequency bands well defined such as used in microwave sweepers, for example, 2 to 4 GHz, 4 to 8, 8 to 12 GHz. This time consuming testing may enter as much as 75% in the total cost of a broadband unit.

It was felt then, that a re-direction of the contract was necessary in order to achieve the development of a usable noise source, system oriented and at a minimum cost. The new objectives are as follows:

- Development of a noise source at X-Band, covering 8 to 12.4 GHz
- Output: 20 dB of excess noise above 300°K
  ±1 dB over the band of 8 to 12.4 GHz, ± 0.2 dB over any 100 MHz bandwidth
- Operating Temperature: -54 to +71°C
- Life Test: 6 units will be tested and evaluated after a limited life burn-in

The work accomplished during the fourth quarterly period with this new re-direction of the program is discussed in this report.

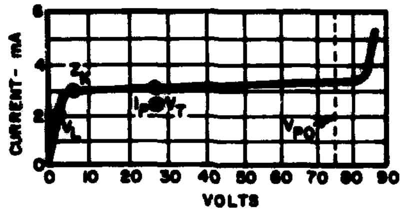
II CONSTANT CURRENT REGULATOR

The output noise for microwave integrated circuit noise source is very dependent of the current flowing through the avalanche diode as shown in the first three quarterly reports (1,2,3). In order to maintain a constant noise spectrum density, it is necessary, in a first step, to keep relatively constant the current flowing through the avalanche diode used in this case as noise generator. And as the noise source must be connected to a positive 28 volts - constant voltage supply, it is necessary to have a constant current regulator to be used as our interface between voltage supply and avalanche diode.

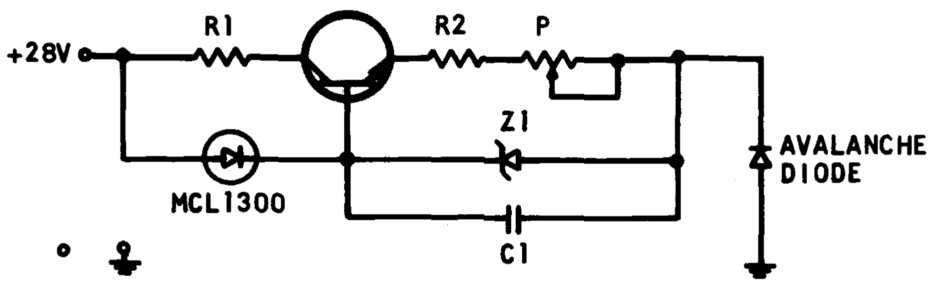
A first circuit was designed around a current reference diode as shown in Figure 1. The D.C. characteristic of the diode used, for example, MCL1303, a field effect current limiting diode, is shown in Figure 1a. It gives, when connected to a voltage source, a current reference or a constant current over a variable input voltage of 6 to 75 volts. This reference current was fed to the base of a transistor regulator and a zener diode, keeping the emitter to base voltage constant. The potentiometer P is adjusted for the wanted output current.

This type of series current regulator very economical and effective performed well, but was discarded because of the 9 volts minimum drop throughout the circuit necessary for current regulation (a 6 to 7 volts drop is necessary for the nominal pinch off current of the diode MCL1303).

The second type of current regulator chosen above the previous design is shown in Figure 2. It delivers a constant current bias source, adjustable between 7 and 60 mA, when connected to a +28 volts supply. This circuit is based on the properties of an amplifier named "compound follower" obtained from two transistors PNP and NPN, Q1 and Q2 connected, as in Figure 2. The



(a) CURRENT LIMITER DIODE CHARACTERISTICS



(b) CONSTANT CURRENT REGULATOR

FIGURE 1 CONSTANT CURRENT REGULATOR TYPE I

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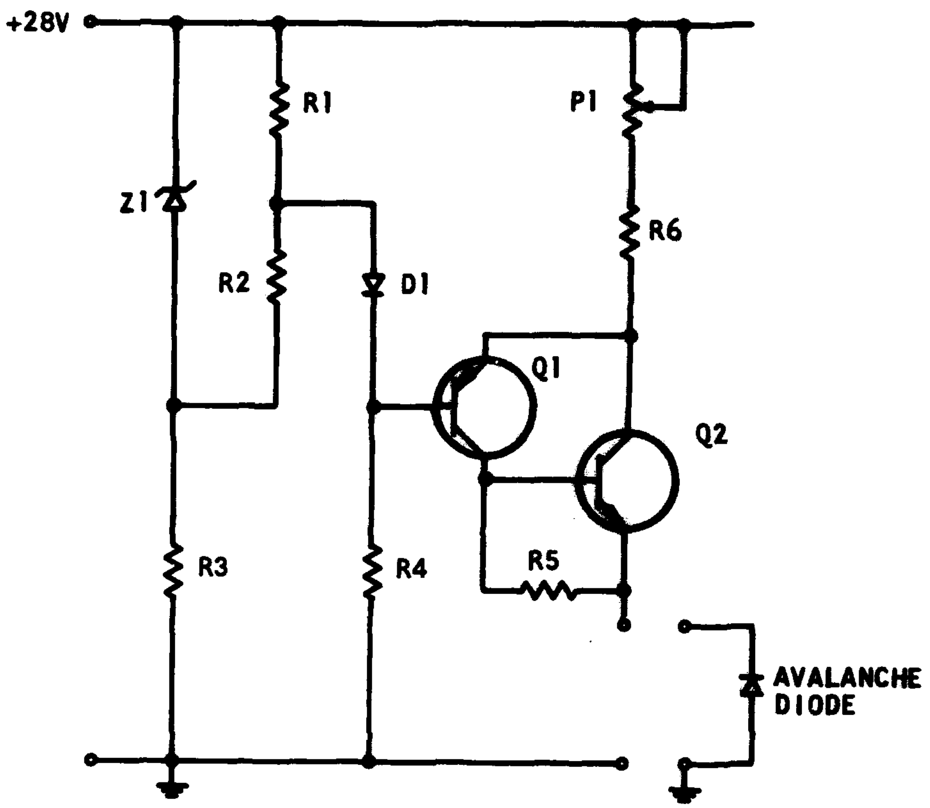

FIGURE 2 CONSTANT CURRENT REGULATOR TYPE II

D-9343

bias of transistor Q1 is derived from a voltage divider, R1, R2, connected across a stable zener diode Z.

Correct biasing of the Zener diode Z is obtained by the resistance R3.

- Temperature compensation of the transistor Q1 is given by the diode D1, neutralizing drift of the base emitter junction of Q1.
- The DC current return path of the base emitter junction of Q1 is made through R4.
- Resistance R6 sets the high current limit of the regulator.
- P1 is a potentiometer which permits current setting and is a 20 turns type potentiometer with infinite resolution. Its nominal value, in conjuction with R6, sets the lowest limit of the output current.
- The DC current gain of transistor Q1 is approximately 200, while the current gain of Q2 is 50. The total gain of the compound amplifier combination of Q1, Q2 can be approximated to be the product of individual transistor gains, i.e.:

  Gain of the compound amplifer = gain of Q1 x Gain of Q2

  = 200 x 50 = 10000

(The component values are given in Table 1)

After building and testing this circuit, it was decided to put all components on a printed circuit card, rather than to integrate on a ceramic board, for example, all the components. It is more economical and more feasible to assemble standard components on a glass epoxy circuit board when considering the relative size of board assemblies, the problems associated with heat sinking of transistors, availability of transistors and diode chips, resistance triming and the lack of external current adjustability, if desired, given by the potentiometer P1 if the circuit is integrated. In effect, the potentiometer P1 gives a tremendous advantage for fabrication of the complete noise source. The dispersion of the output noise magnitude from avalanche diode to avalanche diode, or circuits to circuits, or consideration of both, is narrowed down by simply adjusting the output current flowing through the avalanche diode. It gives also another feature to the source, that is, the noise source becomes field adjustable. In such case, a calibration chart would be necessary.

TABLE 1

Q1	2N3906	Plastic Type Case
Q2	2N4922	Plastic Type Case
D1	IN914	Glass Type
Z1	IN752A	Glass Type
R1	1.8K ohms	1/10 of Watt
R2	8.2K ohms	1/10 of Watt
R3	3.9K ohms	1/4 of Watt
R4	27K ohms	1/10 of Watt
R5	680 ohms	1/10 of Watt
R6	39 ohms	1/10 of Watt
P1	200 ohms	2 Watts

III PACKAGING OF THE CURRENT REGULATOR

The components of the current regulator are mounted on a glass epoxy board - G10-type 2 ounces, one sided, tin plated, measuring 1.325" x .725. It is shown in Figure 3, mounted in an aluminum housing, which provides also a heat sink to the insulated plastic type transistor Q2 (mounted on the side of the case). DC current is fed to the printed circuit board through a low pass filtercon and to the microwave integrated circuit also through a low pass filtercon having an attenuation of up to 80 dB from 1 GHz to 30 GHz (commercially available).

IV EXTERNAL PULSE OPTION

Pulsing the microwave integrated noise source is possible when the DC constant current regulator is modified such as in Figure 4. The circuit used is the same as in Figure 2, but a transistorized switch is added to the Zener diode and transistor Q1 biasing circuit path. Figure 4 shows a PNP transistor switch Q3 and its biasing resistor. External pulses are fed through the RC network R7 and C1.

Pulsing the circuit was verified to be possible for frequencies of several hundred Kilohertz without difficulties and up to 1 MHz, when careful considerations were given to the values of components, characteristic of transistors and layout of the circuit.

This external pulse option was not added to the printed circuit board. But, if such an option is necessary, the board can be easily modified to accommodate the necessary components Q3, R7, C1, R8.

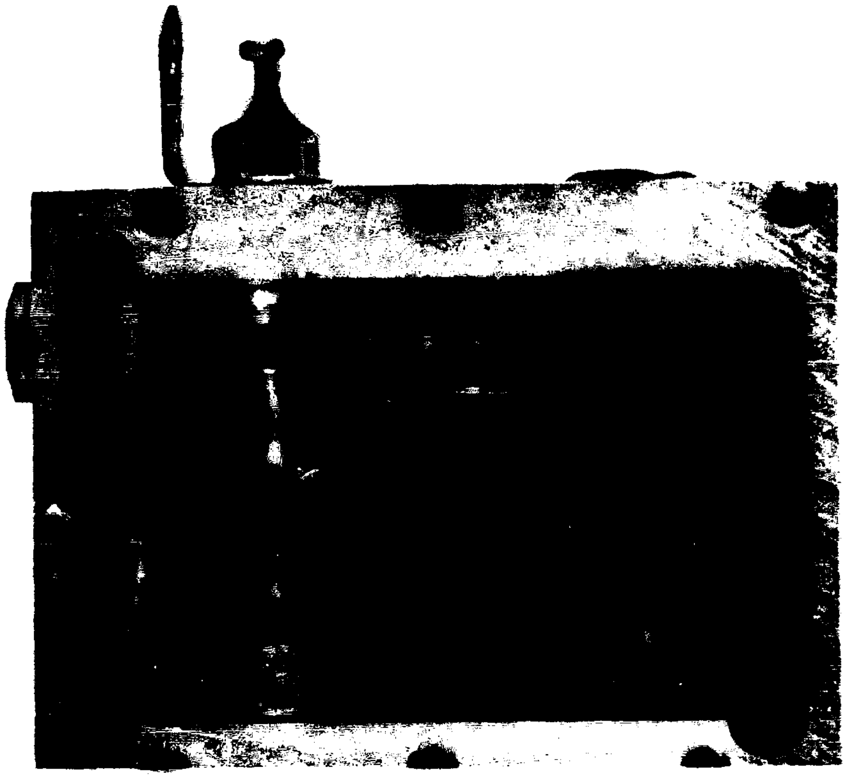

FIGURE 3 PRINTED CIRCUIT OF THE CURRENT REGULATOR MOUNTED IN AN ALUMINUM HOUSING.

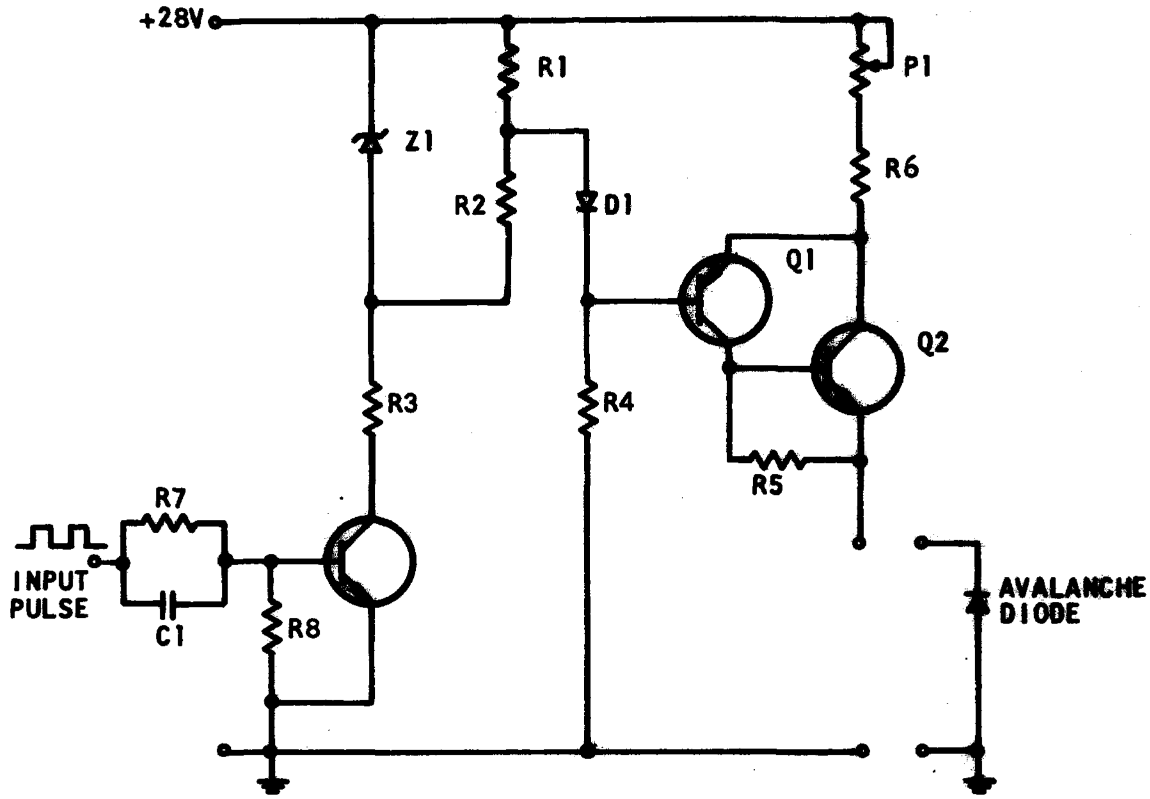

FIGURE 4 CONSTANT CURRENT REGULATOR TYPE II
WITH PULSING CIRCUIT

D-9341

V NOISE SOURCE CIRCUIT - R.F. SECTION

Measurements of the output noise of microwave integrated circuit noise source was presented in the Third Quarterly Report. Some abnormalities, especially around 12.4 GHz, where the output noise drops sharply, were noted in conjunction with a ripple of $\pm$ 1 dB from 8 to 11.6 GHz for a current of 20 mA. This problem of output spectrum flatness is associated to the circuit characteristic, i.e. coupler and biasing components, in conjunction with the line length between diode and coupler. A separate circuit was constructed by a thick film process on a 20 mil thick ceramic and analyzed on a microwave analyzer for transmission losses and VSWR at the input port and output port. It was found that the VSWR was high at some points of the frequency band and correction of the circuit was necessary. This was accomplished by two slight circuit modifications as shown in Figure 5 - the first prototype being shown in Figure 6. Data obtained from the network analyzer is shown in Figure 7 or 8 and is best possible data that we obtained. VSWR and coupling ripple could not be brought down further. In this testing circuit, some losses and VSWR were associated to the two coaxial to microstrip junction, one at the output port, one at the place of the avalanche diode input port. Because in the final circuit, only one transition of microstrip to coaxial is used, thus, eliminating errors and because a circuit with such characteristics would compensate the diode output noise behavior, especially at the high frequency end of the band, it was felt, then, that this type of modified circuit could be used readily in the final source. Results of the six circuits built and tested are presented in the following pages.

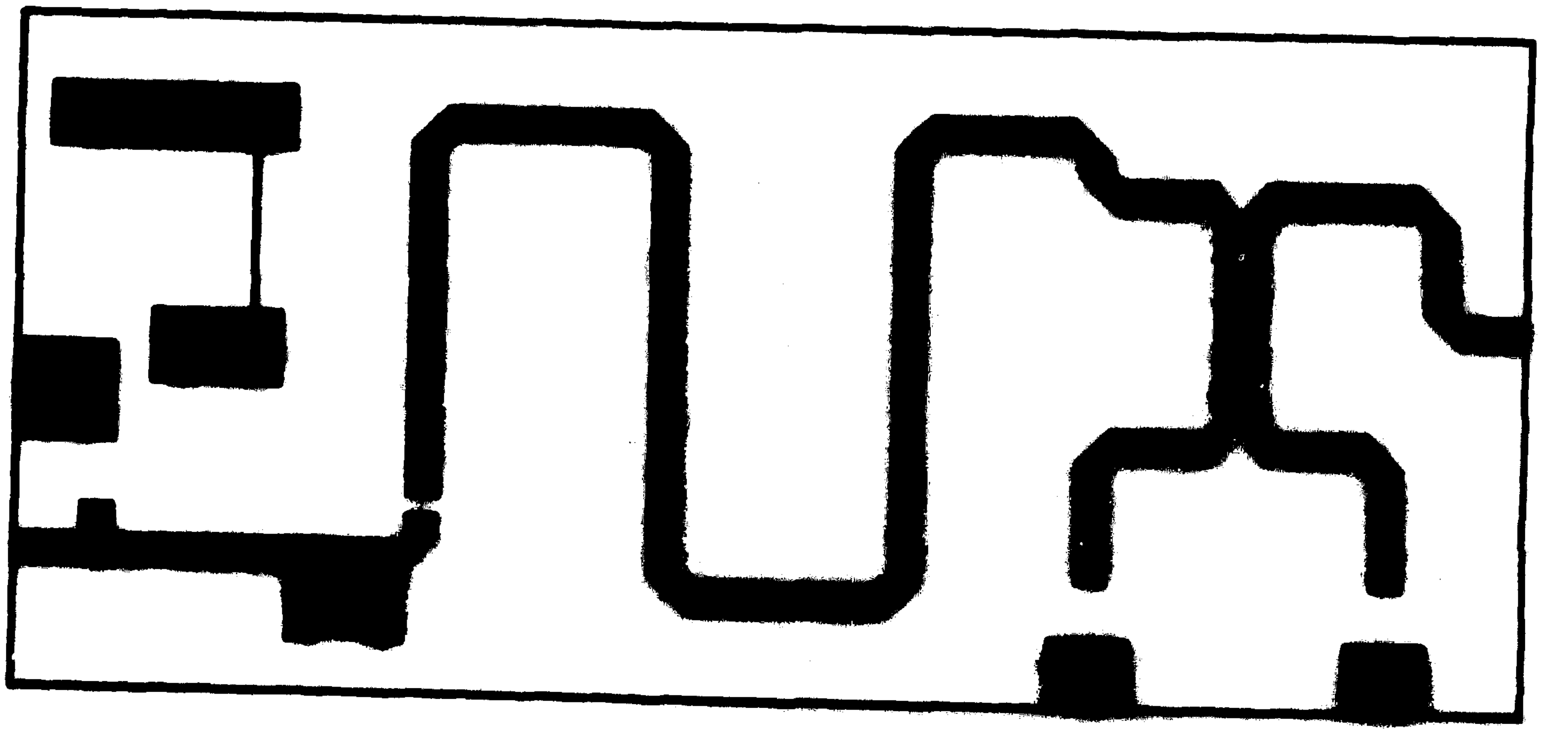

FIGURE 5 MODIFICATION OF THE MICROSTRIP CIRCUIT

D-9340

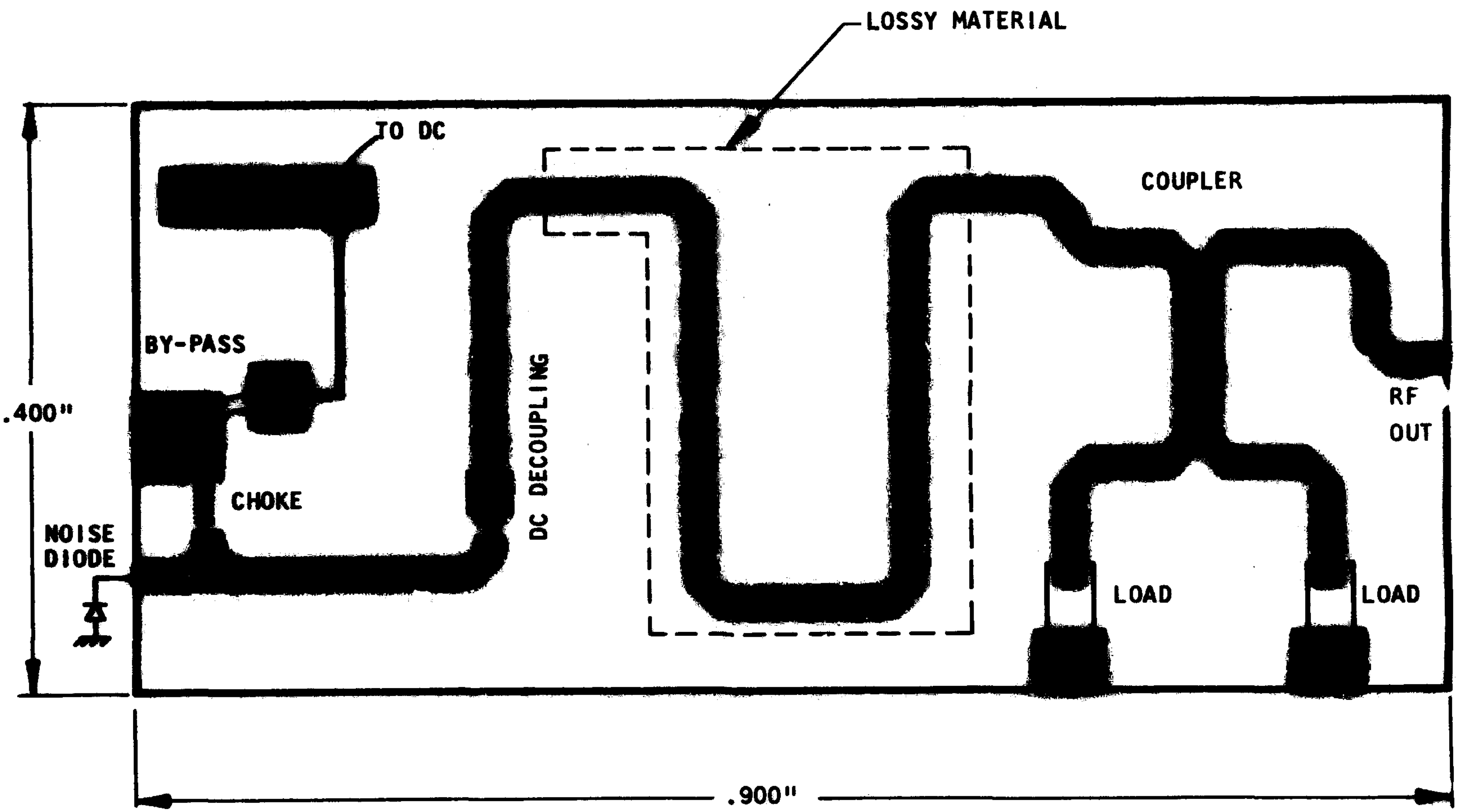

FIGURE 6 1st PROTOTYPE OF THE MICROSTRIP CIRCUIT BEFORE MODIFICATION

D-9203

FREQ	VSWR	LOSS
8000.0	1.516	-10.11
8100.0	1.318	-10.03
8200.0	1.165	-9.96
8300.0	1.126	-9.96
8400.0	1.243	-9.99
8500.0	1.410	-9.99
8600.0	1.560	-10.06
8700.0	1.690	-10.12
8800.0	1.769	-10.17
8900.0	1.812	-10.14
9000.0	1.812	-10.08
9100.0	1.797	-10.01
9200.0	1.778	-9.94
9300.0	1.764	-9.85
9400.0	1.768	-9.64
9500.0	1.787	-9.51
9600.0	1.810	-9.49
9700.0	1.812	-9.51
9800.0	1.788	-9.67
9900.0	1.711	-9.79
10000.0	1.605	-9.95
10100.0	1.511	-10.25
10200.0	1.474	-10.65
10300.0	1.474	-10.60
10400.0	1.486	-10.10
10500.0	1.573	-9.79
10600.0	1.735	-9.59
10700.0	1.927	-9.65
10800.0	2.118	-9.74
10900.0	2.261	-9.81
11000.0	2.280	-9.83
11100.0	2.202	-9.73
11200.0	2.000	-9.47
11300.0	1.694	-9.13
11400.0	1.330	-8.90
11500.0	1.046	-8.90
11600.0	1.338	-9.09
11700.0	1.801	-9.45
11800.0	2.332	-9.84
11900.0	2.899	-10.29
12000.0	3.416	-10.61
12100.0	3.858	-10.89
12200.0	3.997	-11.17
12300.0	3.804	-11.30
12400.0	3.274	-11.35

FIGURE 7 VSWR AND TRANSMISSION LOSS OF THE MICROSTRIP CIRCUIT INPUT TO OUTPUT PORT

FREQ	VSWR	LØSS
8000.0	2.029	-10.24
8100.0	2.070	-9.99
8200.0	2.087	-9.84
8300.0	2.085	-9.76
8400.0	2.065	-9.68
8500.0	2.021	-9.76
8600.0	1.974	-9.87
8700.0	1.932	-9.98
8800.0	1.894	-9.97
8900.0	1.880	-9.85
9000.0	1.862	-9.73
9100.0	1.844	-9.66
9200.0	1.800	-9.68
9300.0	1.758	-9.67
9400.0	1.689	-9.68
9500.0	1.625	-9.74
9600.0	1.566	-9.87
9700.0	1.519	-9.86
9800.0	1.480	-9.80
9900.0	1.452	-9.74
10000.0	1.443	-9.84
10100.0	1.442	-10.12
10200.0	1.421	-10.50
10300.0	1.372	-10.46
10400.0	1.318	-10.02
10500.0	1.295	-9.67
10600.0	1.290	-9.54
10700.0	1.311	-9.58
10800.0	1.355	-9.68
10900.0	1.413	-9.78
11000.0	1.468	-9.73
11100.0	1.523	-9.62
11200.0	1.568	-9.32
11300.0	1.607	-8.96
11400.0	1.653	-8.79
11500.0	1.719	-8.84
11600.0	1.831	-9.01
11700.0	1.979	-9.28
11800.0	2.152	-9.56
11900.0	2.345	-9.94
12000.0	2.545	-10.28
12100.0	2.772	-10.64
12200.0	3.019	-11.02
12300.0	3.209	-11.23
12400.0	3.333	-11.30

FIGURE 8 VSWR AND TRANSMISSION LOSS OF THE MICROSTRIP OUTPUT TO INPUT PORT

VI PACKAGING OF THE RF SECTION

The Microwave integrated circuit, fabricated on a 20 mil thick ceramic, is shown in Figure 9, where the following components can be readily recognized.

- Avalanche diode in its package
- 10 dB coupler 8 to 12.4 GHz
- 50 ohm loads
- DC de-coupling capacitance
- DC feed - coil and by-pass

VII PACKAGING OF THE COMPLETE MICROWAVE INTEGRATED NOISE SOURCE

Figure 10 shows the complete opened integrated noise source in an aluminum housing, divided in two sections. One side shows the current regulator and its printed circuit board, the plastic package power transistor mounted on the side of the housing. The second compartment encloses the microwave integrated circuit and the avalanche diode and a load to absorb all radiated energy leaking in the housing, which might disturb the characteristic of the circuit.

VIII TEST OF THE COMPLETE SOURCE

After complete assembly of all components in the housing and with the cover on, 7 units were tested between the frequency band of 8 to 12.4 GHz. Measurements were made in the same manner as previously reported [1,2,3], i.e. comparison to a standard noise tube.

FIGURE 9 MICROWAVE INTEGRATED CIRCUIT IN ITS ALUMINUM HOUSING .

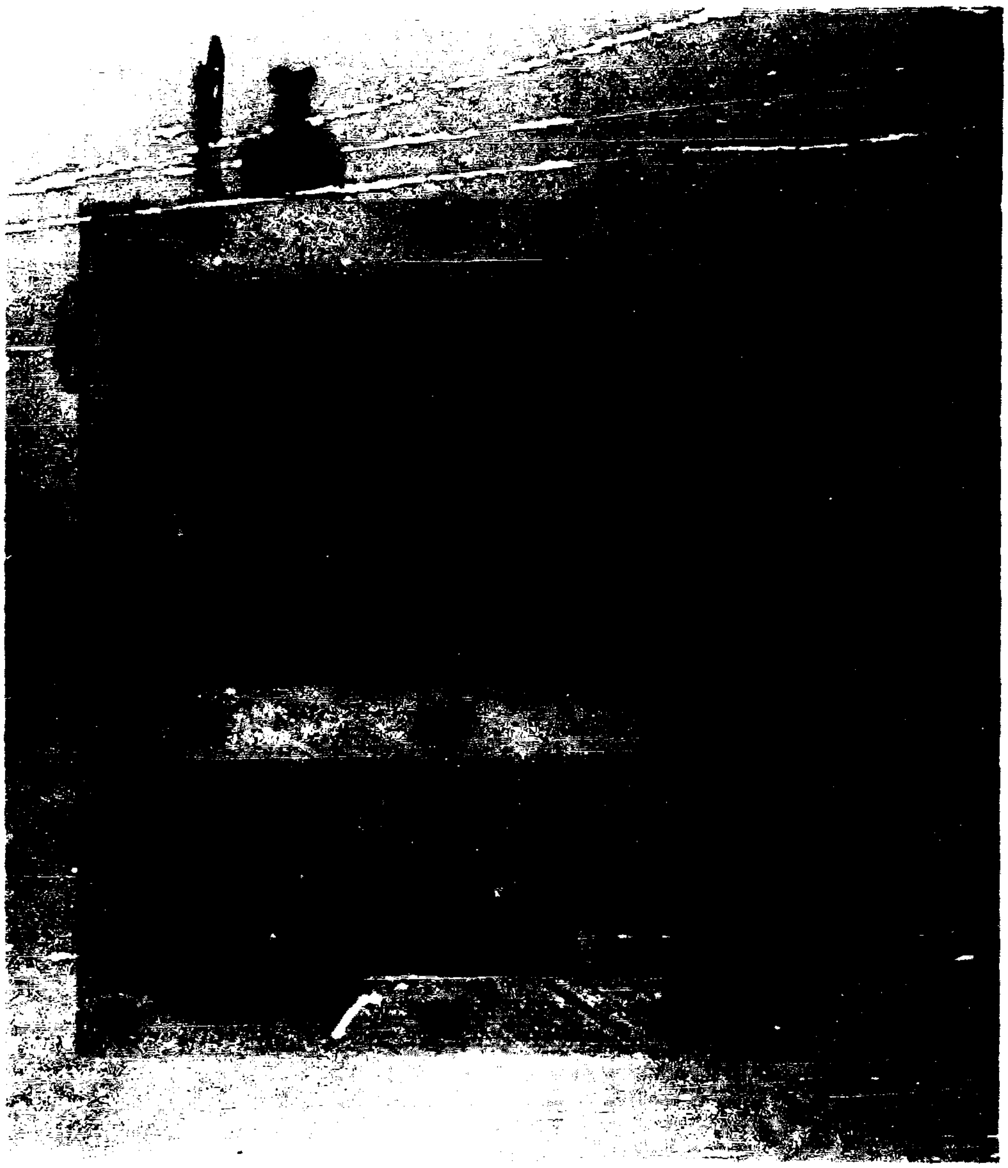

FIGURE 10 MICROWAVE INTEGRATED CIRCUIT NOISE SOURCE AND ITS CURRENT CONTROLLED REGULATOR.

Results are shown in Figures 11, 12, 13. 14, 15 for only three noise sources, for a total current flowing through the source, current regulator and avalanche diode, variable between 10 and 60 mA.

Figure 11 - Noise Source No. 4 - currents of 30, 40, 50 and 60 mA.

Figure 12 - Noise Source No. 4 - current of 50 and 60 mA.

Figure 13 - Noise Source No. 7 - current of 50 and 60 mA.

Figure 14 - Noise Source No. 1 - current of 20, 40, 60 mA.

Figure 15 - Noise Source No. 1 - current of 45, 50, 55 mA.

The output noise spectrum presents some abnormalities, especially a high ripple, which can go as high as $\pm$ 2 dB in some frequencies, plus a recurrence in high and low output noise value every 600 MHz, approximately. The high peak values are at 8.8 GHz, 10.2 GHz, 11.4 GHz, 12.2 GHz, while the low readings are at 9.6 GHz, 10.8 GHz, 12 GHz.

The mean output noise value is set around 25 dB. This was set deliberately, so each source could be adjusted to the specification of 20 dB by the addition of lossy material over the line connecting diode to coupler (Third Quarterly Report).

Further study of the sources 2, 3, 5 and 6 have shown also the same behavior of ripple across the band of 8 to 12.4 GHz. Spurious modes of propagation were then suspected and an attempt to suppress them was made through the following experiments.

(1) A load .250" x .400" and .100" thick of material, having a specified absorption of 80 dB/inch, was placed on the top line connecting diode to coupler. (Line enclosed by dotted line on Figure 6). Results are shown in Figure 16. As expected, because the dimensions of the load are too large, the output spectrum falls off with increasing frequency, being around 20 dB (for 50 mA) at 8.4 GHz and 15 dB at 12.4 GHz (50 mA also). But the ripple is still present and occurs at regular frequency intervals.

(2) A load of lossy material .100" x .100" and 3 mils thick of 25 ohms per square characteristics, was placed on one part of the S shape lossy line section. Results, shown on Figure 17, shows a frequency dependence of the losses added to the circuit, but the ripple is down to a value as low as ± 0.5 dB between 8.4 and 10.8 GHz, to increase to ± 1 dB at 12.4 GHz.

(3) Another test made with two lossy sheets of 200 ohm/square placed on the two parallel lines of the S shape lossy line section is shown in Figure 18. Frequency dependence occurs with a slope of 1.5 dB/GHz from 8.4 to 12.4 GHz, while the ripple is at a low value of ± .5 dB (for a current of 55 mA).

(4) Addition of a lossy paint all over the S shaped line length produces the spectrum shown in Figure 19. These experiments have shown with certitude that other phenomena than a single VSWR variation of the microstrip lines were involved and can be defined as spurious modes of propagation taking place in-

side the ceramic substrate itself. In fact, an experiment was set up to prove that waveguide modes could propagate in a microstrip ceramic board.

In Figure 20 is shown a ceramic substrate plated on both sides, one side being grounded, the other side is connected to two OSM connectors. Energy is transferred from one connector to the other when the width of the substrate becomes approximately a quarter wavelength. All frequencies can be transmitted above this point and the ceramic board becomes a high-pass filter. Other surface modes are also present in any substrate and, in our case, gives us the high ripple encountered. Because of the lines of the microstrip circuit running parallel, although they are far away from each other, reinforcements and diminutions of the coupling factor of the coupler will be present at some frequencies and this can be encountered periodically, which is presently our case.

IX NEW APPROACH OF THE RF CIRCUIT

Another approach being studied is shown in Figure 21. Lines are kept short in length, the coupler is increased to 13 dB and plated through holes are used extensively to suppress all spurious modes of propagation.

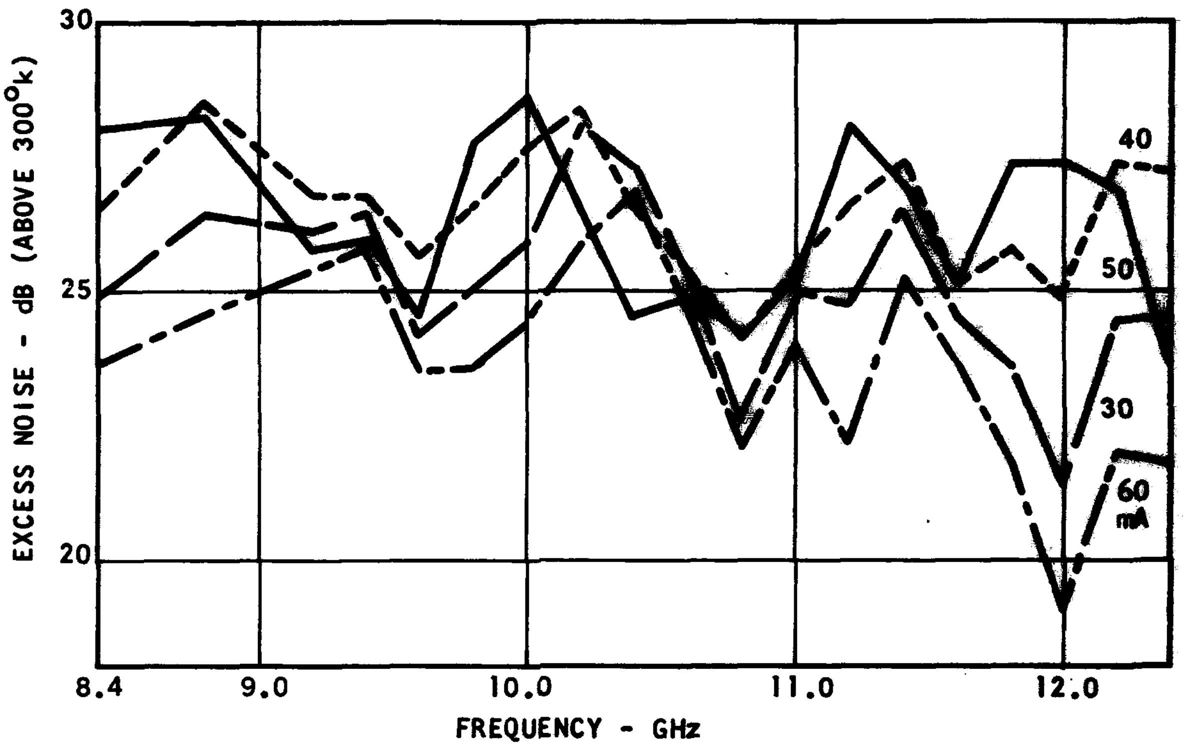

FIGURE 11 NOISE POWER VS FREQUENCY SOURCE NO. 4
CURRENT OF 30, 40, 50, 60 mA

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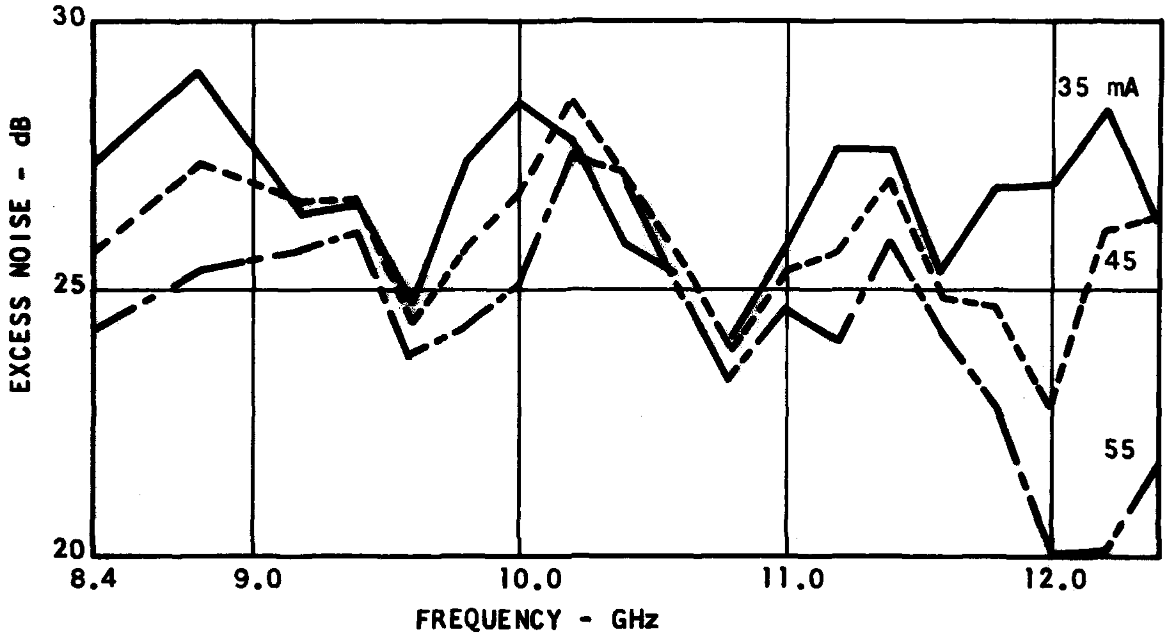

FIGURE 12 NOISE POWER VS FREQUENCY SOURCE NO. 4
CURRENT OF 35, 45, 55 mA

D-9349

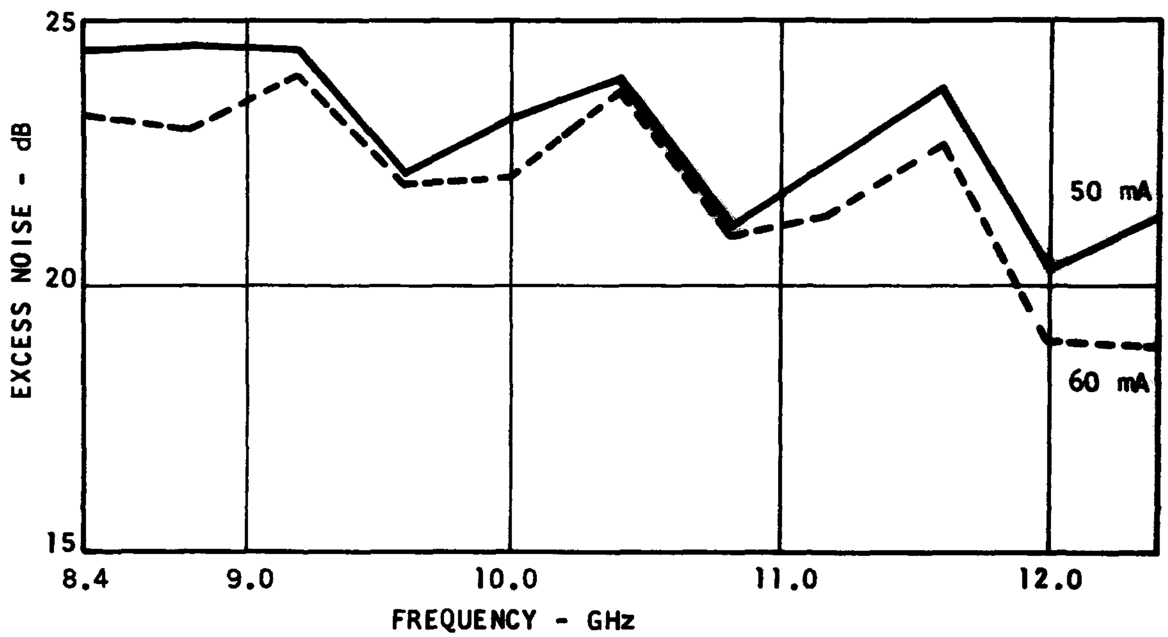

FIGURE 13 NOISE POWER VS FREQUENCY SOURCE NO. 7
CURRENT OF 50, 60 mA

D-9350

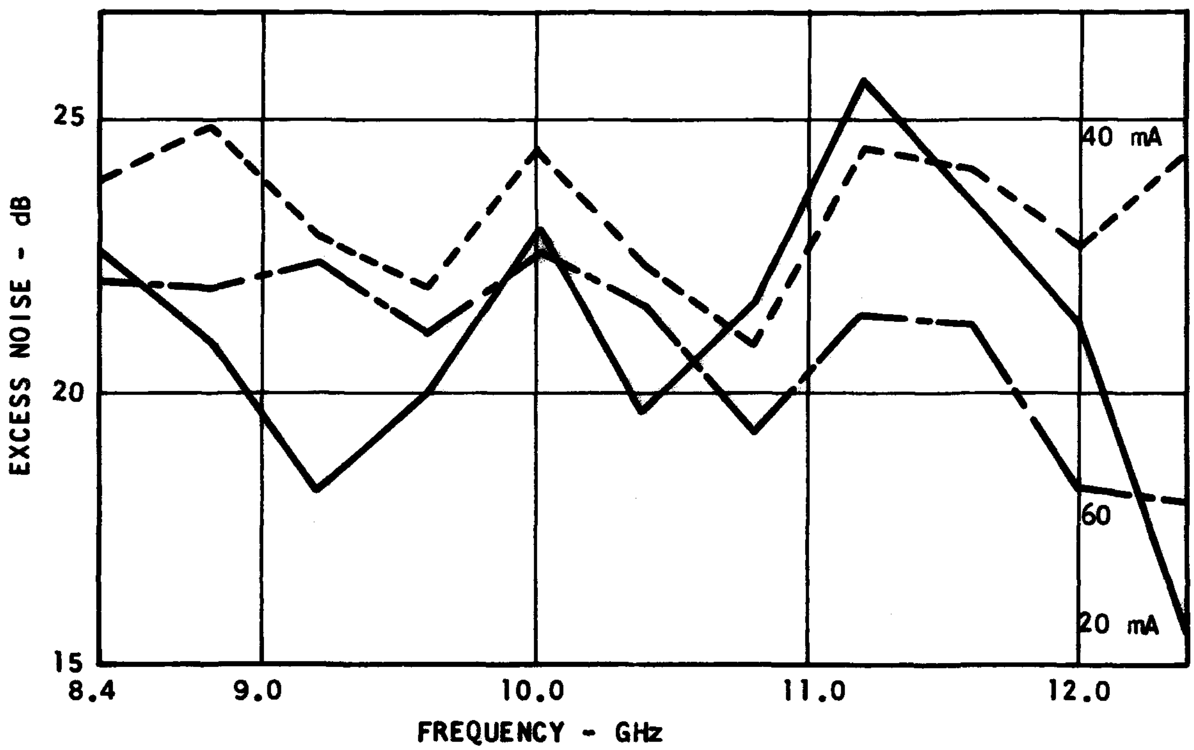

FIGURE 14 NOISE POWER VS FREQUENCY SOURCE NO. 1
CURRENT OF 20, 60 mA

D-9351

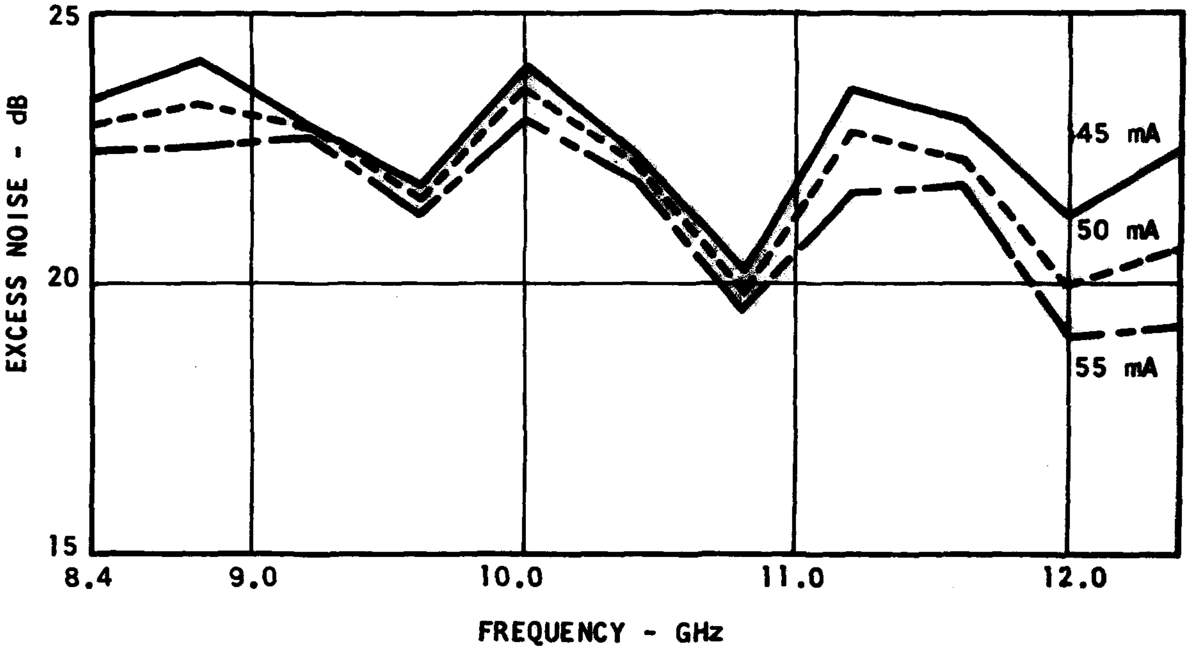

FIGURE 15 NOISE POWER VS FREQUENCY SOURCE NO. 1
CURRENT OF 45, 50, 55 mA

D-9352

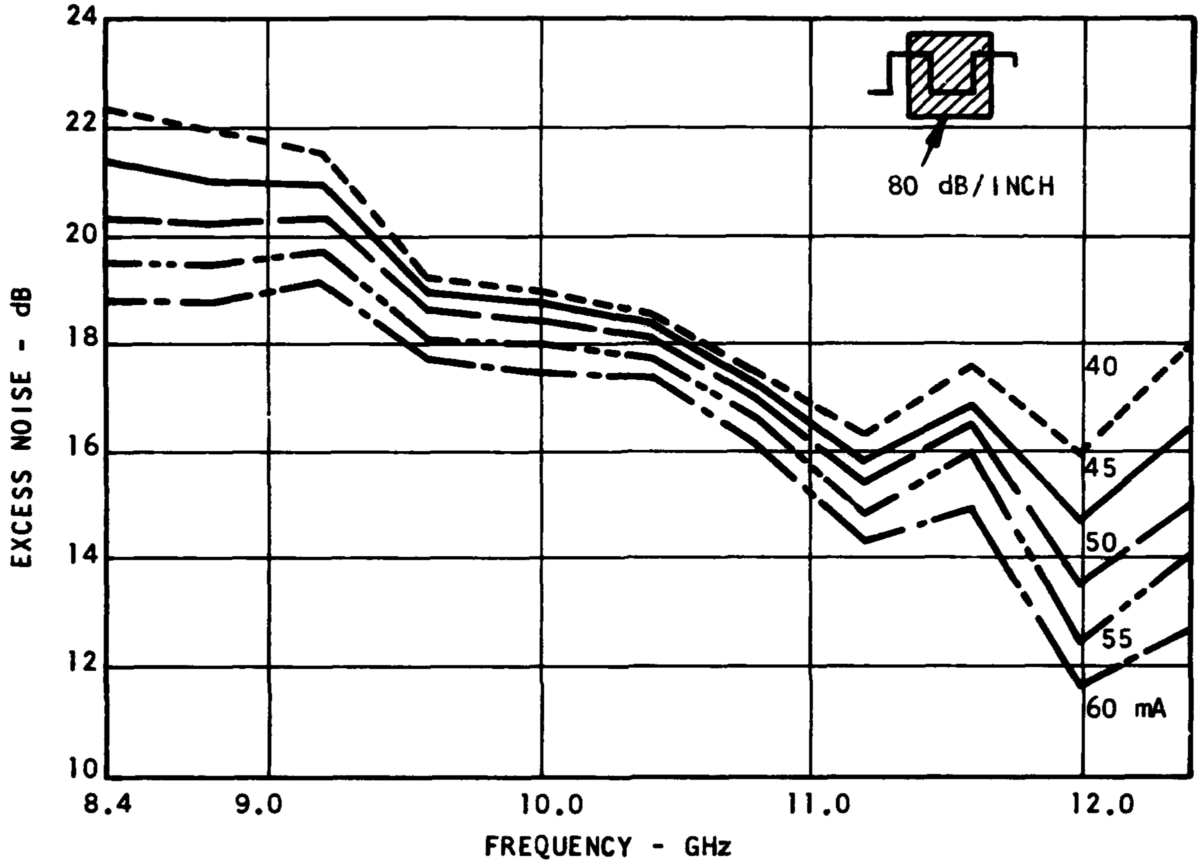

FIGURE 16 NOISE POWER VS FREQUENCY EFFECT OF AN 80 dB/INCH LOAD

D-9347

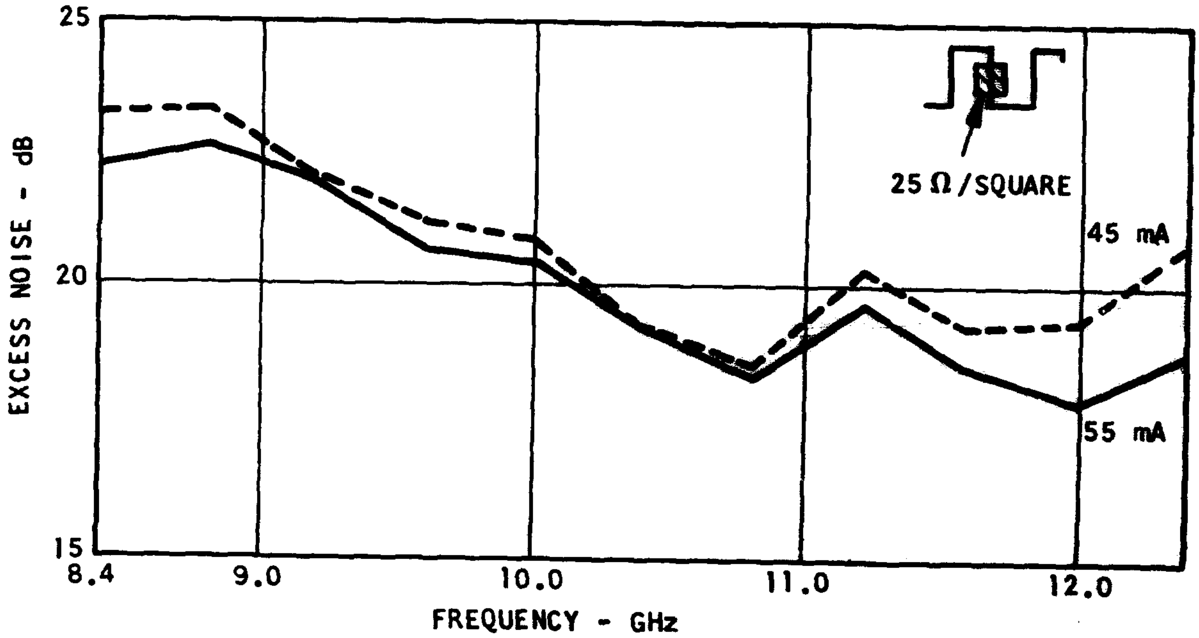

FIGURE 17 NOISE POWER VS FREQUENCY EFFECT OF A 25 Ω /SQUARE LOAD

D-9353

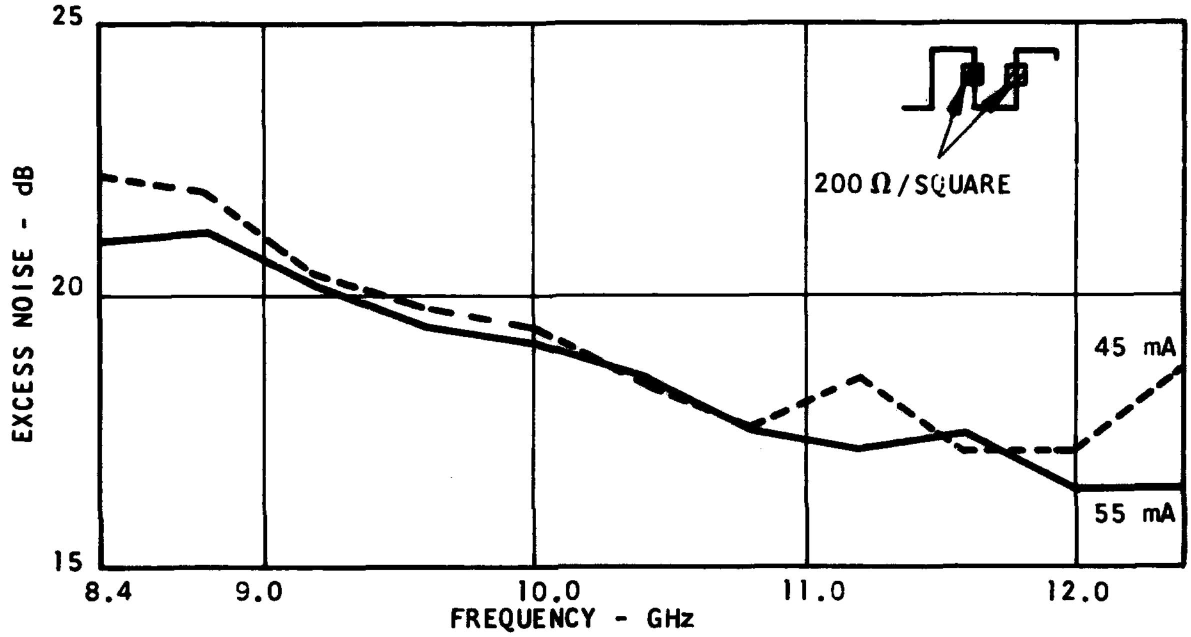

FIGURE 18 NOISE POWER VS FREQUENCY EFFECT OF TWO 200 Ω/SQUARE LOADS

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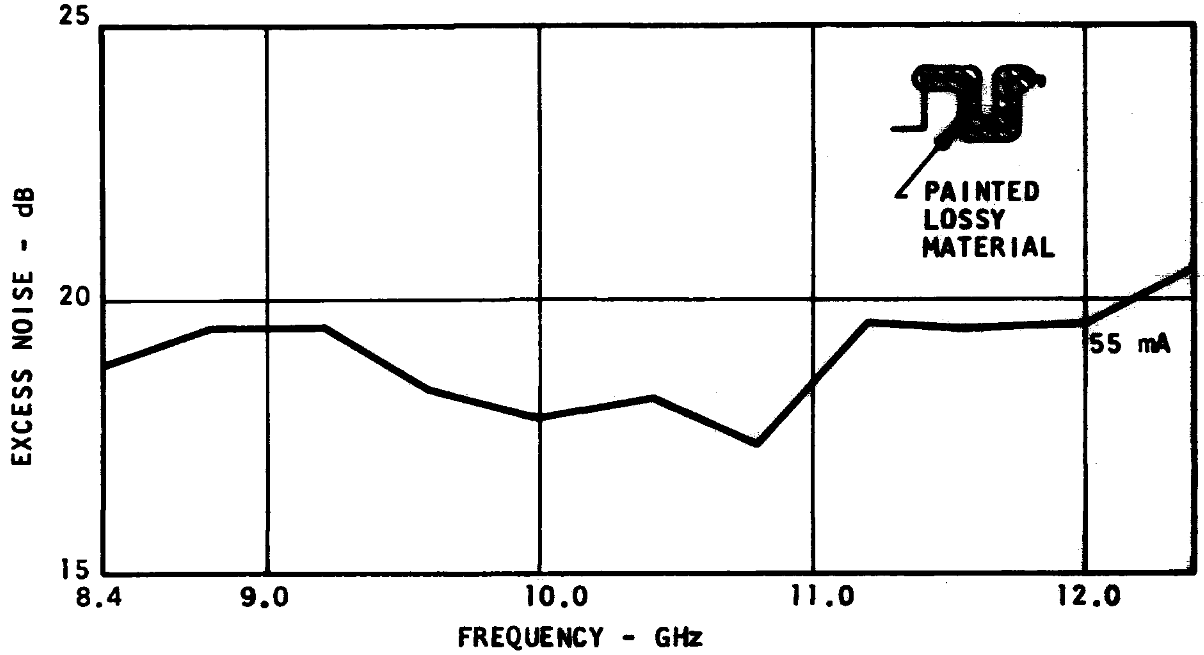

FIGURE 19 NOISE POWER VS FREQUENCY EFFECT OF A PAINTED LOSSY MATERIAL

D-9355

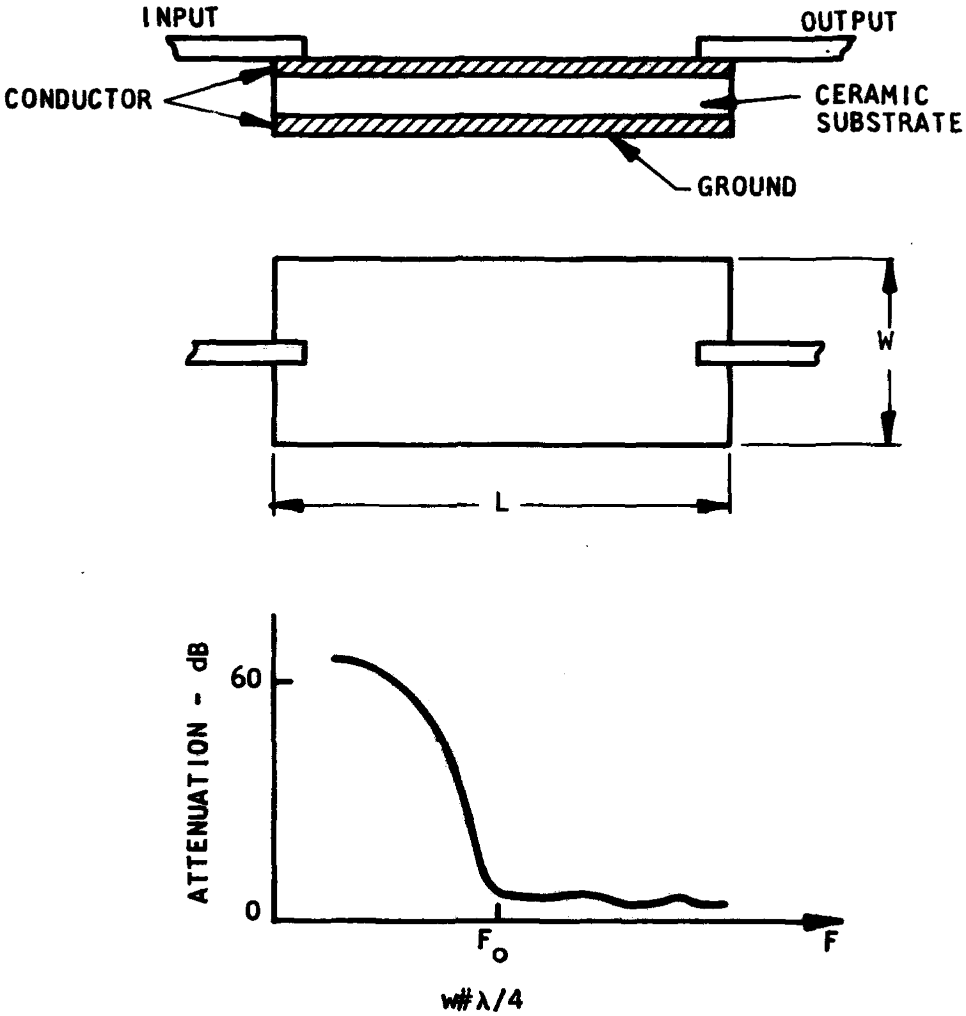

FIGURE 20 FILTERING EFFECT BY AN OVERSIZED CERAMIC SUBSTRATE

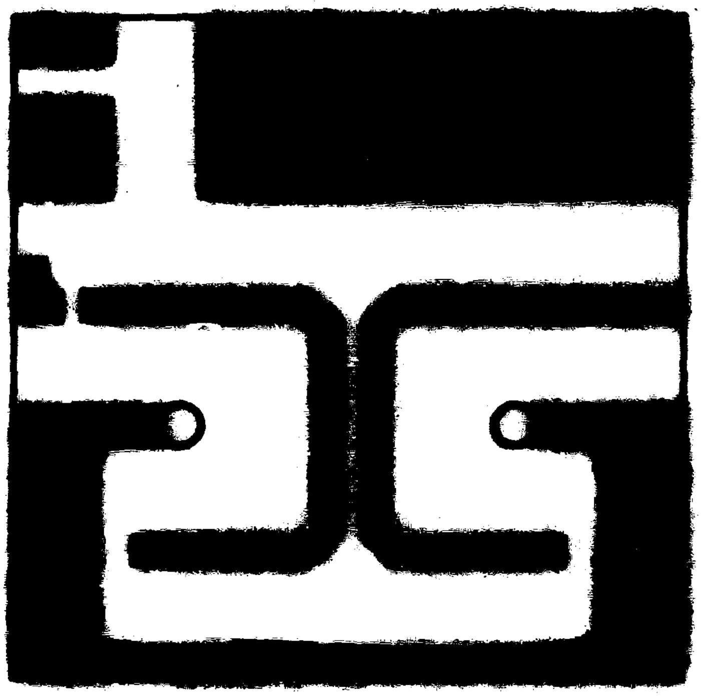

FIGURE 21 NEW MICROSTRIP CIRCUIT WITH 13 dB COUPLER AND MODE SUPPRESSORS

D-9339

X PLANS FOR THE NEXT INVERVAL

A microstrip circuit will be designed, using the last approach, built and tested. Modifications, if necessary, will be made and 6 circuits will be fabricated.

Design for frequencies of 2 to 12.4 GHz will be given upon the results obtained at X-Band.

Testing of the circuits made for the frequency band of 8 to 12.4 GHz will be recorded before and after life test.

XI REFERENCES

(1) First Quarterly Report - Development of Microwave Semiconductor Noise Diode and Diode Holder

16 April to 16 July 1969

Department of the Navy
Naval Electronic Systems Command
Washington, D.C.

Contract No. N00039-69-C-1573

(2) Second Quarterly Report - Development of Microwave Semiconductor Noise Diode and Diode Holder

17 July to 16 October 1969

Department of the Navy
Naval Electronic Systems Command
Washington, D.C.

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13. ABSTRACT

Six Microwave integrated circuit, solid state noise sources have been built and tested between the frequency of 8 to 12.4 GHz. Results of the output spectrum noise measurements are presented.

DD FORM 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

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