W. W. GAERTNER RESEARCH INC.

FINAL REPORT

ON

ADVANCED MICROELECTRONICS RESEARCH FOR SPACE APPLICATIONS PHASE II

COVERING PERIOD

FROM MAY 1, 1970 THROUGH MARCH 31, 1971

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GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND 20771

CONTRACT NO.: NAS5-21186

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1.0 INTRODUCTION

For a number of years W. W. Gaertner Research Inc. under the sponsorship of the Goddard Space Flight Center, and in close co-operation with the GSFC Technical Officer, Mr. L. Kleinberg, has explored various designs for RF circuits which appear particularly suitable for space applications, allowing microelectronic fabrication with low power consumption, low noise and relatively low cost. The basic design approach which has evolved is to use impedance rotation, i. e. the conversion from capacitance to negative resistance, and from resistance to inductance by the phase shift of the transistor current gain at high frequencies. Through a detailed analysis of this phenomenon it has become possible to design active filters, high-Q and wide band amplifiers which operate in the conditionally stable frequency regions. In this frequency range oscillation may occur if the terminating impedances are improperly chosen. For this reason it is usually avoided by conventional designers. The design technique developed under the earlier Contract, however, showed how oscillations can be positively prevented.

This class of circuits then exhibits the following significant advantages over conventional circuits:

(a) A given transistor can be operated close to or beyond fT thus producing the highest frequency response for a given power consumption and cost.

(b) For reasons partly explained below the noise figures of these circuits are low.

(c) Since negative resistance can be produced at will to overcome losses in passive components there is no need for high-Q circuit elements which become increasingly costly at high frequencies and are finally impossible to produce as one moves up in the microwave region. This feature reduces circuit costs considerably since cheaper components, materials and fabrication techniques can be used.

(d) The utilization of the phase shift within the transistor produces a multipole filter response with a minimum number of components, contributing to low component count and thereby to small size.

(e) Electronic tuning of the circuits can be used widely, reducing greatly the need for mechanical tuning which in the microwave range is difficult and requires components which are large compared to microelectronic elements.

These advantages combine to allow the construction of VHF, UHF and microwave circuits which are considerably smaller and cheaper than presently available units, and consume considerably less power.

Fig. 4012-1001 shows the topology of the most successful inductorless high-Q filter/amplifier circuit, invented by L. Kleinberg of the Goddard Space Flight Center, and extensively explored in past Contracts. At the juncture point between the two stages the first stage presents a low-Q inductive impedance, the second stage a capacitive/negative-resistance impedance. Under the conditions outlined below such a circuit can be tuned to very high Qs. Figs. 4012-1051 through -1055 show some typical experimental results obtained with such circuits in the past.

An extensive and computer-aided theoretical foundation for the design of these circuits has been laid under earlier contracts. It has also become apparent in this earlier work that these circuits have applications in many different areas and that the detailed exploration of any of these would take an effort many times larger than the funding of the current contract. This Report therefore deals with various questions on the use of the negative-resistance circuits in applications of interest to the NASA Goddard Space Flight Center.

These are:

(a) The hybrid fabrication of VHF and UHF negative-resistance stages with lumped passive elements;

(b) The formulation of measurement techniques to characterize transistors and to extend the frequency of negative-resistance transistor amplifiers to higher microwave frequencies; and

(c) The derivation of transistor characteristics required to substantially increase the frequency range of negative-resistance transistor stages.

These subjects are discussed in detail in the following Chapters.

Figs. 4012-1001, and -1051 through -1055 follow this page.

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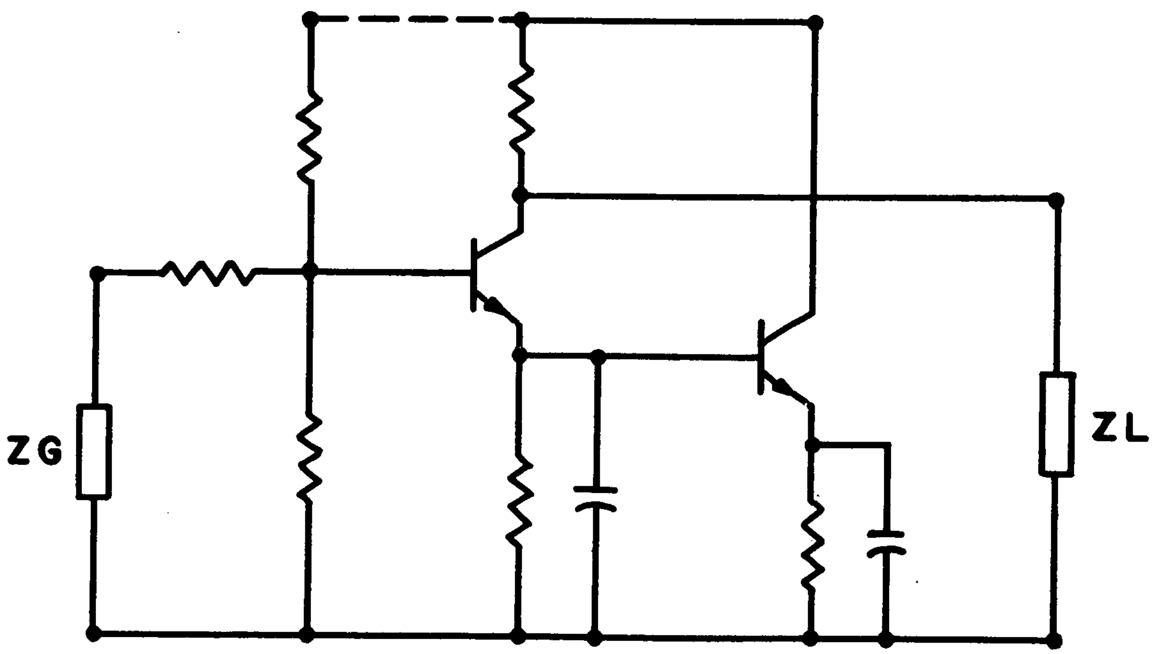

FIG. 4012-1001 - BASIC INDUCTORLESS HIGH-Q
AMPLIFIER STAGE.

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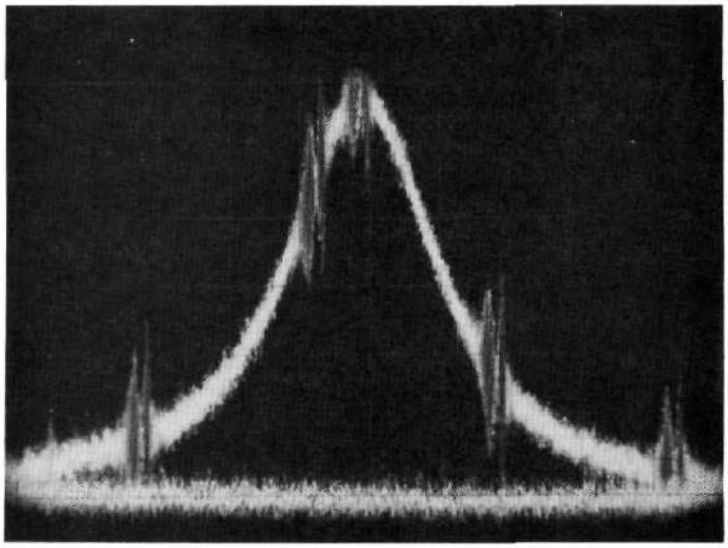

FIG. 4012-1051 - GAIN VERSUS FREQUENCY CURVE MEASURED ON 2-TRANSISTOR NEGATIVE-RESISTANCE/INDUCTIVE AMPLIFIER.

PEAK POWER GAIN: 30 DB
CENTER FREQUENCY: 103 MHZ
Q: 130

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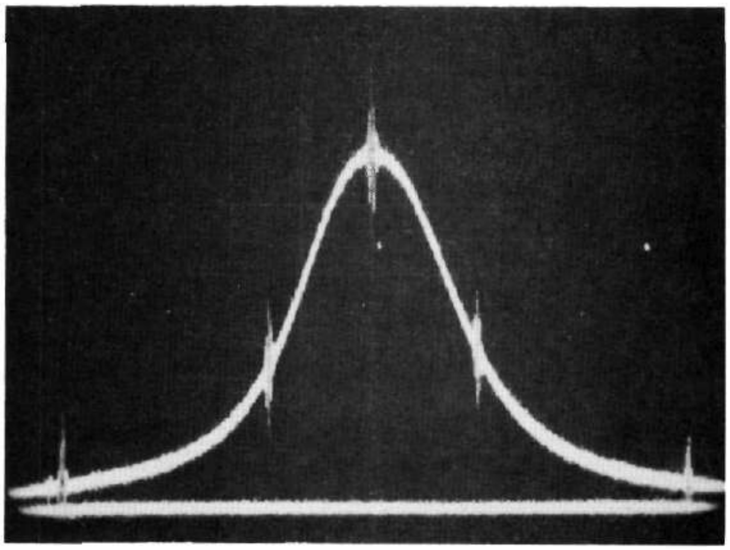

FIG. 4012-1052 - GAIN VERSUS FREQUENCY CURVE MEASURED ON 2-TRANSISTOR NEGATIVE-RESISTANCE/INDUCTIVE AMPLIFIER.

PEAK POWER GAIN: 30 DB
CENTER FREQUENCY: 165 MHZ
Q: 80

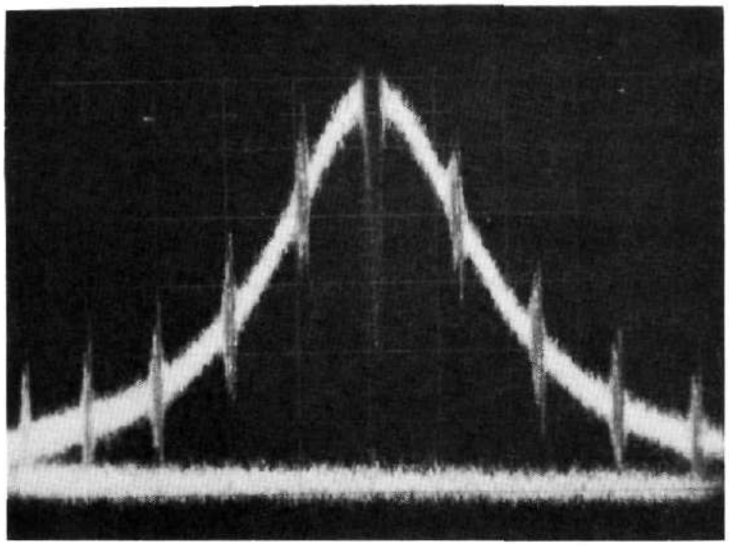

FIG. 4012-1053 - GAIN VERSUS FREQUENCY CURVE MEASURED ON 2-TRANSISTOR NEGATIVE-RESISTANCE/INDUCTIVE AMPLIFIER.

PEAK POWER GAIN: 42 DB
CENTER FREQUENCY: 275 MHZ
Q: 180

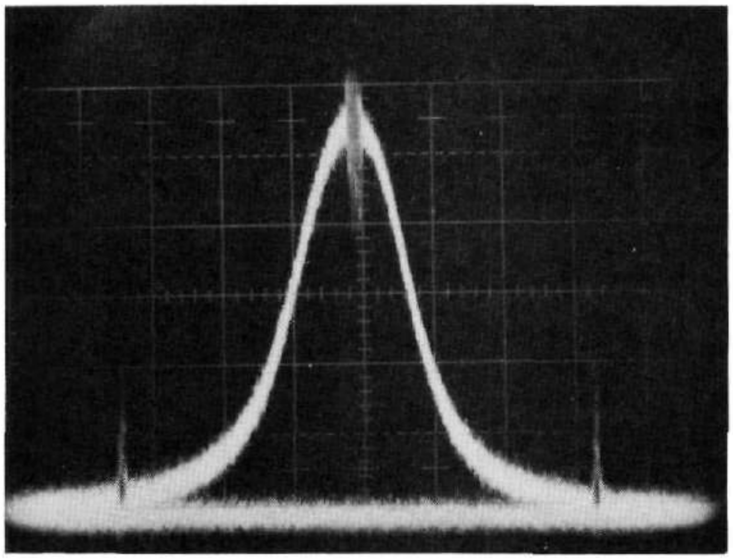

FIG. 4012-1054 - GAIN VERSUS FREQUENCY CURVE MEASURED ON 2-TRANSISTOR NEGATIVE-RESISTANCE/INDUCTIVE AMPLIFIER.

PEAK POWER GAIN: 35 DB
CENTER FREQUENCY: 400 MHZ
Q: 660

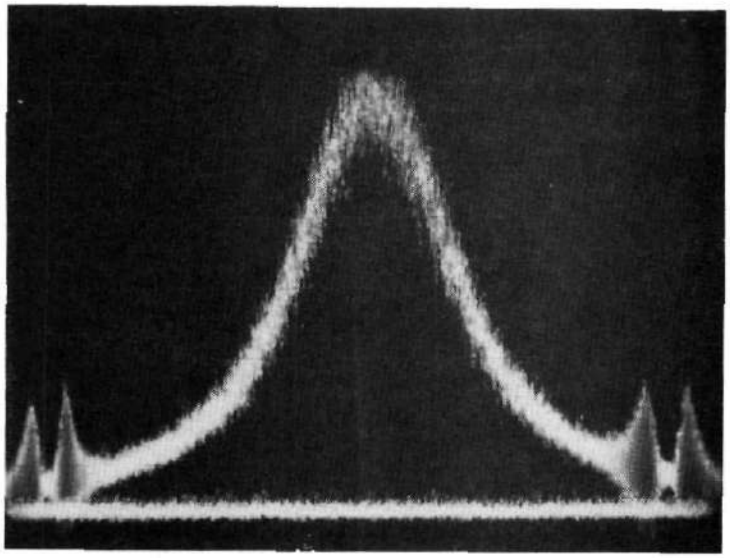

FIG. 4012-1055 - GAIN VERSUS FREQUENCY CURVE MEASURED ON 2-TRANSISTOR NEGATIVE-RESISTANCE/INDUCTIVE AMPLIFIER.

PEAK POWER GAIN: 55 DB
CENTER FREQUENCY: 660 MHZ
Q: 3300

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2.0 HYBRID FABRICATION OF VHF AND UHF NEGATIVE-RESISTANCE STAGES WITH LUMPED PASSIVE ELEMENTS

The fastest and most economical fabrication of the new circuits in miniature form is by hybrid microelectronic technology. Although it is certain that all these circuits will eventually be fabricated by monolithic technology, this approach at present would be prohibitively expensive in the UHF and microwave frequency ranges. It will take several years before such monolithic circuits become available. On the other hand hybrid fabrication is straightforward and inexpensive. We shall illustrate below a technique which is currently extensively used at W.W.Gaertner Research Inc. The packing density achievable is typically less than 0.02 cu.in. per transistor stage, or more than 50 stages per cu.in. This is adequate for most current VHF and UHF applications, especially since a certain amount of physical separation is often desirable for electrical isolation.

One circuit which has been of interest to the Goddard Space Flight Center is shown in Fig. 4027-4. Its response is centered around 850 MHz and it can be tuned for high Q or a wider bandpass response. As a single stage it, of course, needs physical inductors. These, however, are small in the UHF range and sometimes provide welcome tuning elements. A 4X layout of the substrate metallization and the final mask are shown in Fig. 4027-5. This pattern is then transferred to the ceramic substrate and feedthrough holes are drilled if needed. The results are shown in Fig. 1168-2. Specifically, the right-hand substrate in this figure has been reproduced with the mask of Fig. 4027-5. The finished circuit appears in Fig. 4027-6. Its characteristics depend on the values of the inductances inserted (and adjusted) and on the bias supplied to the transistor. The transistor used was an MMT2857.

Typical achievable performance characteristics are listed below:

<u>Case 1</u>

F_c = 850 MHz

Q = 800

A_v = 30 db

B+ = 2 volts

IC = 1.6 milliampere

Figs. 4027-4, 1168-2, 4027-5 and 4027-6 follow this page.

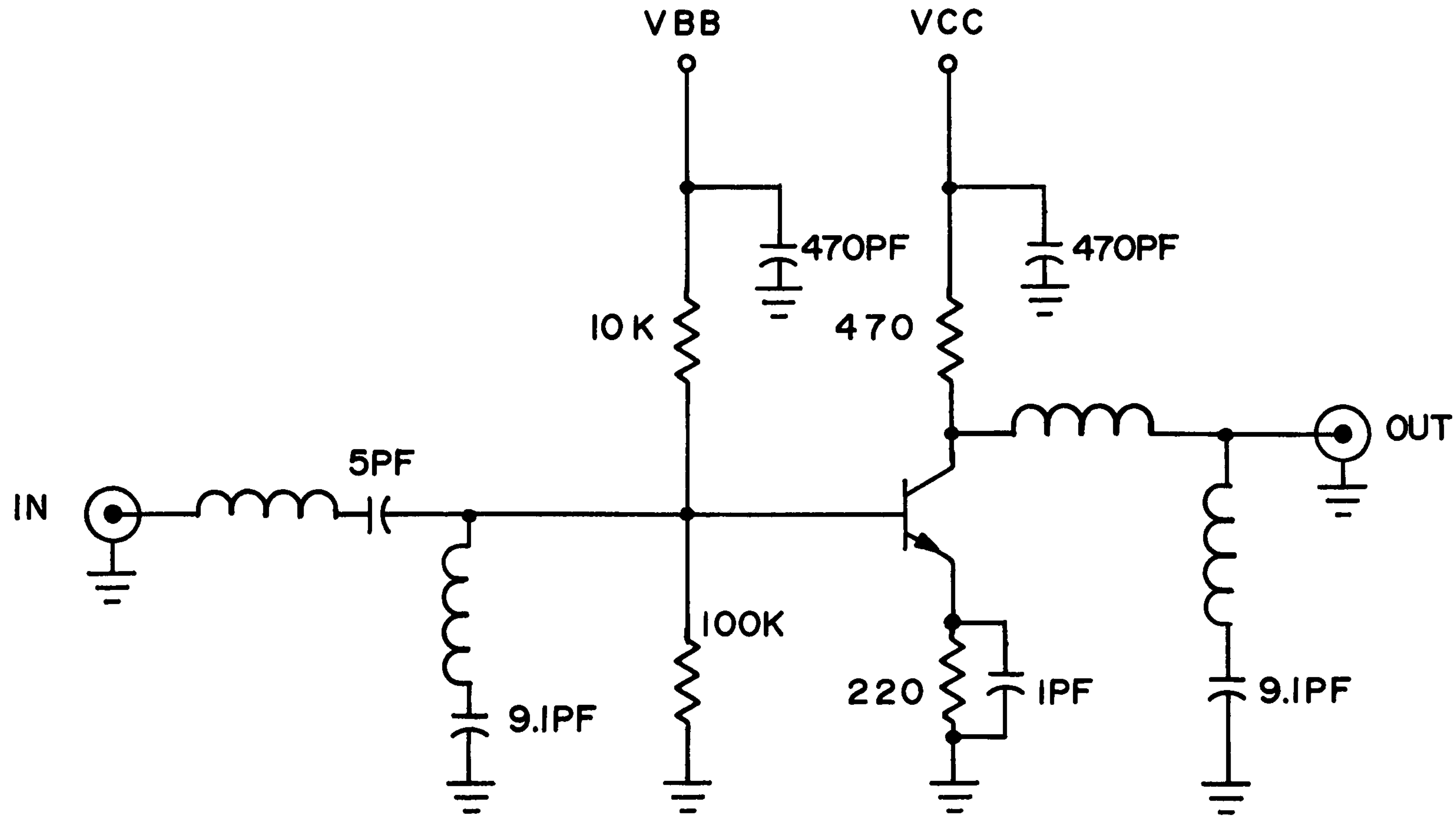

FIG. 4027-4 - SCHEMATIC OF 850 MHZ SINGLE-STAGE NEGATIVE-RESISTANCE AMPLIFIER.

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FIG. 1168-2 - TYPICAL CERAMIC SUBSTRATES WITH INTERCONNECTIONS ETCHED AND CONNECTOR FEED-THROUGH HOLES DRILLED

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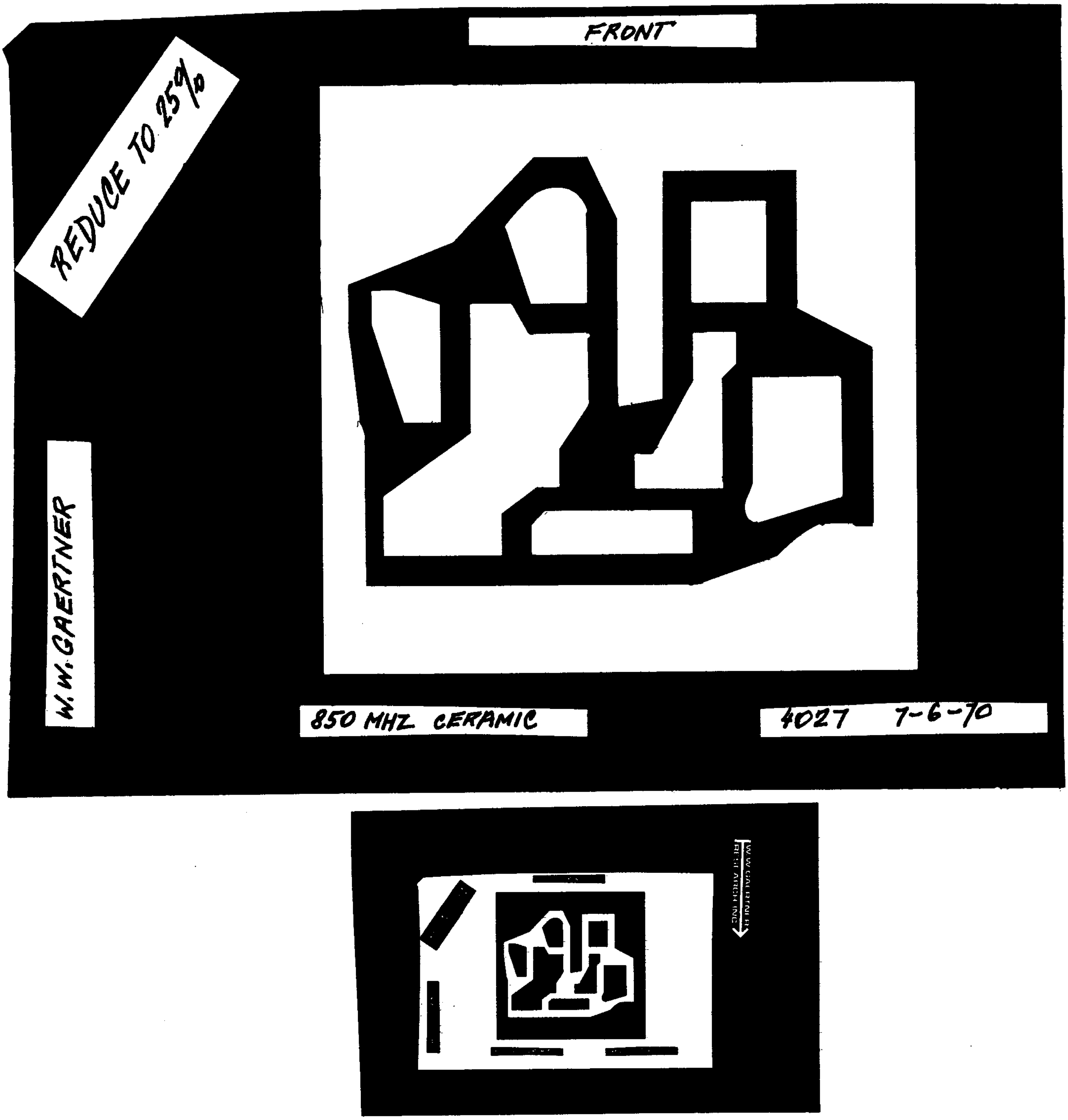

FIG. 4027-5 - 4X LAYOUT AND FINAL MASK FOR CERAMIC SUBSTRATE METALLIZATION PATTERN OF 850 MHZ NEGATIVE-RESISTANCE AMPLIFIER STAGE.

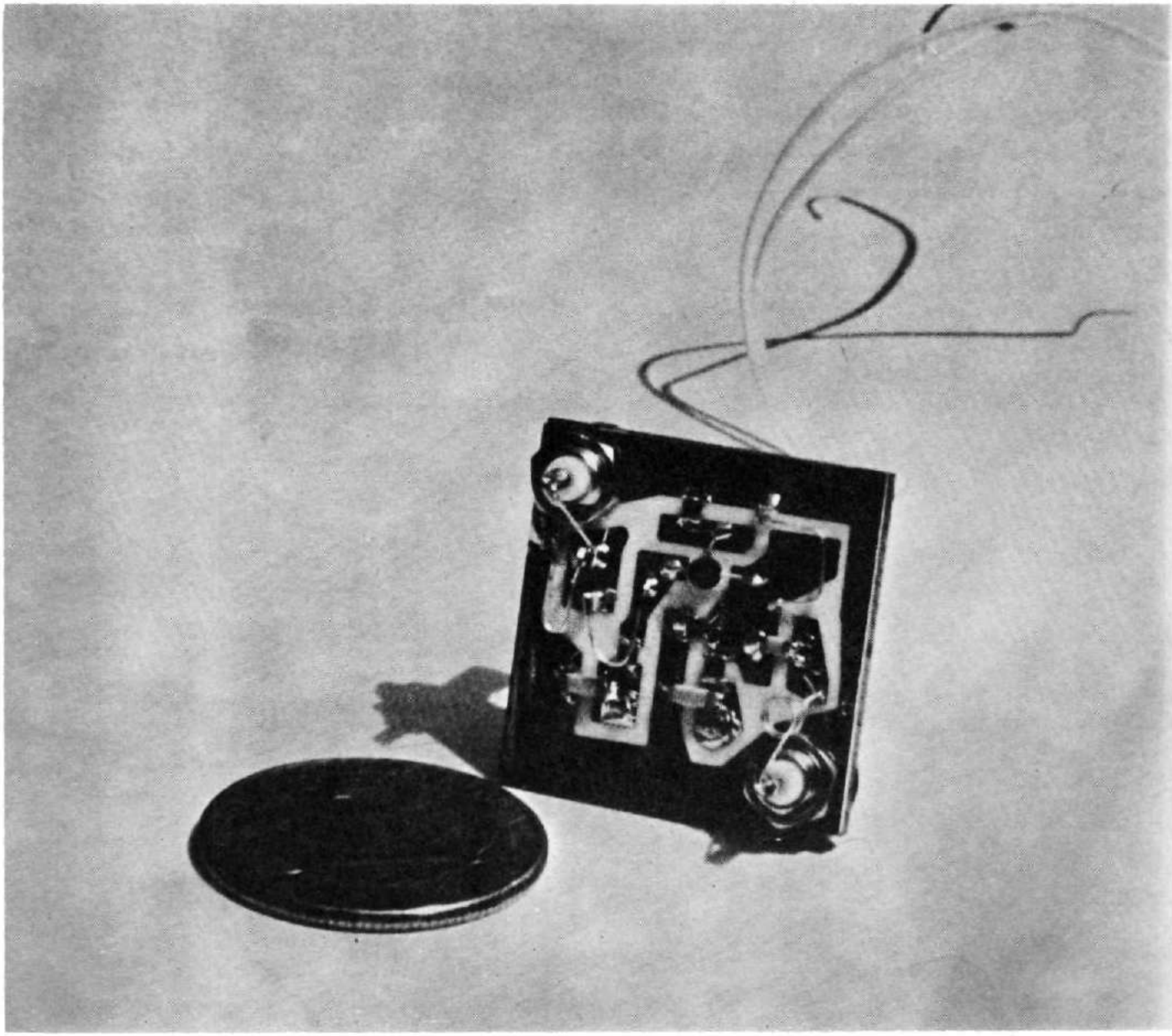

FIG. 4027-6 - SINGLE-STAGE 850 MHZ HYBRID NEGATIVE-RESISTANCE AMPLIFIER

Case 2:

F_c = 850 MHz

Q = 80

A_v = 30 db

B+ = 7 volts

IC = 5.5 milliampere

By stagger tuning the LC networks a 3-db bandwidth of 20 MHz with a peak voltage gain of 10 db has been achieved.

More flexibility especially with wider bandwidth is attained in a 2-stage circuit like the one shown in Fig. 4027-7. The transistor used is a 2N5043.

Its typical performance figures are as follows:

F_c = 850 MHz

BW (3 db) = 50 MHz (10 to 180 MHz)

A_v = 15 db

VCC= 3 V

IC = 1 milliampere

A 4X layout of the substrate metallization for such an amplifier and the final mask are shown in Fig. 4027-8, and a photo of the completed circuit is given as Fig. 4027-9. These circuits constitute by no means the packing density achievable in this technology. As can be seen from Figs. 4027-10 and 1168-1 even a 3-stage amplifier leaves a large percentage of the 1 in. sq. substrate unused. In fact, under another current contract a 7-stage low-frequency amplifier has been produced on a substrate of 0.4x1 in. with a packing density of 0.0057 cu.in. per transistor stage, or 175 stages per cu.in.

We thus find that the design principle briefly outlined in the Introduction and discussed in great detail in earlier reports, coupled with the technology described here, provides great flexibility in achievable circuit performance in a small volume and at low cost.

One outstanding feature of these circuits is the great ease with which they can be voltage tuned:

Changes in frequency response, gain and power consumption can be achieved through changes in the transistor bias currents, through varactors and through variable resistors (typically channel resistance of FETs).

Figs. 4027-7, -8, -9, -10 and 1168-1 follow this page.

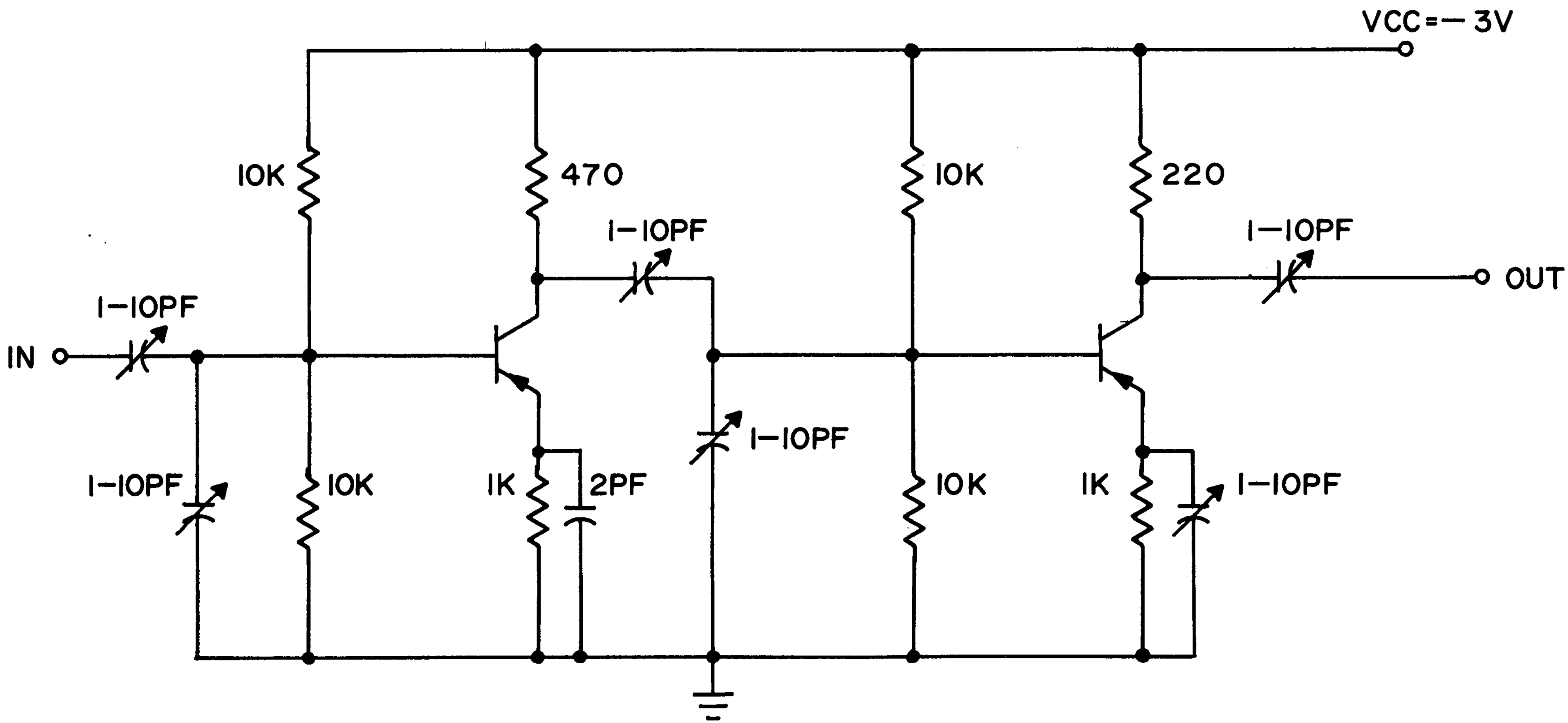

FIG. 4027-7 - SCHEMATIC OF TWO-STAGE NEGATIVE-RESISTANCE AMPLIFIER WITH 50 MHZ BANDWIDTH CENTERED AT 850 MHZ. BAND-WIDTH CAN BE VARIED FROM 10 TO 100 MHZ BY CHANGING CAPACITOR VALUES.

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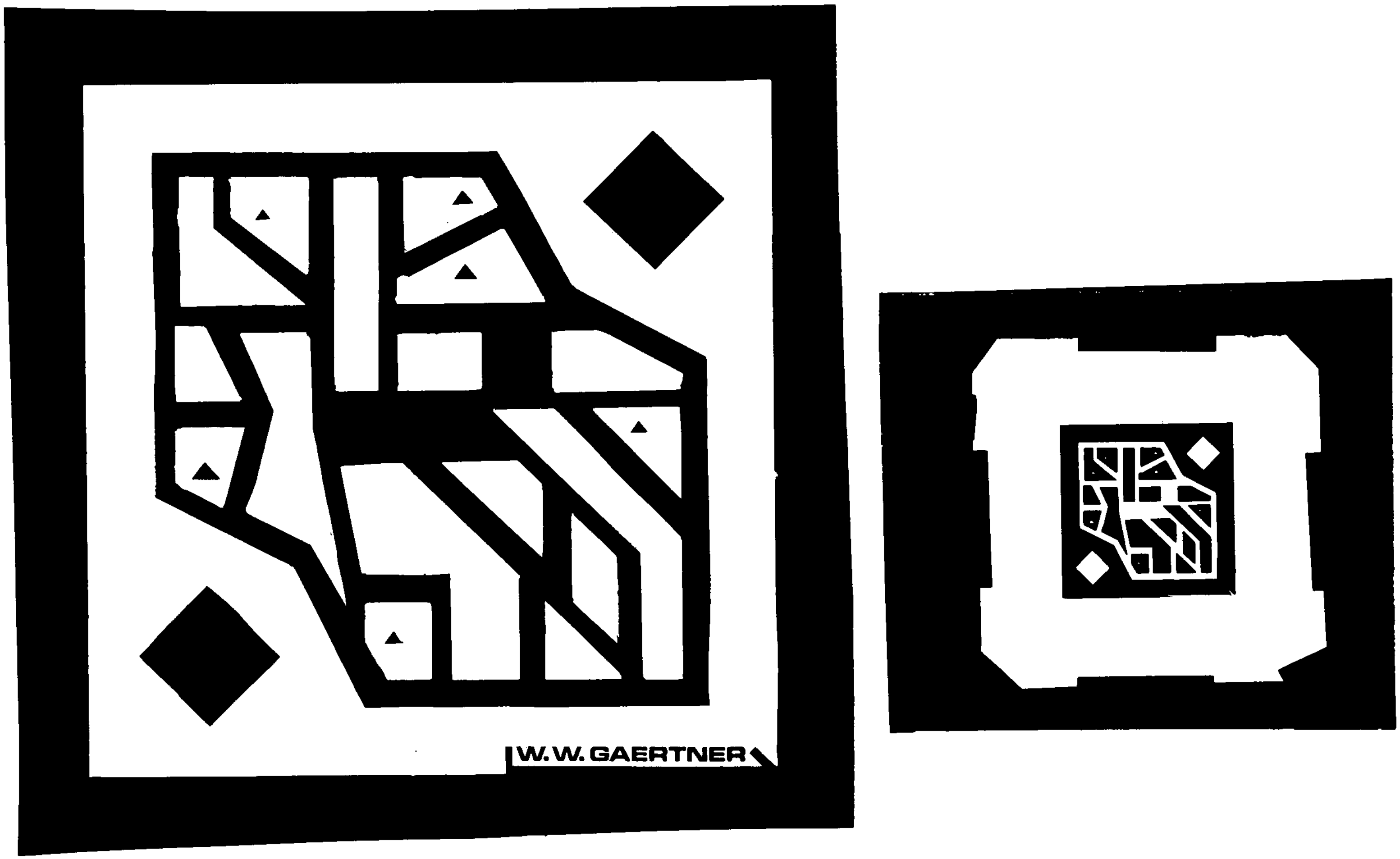

FIG. 4027-8 - 4X LAYOUT AND FINAL MASK FOR CERAMIC SUBSTRATE METALLIZATION PATTERN OF TWO-STAGE (UHF) NEGATIVE-RESISTANCE AMPLIFIER.

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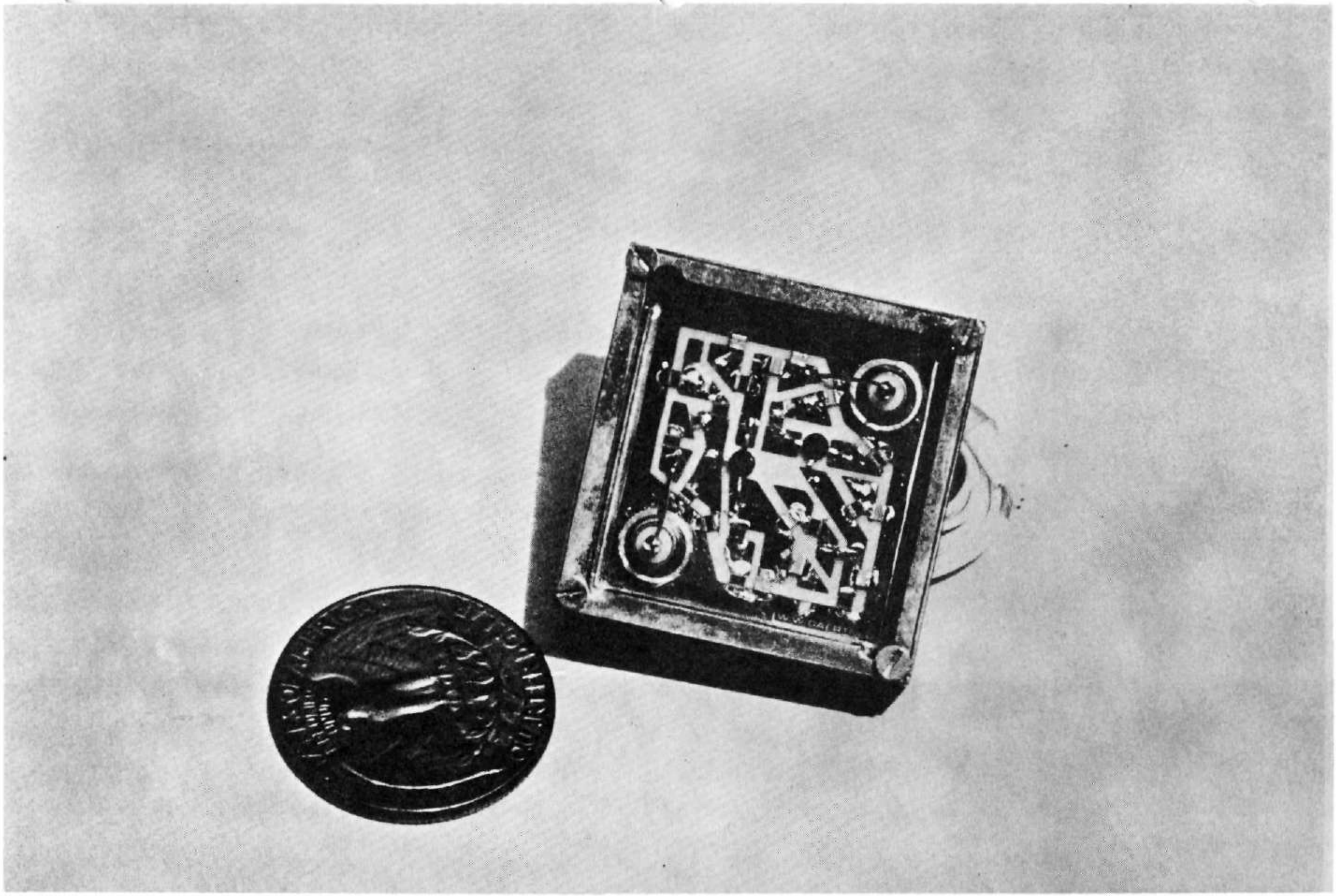

FIG. 4027-9 - TWO-STAGE UHF HYBRID NEGATIVE-RESISTANCE AMPLIFIER

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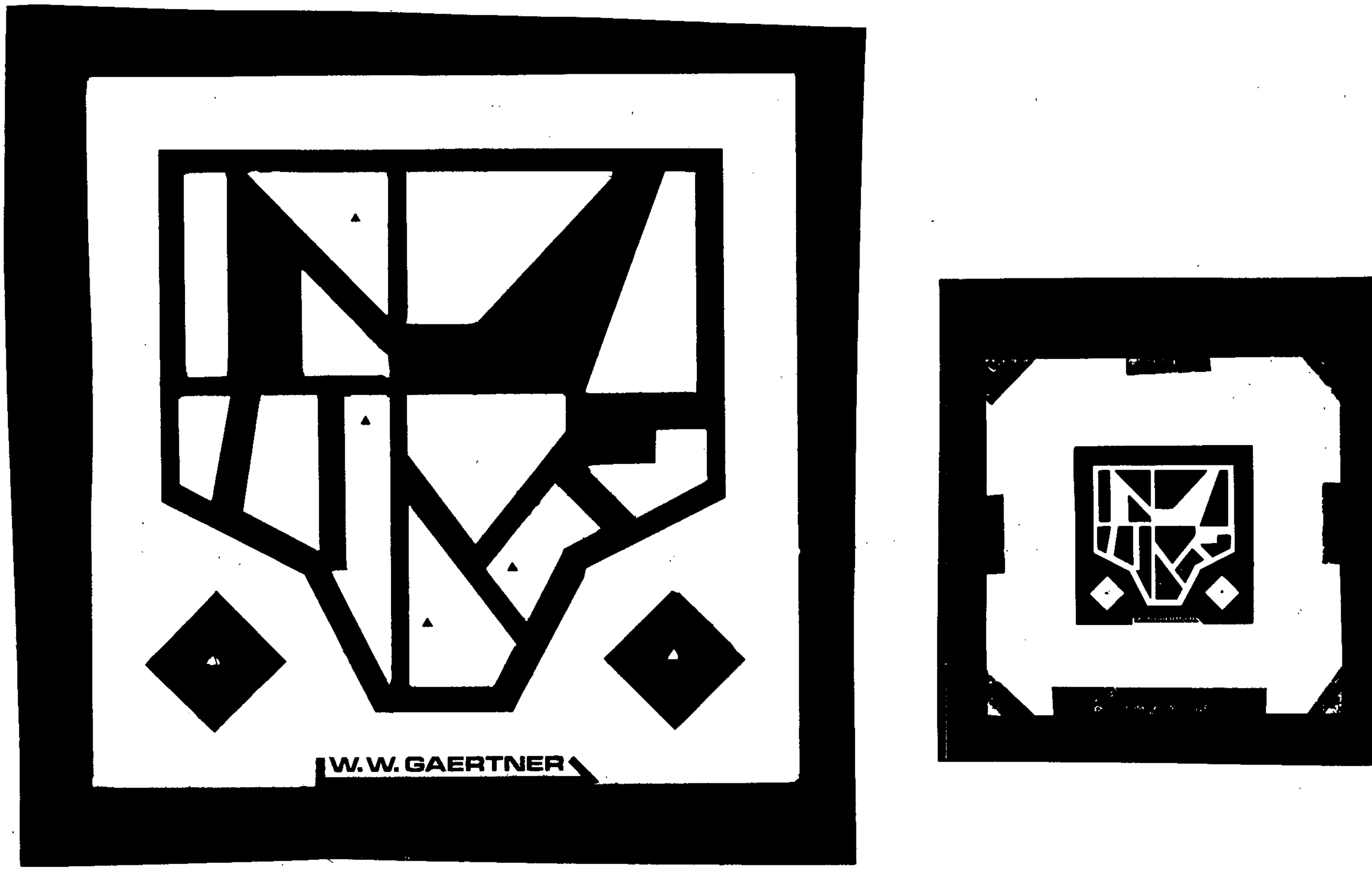

FIG. 4027-10 - 4X LAYOUT AND FINAL MASK FOR CERAMIC SUBSTRATE METALLIZATION PATTERN OF THREE-STAGE WIDEBAND AMPLIFIER.

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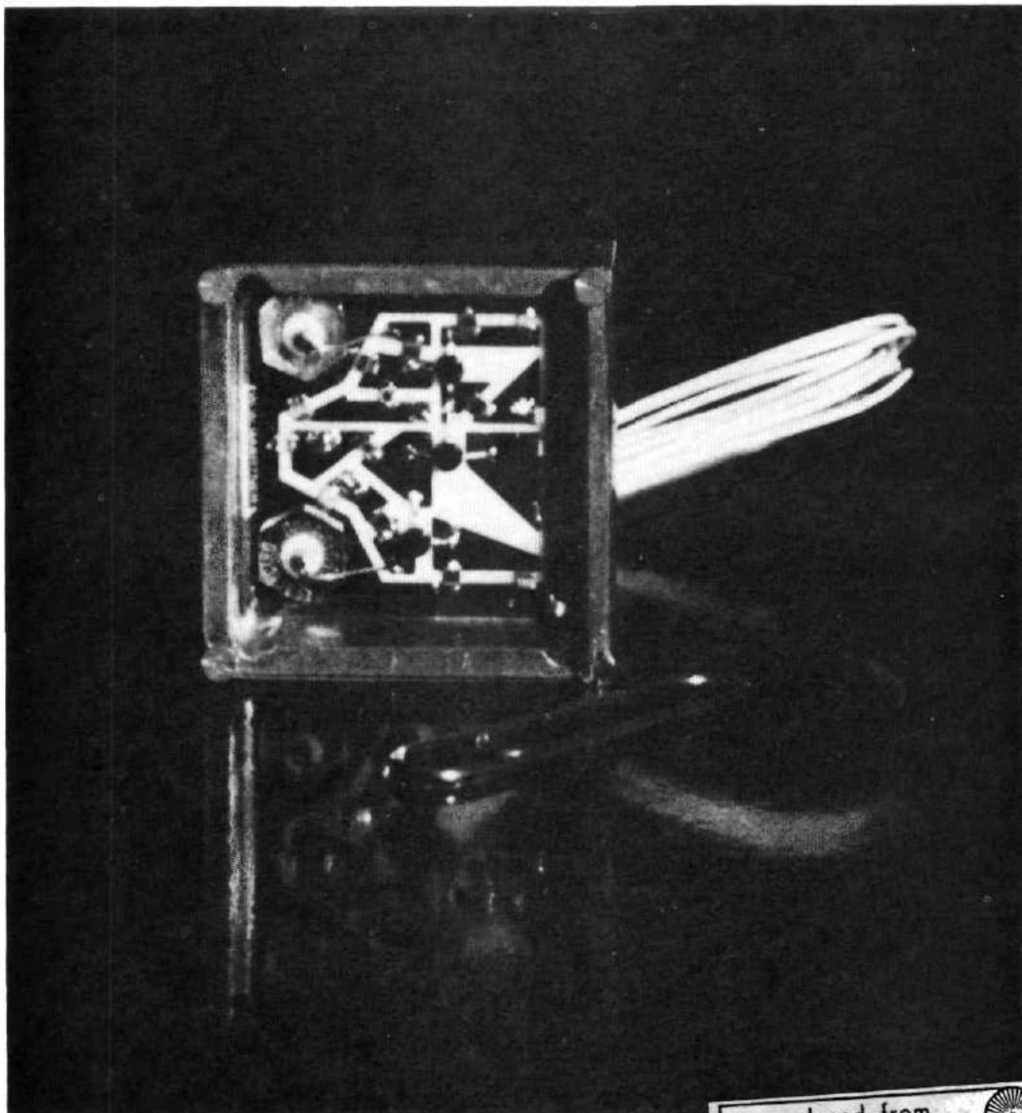

FIG. 1168-1 - TYPICAL RF HYBRID MICROCIRCUIT ON CERAMIC SUBSTRATE (THREE-STAGE LOW-POWER WIDE-BAND AMPLIFIER)

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These features can be used for tuning, agc, afc and temperature and bias compensation. This is illustrated in Figs. 4027-11 and -12 which show a circuit development under another Contract and which will be discussed at WESCON 1971*). The circuit response peaks at 300 MHz with a Q of over 170 at all temperatures. It is stabilized for a 30% voltage change from 1.0 to 1.3 volts, and a temperature range from 7 to 75 degree C. It draws DC currents of 63, 72 and 100 microamperes at 7, 25 and 75 degrees C respectively. This unique performance stability is achieved by controlling the DC bias current of the RF transistor with a micropower DC transistor stage which contains a (chip) thermistor network. Within the RF network only the base current of the RF transistor is used to compensate for both voltage and temperature variations.

We believe the examples given above clearly demonstrate that these negative-resistance stages are well-suited to any VHF and UHF application where small size and low power consumption must be achieved with reasonable development and low production cost.

*) W.W.Gaertner, L.Kleinberg, F.K.Weinert, "Micropower Active Filters for VHF Applications", WESCON 1971

Figs. 4027-11 and 4027-12 follow this page.

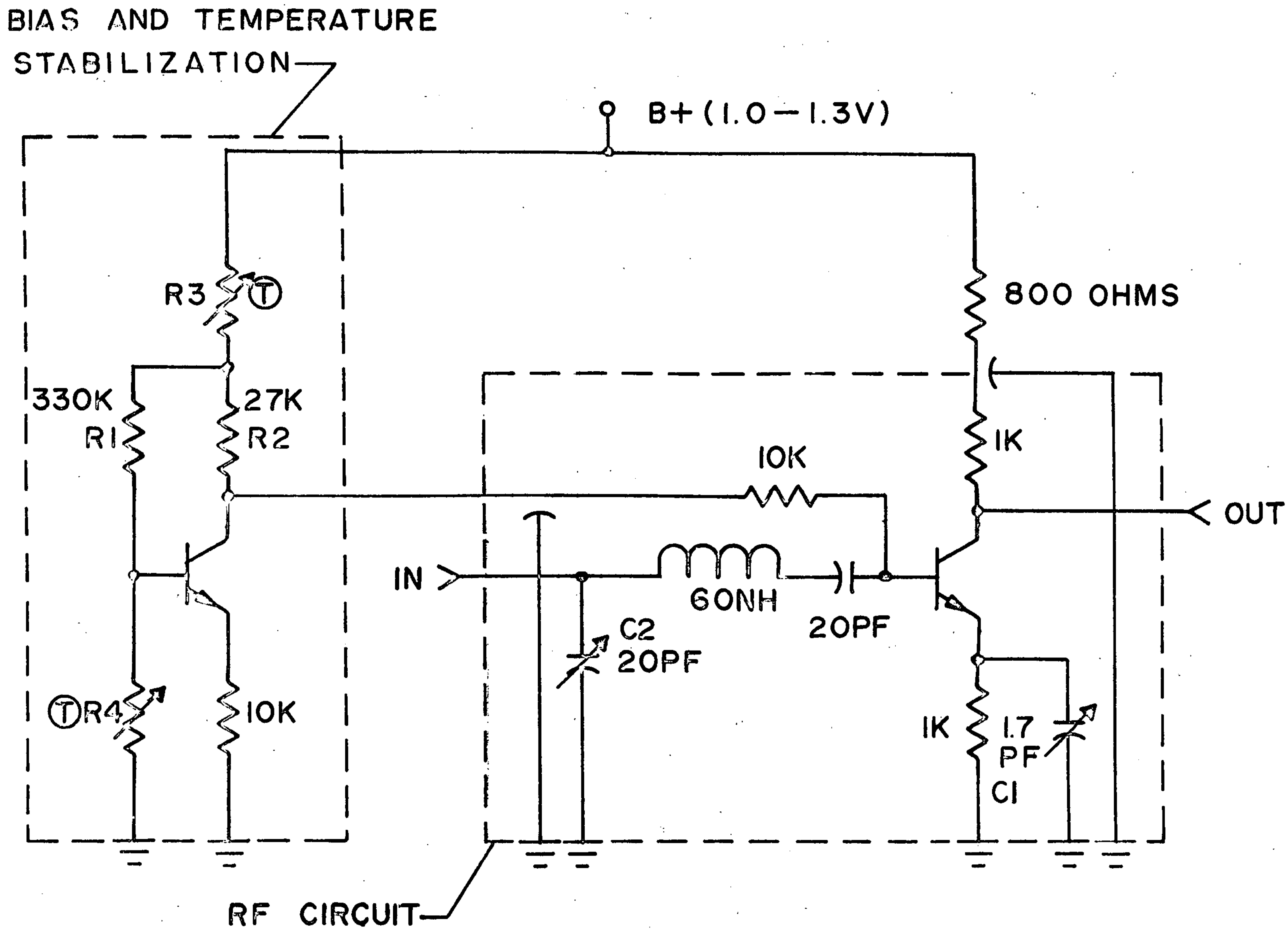
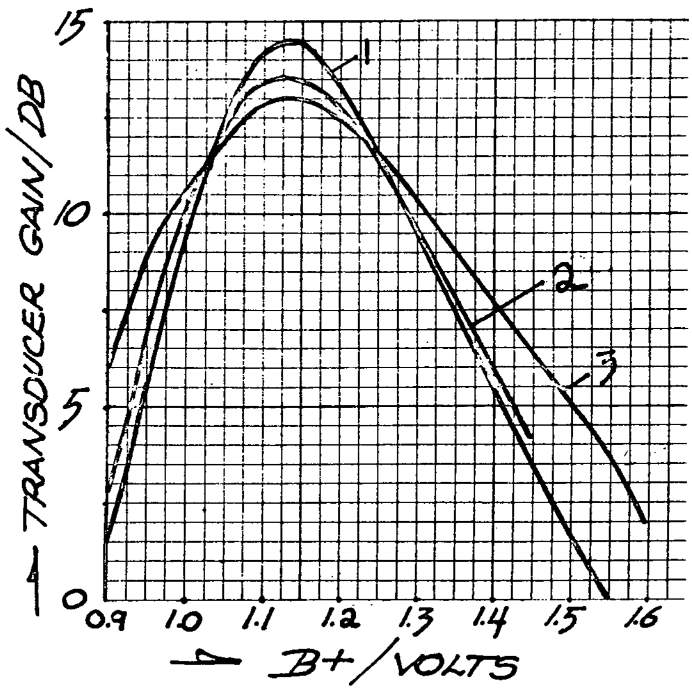


FIG. 4027-11 - SINGLE-STAGE HIGH-Q MICROPOWER ACTIVE FILTER WITH BIAS AND TEMPERATURE COMPENSATION. TERMINATIONS ARE 50 OHMS.



CURVE NO.	TEMP./DEG. C	R3	R4
1	7	53K	660K
2	25	44K	560K
3	75	13K	350K

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FIG. 4027-12 - PEAK TRANSDUCER GAIN VERSUS SUPPLY VOLTAGE AT DIFFERENT TEMPERATURES AND FOR DIFFERENT RESISTOR VALUES IN THE VOLTAGE DIVIDER OF THE STABILIZATION NETWORK.

3.0 MEASUREMENT TECHNIQUES REQUIRED TO EXTEND THE FREQUENCY RANGE OF NEGATIVE-RESISTANCE TRANSISTOR AMPLIFIERS TO HIGHER MICROWAVE FREQUENCIES

3.1 General Comments

The need for amplifiers and oscillators over the entire microwave frequency range up to 100 GHz is well established. At the present time all but the low frequency end of this spectrum is serviced by tubes, parametric amplifiers, frequency multipliers, tunnel diodes and other two-terminal solid-state devices like avalanche diodes and Gunn oscillators. All of these suffer from shortcomings such as high power consumption, high volume and weight, poor reliability, high noise, poor adjustability and high cost.

The transistor on the other hand has many desirable attributes such as small size, low power consumption, isolation between input and output, and high reliability. However, existing transistors have never been operated above approximately 15 GHz, and these experimental units are very expensive.

The circuit configurations proposed by L. Kleinberg, and extensively investigated under the earlier phases of this Contract, exploit the frequency capabilities of a transistor to the fullest and allow it to operate close to or above the conventional fT of the transistor.

However, most experimentation with these circuits has been limited to frequencies below 2 GHz.

To extend the operation of these circuits to higher frequencies a number of questions must be answered, namely:

(a) What measurement techniques should be developed both for the characterization of the devices (chips) and for the evaluation of complete circuit performance.

(b) What is the highest frequency up to which presently available transistors can be operated in the negative-resistance mode.

(c) What changes in the transistor design are necessary to increase their frequency range of operation in the negative-resistance mode.

Each of these questions requires a major investigation, and approaches towards solutions are outlined in the remainder of this Report.

Chapter 3.0 is concerned with the measurement problem. Measurements of device and circuit properties in the microwave range, especially at high frequencies, are difficult and often unreliable. This situation is aggravated by the fact that most of the new transistor circuits are extremely small, and therefore difficult to contact without the introduction of stray capacitances and inductances which can readily overshadow the device performance itself. As an example, the emitter and base stripes of a highest-frequency microwave transistor will only be 1 micron wide and they will be separated by a 1 micron line. It is obviously impossible to make a wire contact to these devices directly, but rather this must be accomplished through a deposited contact pattern which will have stray reactance. Special techniques will therefore be necessary to measure the characteristics of the transistor itself, minus the effects of its contact structure.

In the following Chapter will shall therefore discuss the requirements imposed on the measurement technique, followed by a discussion of suggested approaches.

3.2 Requirements

The test technique to be developed should satisfy the following requirement:

3.2.1 It should be able to characterize a transistor chip without the effects of any contact and mounting structure and any inclosure. This is essential in any research geared towards improving transistor performance through changes in its basic geometry and processing variables.

3.2.2 The test technique should allow the measurement of active and passive, lumped and distributed circuit elements over a wide range of power levels.

3.2.3 The test technique should allow a complete characterization of individual devices, and of partial and complete circuits, by measuring any desired impedance or admittance, any s parameter, any desired gain (voltage, power, transducer, unilaterized power gain, etc.) and actual power levels.

3.2.4 The technique should produce all the quantities needed for circuit design. There should be no need to supplement the test data with assumed theoretical quantities for certain components, and there should be no need to introduce models into the circuit design.

3.2.5 The measurements should be carried out with reasonable speed. This implies that as certain quantities are measured as functions of frequency, there should be no need for extensive adjustments of the test equipment at each frequency. Swept-frequency measurements would be preferred.

3.2.6 The terminations needed while performing the various test should be readily realizable at the particular frequency. This implies e. g. it should not be necessary to generate perfect short or open circuits at high microwave frequencies.

3.2.7 The calibration of the test equipment should be achievable with reasonable ease, and hopefully will be automatic.

3.2.8 There should be provisions for measuring all desired circuit properties as a function of temperature. This is not trivial since the heavy microwave "plumbing" which is usually used to contact the device under test, has high thermal conductivity and makes it difficult to maintain a uniform temperature in the test chamber.

3.3 Suggested Approaches

3.3.1 Basic Characterization by S-Parameters

Every measurement technique is based on a set of prime parameters which are measured directly and from which all other quantities of interest are derived. For the microwave circuits discussed in this Report the s-parameters seem to be the best choice. An introduction to these is contained in the following publications:

Penfield, P., Jr., "Noise in Negative Resistance Amplifiers", IRE Trans., vol CT-7, pp 166-170, June 1960.

Youla, D. C., "On Scattering Matrices Normalized to Complex Port Numbers", Proc. IRE, vol 49, p 122, July 1961

Penfield, P., Jr., "A Classification of Lossless Three-Ports", IRE Trans., vol CT-9, pp 215-223, September 1962

Kurokawa, K., "Power Waves and the Scattering Matrix", IEEE Trans., vol MTT-13, p 194-202, March 1965

Weinert, F. K.*), "Scattering Parameters Speed Design of High-Frequency Transistor Circuits", Electronics, September 1966

Besser, L., "Combine S Parameters with Time Sharing", Electronic Design, vol 16, August 1968

Froehner, W. H., "Quick Amplifier Design with Scattering Parameters", Electronics, October 1967

Bodway, G. E., "Two-Port Power Flow Analysis Using Generalized Scattering Parameters", Microwave Journal, vol 10, May 1967

The main reasons for choosing the s-parameters as the prime quantities to be measured at microwave frequencies are as follows:

They do not require short or open-circuit terminations (like the h, y or z parameters) which are difficult to produce at microwave frequencies.

In addition, a short circuit may cause a transistor under test to oscillate.

Measurements can be taken on a device or circuit located at some distance from the test generator and the load (input of volt meter) by connecting them to the device under test through low-loss transmission lines.

Swept-frequency measurements are possible instead of point-by-point methods requiring adjustments between measurements.

S-parameters provide a total characterization of the network. A computer can transform the s-parameters to any other consistent parameter set, such as h, y or z parameters. In addition, group delay, VSWR and return loss can be derived. Transformation from the frequency domain to the time domain is possible.

*) presently Consultant to W.W.Gaertner Research Inc.

Additional reasons for the choice of the s parameters can be found in the publications listed above.

Ordinarily, the s-parameters of an active three-terminal device (transistor) are determined by two-port measurements, connecting the common lead to ground. Unfortunately, the physical length between the device and the ground plane usually introduces a serious parasitic common-lead inductance, especially if the spacings are made large enough to obtain a very accurate 50-ohm system. This difficulty can be overcome by using three-port scattering parameters as described in the following article:

George E. Bodway, "Circuit Design and Characterization of Transistors by Means of Three-Port Scattering Parameters", Microwave Journal, vol 11, No. 5, May 1968.

In this technique three 50-ohm transmission lines are connected to the base-emitter, emitter-collector, and base-collector ports of the transistor. This eliminates the common-lead inductance, insures accurate reference planes and results in a very stable measurement system. The incident and reflected power waves are then represented by a three-port scattering matrix

$$\begin{bmatrix} b_1 \\ b_2 \\ b_3 \end{bmatrix} = \begin{bmatrix} s_{11} & s_{12} & s_{13} \\ s_{21} & s_{22} & s_{23} \\ s_{31} & s_{32} & s_{33} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ a_3 \end{bmatrix}$$

where $|s_{ij}|^2 (i \neq j)$ is the transducer gain from port j to port i, and $|s_{ii}|^2$ is the available generator power which is reflected from the device at the ith port.

We thus come to the conclusion that individual microwave transistor chips should be measured via three-port scattering parameters, and completed microwave circuits should be measured via two-port scattering parameters. The test-system approach outlined below applies to both cases.

3.3.2 The Computer-Aided Test System

Through the extensive design work at VHF, UHF and low microwave frequencies we have come to the conclusion that an efficient measurement system must combine the capabilities of a swept-frequency test equipment and a digital computer. Under "swept-frequency" equipment we include any instrument which does not require manual adjustments (stub tuners etc) when the test frequency is changing. This allows the rapid measurement of all s-parameters as functions of frequency.

The computer which is already very valuable at lower frequencies becomes indispensable at the higher microwave frequencies since it assumes an ever increasing share of the measuring process, and even more of the design process.

The following is a partial list of the functions performed by the computer:

(a) Calibration: The computer stores the test results of a group of standards like open, shorts, and sliding loads and later corrects the test results of the actual devices accordingly.

(b) Conversion to Other Types of Characterization: The computer can immediately convert the s-parameters to other parameters such as y, or compute and display or plot various gains, VSWR etc.

(c) Optimization: If used in an on-line feedback system the computer can modify bias conditions to optimize a given quantity e.g. transducer gain at a given frequency. This would be valuable in the design of negative-resistance microwave stages which are sensitive to bias currents; the computer could readily find the bias condition which maximizes the gain at a given frequency under the constraint of a specified stability criterion.

(d) Simulation of Different Loads and Multiple Stages: The computer can readily simulate the performance of the device under test for other loads than the one actually used. The computer can also simulate the results of cascading any number of stages identical to the one under test. This is of obvious value in multistage amplifier and filter design.

(e) On-Line Design: One of the most advanced uses of the computer is in on-line design. In a typical example the transistor to be used in a multi-stage circuit would be placed into the test apparatus. The effects of all bias, coupling, tuning, feedback etc. networks, however, would be simulated by the computer. As the bias and temperature of the device under test are varied the simulated passive circuit elements are changed until an optimum circuit design has been found. This procedure on the one hand eliminates the need for storing the transistor s-parameters at all bias and temperature levels of potential interest, and it also eliminates much breadboarding which is very costly at microwave frequencies.

The computer may be used on-line or off-line. In on-line operation the computer is directly connected to the test equipment, controlling the test sequence and receiving test data as they are generated. In off-line operation the computer is not in direct communication with the test equipment. The test sequence is controlled by an operator and the test data are subsequently entered into the computer. In the simplest case the data are first recorded by hand and then entered into the computer via card punch or keyboard terminal. In a more elegant and expensive off-line installation the test data can be recorded on magnetic tape as they are created and the tape is then fed into the computer.

To illustrate the approach we shall show below how the basic elements of such a computer-aided test system are currently used by W.W.Gaertner Research Inc. for designs in the VHF and UHF ranges.

Fig. 4018-120 shows the block diagram and Fig. 4026-16 shows a photograph of a typical s-parameter test system using the Hewlett-Packard 8405A vector volt meter. Data are normally taken manually and must subsequently be entered into the computer. To facilitate this step and to create the proper format of the data for further processing, a program has been written which adds the logarithm of the frequency (often needed for logarithmic plots) and arranges the data in the standard format for all subsequent processing. Table 4018-129 shows typical input and output files of this program and Table 4027-13 gives a listing of the program itself.

Figs. 4018-120, 4026-16, 4018-129 and Table 4027-13 follow this page.

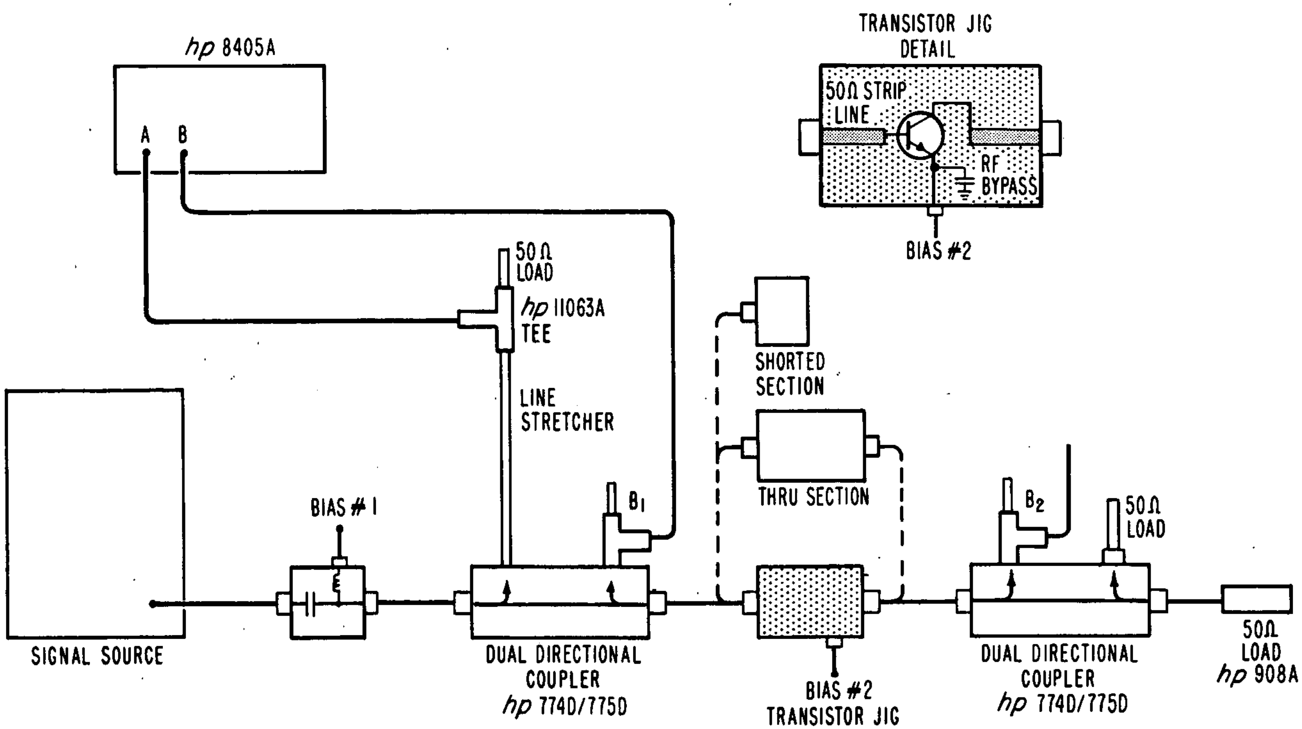

FIG. 4018-120 - BLOCK DIAGRAM OF A TYPICAL S PARAMETER MEASUREMENT SYSTEM.

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FIG. 4026-16 - TYPICAL INSTRUMENT ARRANGEMENT FOR MEASUREMENT OF TRANSISTOR SCATTERING PARAMETERS (HEWLETT-PACKARD PHOTOGRAPH)

W.W. GAERTNER RESEARCH INC.

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20.36.23 PRINTF SOLD DATA

        S PARAMETERS OF TWO-PORT NO.: 99 FOR ZREF= 5.0000E 01 +J 0.0        OHMS

 LOG(FREQ)  FREQUENCY      MAG(S11)  PHASE(S11)    MAG(S12)  PHASE(S12)    MAG(S21)  PHASE(S21)    MAG(S22)  PHASE(S22)
     .          .     E        .          .             .          .            .          .            .          .
          4.366000E 07     0.98900     0.0         0.00780    91.89999     3.21000   173.00000     1.00000     1.65000
          4.571000E 07, 0.989, -0.9, 0.0083, 91.9, 3.21, 172.5, 1.0, 1.65
          4.787000E 07, 0.934, -0.256, 0.0086, 91.8, 3.22, 172.09, 0.9768, 1.67

        S PARAMETERS OF TWO-PORT NO.: 99 FOR ZREF= 5.0000E 01 +J 0.0        OHMS

 LOG(FREQ)  FREQUENCY      MAG(S11)  PHASE(S11)    MAG(S12)  PHASE(S12)    MAG(S21)  PHASE(S21)    MAG(S22)  PHASE(S22)
     .          .     E        .          .             .          .            .          .            .          .
  7.640080 4.366000E 07    0.98900     0.0         0.00780    91.89998     3.21000   173.00000     1.00000     1.65000
  7.660007 4.571000E 07    0.98900    -0.90000     0.00830    91.89999     3.21000   172.50000     1.00000     1.65000
  7.680059 4.787000E 07    0.93400    -0.25600     0.00860    91.79999     3.22000   172.09000     0.97680     1.67000
```

TABLE 4018-129 - INPUT (TOP) AND OUTPUT (BOTTOM) TABLES OF ADLOGS COMPUTER PROGRAM WHICH ADDS LOG OF FREQUENCY AND REFORMATS.

W.W.GAERTNER RESEARCH INC
STAMFORD, CT 06903

W. W. GAERTNER RESEARCH INC.

TABLE 4027-13 - THE NEXT 2 PAGES CONTAIN A LISTING OF THE "ADLOGS" PROGRAM WHICH ADDS THE LOG(FREQ) COLUMN TO THE TEST DATA AND REFORMATS THEM.

```
ADLOGS   EXEC     P1    ID=GRI              12/21/70    21.26.55         PAGE 1
       VP/CSS    ---       NATIONAL CSS, INC. (STAMFORD DATA CENTER)

&COMMENT READ FROM 9 DSK WRITE ON 8 DSK.                                ADL00010
FILEDEF * CLEAR                                                         ADL00020
ERASE TESTN DATA                                                        ADL00030
FILEDEF 8 DSK TESTN DATA RECFM F LRECL 130                              ADL00040
FILEDEF 9 DSK TEST  DATA RECFM F LRECL 130                              ADL00050
RUN ADLOGS                                                              ADL00060
PRINTF TEST  DATA                                                       ADL00070
PRINTF TESTN DATA                                                       ADL00080
```

```
C     ** W. W. GAERTNER RESEARCH INC.        ***** MAIN ADLOGS  5/23/70
C     ADDS LOG COLUMN TO TABLE OF S PARAM. MEASMTS. WITH FREQ SPECIFIED.
      DIMENSION  SARRAY(8)
C     ** STABLE IS READ IN NOW FROM 9.
      READ(9,4) KFP,RREF,XREF
      READ(9,5)
4     FORMAT(/10X,'S PARAMETERS OF TWO-PORT NO.:',I3,' FOR ZREF=',
     $1PE11.4,' +J',1PE11.4,' OHMS'/)
5     FORMAT(2X,9HLOG(FREQ),2X,9HFREQUENCY,6X,8HMAG(S11),
     $2X,10HPHASE(S11),4X,8HMAG(S12),2X,10HPHASE(S12),4X,8HMAG(S21),
     $2X,10HPHASE(S21),4X,8HMAG(S22),2X,10HPHASE(S22)/4X,1H.,8X,1H.,6X,
     $1HE,9X,3(1H.,11X))
      WRITE(8,4) KFP,RREF,XREF
      WRITE(8,5)
      DO 14 IFREQ=1,101
      RLOGFR=0.
      FREQU=0.
      DO 20 L=1,8
      SARRAY(L)=0.
20    CONTINUE
      READ(9,7,END=17) A,B,C,FREQU,(SARRAY(L),L=1,8)
7     FORMAT(1X,2(A4),A2,1PE13.6,8(1X,0PF11.5))
      RLOGFR=ALOG10(FREQU+1.E-99)
      WRITE(8,6) RLOGFR,FREQU,(SARRAY(L),L=1,8)
6     FORMAT(1X,F10.6,1PE13.6,8(1X,0PF11.5))
14    CONTINUE
17    CONTINUE
      STOP
      END
```

A typical test data listing appears in Fig. 1163-6. While the s-parameters and their power-flow interpretation often provides direct insight into the design at hand it is still frequently desirable to convert the s-parameters to other forms of characterization. As a typical example Table 4027-1 shows a conversion from s to y parameters, with the actual program listing given in Table 4027-14. This program allows one to immediately compare the measured transistor performance with data sheet tables or graphs of transistor y parameters.

Another useful routine is illustrated in Table 4027-2. It converts y to s parameters. If these have been derived from a given transistor model one may compare the computed s parameters with the measured s parameters (and thus verify the validity of the transistor model) without having to enter the latter into the computer.

Or, one may want to examine the behavior of hfe versus frequency. In this case the program illustrated in Fig. 4027-3 is useful: It converts the measured s parameters into a table and plot of hfe. Thus one may verify the drop of hfe with frequency. Any erratic behavior in this function would indicate a measurement error.

These few examples illustrate the contention that the computer can greatly expand the significance of the measurements taken, and aid in their verification by providing cross checks with theory and among different types of measurements. If the computer is readily accessible to the persons taking the measurements the computed results will be a valuable guide in planning further measurements, and of course, in the circuit design itself. At W.W.Gaertner Research Inc. the computations are carried out on a large time-share system (IBM360, Model 67) with ample disk support. Thus very large programs can be run within a very short time and all results are recorded on disk for further use, and can be printed on a high-speed printer. However, there is no capability for the computer to control the test sequence or any test parameters directly.

The most advanced commercially available system in the latter category is the Automatic Network Analyser by Hewlett Packard, shown in Fig. 4027-15. A list of available options up to frequencies of 18 GHz is given in Table 4027-16.

Figs. 1163-6, Tables 4027-1, -14, -2, Figs. 4027-3, -15 and -16 follow this page.

13.41.17 PRINTF R807-1N DATA

S PARAMETERS OF TWO-PORT NO.: 91 FOR ZREF= 5.0000E 01 +J 0.0 OHMS

LOG(FREQ)	FREQUENCY E	MAG(S11)	PHASE(S11)	MAG(S12)	PHASE(S12)	MAG(S21)	PHASE(S21)	MAG(S22)	PHASE(S22)
7.599988	3.981000E 07	0.98900	0.20000	0.00720	92.20000	3.24000	173.50000	1.00000	1.65000
7.620028	4.169000E 07	0.98900	0.10000	0.00750	92.00000	3.22000	173.20000	1.00000	1.65000
7.640080	4.366000E 07	0.98900	0.0	0.00780	91.89999	3.21000	173.00000	1.00000	1.65000
7.660007	4.571000E 07	0.98900	-0.20000	0.00830	91.89999	3.21000	172.50000	1.00000	1.65000
7.680059	4.787000E 07	0.98200	-0.25000	0.00860	91.79999	3.21000	172.09999	1.00000	1.65000
7.700006	5.012000E 07	0.98200	-0.40000	0.00900	91.59999	3.20000	171.70000	1.00000	1.65000
7.719993	5.248000E 07	0.98000	-0.50000	0.00950	91.50000	3.20000	171.29999	1.00000	1.65000
7.739966	5.495000E 07	0.98000	-0.60000	0.00980	91.39999	3.20000	170.79999	1.00000	1.65000
7.759966	5.754000E 07	0.98000	-0.70000	0.01020	91.29999	3.20000	170.39999	1.00000	1.65000
7.779594	6.020000E 07	0.97800	-0.90000	0.01060	91.20000	3.20000	169.89999	1.00000	1.65000
7.800025	6.310000E 07	0.97500	-1.00000	0.01110	91.09999	3.20000	169.29999	1.00000	1.6500
7.820004	6.607000E 07	0.97500	-1.10000	0.01180	91.00000	3.20000	168.70000	1.00000	1.65000
7.839978	6.918000E 07	0.97200	-1.40000	0.01220	90.89999	3.18000	168.29999	1.00000	1.60000
7.859978	7.244000E 07	0.97000	-1.50000	0.01280	90.70000	3.18000	167.79999	1.00000	1.60000
7.880011	7.586000E 07	0.96700	-1.70000	0.01340	90.59999	3.18000	166.89999	1.00000	1.60000
7.899983	7.943000E 07	0.96400	-1.90000	0.01400	90.39999	3.16000	166.59999	1.00000	1.60000
7.920016	8.318000E 07	0.96200	-2.05000	0.01470	90.39999	3.15000	165.39999	1.00000	1.60000
7.940016	8.710000E 07	0.96000	-2.20000	0.01520	90.29999	3.12000	164.70000	1.00000	1.55000
7.959990	9.120000E 07	0.95900	-2.40000	0.01600	90.20000	3.10000	164.0r000	1.00000	1.55000
7.980002	9.550000E 07	0.95200	-2.60000	0.01680	90.00000	3.10000	163.2'000	1.00000	1.55000
7.999995	1.000000E 08	0.95000	-2.80000	0.01750	89.89999	3.08000	162.50000	0.99900	1.50000
8.019942	1.047000E 08	0.94800	-3.00000	0.01830	89.79999	3.06000	161.50000	0.99800	1.50000
8.039809	1.096000E 08	0.94000	-3.20000	0.01910	89.59999	3.02000	160.70000	0.99700	1.50000
8.059941	1.148000E 08	0.94000	-3.40000	0.02000	89.50000	3.01000	159.79999	0.99300	1.50000
8.079902	1.202000E 08	0.93100	-3.60000	0.02080	89.29999	3.00000	159.00000	0.99100	1.50000
8.100020	1.259000E 08	0.93000	-3.80000	0.02170	89.09999	3.00000	158.00000	0.99000	1.50000
8.119914	1.318000E 08	0.92000	-4.00000	0.02260	88.89999	2.99000	157.09999	0.98400	1.50000
8.139874	1.380000E 08	0.91400	-4.00000	0.02380	88.70000	2.97000	156.20000	0.98200	1.60000
8.159867	1.445000E 08	0.90300	-4.20000	0.02540	88.39999	2.90000	153.70000	0.98000	1.65000
8.180125	1.514000E 08	0.90000	-4.25000	0.02570	88.39999	2.85000	153.50000	0.97500	1.65000
8.200026	1.585000E 08	0.89100	-4.25000	0.02680	88.29999	2.81000	152.20000	0.97000	2.00000
8.220105	1.660000E 08	0.88500	-4.20000	0.02780	88.29999	2.77000	151.59999	0.96800	2.20000
8.240045	1.738000E 08	0.87800	-4.20000	0.02880	88.29999	2.74000	150.20000	0.96500	2.50000
8.260071	1.820000E 08	0.87800	-4.20000	0.03000	88.20000	2.66000	149.50000	0.96500	2.70000
8.279892	1.905000E 08	0.87000	-4.10000	0.03120	88.50000	2.62000	148.79999	0.96100	2.90000
8.299938	1.995000E 08	0.86200	-4.10000	0.03270	88.59999	2.57000	147.89999	0.96000	3.10000
8.319938	2.089000E 08	0.86000	-3.90000	0.03400	88.79999	2.54000	147.00000	0.95900	3.40000
8.340043	2.188000E 08	0.85600	-3.70000	0.03550	89.20000	2.48000	146.39999	0.95900	3.80000
8.360023	2.291000E 08	0.85100	-3.70000	0.03700	89.29999	2.48000	145.20000	0.95900	4.00000
8.380030	2.399000E 08	0.85000	-3.90000	0.03860	89.39999	2.42000	144.00000	0.95900	4.00000
8.400016	2.512000E 08	0.83800	-4.00000	0.04020	89.29999	2.35000	143.00000	0.95900	4.00000
8.419956	2.630000E 08	0.83000	-3.95000	0.04200	89.29999	2.31000	141.70000	0.95200	4.20000
8.439962	2.753999E 08	0.81900	-3.60000	0.04350	89.29999	2.26000	140.70000	0.94800	4.50000
8.459995	2.883999E 08	0.81100	-3.40000	0.04580	89.29999	2.21000	139.89999	0.94500	4.80000
8.480001	3.019999E 08	0.80000	-3.20000	0.04710	89.59999	2.14000	138.50000	0.93900	5.00000
8.499962	3.161999E 08	0.78900	-2.80000	0.04900	89.70000	2.08000	137.59999	0.93200	5.60000
8.519955	3.310999E 08	0.78000	-2.30000	0.05020	90.29999	2.01000	137.00000	0.92500	6.60000
8.540073	3.467999E 08	0.77800	-1.70000	0.05210	91.20000	1.97000	136.00000	0.93000	7.40000
8.559901	3.629998E 08	0.77000	-1.70000	0.05500	91.70000	1.93000	135.29999	0.93200	7.50000
8.580007	3.801999E 08	0.76000	-1.80000	0.05740	92.20000	1.86000	134.70000	0.93000	7.50000
8.599987	3.981000E 08	0.74300	-1.40000	0.06000	93.09999	1.82000	134.59999	0.92000	8.00000
8.620032	4.168998E 08	0.73200	-1.10000	0.06320	93.50000	1.81000	134.00000	0.91500	8.40000
8.640079	4.365998E 08	0.71500	-0.60000	0.06620	93.79999	1.79000	132.89999	0.90000	9.00000
8.660006	4.570998E 08	0.71200	0.40000	0.07020	94.20000	1.76000	132.39999	0.90200	10.20000
8.689058	4.786998E 08	0.70100	0.80000	0.07300	93.95000	1.72000	130.70000	0.90000	10.70000

FIG. 1163-6 - TABULAR LISTING OF MEASURED OR COMPUTED TRANSISTOR SCATTERING PARAMETERS VERSUS FREQUENCY

W.W. GAERTNER RESEARCH INC.
205 SADDLE HILL ROAD
STAMFORD, CONNECTICUT 06903

****** INPUT: ******
*
*

S PARAMETERS OF TWO-PORT NO.: 10 FOR ZREF= 5.0000E 01 +J 0.0 OHMS

LOG(FREQ)	FREQUENCY	MAG(S11)	PHASE(S11)	MAG(S12)	PHASE(S12)	MAG(S21)	PHASE(S21)	MAG(S22)	PHASE(S22)
.	. E	.	.	.	.	.	.	.	.
8.800005	6.309522E 08	0.35890	-4.76688	0.03167	16.07887	0.96043	77.25063	0.28779	-65.18988
8.820004	6.606879E 08	0.35852	-4.45490	0.03166	16.53081	0.91756	76.30315	0.29145	-66.46506
8.840004	6.918244E 08	0.35816	-4.15069	0.03165	17.03185	0.87659	75.33321	0.29550	-67.80115
8.860003	7.244288E 08	0.35785	-3.85391	0.03163	17.58354	0.83744	74.33922	0.29997	-69.18921
8.880003	7.585695E 08	0.35756	-3.56390	0.03163	18.18896	0.80007	73.32033	0.30486	-70.63065
8.900002	7.943194E 08	0.35730	-3.28029	0.03162	18.85155	0.76433	72.27519	0.31019	-72.12122
8.920002	8.317540E 08	0.35707	-3.00242	0.03162	19.57492	0.73020	71.20357	0.31595	-73.66107
8.940001	8.709524E 08	0.35686	-2.72998	0.03162	20.36179	0.69757	70.10385	0.32214	-75.25162
8.960001	9.119990E 08	0.35667	-2.46202	0.03163	21.21802	0.66644	68.97697	0.32879	-76.88049
8.980000	9.549791E 08	0.35651	-2.19820	0.03165	22.14526	0.63669	67.82050	0.33591	-78.55273
9.000000	9.999852E 08	0.35636	-1.93815	0.03169	23.14946	0.60826	66.63564	0.34348	-80.26395

****** OUTPUT: ******
*
*

PARAMETERS OF FOURPOLE NO.: 10

LOG(FREQ)	FREQUENCY	G11	B11	G12	B12	G21	B21	G22	B22
8.800005	6.309522E 08	9.2532E-03	1.1823E-03	-6.8688E-04	-4.2114E-04	1.1447E-03	-2.4407E-02	1.3496E-02	8.4610E-03
8.820004	6.606879E 08	9.2712E-03	1.1184E-03	-6.8380E-04	-4.3027E-04	7.9748E-04	-2.3401E-02	1.3547E-02	8.6593E-03
8.840004	6.918244E 08	9.2879E-03	1.0564E-03	-6.8010E-04	-4.4038E-04	4.7998E-04	-2.2435E-02	1.3598E-02	8.8758E-03
8.860003	7.244288E 08	9.3026E-03	9.9591E-04	-6.7548E-04	-4.5133E-04	1.8953E-04	-2.1508E-02	1.3648E-02	9.1107E-03
8.880003	7.585695E 08	9.3159E-03	9.3743E-04	-6.7055E-04	-4.6359E-04	-7.5527E-05	-2.0620E-02	1.3698E-02	9.3652E-03
8.900002	7.943194E 08	9.3279E-03	8.8036E-04	-6.6457E-04	-4.7677E-04	-3.1757E-04	-1.9768E-02	1.3748E-02	9.6396E-03
8.920002	8.317540E 08	9.3384E-03	8.2492E-04	-6.5792E-04	-4.9120E-04	-5.3817E-04	-1.8953E-02	1.3799E-02	9.9348E-03
8.940001	8.709522E 08	9.3477E-03	7.7090E-04	-6.5031E-04	-5.0677E-04	-7.3931E-04	-1.8173E-02	1.3852E-02	1.0252E-02
8.960001	9.119990E 08	9.3560E-03	7.1827E-04	-6.4179E-04	-5.2366E-04	-9.2220E-04	-1.7428E-02	1.3906E-02	1.0591E-02
8.980000	9.549791E 08	9.3629E-03	6.6694E-04	-6.3226E-04	-5.4190E-04	-1.0884E-03	-1.6716E-02	1.3962E-02	1.0954E-02
9.000000	9.999852E 08	9.3690E-03	6.1694E-04	-6.2180E-04	-5.6174E-04	-1.2393E-03	-1.6036E-02	1.4021E-02	1.1341E-02

TABLE 4027-1 - EXAMPLES OF INPUT AND OUTPUT TABLES OF PROGRAM WHICH CONVERTS S PARAMETERS INTO Y PARAMETERS.

21.58.44

W.W. GAERTNER RESEARCH INC.

TABLE 4027-14 - THE NEXT FOUR PAGES CONTAIN A LISTING OF THE "S-TO-Y" PROGRAM WHICH CONVERTS S TO Y PARAMETERS.

```
FILEDEF * CLEAR                                          Y-T00010
ERASE YTABL10 DATA                                       Y-T00020
FILEDEF 8 DSK YTABL10 DATA RECFM F LRECL 130             Y-T00030
FILEDEF 9 DSK STABLE9 DATA RECFM F LRECL 130             Y-T00040
LOAD S-TO-Y-1 STOY                                       Y-T00050
START                                                    Y-T00060
PRINTF STABLE9 DATA                                      Y-T00070
PRINTF YTABL10 DATA                                      Y-T00080
```

```
C       ** W. W. GAERTNER RESEARCH INC.        ***** MAIN S-TO-Y-1  5/18/70
C       ** COMPUTES YIK FROM TABLES OF SIK PREPARED BY OTHER PROGRAM OR
C       MEASURED.
C       *REFERENCE IMPEDANCE, ZREF, IS READ IN FROM TITLE.
C       * NORMALIZED YIK ARE CALLED YIKN=YIK*ZREF     ***
        COMPLEX Y11,Y12,Y21,Y22,Y11N,Y12N,Y21N,Y22N,S11,S12,S21,S22,ZREF
        DIMENSION YARRAY(8), SARRAY(8)
7       FORMAT(/10X,27HPARAMETERS OF FOURPOLE NO.:,I3/)
8       FORMAT(2X,9HLOG(FREQ),2X,9HFREQUENCY,7X,3HG11,9X,3HB11,9X,3HG12,
       X   9X,3HB12,9X,3HG21,9X,3HB21,9X,3HG22,9X,3HB22)
3       FORMAT(1X,F10.6,1PE13.6,8(1X,1PE11.4))
C       ** STABLE IS READ IN NOW FROM 9.
        READ(9,4) KFP,RREF,XREF
        READ(9,5)
4       FORMAT(/10X,'S PARAMETERS OF TWO-PORT NO.:',I3,' FOR ZREF=',
       $1PE11.4,' +J',1PE11.4,' OHMS'/)
5       FORMAT(2X,9HLOG(FREQ),2X,9HFREQUENCY,6X,8HMAG(S11),
       $2X,10HPHASE(S11),4X,8HMAG(S12),2X,10HPHASE(S12),4X,8HMAG(S21),
       $2X,10HPHASE(S21),4X,8HMAG(S22),2X,10HPHASE(S22)/4X,1H.,8X,1H.,6X,
       $1HE,9X,8(1H.,11X))
        WRITE(8,7) KFP
        WRITE(8,8)
        DO 14 IFREQ=1,101
        RLOGFR=0.
        FREQU=0.
        DO 20 L=1,8
        SARRAY(L)=0.
20      CONTINUE
        READ(9,6,END=17) RLOGFR,FREQU,(SARRAY(L),L=1,8)
6       FORMAT(1X,F10.6,1PE13.6,8(1X,0PF11.5))
        IMAX=IFREQ
        ABSS11=SARRAY(1)
        PHAS11=SARRAY(2)
        ABSS12=SARRAY(3)
```


W.W. GAERTNER RESEARCH INC.

```
      PHAS12=SARRAY(4)                                                  YPL00350
      ABSS21=SARRAY(5)                                                  YPL00360
      PHAS21=SARRAY(6)                                                  YPL00370
      ABSS22=SARRAY(7)                                                  YPL00380
      PHAS22=SARRAY(8)                                                  YPL00390
      RES11=ABSS11*COS(PHAS11/57.29578)                                 YPL00400
      RES12=ABSS12*COS(PHAS12/57.29578)                                 YPL00410
      RES21=ABSS21*COS(PHAS21/57.29578)                                 YPL00420
      RES22=ABSS22*COS(PHAS22/57.29578)                                 YPL00430
      AIMS11=ABSS11*SIN(PHAS11/57.29578)                                YPL00440
      AIMS12=ABSS12*SIN(PHAS12/57.29578)                                YPL00450
      AIMS21=ABSS21*SIN(PHAS21/57.29578)                                YPL00460
      AIMS22=ABSS22*SIN(PHAS22/57.29578)                                YPL00470
      S11=CMPLX(RES11,AIMS11)                                           YPL00480
      S12=CMPLX(RES12,AIMS12)                                           YPL00490
      S21=CMPLX(RES21,AIMS21)                                           YPL00500
      S22=CMPLX(RES22,AIMS22)                                           YPL00510
C     ***                                                               YPL00520
      CALL  STOY(S11,S12,S21,S22,Y11N,Y12N,Y21N,Y22N)                   YPL00530
      ZREF=CMPLX(RREF,XREF)                                             YPL00540
      YARRAY(1)=REAL(Y11N/ZREF)                                         YPL00550
      YARRAY(3)=REAL(Y12N/ZREF)                                         YPL00560
      YARRAY(5)=REAL(Y21N/ZREF)                                         YPL00570
      YARRAY(7)=REAL(Y22N/ZREF)                                         YPL00580
      YARRAY(2)=AIMAG(Y11N/ZREF)                                        YPL00590
      YARRAY(4)=AIMAG(Y12N/ZREF)                                        YPL00600
      YARRAY(6)=AIMAG(Y21N/ZREF)                                        YPL00610
      YARRAY(8)=AIMAG(Y22N/ZREF)                                        YPL00620
      WRITE(8,3) RLOGFP,FREQU,(YARRAY(L),L=1,8)                         YPL00630
14    CONTINUE                                                          YPL00640
17    CONTINUE                                                          YPL00650
      STOP                                                              YPL00660
      END                                                               YPL00670
```

```
C     ** W.W.GAERTNER RES. INC.     ***** SUB STOY  5/18/70
C     ** CONVERTS SIK TO NORMALIZED YIKN
      SUBROUTINE STOY(S11,S12,S21,S22,Y11N,Y12N,Y21N,Y22N)
      COMPLEX Y11N,Y12N,Y21N,Y22N,S11,S12,S21,S22,DENOM
      DENOM=(1.+S11)*(1.+S22)-S12*S21
      Y11N=((1.-S11)*(1.+S22)+S12*S21)/DENOM
      Y12N=-2.*S12/DENOM
      Y21N=-2.*S21/DENOM
      Y22N=((1.+S11)*(1.-S22)+S12*S21)/DENOM
      RETURN
      END
```

****** INPUT: ******
*
*

PARAMETERS OF FOURPOLE NO.: 10

LOG(FREQ)	FREQUENCY	G11	B11	G12	B12	G21	B21	G22	B22
8.800005	6.309524E 08	9.2531E-03	1.1823E-03	-6.8686E-04	-4.2113E-04	1.1447E-03	-2.4407E-02	1.3496E-02	8.4609E-03
8.820004	6.606879E 08	9.2713E-03	1.1184E-03	-6.8375E-04	-4.3024E-04	7.9755E-04	-2.3401E-02	1.3547E-02	8.6593E-03
8.840004	6.918246E 08	9.2878E-03	1.0563E-03	-6.8000E-04	-4.4032E-04	4.7999E-04	-2.2435E-02	1.3598E-02	8.8758E-03
8.860003	7.244288E 08	9.3026E-03	9.9598E-04	-6.7558E-04	-4.5140E-04	1.8967E-04	-2.1508E-02	1.3648E-02	9.1108E-03
8.880003	7.585697E 08	9.3159E-03	9.3736E-04	-6.7045E-04	-4.6353E-04	-7.5468E-05	-2.0620E-02	1.3698E-02	9.3652E-03
8.900002	7.943194E 08	9.3278E-03	8.8035E-04	-6.6457E-04	-4.7677E-04	-3.1752E-04	-1.9768E-02	1.3748E-02	9.6396E-03
8.920002	8.317540E 08	9.3384E-03	8.2489E-04	-6.5788E-04	-4.9117E-04	-5.3817E-04	-1.8953E-02	1.3799E-02	9.9348E-03
8.940001	8.709527E 08	9.3477E-03	7.7090E-04	-6.5032E-04	-5.0678E-04	-7.3923E-04	-1.8173E-02	1.3852E-02	1.0252E-02
8.960001	9.119990E 08	9.3559E-03	7.1829E-04	-6.4183E-04	-5.2369E-04	-9.2217E-04	-1.7428E-02	1.3906E-02	1.0591E-02
8.980000	9.549793E 08	9.3629E-03	6.6698E-04	-6.3233E-04	-5.4196E-04	-1.0884E-03	-1.6716E-02	1.3962E-02	1.0954E-02
9.000000	9.999854E 08	9.3689E-03	6.1690E-04	-6.2173E-04	-5.6167E-04	-1.2393E-03	-1.6036E-02	1.4021E-02	1.1341E-02

****** OUTPUT: ******
*
*

S PARAMETERS OF TWO-PORT NO.: 10 FOR ZREF= 5.0000E 01 +J 0.0 OHMS

LOG(FREQ)	FREQUENCY	MAG(S11)	PHASE(S11)	MAG(S12)	PHASE(S12)	MAG(S21)	PHASE(S21)	MAG(S22)	PHASE(S22)
.	. E	.	.	.	.	.	.	.	.
8.800005	6.309522E 08	0.35890	-4.76688	0.03167	16.07887	0.96043	77.25063	0.28779	-65.18988
8.820004	6.606879E 08	0.35852	-4.45490	0.03166	16.53081	0.91756	76.30315	0.29145	-66.46506
8.840004	6.918244E 08	0.35816	-4.15069	0.03165	17.03185	0.87659	75.33321	0.29550	-67.80115
8.860003	7.244288E 08	0.35785	-3.85391	0.03163	17.58354	0.83744	74.33922	0.29997	-69.18921
8.880003	7.585695E 08	0.35756	-3.56390	0.03163	18.18896	0.80007	73.32033	0.30486	-70.63065
8.900002	7.943194E 08	0.35730	-3.28029	0.03162	18.85155	0.76433	72.27519	0.31019	-72.12122
8.920002	8.317540E 08	0.35707	-3.00242	0.03162	19.57492	0.73020	71.20357	0.31595	-73.66107
8.940001	8.709524E 08	0.35686	-2.72998	0.03162	20.36179	0.69757	70.10385	0.32214	-75.25162
8.960001	9.119990E 08	0.35667	-2.46202	0.03163	21.21802	0.66644	68.97697	0.32879	-76.88049
8.980000	9.549791E 08	0.35651	-2.19820	0.03165	22.14526	0.63669	67.82050	0.33591	-78.55273
9.000000	9.999852E 08	0.35636	-1.93815	0.03169	23.14946	0.60826	66.63564	0.34348	-80.26395

TABLE 4027-2 - EXAMPLES OF INPUT AND OUTPUT TABLES OF PROGRAM WHICH CONVERTS Y PARAMETERS INTO S PARAMETERS.

22.26.38

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****

ORIGINAL INPUT OF MEASURED S PARAMETERS:

S PARAMETERS OF TWO-PORT NO.: 01 FOR ZREF= 5.0000E 01 +J 0.0 OHMS

LOG(FREQ)	FREQUENCY	MAG(S11)	PHASE(S11)	MAG(S12)	PHASE(S12)	MAG(S21)	PHASE(S21)	MAG(S22)	PHASE(S22)
	1.000000E 08	0.62	-44.	0.0115	75.	9.	130.	0.955	-6.
	3.000000E 08	0.305	-81.	0.024	93.	3.85	91.	0.86	-14.
	5.900000E 08	0.238	-119.	0.0385	110.	2.19	66.	0.83	-26.
	1.000000E 09	0.207	175.	0.178	110.	1.3	33.	0.838	-49.5

****

LOG(FREQ) COLUMN ADDED TO TABLE OF MEASURED S PARAMETERS:

S PARAMETERS OF TWO-PORT NO.: 1 FOR ZREF= 5.0000E 01 +J 0.0 OHMS

LOG(FREQ)	FREQUENCY	MAG(S11)	PHASE(S11)	MAG(S12)	PHASE(S12)	MAG(S21)	PHASE(S21)	MAG(S22)	PHASE(S22)
7.999995	1.000000E 08	0.62000	-44.00000	0.01150	75.00000	9.00000	130.00000	0.95500	-6.00000
8.477119	3.000000E 08	0.30500	-81.00000	0.02400	93.00000	3.85000	91.00000	0.86000	-14.00000
8.770852	5.899999E 08	0.23800	-119.00000	0.03850	110.00000	2.19000	66.00000	0.83000	-26.00000
9.000001	1.000000E 09	0.20700	175.00000	0.17800	110.00000	1.30000	33.00000	0.83800	-49.50000

****

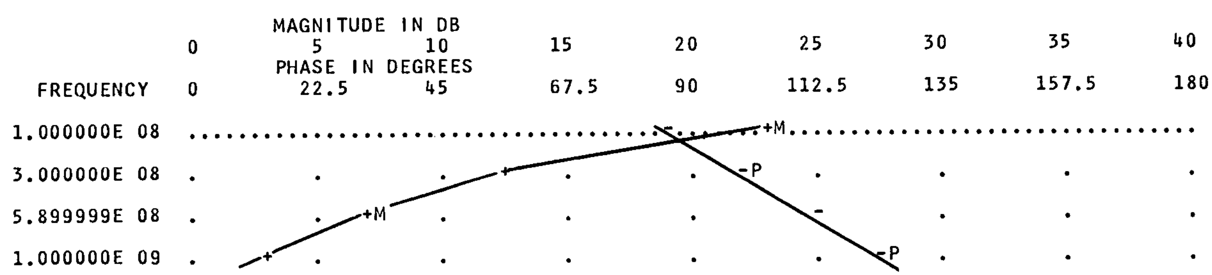
HFE COMPUTED FROM MEASURED S PARAMETERS:

HFE OF FOURPOLE NO.: 1 AS A FUNCTION OF FREQUENCY

LOG(FREQ)	FREQUENCY	ABS(HFE)/DB	PHASE	ABS(HFE)
7.999994	1.000000E 08	23.04187	-85.73717	1.4194E 01
8.477118	3.000000E 08	12.85745	-100.45633	4.3941E 00
8.770851	5.899999E 08	7.07599	-112.92165	2.2584E 00
9.000001	1.000000E 09	3.23609	-125.47559	1.4515E 00

****

HFE PLOTTED:



HFE OF FOURPOLE NO.: 1 AS A FUNCTION OF FREQUENCY

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FIG. 4027-3 - EXAMPLE OF CONVERSION OF MEASURED S PARAMETERS (PUBLISHED VALUES FOR T.I. 2N3571 TRANSISTOR AT IC=5MA, VCE=10VOLTS,TEMP=25 DEG C) TO TABLE AND PLOT OF HFE.

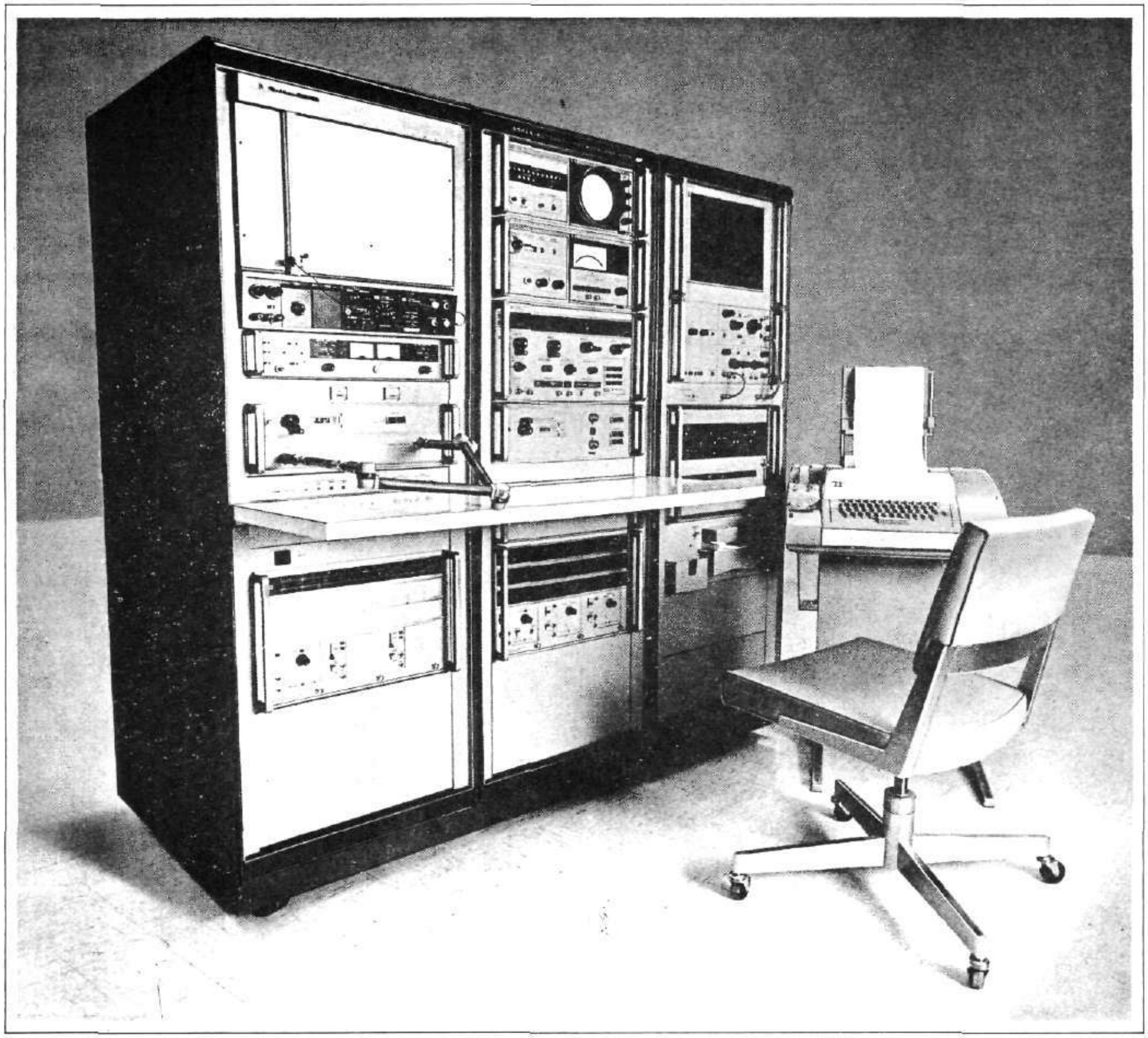

FIG. 4027-15 - EXAMPLE OF AUTOMATIC NETWORK ANALYZER SYSTEM WITH S PARAMETER TEST SET, MINICOMPUTER, X-Y RECORDER, OSCILLOSCOPE DISPLAYS, AND TELEPRINTER. TEST FREQUENCIES UP TO 18 GHZ CAN BE REACHED (HEWLETT PACKARD PHOTOGRAPH)

SPECIFICATIONS
HP Model 8542A
Automatic Network Analyzer

AVAILABLE CONFIGURATIONS AND CAPABILITIES

RF STIMULUS OPTIONS

STANDARD SIGNAL SOURCE

Plug-in oscillator covering 0.11–12.4 GHz with three rf units. Analyzer available with one, two, or three rf units to cover part or all of range. Automatic frequency setting ±0.25% + 10 MHz. Max. output power at least 0 dBm, 0.11 to 4.0 GHz, at least +10 dBm, 4 to 12.4 GHz. Broadband power leveling and automatic band selection in multi-band versions.

FREQUENCY-STABILIZED SIGNAL SOURCE

Uses modules from Standard source and incorporates Frequency Synthesizer as precision frequency reference. Resulting source has frequency accuracy ±1 part in 10^6 + 5 kHz. Frequency-stabilized source available with fourth rf unit to extend Analyzer coverage to 18.0 GHz.

DC STIMULUS OPTION

DC BIAS SUPPLY

Programmable, dual-output power supply provides ±30 V ±0.5 A output to bias transistors, diodes, solid-state amplifiers, etc.

MEASUREMENT OPTIONS

NETWORK ANALYZER

Two channels (reference and test). Makes amplitude and phase measurements from 0.11 to 12.4 GHz (18.0 GHz optional) to determine both reflection and transmission coefficients of device under test. Includes integrating analog-to-digital converter to digitize measured information for data manipulation in the Control and Digital Processor Sub-system, and CRT readout devices for both corrected and uncorrected displays.

TEST SETS

Passive instruments selectively feed proper signals to Network Analyzer to determine both reflection and transmission coefficients of two-port network under test. Contain broadband directional couplers, calibrated line stretcher, and an array of microwave switches. Test sets available: one for frequency range 0.11–2.0 GHz, one for range 2.0–18.0 GHz. Under normal system configurations, power incident on device under test can typically be set manually anywhere between −26 and −2 dBm in the range 0.11 to 2.0 GHz, and between −34 and −14 dBm in the range 2.0 to 18.0 GHz.

Transistor fixtures available to measure TO-18 (TO-72) and TO-5 (TO-12) packaged devices from 0.11 to 2.0 GHz. Accommodate standard lead configurations without need to cut leads.

Bias insertion networks, 50Ω, apply dc to test device via center conductors of input and/or output coaxial transmission lines. Two different bias tees available, one covering 0.1–3.0 GHz, another covering 1.0–12.4 GHz.

CALIBRATION EQUIPMENT

Calibration programs supplied with 8452A Automatic Network Analyzers require a set of standards for given connector type (APC-7, N, OSM, GR-900) or waveguide size. Each basic calibration kit contains standards common to entire frequency range covered by that connector or waveguide size. Additional standards required in specific frequency ranges are separately available.

CONTROL AND DIGITAL PROCESSING OPTIONS

INSTRUMENTATION COMPUTERS

Choice of Model 2114B (8,192-word, stored-program computer with seven I/O channels, expandable to 24) or Model 2116B (8,192-word stored-program computer, with 16,384-word option, sixteen I/O channels, expandable to 48. High-speed punched tape input is standard with each computer. Optional memory expansion: both magnetic tape and disc memory peripherals are available.

INPUT/OUTPUT OPTIONS

TELEPRINTERS

Model 2572A (modified ASR-33) for systems where teleprinter use is 5 hours per day or less; for heavier duty, Model 2754B (modified ASR-35) is available.

PUNCHED TAPE OUTPUT

120 character/second tape punch, recommended for systems expected to deliver considerable hard-copy output or where FORTRAN is anticipated to modify standard software. (Both teleprinters have punched tape output of more limited speed and format.)

OSCILLOSCOPE

Measurement subsystem includes CRT display of polar or rectangular plots, corrected or uncorrected, in usual size screens. Large-screen scope, readable at distances up to 10 feet, optional.

X-Y PLOTTER

Optional X-Y point plotter makes hard copy replicas, up to 11" x 17", of any oscilloscope display. Typically a 50-point display can be transferred in less than 15 seconds, including alpha/numeric labels.

TABLE 4027-16 - LIST OF OPTIONS AVAILABLE IN THE HEWLETT-PACKARD AUTOMATIC NETWORK ANALYZER

A summary of the capabilities and applications of this complex and expensive equipment is contained in the February 1970 issue of the Hewlett Packard Journal. We believe this equipment constitutes a starting point towards extending the frequency range of computer-aided test equipment towards the 100 GHz mark.

3.3.3 Transistor Chip Test Holders

It has been mentioned earlier that special attention will have to be paid to transistor chip test holders as the frequencies increase and the device geometries become extremely small. At frequencies in the VHF and UHF ranges one simply tries to contact the transistor with 50-ohm lines as shown in Figs. 4018-127 and 4026-20 for a TO-18 package, and in Figs. 4018-124 and 4026-17 for a "micro-tee" package. In the TO-18 case the emitter lead is connected directly to the ground plane, whereas a separate ground lead is provided for the strip-line (micro-tee) package. At higher UHF frequencies these test holders already show the inductive effects of the common ground lead.

The approach suggested for future transistor holder development is therefore as follows:

The transistor measurements should be based on three-port parameters as described earlier. The test jig therefore has three transmission-line terminals. Every attempt shall be made to bring the 50-ohm lines as close to the transistor as possible. However, considering that the active transistor area will only be a few microns sq. it will probably be impossible to produce wideband 50-ohm terminations. Rather than work with approximations and possibly significant errors it is therefore suggested to use the computer to make the necessary corrections. One would look upon the transmission lines not as perfect 50-ohm lines but rather as two-ports with arbitrary frequency characteristics in series with each transistor port. As a first step one would determine the transfer functions (s-parameters) of these two ports by measuring the transistor test jig empty and with various known impedances (including opens and shorts) replacing the transistor.

Figs. 4018-127, 4026-20, 4018-124 and 4026-17 follow this page.

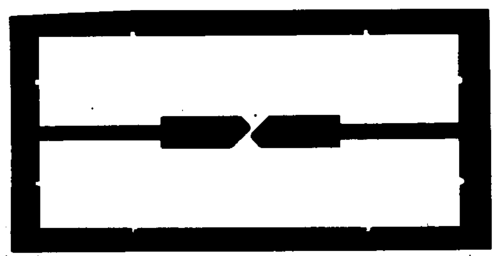

FIG. 4018-127 - PHOTORESIST MASK FOR ETCHING OF PC BOARD FOR TO-18 TRANSISTOR TEST HOLDER

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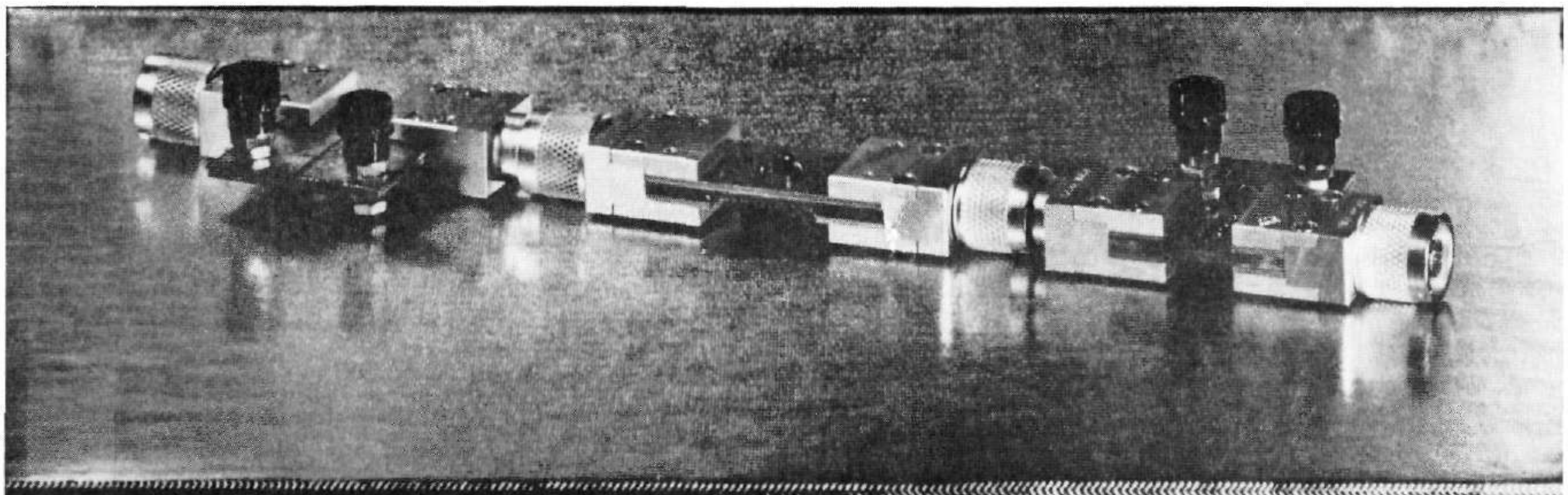

FIG. 4026-20 - PHOTOGRAPH OF TO-18 TRANSISTOR TEST HOLDER

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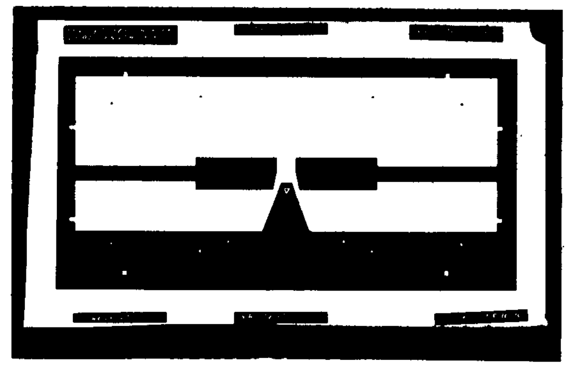

FIG. 4018-124 - PHOTORESIST MASK FOR ETCHING OF PC BOARD FOR TRANSISTOR STRIPLINE TEST JIG

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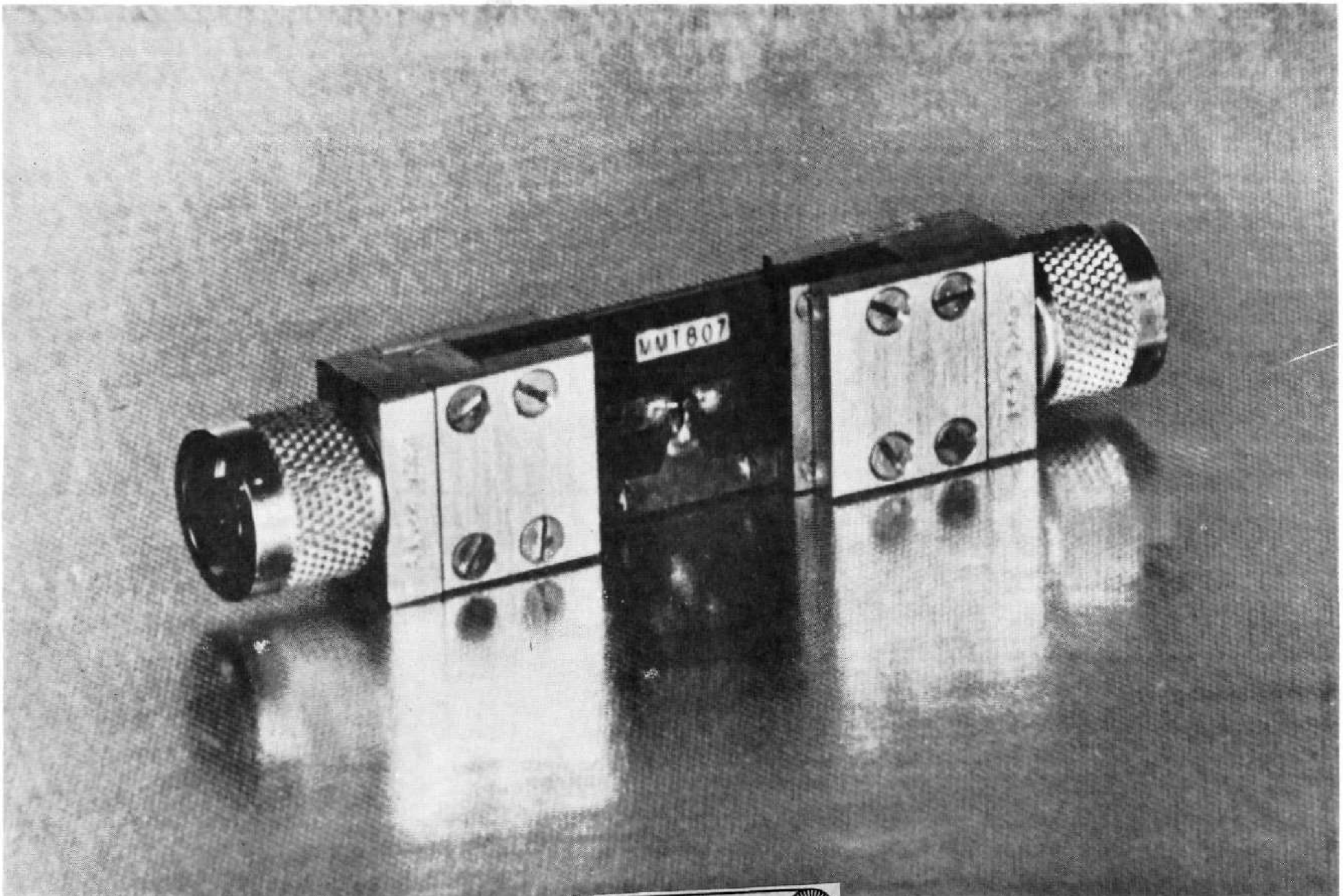

FIG. 4026-17 - PHOTOGRAPH OF TEST HOLDER FOR MICRO-TEE (STRIPLINE) TRANSISTOR

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Then the transistor would be mounted and the test results would be fed into the computer where the effects of the series two-ports of the jig would be subtracted and the s-parameters of the transistor alone would be computed. We believe this approach would be much faster and accurate than trying to construct perfect wide-band 50-ohm lines.

3.3.4 Conclusion

From the preceding discussion we draw the conclusion that future developments of test techniques for microwave transistor circuits for the 2 to 100 GHz range should be based on s parameters and should employ heavily computer-aided test equipment. The latter in addition to using a dedicated minicomputer, should also have communication capability to a large time-share computer.

Considering that an off-the-shelf automatic network analyser with capabilities up to 18 GHz costs approximately $100,000.- it is obvious that several million dollars of development money will be spent before the objectives outlined in Chapter 3.0 will be realized.

4.0 NEGATIVE-RESISTANCE TRANSISTOR CIRCUITS FOR THE 2-100 GHz FREQUENCY RANGE

4.1 Requirements

The usefulness of the negative-resistance circuits in the UHF and low microwave frequency ranges is well established. As the demand for higher bandwidth and therefore for utilization of higher microwave frequencies increases, the question arises as to the upper limit at which this type of circuit could be operated.

In the following paragraph we shall therefore derive the properties of transistors which would allow a substantial increase in the operating frequency of negative-resistance circuits. Technological approaches to achieve these characteristics are also suggested.

4.2 Approaches and Ultimate Limitations

It has become clear in earlier work on these circuits that increases in operating frequency are achieved by increasing the fT of the transistor and by reducing all stray reactances as much as possible.

One of the limitations on the fT of a transistor is the base transit time which in a first approximation is given by:

$$T=W^2/(2D)$$

where

W is the base width

and

D is the carrier diffusion constant.

A W=1/3 micron is definitely feasible, which with D=34 sq.cm/sec (electrons in silicon) yields

T=16.3 picoseconds.

This corresponds to an fT=61 GHz.

The other frequency limitations arise from RC time constants of device and stray capacitances and resistances. To determine desirable and permissible values for these components we shall use the computer-aided design theory for these circuits which was developed earlier.

Fig. 4027-17 shows the basic negative-resistance circuit stage and Fig. 4012-1003 contains the transistor model used. These two schematics include all possible parasitics and strays in the circuit. The numbering of the circuit elements in Fig. 4027-17 corresponds to their number in the listing of component values used in the computer-aided design programs presented later, i.e. A(29) is the 29th component on the list. The component lists themselves which are given below together with each computer run contain more elements than used in this particular circuit since they apply also to more complex multistage circuitry.

The input impedance of the circuit in Fig. 4027-17 has been calculated for various transistor characteristics and external component values and the results are shown in Fig. 4027-18 through 4027-28.

The key characteristics of interest are the fT of the transistor and the emitter series capacitance, C1X2. Initially all other circuit components have been made negligible.

The dependence of the input impedance on fT and C1X2 is illustrated in Figs. 4027-18 through -24. Starting at the low frequency end with fT=10 GHz and C1X2=12 pF we obtain negative resistance up to approximately 6.3 GHz (Fig. 4027-18). Increasing fT to 15 GHz and decreasing C1X2 to 0.5 pF (Fig. 4027-20) creates negative resistance up to approximately 20 GHz. While an fT of 15 GHz is already being achieved at the present time, the parasitic capacitances of current devices are too large, as will be seen later. Since most microwave transistor technologists believe an fT of 30 GHz to be within reach over the next few years we have computed additional cases up to an fT=30 GHz and C1X2=0.25 pF (Fig. 4027-23). Negative resistance occurs up to 31.6 GHz. Decreasing capacitance C1X2 to 0.1 pF (Fig. 4027-24) lowers the maximum frequency limit, and a capacitance C1X2 of 0.15 to 0.25 pF would be considered optimum for the 30 GHz range.

Based on the fT for a 1/3 micron base width given earlier we believe that the frequency range of these transistors and the negative resistance circuit could be extended beyond 60 GHz.

Figs. 4027-17, 4012-1003, 4027-18 through -24 follow this page.

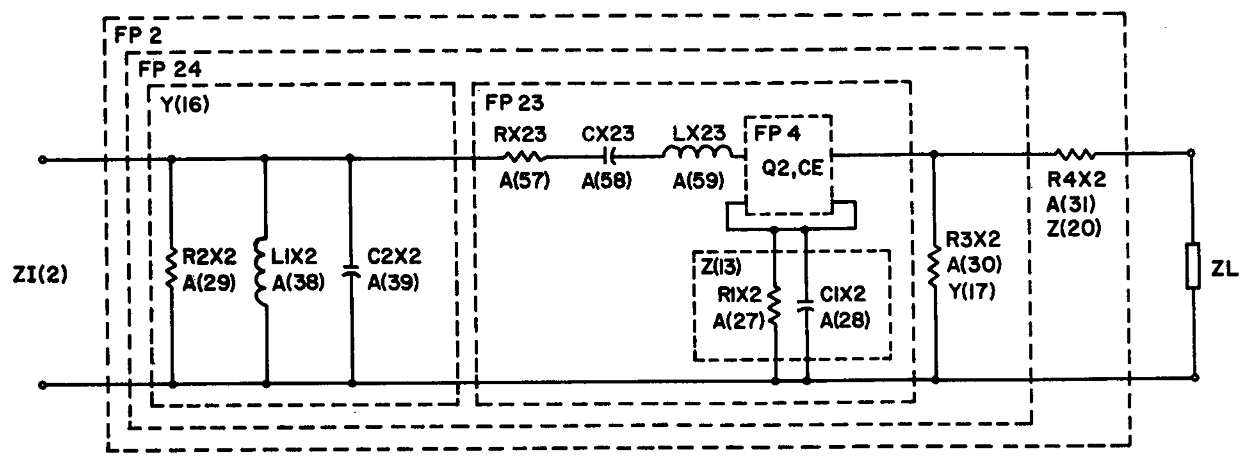

FIG. 4027-17 - BASIC NEGATIVE-RESISTANCE CIRCUIT WITH ALL POSSIBLE PARASITIC ELEMENTS, ARRANGED FOR COMPUTER-AIDED FOURPOLE ANALYSIS. THE TRANSISTOR, FP4, IS REPRESENTED BY THE MODEL IN FIG. 4012-1003. THE NOTATION AND NUMBERING FOR THE INDIVIDUAL ELEMENTS CORRESPONDS TO THE COMPONENT LISTINGS GIVEN WITH THE COMPUTER RUNS.

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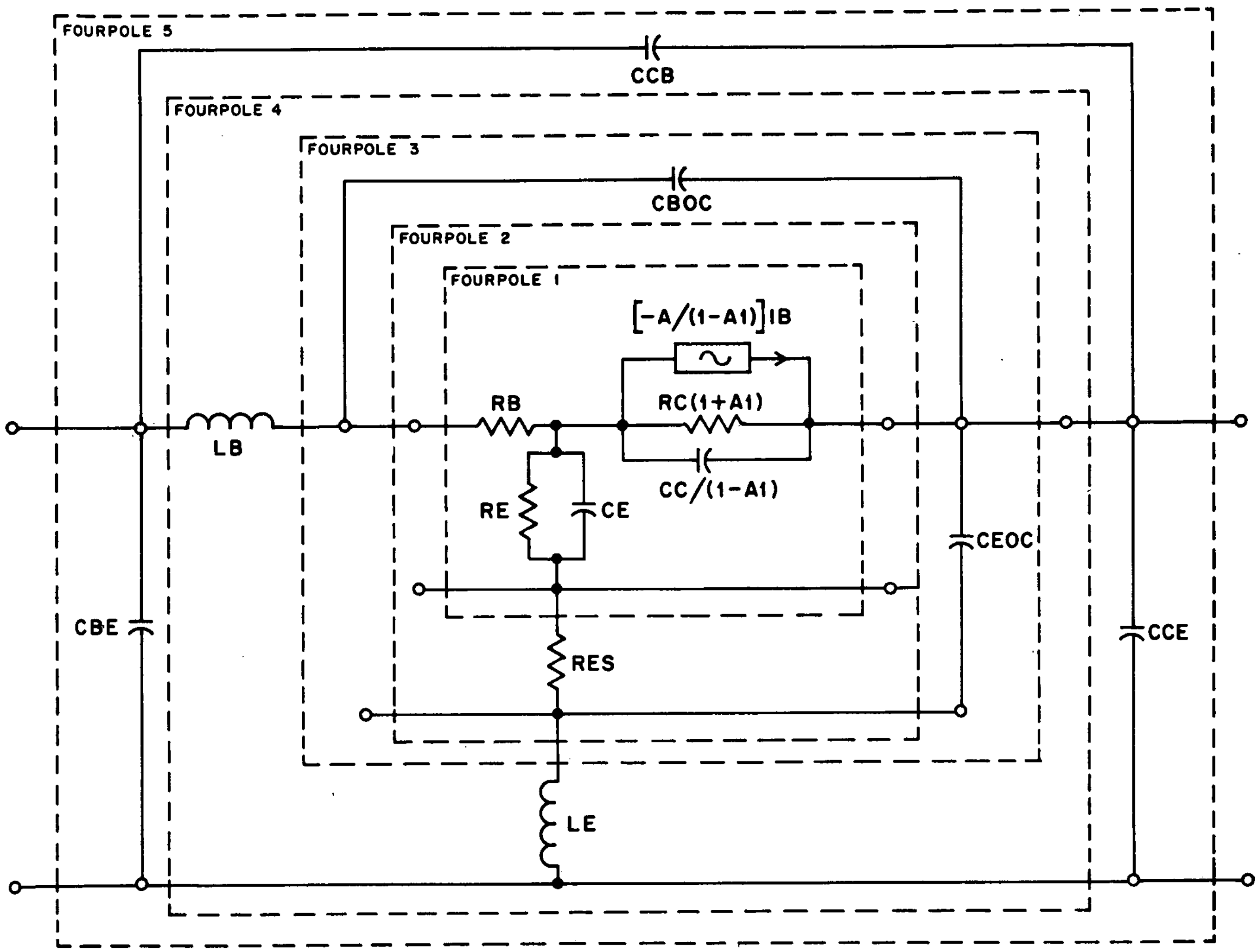

$A = A_0 \times EXP(-J \cdot M \cdot F/F_\alpha)/(1+J \cdot F/F_\alpha)$

$C_E = 1/(\omega_\alpha \cdot R_E) + C_{TE}$

$F_\alpha = (1+M \cdot \alpha_0) \cdot F_T$

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FIG. 4012-1003 - TRANSISTOR MODEL USED IN COMPUTER-AIDED ANALYSIS.

CASE NO. 4027-1236:
FT = 10 GHZ, C1X2 = 12 PF.

20.20.09 PRINTF MISC DATA 1 34

NUMBER OF ITEMS= 64

1	1 ICIRCT	1.000001E 00
2	2 IFP1	2.000000E 00
3	3 IFP2	3.000000E 00
4	4 IFP3	1.000010E 01
5	NO POINT	1.600000E 01
6	6 RLOGF	8.700005E 00
7	7 DLLOGF	1.000010E-01
8	8 RG	5.000009E 01
9	9 RL	5.000009E 01
10	TEMP(C)	2.500000E 01
11	11 IC	5.000006E-03
12	12 BETA0	1.000010E 02
13	M FACTOR	-1.000001E-01
14	14 FT2	1.000005E 10
15	15 CTE	1.000001E-14
16	16 RB	1.000010E 00
17	17 RC	1.000001E 07
18	18 CC	1.000001E-14
19	19 RES	1.000010E 00
20	20 CEOC	3.000010E-14
21	21 CBOC	3.000010E-14
22	22 LE	3.000010E-12
23	23 LB	3.000010E-12
24	24 CBE	2.000010E-14
25	25 CCE	2.000010E-14
26	26 CCB	2.000001E-14
27	27 R1X2	1.000010E 07
28	28 C1X2	1.200010E-11
29	29 R2X2	1.000010E 07
30	30 R3X2	2.000010E 07
31	31 R4X2	1.000010E-02

20.21.39 EXEC ZITABLE
EXECUTION:

INPUT IMPEDANCE OF FOURPOLE NO.: 2 AS A FUNCTION OF FREQUENCY

LOG(FREQ)	FREQUENCY	RI	XI
8.800005	6.309522E 08	-2.0929E 02	-1.1464E 02
8.900004	7.943314E 08	-1.3258E 02	-8.1016E 01
9.000006	1.000001E 09	-8.3403E 01	-5.9233E 01
9.100005	1.258922E 09	-5.2056E 01	-4.4449E 01
9.200006	1.584908E 09	-3.2148E 01	-3.3985E 01
9.300007	1.995274E 09	-1.9536E 01	-2.6316E 01
9.400006	2.511893E 09	-1.1559E 01	-2.0545E 01
9.500008	3.162275E 09	-6.5175E 00	-1.6119E 01
9.600007	3.981115E 09	-3.3333E 00	-1.2676E 01
9.700007	5.011911E 09	-1.3234E 00	-9.9719E 00
9.800009	6.309597E 09	-5.5480E-02	-7.8301E 00
9.900008	7.943410E 09	7.4340E-01	-6.1209E 00
10.000010	1.000013E 10	1.2452E 00	-4.7453E 00
10.100010	1.258937E 10	1.5585E 00	-3.6251E 00
10.200009	1.584903E 10	1.7512E 00	-2.6969E 00
10.300011	1.995298E 10	1.8668E 00	-1.9081E 00

20.22.57 EXEC ZIPLOT
EXECUTION:

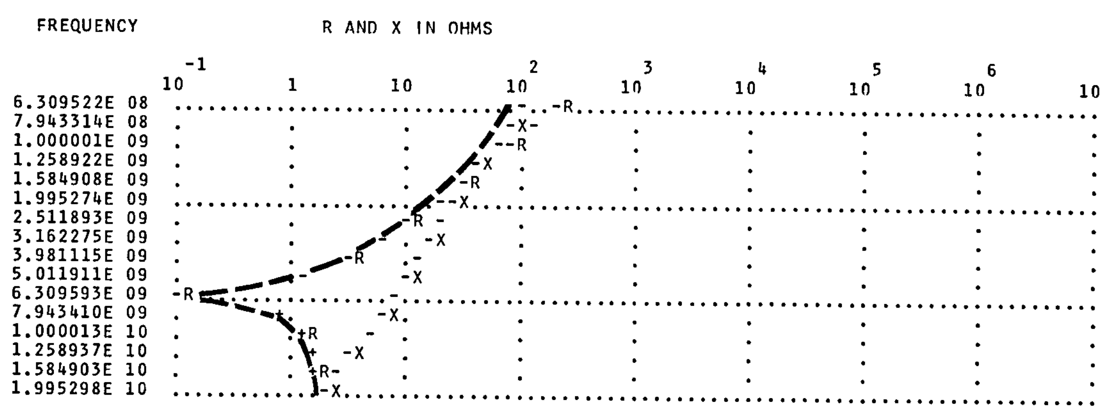

FIG. 4027-18 INPUT IMPEDANCE OF FOURPOLE NO.: 2 AS A FUNCTION OF FREQUENCY

CASE NO. 4027-1236:
FT = 10 GHZ, C1X2 = 12 PF.

CIRCUIT DIAGRAM IS SHOWN IN FIGS. 4027-17 AND 4012-1003. COMPONENT VALUES ARE GIVEN AT TOP OF FIGURE.

2

CASE NO. 4027-1237:
FT = 15 GHZ, C1X2 = 12 PF.

20.30.39 PRINTF MISC DATA 1 34

NUMBER OF ITEMS= 64

1	1 ICIRCT	1.000001E 00
2	2 IFP1	2.000000E 00
3	3 IFP2	3.000000E 00
4	4 IFP3	1.000010E 01
5	NO POINT	1.600000E 01
6	6 RLOGF	8.700005E 00
7	7 DLLOGF	1.000010E-01
8	8 RG	5.000009E 01
9	9 RL	5.000009E 01
10	TEMP(C)	2.500000E 01
11	11 IC	5.000006E-03
12	12 BETA0	1.000010E 02
13	M FACTOR	-1.000001E-01
14	14 FT2	1.500005E 10
15	15 CTE	1.000001E-14
16	16 RB	1.000010E 00
17	17 RC	1.000001E 07
18	18 CC	1.000001E-14
19	19 RES	1.000010E 00
20	20 CEOC	3.000010E-14
21	21 CBOC	3.000010E-14
22	22 LE	3.000010E-12
23	23 LB	3.000010E-12
24	24 CBE	2.000010E-14
25	25 CCE	2.000010E-14
26	26 CCB	2.000001E-14
27	27 R1X2	1.000010E 07
28	28 C1X2	1.200010E-11
29	29 R2X2	1.000010E 07
30	30 R3X2	2.000010E 07
31	31 R4X2	1.000010E-02

20.32.18 EXEC ZITABLE
EXECUTION:

INPUT IMPEDANCE OF FOURPOLE NO.: 2 AS A FUNCTION OF FREQUENCY

log9freq0	frequency	ri	xi
8.800005	6.309522E 08	-2.8022E 02	-1.6910E 02
8.900004	7.943314E 08	-1.7933E 02	-1.1590E 02
9.000006	1.000001E 09	-1.1369E 02	-8.2536E 01
9.100005	1.258922E 09	-7.1460E 01	-6.0685E 01
9.200006	1.584908E 09	-4.4478E 01	-4.5720E 01
9.300007	1.995274E 09	-2.7319E 01	-3.5052E 01
9.400006	2.511893E 09	-1.6438E 01	-2.7191E 01
9.500008	3.162275E 09	-9.5522E 00	-2.1253E 01
9.600007	3.981115E 09	-5.1990E 00	-1.6686E 01
9.700007	5.011911E 09	-2.4500E 00	-1.3128E 01
9.800009	6.309597E 09	-7.1589E-01	-1.0328E 01
9.900008	7.943410E 09	3.7623E-01	-8.1083E 00
10.000010	1.000013E 10	1.0612E 00	-6.3344E 00
10.100010	1.258937E 10	1.4872E 00	-4.9036E 00
10.200009	1.584903E 10	1.7469E 00	-3.7332E 00
10.300011	1.995298E 10	1.8989E 00	-2.7556E 00

20.33.34 EXEC ZIPLOT
EXECUTION:

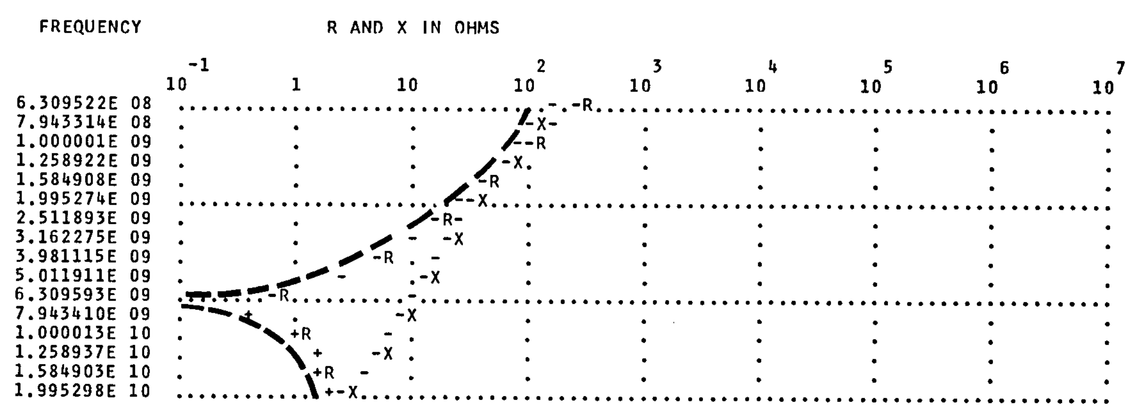

FIG. 4027-19 INPUT IMPEDANCE OF FOURPOLE NO.: 2 AS A FUNCTION OF FREQUENCY

CASE NO. 4027-1237:
FT = 15 GHZ, C1X2 = 12 PF.

CIRCUIT DIAGRAM IS SHOWN IN FIGS. 4027-17 AND 4012-1003. COMPONENT VALUES ARE GIVEN AT TOP OF FIGURE.

CASE NO. 4227-1240:
FT = 15 GHZ, C1X2 = 0.5 PF.

21.22.11 PRINTF MISC DATA 1 34

NUMBER OF ITEMS= 64

1	1 ICIRCT	1.000001E 00
2	2 IFP1	2.000000E 00
3	3 IFP2	3.000000E 00
4	4 IFP3	1.000010E 01
5	NO POINT	1.600000E 01
6	6 RLOGF	9.200005E 00
7	7 DLLOGF	1.000010E-01
8	8 RG	5.000009E 01
9	9 RL	5.000009E 01
10	TEMP(C)	2.500000E 01
11	11 IC	5.000006E-03
12	12 BETA0	1.000010E 02
13	M FACTOR	-1.000001E-01
14	14 FT2	1.500005E 10
15	15 CTE	1.000001E-14
16	16 RB	1.000010E 00
17	17 RC	1.000001E 07
18	18 CC	1.000001E-14
19	19 RES	1.000010E 00
20	20 CEOC	3.000010E-14
21	21 CBOC	3.000010E-14
22	22 LE	3.000010E-12
23	23 LB	3.000010E-12
24	24 CBE	2.000010E-14
25	25 CCE	2.000010E-14
26	26 CCB	2.000001E-14
27	27 R1X2	1.000010E 07
28	28 C1X2	5.000010E-13
29	29 R2X2	1.000010E 07
30	30 R3X2	2.000010E 07
31	31 R4X2	1.000010E-02

21.23.44 EXEC ZITABLE
EXECUTION:

INPUT IMPEDANCE OF FOURPOLE NO.: 2 AS A FUNCTION OF FREQUENCY

LOG(FREQ)	FREQUENCY	RI	XI
9.300005	1.995274E 09	-4.5800E 02	-3.8177E 02
9.400004	2.511893E 09	-3.1582E 02	-2.3939E 02
9.500006	3.162275E 09	-2.1081E 02	-1.5273E 02
9.600005	3.981055E 09	-1.3709E 02	-1.0048E 02
9.700006	5.011911E 09	-8.7201E 01	-6.8651E 01
9.800007	6.309597E 09	-5.4263E 01	-4.8728E 01
9.900006	7.943291E 09	-3.2881E 01	-3.5777E 01
10.000008	1.000013E 10	-1.9167E 01	-2.6997E 01
10.100007	1.258937E 10	-1.0462E 01	-2.0810E 01
10.200007	1.584903E 10	-5.0035E 00	-1.6296E 01
10.300009	1.995267E 10	-1.6467E 00	-1.2902E 01
10.400008	2.511923E 10	3.4494E-01	-1.0265E 01
10.500010	3.162313E 10	1.4494E 00	-8.1322E 00
10.600010	3.981102E 10	1.9903E 00	-6.3127E 00
10.700009	5.011894E 10	2.1980E 00	-4.6648E 00
10.800011	6.309675E 10	2.2412E 00	-3.0882E 00

21.25.02 EXEC ZIPLOT
EXECUTION:

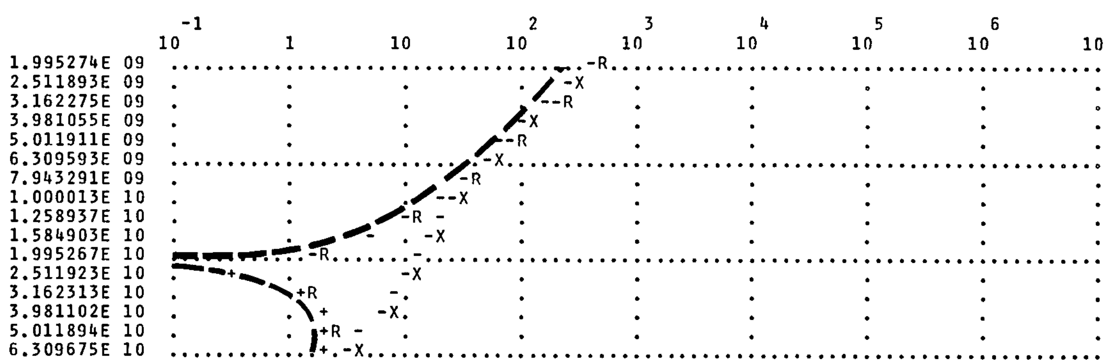

FIG. 4027-20 INPUT IMPEDANCE OF FOURPOLE NO.: 2 AS A FUNCTION OF FREQUENCY

CASE NO. 4227-1240:
FT = 15 GHZ, C1X2 = 0.5 PF.

CIRCUIT DIAGRAM IS SHOWN IN FIGS. 4027-17 AND 4012-1003. COMPONENT VALUES ARE GIVEN AT TOP OF FIGURE.

CASE NO. 4027-1242:
FT = 20 GHZ, C1X2 = 0.5 PF.

21.31.13 PRINTF MISC DATA 1 34

NUMBER OF ITEMS= 64

1	1 ICIRCT	1.000001E 00
2	2 IFP1	2.000000E 00
3	3 IFP2	3.000000E 00
4	4 IFP3	1.000010E 01
5	NO POINT	1.600000E 01
6	6 RLOGF	9.200005E 00
7	7 DLLOGF	1.000010E-01
8	8 RG	5.000009E 01
9	9 RL	5.000009E 01
10	TEMP(C)	2.500000E 01
11	11 IC	5.000006E-03
12	12 BETAO	1.000010E 02
13	M FACTOR	-1.000001E-01
14	14 FT2	2.000005E 10
15	15 CTE	1.000001E-14
16	16 RB	1.000010E 00
17	17 RC	1.000001E 07
18	18 CC	1.000001E-14
19	19 RES	1.000010E 00
20	20 CEOC	3.000010E-14
21	21 CBOC	3.000010E-14
22	22 LE	3.000010E-12
23	23 LB	3.000010E-12
24	24 CBE	2.000010E-14
25	25 CCE	2.000010E-14
26	26 CCB	2.000001E-14
27	27 R1X2	1.000010E 07
28	28 C1X2	5.000010E-13
29	29 R2X2	1.000010E 07
30	30 R3X2	2.000010E 07
31	31 R4X2	1.000010E-02

21.32.49 EXEC ZITABLE
EXECUTION:

INPUT IMPEDANCE OF FOURPOLE NO.: 2 AS A FUNCTION OF FREQUENCY

LOG(FREQ)	FREQUENCY	RI	XI
9.300005	1.995274E 09	-5.0512E 02	-4.8566E 02
9.400004	2.511893E 09	-3.6261E 02	-3.0497E 02
9.500006	3.162275E 09	-2.4976E 02	-1.9147E 02
9.600005	3.981055E 09	-1.6635E 02	-1.2230E 02
9.700006	5.011911E 09	-1.0777E 02	-8.0571E 01
9.800007	6.309597E 09	-6.8124E 01	-5.5142E 01
9.900006	7.943291E 09	-4.1950E 01	-3.9221E 01
10.000008	1.000013E 10	-2.4972E 01	-2.8871E 01
10.100007	1.258937E 10	-1.4108E 01	-2.1860E 01
10.200007	1.584903E 10	-7.2445E 00	-1.6919E 01
10.300009	1.995267E 10	-2.9861E 00	-1.3304E 01
10.400008	2.511923E 10	-4.2299E-01	-1.0558E 01
10.500010	3.162313E 10	1.0368E 00	-8.3762E 00
10.600010	3.981102E 10	1.7895E 00	-6.5386E 00
10.700009	5.011894E 10	2.1142E 00	-4.8860E 00
10.800011	6.309675E 10	2.2132E 00	-3.3059E 00

21.34.10 EXEC ZIPLOT
EXECUTION:

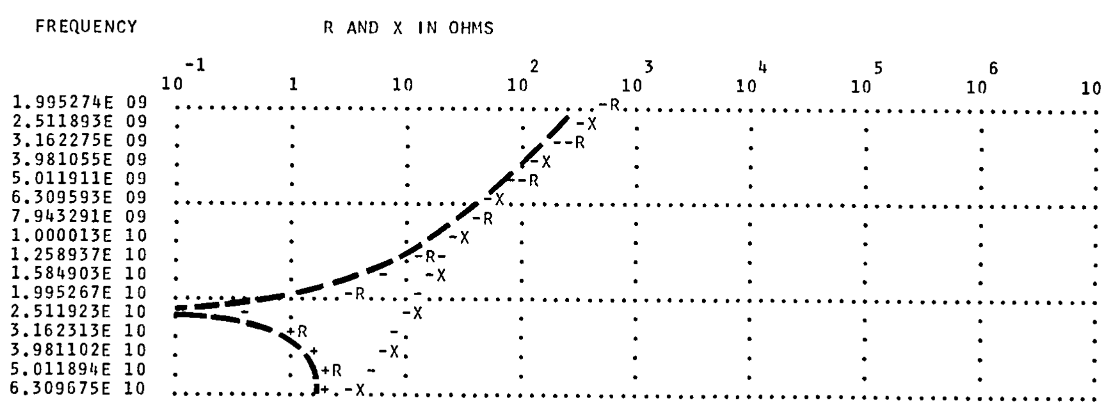

FIG. 4027-21 INPUT IMPEDANCE OF FOURPOLE NO.: 2 AS A FUNCTION OF FREQUENCY

CASE NO. 4027-1242:
FT = 20 GHZ, C1X2 = 0.5 PF.

CIRCUIT DIAGRAM IS SHOWN IN FIGS. 4027-17 AND 4012-1003. COMPONENT VALUES ARE GIVEN AT TOP OF FIGURE.

CASE NO. 4027-1244:
FT = 30 GHZ, C1X2 = 0.5 PF.

21.49.09 PRINTF MISC DATA 1 34

NUMBER OF ITEMS= 64

1	1 ICIRCT	1.000001E 00
2	2 IFP1	2.000000E 00
3	3 IFP2	3.000000E 00
4	4 IFP3	1.000010E 01
5	NO POINT	1.600000E 01
6	6 RLOGF	9.200005E 00
7	7 DLLOGF))=)E-01	
8	8 RG	5.000009E 01
9	9 RL	5.000009E 01
10	TEMP(C)	2.500000E 01
11	11 IC	5.000006E-03
12	12 BETAO	1.000010E 02
13	M FACTOR	-1.000001E-01
14	14 FT2	3.000005E 10
15	15 CTE	1.000001E-14
16	16 RB	1.000010E 00
17	17 RC	1.000001E 07
18	18 CC	1.000001E-14
19	19 RES	1.000010E 00
20	20 CEOC	3.000010E-14
21	21 CBOC	3.000010E-14
22	22 LE	3.000010E-12
23	23 LB	3.000010E-12
24	24 CBE	2.000010E-14
25	25 CCE	2.000010E-14
26	26 CCB	2.000001E-14
27	27 R1X2	1.000010E 07
28	28 C1X2	5.000010E-13
29	29 R2X2	1.000010E 07
30	30 R3X2	2.000010E 07
31	31 R4X2	1.000010E-02

21.50.44 EXEC ZITABLE
EXECUTION:

INPUT IMPEDANCE OF FOURPOLE NO.: 2 AS A FUNCTION OF FREQUENCY

LOG(FREQ)	FREQUENCY	RI	XI
9.300005	1.995274E 09	-5.3173E 02	-6.4454E 02
9.400004	2.511893E 09	-4.0698E 02	-4.1621E 02
9.500006	3.162275E 09	-2.9598E 02	-2.6299E 02
9.600005	3.981055E 09	-2.0585E 02	-1.6529E 02
9.700006	5.011911E 09	-1.3789E 02	-1.0523E 02
9.800007	6.309597E 09	-8.9491E 01	-6.8891E 01
9.900006	7.943291E 09	-5.6406E 01	-4.6810E 01
10.000008	1.000013E 10	-3.4430E 01	-3.3090E 01
10.100007	1.258937E 10	-2.0132E 01	-2.4263E 01
10.200007	1.584903E 10	-1.0985E 01	-1.8349E 01
10.300009	1.995267E 10	-5.2353E 00	-1.4216E 01
10.400008	2.511923E 10	-1.7137E 00	-1.1199E 01
10.500010	3.162313E 10	3.5005E-01	-8.8822E 00
10.600010	3.981102E 10	1.4692E 00	-6.9850E 00
10.700009	5.011894E 10	1.9985E 00	-5.3103E 00
10.800011	6.309675E 10	2.1954E 00	-3.7204E 00

21.52.02 EXEC ZIPLOT
EXECUTION:

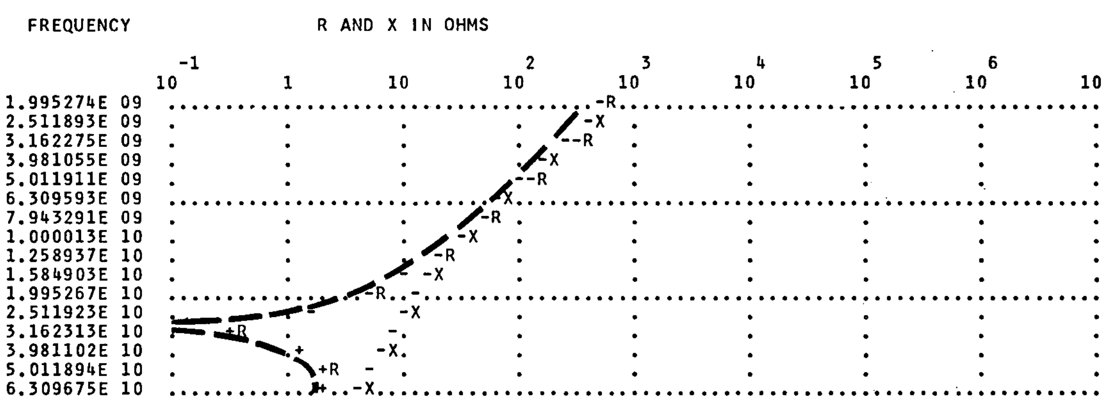

FIG. 4027-22 INPUT IMPEDANCE OF FOURPOLE NO.: 2 AS A FUNCTION OF FREQUENCY

CASE NO. 4027-1244:
FT = 30 GHZ, C1X2 = 0.5 PF.

CIRCUIT DIAGRAM IS SHOWN IN FIGS. 4027-17 AND 4012-1003. COMPONENT VALUES ARE GIVEN AT TOP OF FIGURE.

CASE NO. 4027-1248:
FT = 30 GHZ, C1X2 = 0.25 PF.

09.23.20 PRINTF MISC DATA 1 34

NUMBER OF ITEMS= 64

1	1	ICIRCT	1.000001E 00
2	2	IFP1	2.000000E 00
3	3	IFP2	3.000000E 00
4	4	IFP3	1.000010E 01
5	NO	POINT	1.600000E 01
6	6	RLOGF	9.200005E 00
7	7	DLLOGF	1.000010E-01
8	8	RG	5.000009E 01
9	9	RL	5.000009E 01
10	TEMP(C)		2.500000E 01
11	11	IC	5.000006E-03
12	12	BETA0	1.000010E 02
13	M	FACTOR	-1.000001E-01
14	14	FT2	3.000005E 10
15	15	CTE	1.000001E-14
16	16	RB	1.000010E 00
17	17	RC	1.000001E 07
18	18	CC	1.000001E-14
19	19	RES	1.000010E 00
20	20	CEOC	3.000010E-14
21	21	CBOC	3.000010E-14
22	22	LE	3.000010E-12
23	23	LB	3.000010E-12
24	24	CBE	2.000010E-14
25	25	CCE	2.000010E-14
26	26	CCB	2.000001E-14
27	27	R1X2	1.000010E 07
28	28	C1X2	2.500010E-13
29	29	R2X2	1.000010E 07
30	30	R3X2	2.000010E 07
31	31	R4X2	1.000010E-02

09.24.56 EXEC ZITABLE
EXECUTION:

INPUT IMPEDANCE OF FOURPOLE NO.: 2 AS A FUNCTION OF FREQUENCY

LOG(FREQ)	FREQUENCY	RI	XI
9.300005	1.995274E 09	-4.5391E 02	-9.7375E 02
9.400004	2.511893E 09	-3.9310E 02	-6.9179E 02
9.500006	3.162275E 09	-3.2384E 02	-4.7567E 02
9.600005	3.981055E 09	-2.5252E 02	-3.1749E 02
9.700006	5.011911E 09	-1.8628E 02	-2.0775E 02
9.800007	6.309597E 09	-1.3046E 02	-1.3536E 02
9.900006	7.943291E 09	-8.7122E 01	-8.9357E 01
10.000008	1.000013E 10	-5.5594E 01	-6.0638E 01
10.100007	1.258937E 10	-3.3756E 01	-4.2674E 01
10.200007	1.584903E 10	-1.9181E 01	-3.1216E 01
10.300009	1.995267E 10	-9.7519E 00	-2.3677E 01
10.400008	2.511923E 10	-3.8590E 00	-1.8516E 01
10.500010	3.162313E 10	-3.5536E-01	-1.4806E 01
10.600010	3.981102E 10	1.5554E 00	-1.1959E 01
10.700009	5.011894E 10	2.4371E 00	-9.5825E 00
10.800011	6.309675E 10	2.7072E 00	-7.4176E 00

09.26.14 EXEC ZIPLOT
EXECUTION:

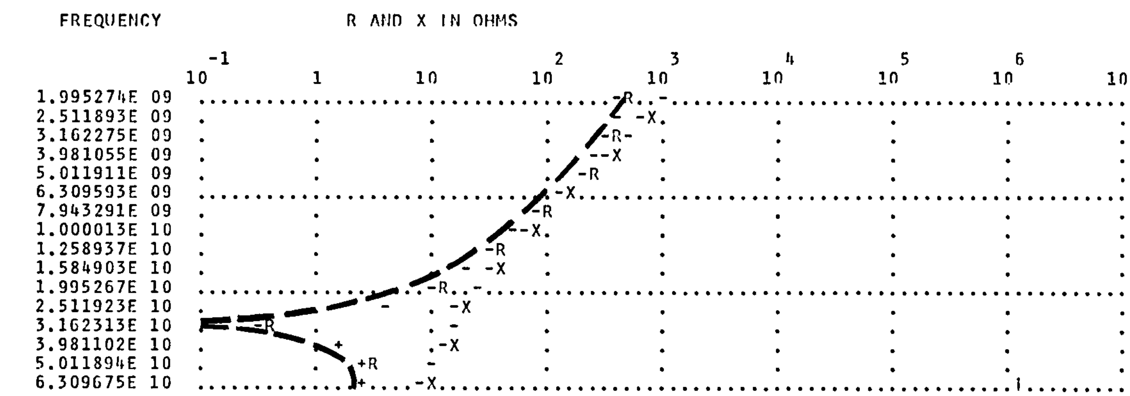

FIG. 4027-23 INPUT IMPEDANCE OF FOURPOLE NO.: 2 AS A FUNCTION OF FREQUENCY

CASE NO. 4027-1248:
FT = 30 GHZ, C1X2 = 0.25 PF.

CIRCUIT DIAGRAM IS SHOWN IN FIGS. 4027-17 AND 4012-1003. COMPONENT VALUES ARE GIVEN AT TOP OF FIGURE.

CASE NO. 4027-1246:
FT = 30 GHZ, C1X2 = 0.1 PF.

08.51.28 PRINTF MISC DATA 1 34

NUMBER OF ITEMS= 64

1	1 ICIRCT	1.000001E 00
2	2 IFP1	2.000000E 00
3	3 IFP2	3.000000E 00
4	4 IFP3	1.000010E 01
5	NO POINT	1.600000E 01
6	6 RLOGF	9.200005E 00
7	7 DLLOGF	1.000010E-01
8	8 RG	5.000009E 01
9	9 RL	5.000009E 01
10	TEMP(C)	2.500000E 01
11	11 IC	5.000006E-03
12	12 BETA0	1.000010E 02
13	M FACTOR	-1.000001E-01
14	14 FT2	3.000005E 10
15	15 CTE	1.000001E-14
16	16 RB	1.000010E 00
17	17 RC	1.000001E 07
18	18 CC	1.000001E-14
19	19 RES	1.000010E 00
20	20 CEOC	3.000010E-14
21	21 CBOC	3.000010E-14
22	22 LE	3.000010E-12
23	23 LB	3.000010E-12
24	24 CBE	2.000010E-14
25	25 CCE	2.000010E-14
26	26 CCB	2.000001E-14
27	27 R1X2	1.000010E 07
28	28 C1X2	1.000010E-13
29	29 R2X2	1.000010E 07
30	30 R3X2	2.000010E 07
31	31 R4X2	1.000010E-02

08.53.04 EXEC ZITABLE
EXECUTION:

INPUT IMPEDANCE OF FOURPOLE NO.: 2 AS A FUNCTION OF FREQUENCY

LOG(FREQ)	FREQUENCY	RI	XI
9.300005	1.995274E 09	-2.5358E 02	-1.1922E 03
9.400004	2.511893E 09	-2.4018E 02	-9.1312E 02
9.500006	3.162275E 09	-2.2143E 02	-6.8779E 02
9.600005	3.981055E 09	-1.9675E 02	-5.0718E 02
9.700006	5.011911E 09	-1.6666E 02	-3.6503E 02
9.800007	6.309597E 09	-1.3324E 02	-2.5671E 02
9.900006	7.943291E 09	-9.9762E 01	-1.7762E 02
10.000008	1.000013E 10	-6.9509E 01	-1.2246E 02
10.100007	1.258937E 10	-4.4655E 01	-8.5444E 01
10.200007	1.584903E 10	-2.5825E 01	-6.1181E 01
10.300009	1.995267E 10	-1.2501E 01	-4.5372E 01
10.400008	2.511923E 10	-3.6356E 00	-3.4966E 01
10.500010	3.162313E 10	1.8495E 00	-2.7951E 01
10.600010	3.981102E 10	4.8682E 00	-2.3019E 01
10.700009	5.011894E 10	6.1379E 00	-1.9292E 01
10.800011	6.309675E 10	6.2348E 00	-1.6158E 01

08.54.22 EXEC ZIPLOT
EXECUTION:

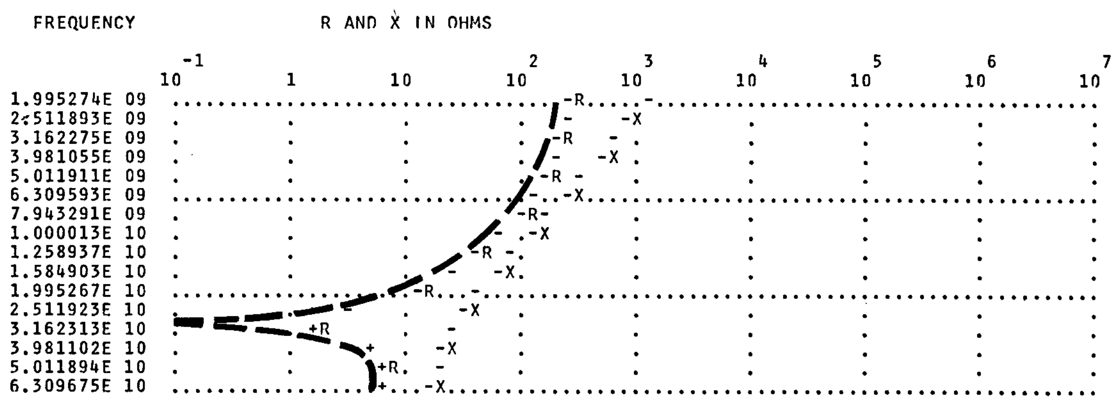

FIG. 4027-24 INPUT IMPEDANCE OF FOURPOLE NO.: 2 AS A FUNCTION OF FREQUENCY

CASE NO. 4027-1246:
FT = 30 GHZ, C1X2 = 0.1 PF.

CIRCUIT DIAGRAM IS SHOWN IN FIGS. 4027-17 AND 4012-1003. COMPONENT VALUES ARE GIVEN AT TOP OF FIGURE.

To obtain information on the desirable transistor geometry we have also calculated the dependence of the negative resistance frequency range on a number of key parasitics (Figs. 4027-25 through -28):

(a) Collector Junction Capacitance, CC:

As seen in Fig. 4027-25, increasing the collector junction capacitance from 0.01 pF to 0.1 pF lowers the maximum frequency of negative resistance from 31.6 to below 20 GHz.

(b) Base Spreading Resistance, RB:

As seen in Fig. 4027-26, increasing the base spreading resistance from 1 to 2 ohms lowers the maximum frequency of negative resistance from 31.6 to approximately 29 GHz.

(c) Emitter Bias Resistor, R1X2:

As seen in Fig. 4027-27, an emitter bias resistor of 1 kilohm has no noticeable effect on the negative-resistance frequency range.

(d) Collector-Base and Collector-Emitter Stray Capacitances, CEOC, CBOC:

As seen in Fig. 4027-28, increasing these parasitic capacitances, which are due largely to chip metallization, from 0.03 pF to 0.3 pF drastically lowers the negative-resistance range from 31.6 to 5 GHz.

From this analysis we draw the conclusion that in order to extend the frequency range of negative-resistance operation to 30 GHz it will be necessary to

(a) raise the fT to 30 GHz, which is not an overwhelmingly difficult problem;

(b) keep all device and stray capacitances in the order of 0.01 pF (see below);

(c) keep the base spreading resistance in the order of a few ohms;

(d) keep all inductances in the order of a few picohenries.

Figs. 4027-25 through -28 follow this page.

CASE NO. 4027-1250:
FT = 30 GHZ, C1X2 = 0.25 PF.
CC = 0.1 PF.

14.02.28 PRINTF MISC DATA 1 34

NUMBER OF ITEMS= 64

1	1 ICIRCT	1.000001E 00
2	2 IFP1	2.000000E 00
3	3 IFP2	3.000000E 00
4	4 IFP3	1.000010E 01
5	NO POINT	1.600000E 01
6	6 RLOGF	9.200005E 00
7	7 DLLOGF	1.000010E-01
8	8 RG	5.000009E 01
9	9 RL	5.000009E 01
10	TEMP(C)	2.500000E 01
11	11 IC	5.000006E-03
12	12 BETA0	1.000010E 02
13	M FACTOR	-1.000001E-01
14	14 FT2	3.000005E 10
15	15 CTE	1.000001E-14
16	16 RB	1.000010E 00
17	17 RC	1.000001E 07
18	18 CC	1.000001E-13
19	19 RES	1.000010E 00
20	20 CEOC	3.000010E-14
21	21 CBOC	3.000010E-14
22	22 LE	3.000010E-12
23	23 LB	3.000010E-12
24	24 CBE	2.000010E-14
25	25 CCE	2.000010E-14
26	26 CCB	2.000001E-14
27	27 R1X2	1.000010E 07
28	28 C1X2	2.500010E-13
29	29 R2X2	1.000010E 07
30	30 R3X2	2.000010E 07
31	31 R4X2	1.000010E-02

14.04.08 EXEC ZITABLE
EXECUTION:

INPUT IMPEDANCE OF FOURPOLE NO.: 2 AS A FUNCTION OF FREQUENCY

LOG(FREQ)	FREQUENCY	RI	XI
9.300005	1.995274E 09	-9.8386E 01	-4.7877E 02
9.400004	2.511893E 09	-9.1432E 01	-3.6525E 02
9.500006	3.162275E 09	-8.2058E 01	-2.7406E 02
9.600005	3.981055E 09	-7.0303E 01	-2.0173E 02
9.700006	5.011911E 09	-5.6790E 01	-1.4574E 02
9.800007	6.309597E 09	-4.2753E 01	-1.0390E 02
9.900006	7.943291E 09	-2.9624E 01	-7.3874E 01
10.000008	1.000013E 10	-1.8522E 01	-5.3074E 01
10.100007	1.258937E 10	-9.9428E 00	-3.8987E 01
10.200007	1.584903E 10	-3.8294E 00	-2.9499E 01
10.300009	1.995267E 10	1.8926E-01	-2.3030E 01
10.400008	2.511923E 10	2.5714E 00	-1.8482E 01
10.500010	3.162313E 10	3.7464E 00	-1.5106E 01
10.600010	3.981102E 10	4.0899E 00	-1.2393E 01
10.700009	5.011894E 10	3.9293E 00	-1.0008E 01
10.800011	6.309675E 10	3.5353E 00	-7.7512E 00

x

EXECUTION:

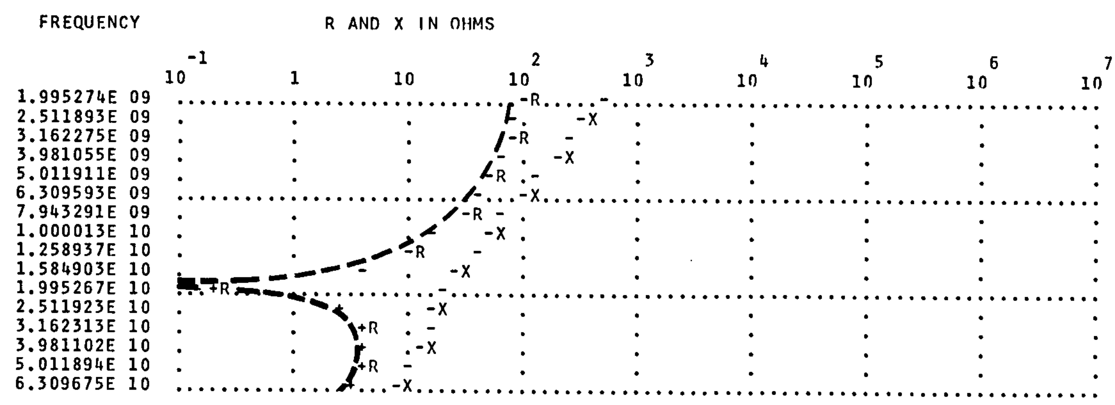

FIG. 4027-25 INPUT IMPEDANCE OF FOURPOLE NO.: 2 AS A FUNCTION OF FREQUENCY

CASE NO. 4027-1250:
FT = 30 GHZ, C1X2 = 0.25 PF.
CC = 0.1 PF.

14.13.49

CIRCUIT DIAGRAM IS SHOWN IN FIGS. 4027-17 AND 4012-1003. COMPONENT VALUES ARE GIVEN AT TOP OF FIGURE.

CASE NO. 4027-1251:
FT = 30 GHZ, C1X2 = 0.25 PF.
RB = 2 OHMS.

14.15.56 PRINTF MISC DATA 1 34

NUMBER OF ITEMS= 64

1	1 ICIRCT	1.000001E 00
2	2 IFP1	2.000000E 00
3	3 IFP2	3.000000E 00
4	4 IFP3	1.000010E 01
5	NO POINT	1.600000E 01
6	6 RLOGF	9.200005E 00
7	7 DLLOGF	1.000010E-01
8	8 RG	5.000009E 01
9	9 RL	5.000009E 01
10	TEMP(C)	2.500000E 01
11	11 IC	5.000006E-03
12	12 BETA0	1.000010E 02
13	M FACTOR	-1.000001E-01
14	14 FT2	3.000005E 10
15	15 CTE	1.000001E-14
16	16 RB	2.000010E 00
17	17 RC	1.000001E 07
18	18 CC	1.000001E-14
19	19 RES	1.000010E 00
20	20 CEOC	3.000010E-14
21	21 CBOC	3.000010E-14
22	22 LE	3.000010E-12
23	23 LB	3.000010E-12
24	24 CBE	2.000010E-14
25	25 CCE	2.000010E-14
26	26 CCB	2.000001E-14
27	27 R1X2	1.000010E 07
28	28 C1X2	2.500010E-13
29	29 R2X2	1.000010E 07
30	30 R3X2	2.000010E 07
31	31 R4X2	1.000010E-02

14.17.35 EXEC ZITABLE
EXECUTION:

INPUT IMPEDANCE OF FOURPOLE NO.: 2 AS A FUNCTION OF FREQUENCY

LOG(FREQ)	FREQUENCY	RI	XI
9.300005	1.995274E 09	-4.5396E 02	-9.7356E 02
9.400004	2.511893E 09	-3.9313E 02	-6.9155E 02
9.500006	3.162275E 09	-3.2381E 02	-4.7535E 02
9.600005	3.981055E 09	-2.5240E 02	-3.1711E 02
9.700006	5.011911E 09	-1.8608E 02	-2.0734E 02
9.800007	6.309597E 09	-1.3015E 02	-1.3495E 02
9.900006	7.943291E 09	-8.6724E 01	-8.8961E 01
10.000008	1.000013E 10	-5.5121E 01	-6.0274E 01
10.100007	1.258937E 10	-3.3224E 01	-4.2344E 01
10.200007	1.584903E 10	-1.8602E 01	-3.0918E 01
10.300009	1.995267E 10	-9.1322E 00	-2.3405E 01
10.400008	2.511923E 10	-3.2000E 00	-1.8266E 01
10.500010	3.162313E 10	3.4605E-01	-1.4574E 01
10.600010	3.981102E 10	2.3052E 00	-1.1747E 01
10.700009	5.011894E 10	3.2430E 00	-9.3973E 00
10.800011	6.309675E 10	3.5765E 00	-7.2699E 00

14.18.50 EXEC ZIPLOT
EXECUTION:

FREQUENCY R AND X IN OHMS

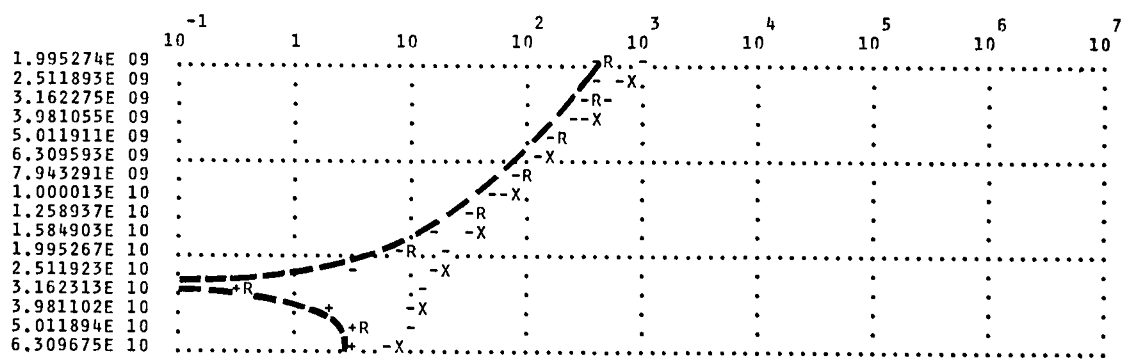

FIG. 4027-26 INPUT IMPEDANCE OF FOURPOLE NO.: 2 AS A FUNCTION OF FREQUENCY

CASE NO. 4027-1251:
FT = 30 GHZ, C1X2 = 0.25 PF.
RB = 2 OHMS.

CIRCUIT DIAGRAM IS SHOWN IN FIGS. 4027-17 AND 4012-1003. COMPONENT VALUES ARE GIVEN AT TOP OF FIGURE.

CASE NO. 4027-1252:
FT = 30 GHZ, C1X2 = 0.25 PF.
R1X2 = 1 K.

14.25.16 PRINTF MISC DATA 1 34

NUMBER OF ITEMS= 64

1	1	ICIRCT	1.000001E 00
2	2	IFP1	2.000000E 00
3	3	IFP2	3.000000E 00
4	4	IFP3	1.000010E 01
5	NO	POINT	1.600000E 01
6	6	RLOGF	9.200005E 00
7	7	DLLOGF	1.000010E-01
8	8	RG	5.000009E 01
9	9	RL	5.000009E 01
10	TEMP(C)		2.500000E 01
11	11	IC	5.000006E-03
12	12	BETAO	1.000010E 02
13	M	FACTOR	-1.000001E-01
14	14	FT2	3.000005E 10
15	15	CTE	1.000001E-14
16	16	RB	1.000010E 00
17	17	RC	1.000001E 07
18	18	CC	1.000001E-14
19	19	RES	1.000010E 00
20	20	CEOC	3.000010E-14
21	21	CBOC	3.000010E-14
22	22	LE	3.000010E-12
23	23	LB	3.000010E-12
24	24	CBE	2.000010E-14
25	25	CCE	2.000010E-14
26	26	CCB	2.000001E-14
27	27	R1X2	1.000010E 03
28	28	C1X2	2.500010E-13
29	29	R2X2	1.000010E 07
30	30	R3X2	2.000010E 07
31	31	R4X2	1.000010E-02

14.26.53 EXEC ZITABLE
EXECUTION:

INPUT IMPEDANCE OF FOURPOLE NO.: 2 AS A FUNCTION OF FREQUENCY

LOG(FREQ)	FREQUENCY	RI	XI
9.300005	1.995274E 09	-3.4906E 02	-9.0610E 02
9.400004	2.511893E 09	-3.1304E 02	-6.5760E 02
9.500006	3.162275E 09	-2.6718E 02	-4.6298E 02
9.600005	3.981055E 09	-2.1573E 02	-3.1619E 02
9.700006	5.011911E 09	-1.6432E 02	-2.1079E 02
9.800007	6.309597E 09	-1.1821E 02	-1.3893E 02
9.900006	7.943291E 09	-8.0589E 01	-9.2064E 01
10.000008	1.000013E 10	-5.2162E 01	-6.2322E 01
10.100007	1.258937E 10	-3.1933E 01	-4.3593E 01
10.200007	1.584903E 10	-1.8180E 01	-3.1664E 01
10.300009	1.995267E 10	-9.1761E 00	-2.3865E 01
10.400008	2.511923E 10	-3.5104E 00	-1.8576E 01
10.500010	3.162313E 10	-1.3278E-01	-1.4809E 01
10.600010	3.981102E 10	1.7035E 00	-1.1942E 01
10.700009	5.011894E 10	2.5385E 00	-9.5624E 00
10.800011	6.309675E 10	2.7777E 00	-7.4018E 00

14.28.14 EXEC ZIPLOT
EXECUTION:

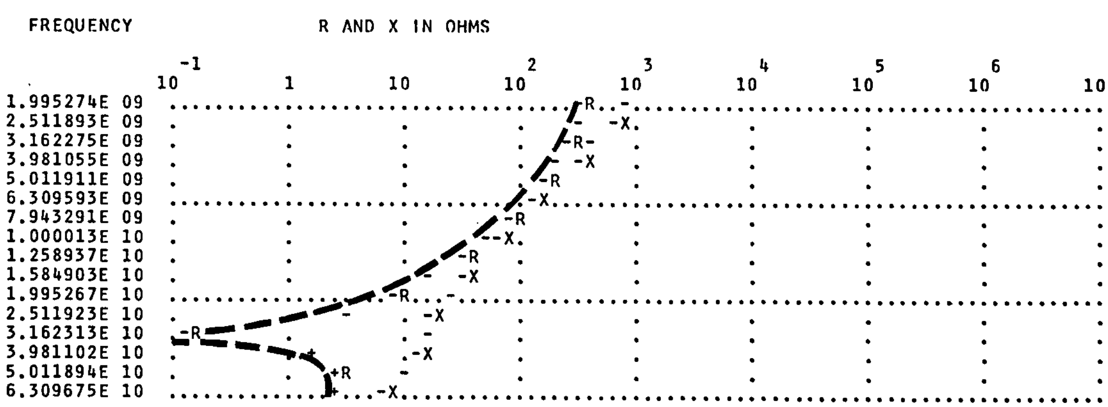

FIG. 4027-27 INPUT IMPEDANCE OF FOURPOLE NO.: 2 AS A FUNCTION OF FREQUENCY

CASE NO. 4027-1252:
FT = 30 GHZ, C1X2 = 0.25 PF.
R1X2 = 1 K.

CIRCUIT DIAGRAM IS SHOWN IN FIGS. 4027-17 AND 4012-1003. COMPONENT VALUES ARE GIVEN AT TOP OF FIGURE.

CASE NO. 4027-1249:
FT = 30 GHZ, C1X2 = 0.25 PF.
CEOC,CBOC = 0.3 PF.

13.53.18 PRINTF MISC DATA 1 34

NUMBER OF ITEMS= 64

1	1	ICIRCT	1.000001E 00
2	2	IFP1	2.000000E 00
3	3	IFP2	3.000000E 00
4	4	IFP3	1.000010E 01
5	NO	POINT	1.600000E 01
6	6	RLOGF	9.200005E 00
7	7	DLLOGF	1.000010E-01
8	8	RG	5.000009E 01
9	9	RL	5.000009E 01
10	TEMP(C)		2.500000E 01
11	11	IC	5.000006E-03
12	12	BETA0	1.000010E 02
13	M	FACTOR	-1.000001E-01
14	14	FT2	3.000005E 10
15	15	CTE	1.000001E-14
16	16	RB	1.000010E 00
17	17	RC	1.000001E 07
18	18	CC	1.000001E-14
19	19	RES	1.000010E 00
20	20	CEOC	3.000010E-13
21	21	CBOC	3.000010E-13
22	22	LE	3.000010E-12
23	23	LB	3.000010E-12
24	24	CBE	2.000010E-14
25	25	CCE	2.000010E-14
26	26	CCB	2.000001E-14
27	27	R1X2	1.000010E 07
28	28	C1X2	2.500010E-13
29	29	R2X2	1.000010E 07
30	30	R3X2	2.000010E 07
31	31	R4X2	1.000010E-02

13.54.59 EXEC ZITABLE
EXECUTION:

INPUT IMPEDANCE OF FOURPOLE NO.: 2 AS A FUNCTION OF FREQUENCY

LOG(FREQ)	FREQUENCY	RI	XI
9.300005	1.995274E 09	-1.6081E 01	-2.2594E 02
9.400004	2.511893E 09	-1.4093E 01	-1.7520E 02
9.500006	3.162275E 09	-1.1353E 01	-1.3457E 02
9.600005	3.981055E 09	-7.8114E 00	-1.0235E 02
9.700006	5.011911E 09	-3.6184E 00	-7.7293E 01
9.800007	6.309597E 09	8.3802E-01	-5.8434E 01
9.900006	7.943291E 09	4.9870E 00	-4.4839E 01
10.000008	1.000013E 10	8.2647E 00	-3.5468E 01
10.100007	1.258937E 10	1.0305E 01	-2.9203E 01
10.200007	1.584903E 10	1.1013E 01	-2.4966E 01
10.300009	1.995267E 10	1.0562E 01	-2.1844E 01
10.400008	2.511923E 10	9.3054E 00	-1.9171E 01
10.500010	3.162313E 10	7.6689E 00	-1.6568E 01
10.600010	3.981102E 10	6.0327E 00	-1.3912E 01
10.700009	5.011894E 10	4.6291E 00	-1.1235E 01
10.800011	6.309675E 10	3.5511E 00	-8.6133E 00

13.56.16 EXEC ZIPLOT
EXECUTION:

FREQUENCY R AND X IN OHMS

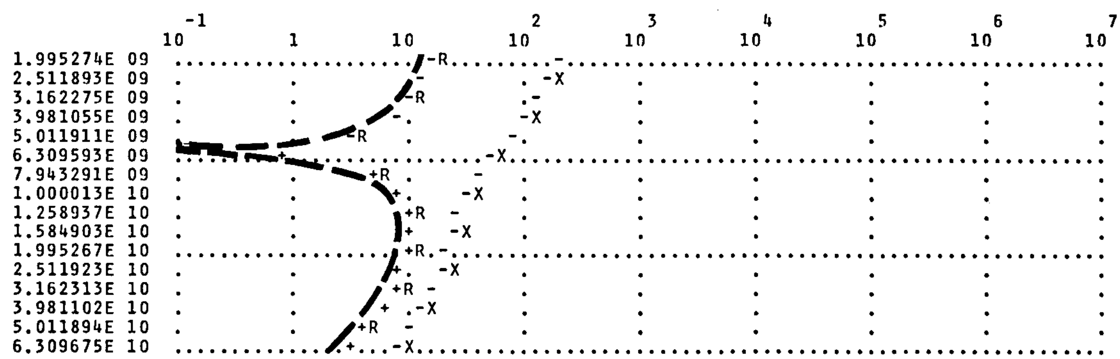

FIG. 4027-28 INPUT IMPEDANCE OF FOURPOLE NO.: 2 AS A FUNCTION OF FREQUENCY

CASE NO. 4027-1249:
FT = 30 GHZ, C1X2 = 0.25 PF.
CEOC,CBOC = 0.3 PF.

CIRCUIT DIAGRAM IS SHOWN IN FIGS. 4027-17 AND 4012-1003. COMPONENT VALUES ARE GIVEN AT TOP OF FIGURE.

These characteristics appear in fact to be within reach of the most advanced current technology. W. W. Gaertner has calculated in 1965*) that a transistor with a 3x3 micron collector area will have a junction capacitance of less than 0.005 pF, i.e. below the values needed here. As further illustrated in the same paper, such geometries will be achievable with either optical projection masking or electron beam masking techniques. In the meantime, W.W.Gaertner Research Inc. has built and delivered a mask projection system with a resolution of less than 1 micron which allows one to produce transistors with 1 micron emitter and base contact lines, i.e. small enough to achieve the capacitance values stipulated above. Additional technological tools which will be used are photoresist exposure by highest-resolution electron beams, and ion implantation to create impurity profiles not achievable by diffusion.

Again we believe that several million dollars of development money will be spent till transistors with the characteristics listed earlier will be produced with reasonable yield.

Considering, however, that the advantages of transistor circuits over other devices have been consistently proven in all application areas where the operating frequencies fall below the achievable fT of transistors, we must assume that transistor circuitry will ultimately dominate at frequencies up to at least 30 GHz and probably higher. Considering further that the negative resistance circuits discussed at length in this Report allow one to operate close to and even above fT, we must further assume that they will spearhead the penetration of the higher microwave frequency range by transistors.

*) Gaertner, W. W., "Nanowatt Devices", Proc. IEEE, vol. 53, pp. 592-604, June 1965