# MILLIMETER WAVE NOISE MEASUREMENT SYSTEMS USING SOLID STATE SOURCES

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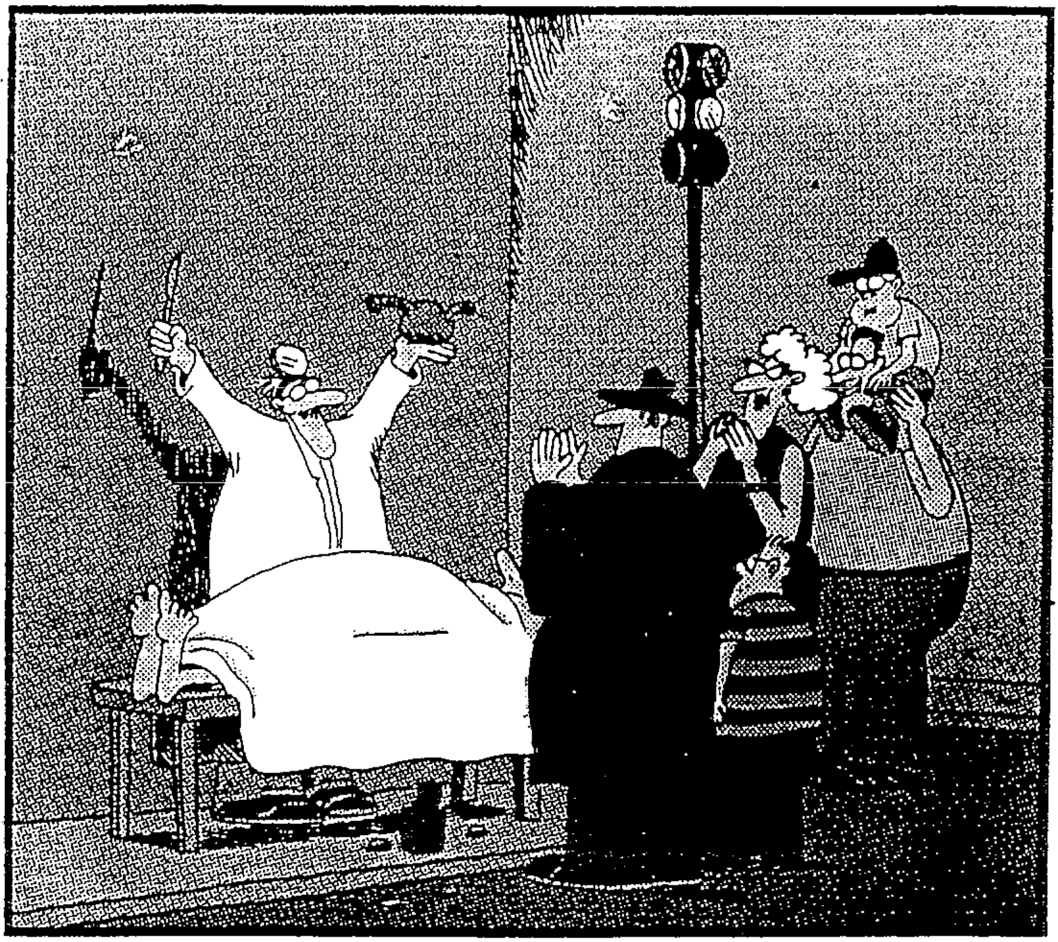
# CONTENTS

# CAUTION!

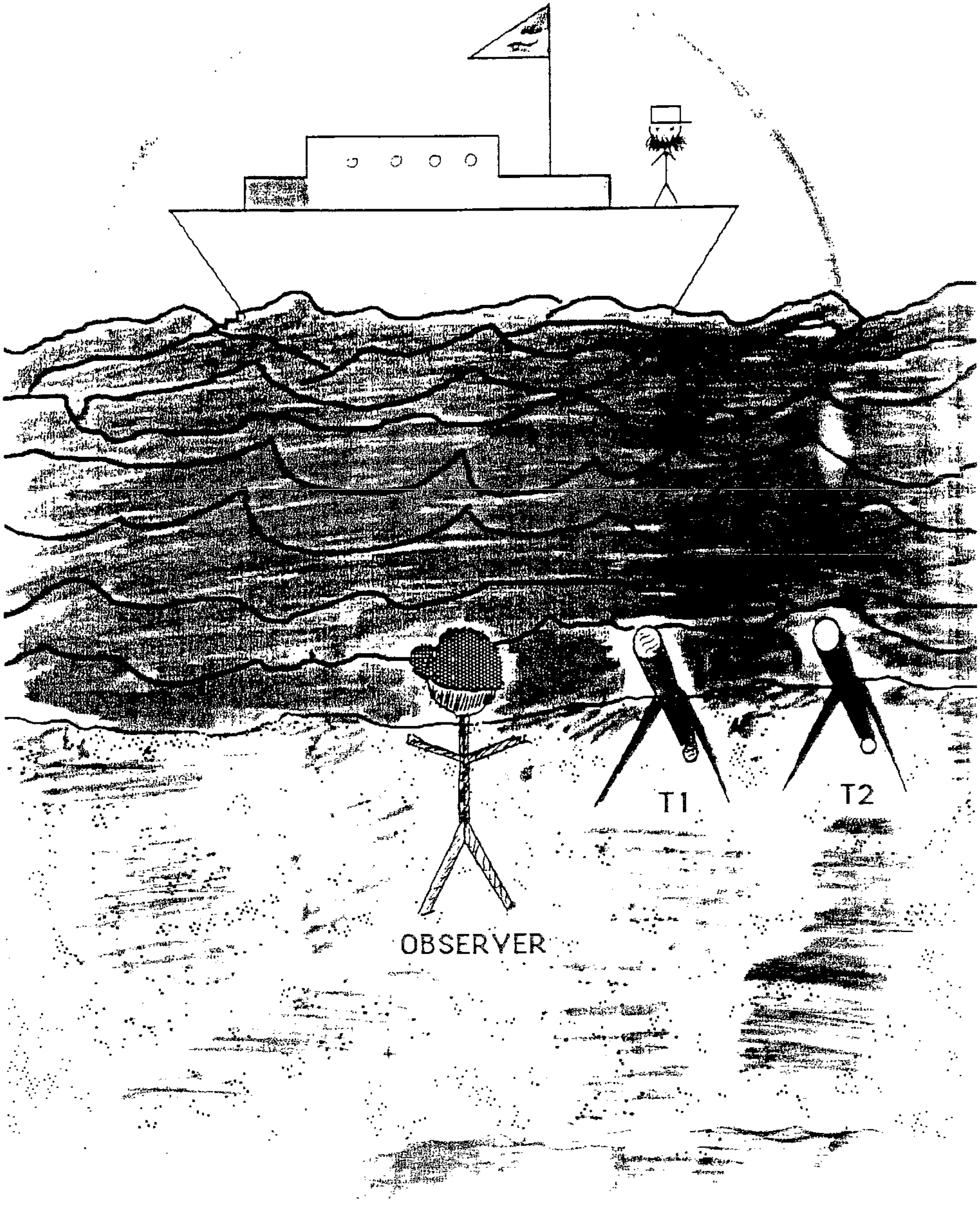


Street physicians

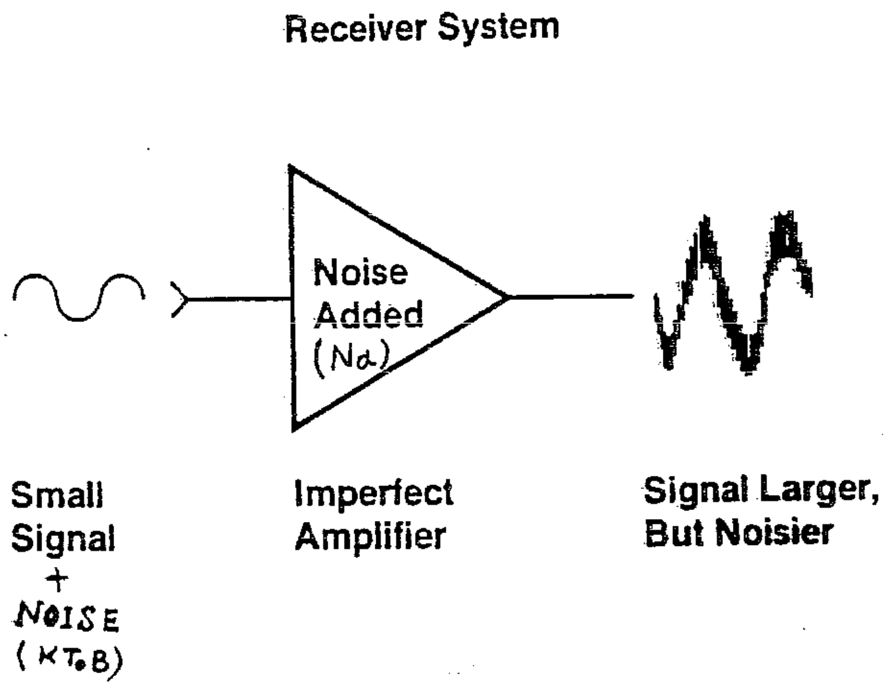
# I) WHY NOISE IS IMPORTANT?

TO UNDERSTAND THE SIGNIFICANCE OF NOISE, LET'S FIRST DEFINE IT.

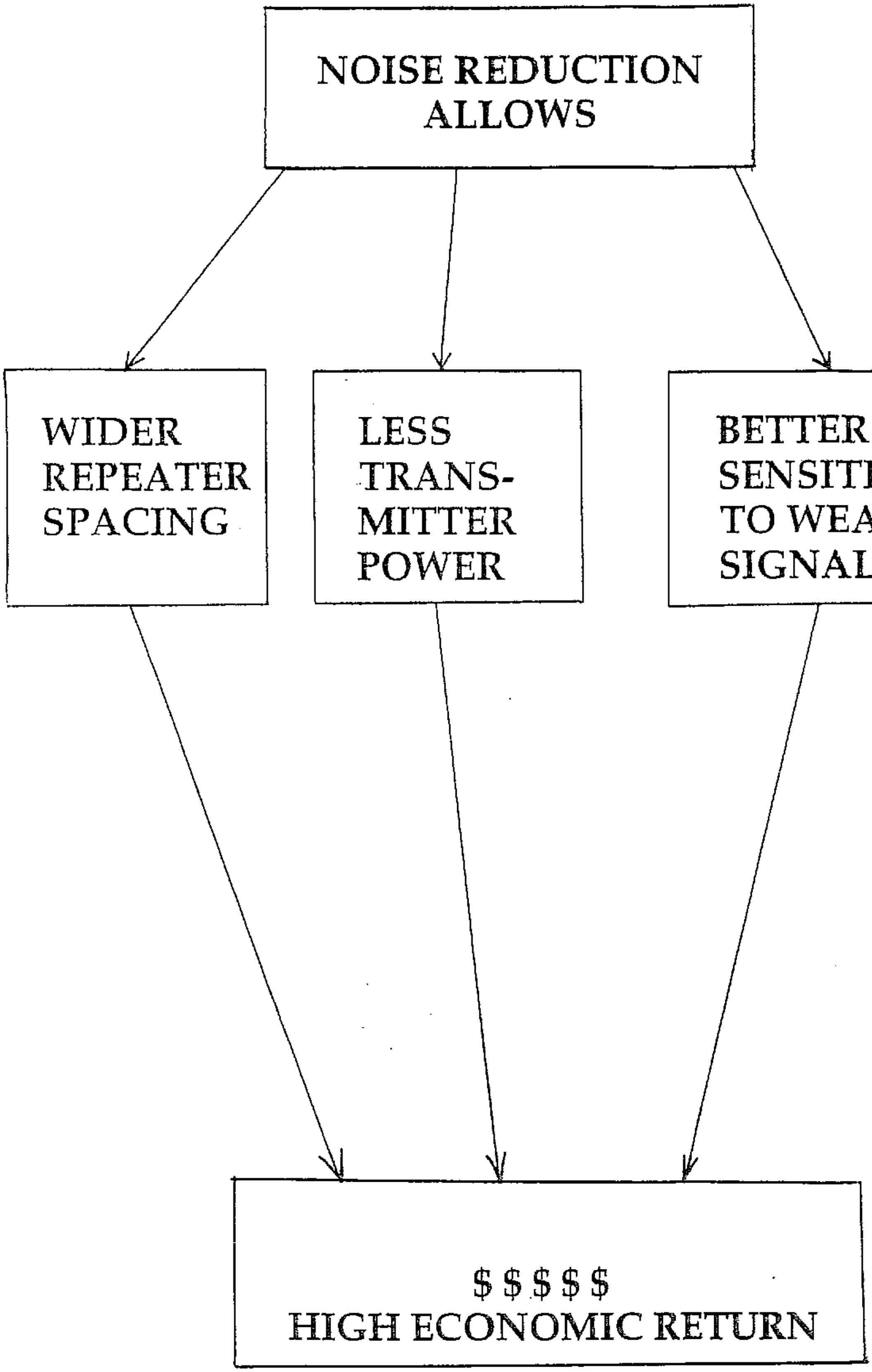
NOISE IS AN INTERNALLY GENERATED INTERFENCE WHICH CAUSES THE CIRCUIT OPERATION TO BE DEGRADED FROM THEORETICAL PREDICTIONS.

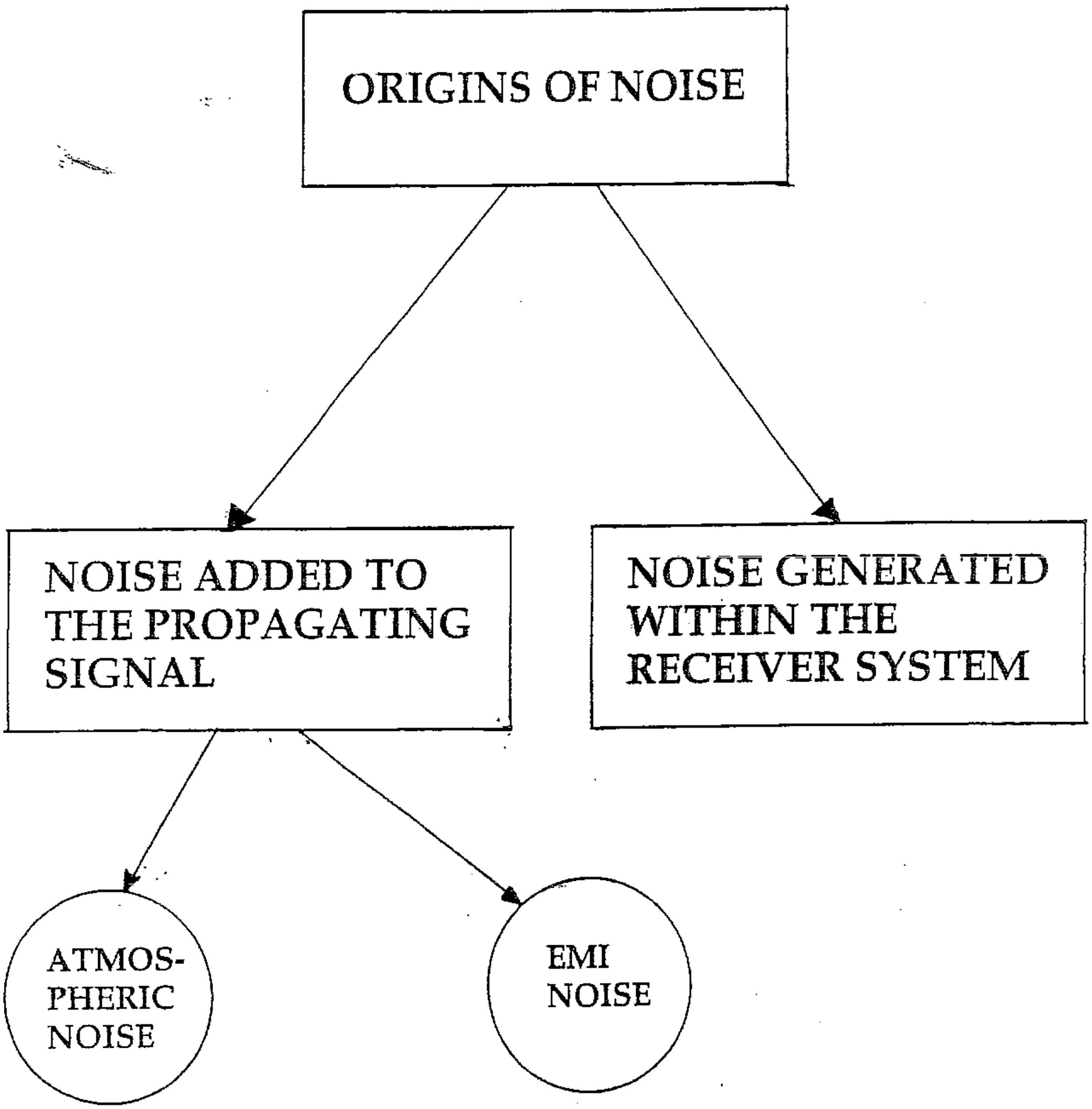

T1
T2
OBSERVER

# SIMILARLY; AT THE FRONT END OF A RECEIVER:

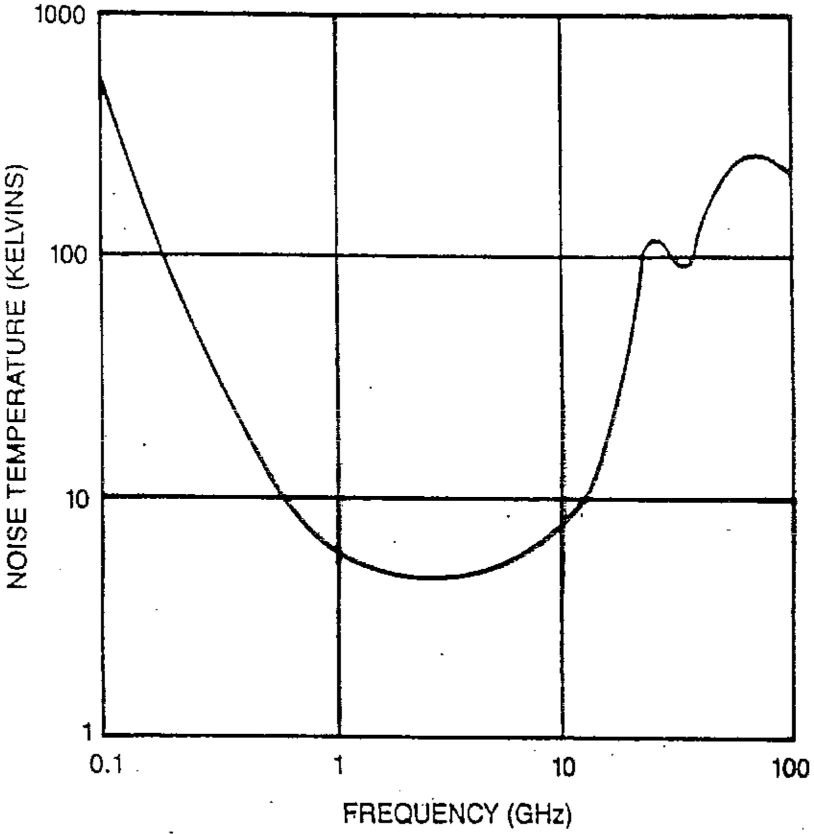


- NOISE ADDED AT THE FRONT END OF AN RF/MW SYSTEM GREATLY INFLUENCES THE COST OF THE OVERALL SYSTEM

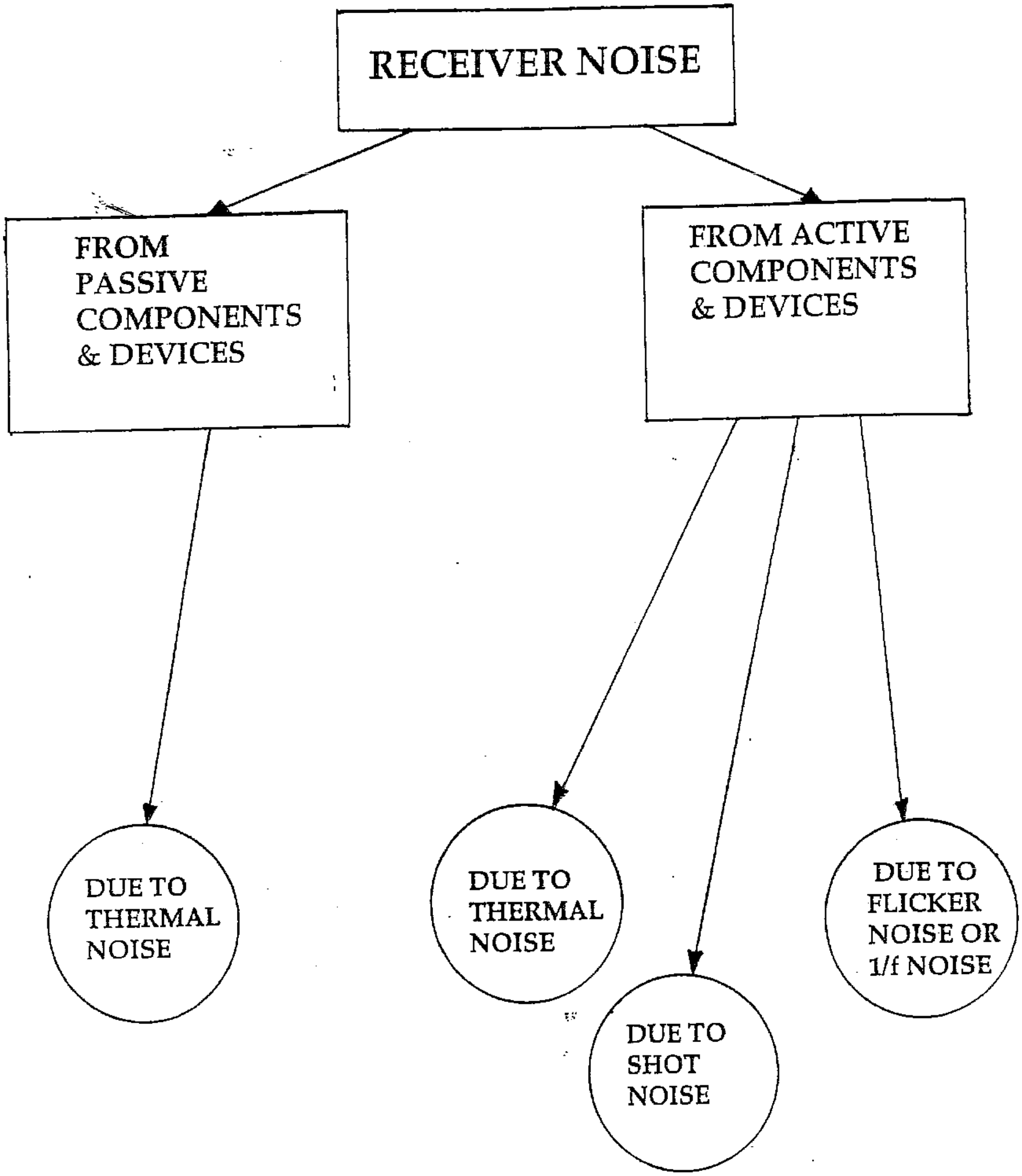

NOISE REDUCTION ALLOWS
WIDER REPEATER SPACING
LESS TRANS-MITTER POWER
BETTER SENSITIVITY TO WEAK SIGNALS
$ $ $ $ $
HIGH ECONOMIC RETURN


ORIGINS OF NOISE
NOISE ADDED TO THE PROPAGATING SIGNAL
NOISE GENERATED WITHIN THE RECEIVER SYSTEM
ATMOS-PHERIC NOISE
EMI NOISE

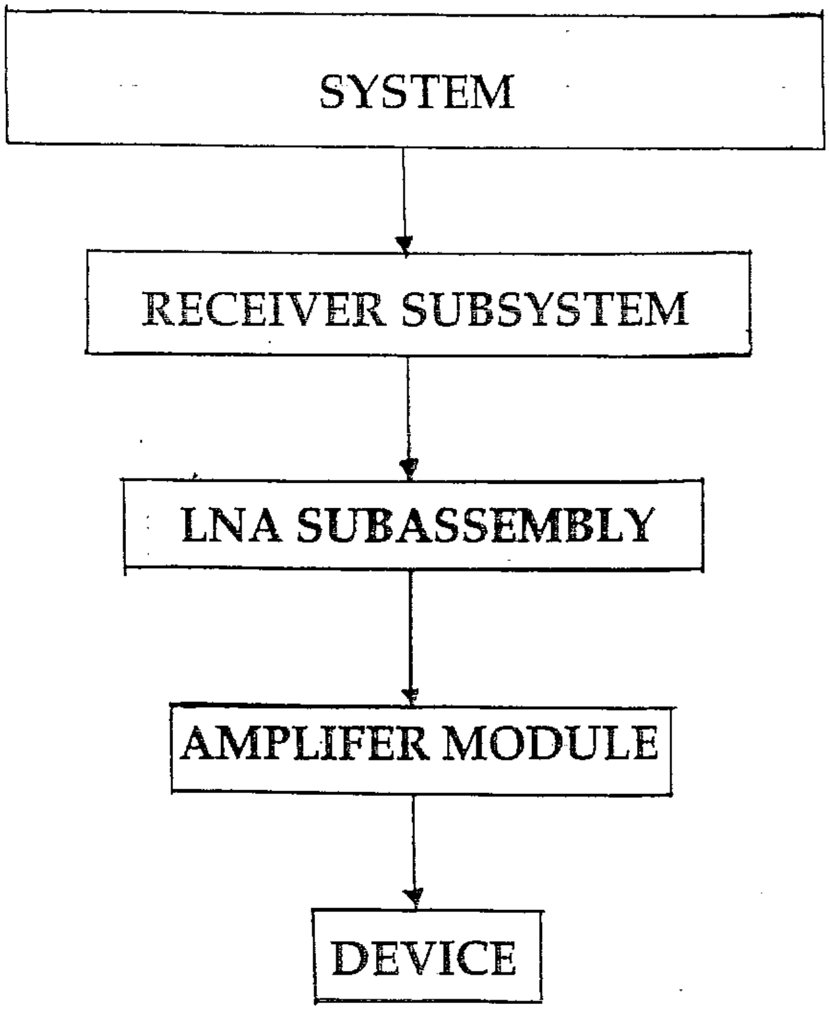
# ATMOSPHERIC NOISE



BATH-TUB GRAPH
PEAKING AROUND 61 & 94 GHz


RECEIVER NOISE
FROM PASSIVE COMPONENTS & DEVICES
FROM ACTIVE COMPONENTS & DEVICES
DUE TO THERMAL NOISE
DUE TO THERMAL NOISE
DUE TO SHOT NOISE
DUE TO FLICKER NOISE OR 1/f NOISE

- NF IS A COMMON LANGUAGE OF NOISE PERFORMANCE FOR ALL LEVELS:



SYSTEM

RECEIVER SUBSYSTEM

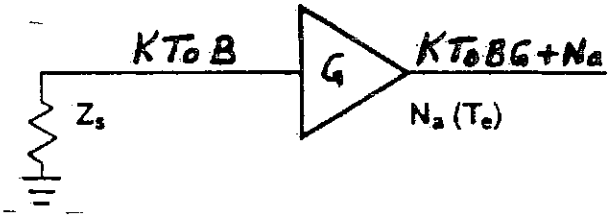
LNA SUBASSEMBLY

AMPLIFER MODULE

DEVICE

# II. NOISE MEASUREMENT

$$NF = \text{NOISE FIGURE} = \frac{(S/N)\,i}{(S/N)\,o} = 1 + Na/KToBG$$



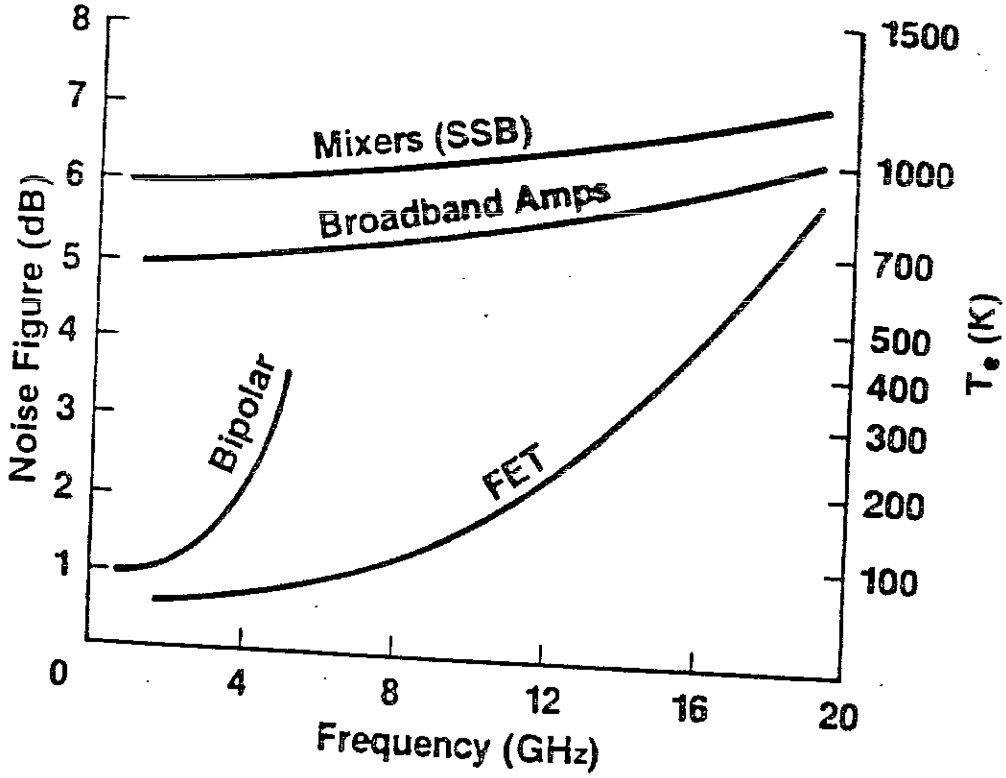
ALSO NF CAN BE WRITTEN AS:

$$NF = 1 + \frac{Te}{T_O} \qquad \begin{cases} Te = \text{Equiv. Noise Temp.} \\ T_O = 290° \ k \end{cases}$$

- NOISE FIGURE (NF) IS A FICTITIOUS FIGURE OF MERIT DESCRIBING THE NOISINESS OF A TRANSDUCER. IT DOES NOT TRULY EXIST IN THE SAME SENSE AS CURRENT AND VOLTAGE DO.

- NOISE FIGURE IS UNIQUE, PERMITTING NOISE PERFORMANCE SPEC. INDEP. OF OTHER PARAMETERS (SUCH AS GAIN, BW, ETC.)

# STATE-OF-THE-ART NOISE FIGURES



# EXAMPLE OF SYSTEM NOISE PERFORMANCE

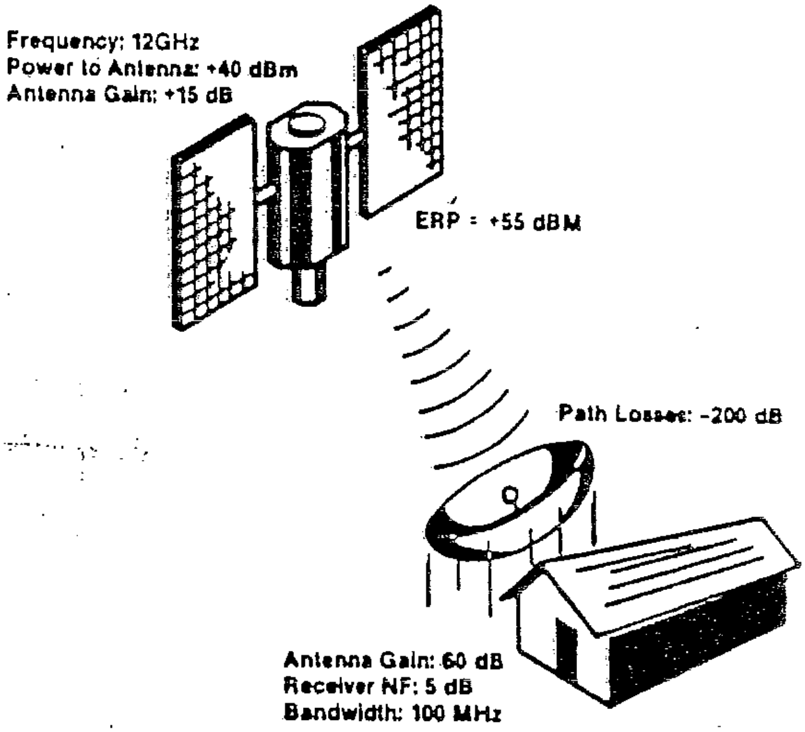
**iGNAL:**

|  |  |
|---|---|
| Transmitter: |  |
| ERP | +55 dBm |
| Path Losses | -200 dB |
| Rcvr. Ant. Gain | 60 dB |
| Power to Receiver | -85 dBm |

**loiSE:**

|  |  |
|---|---|
| ceiver: |  |
| oise Floor @ 290K | -174 dBm/Hz |
| Noise In 100 MHz BW | +80 dB |
| Receiver N.F. | +5 dB |
| Receiver Sensitivity | -89 dBm |

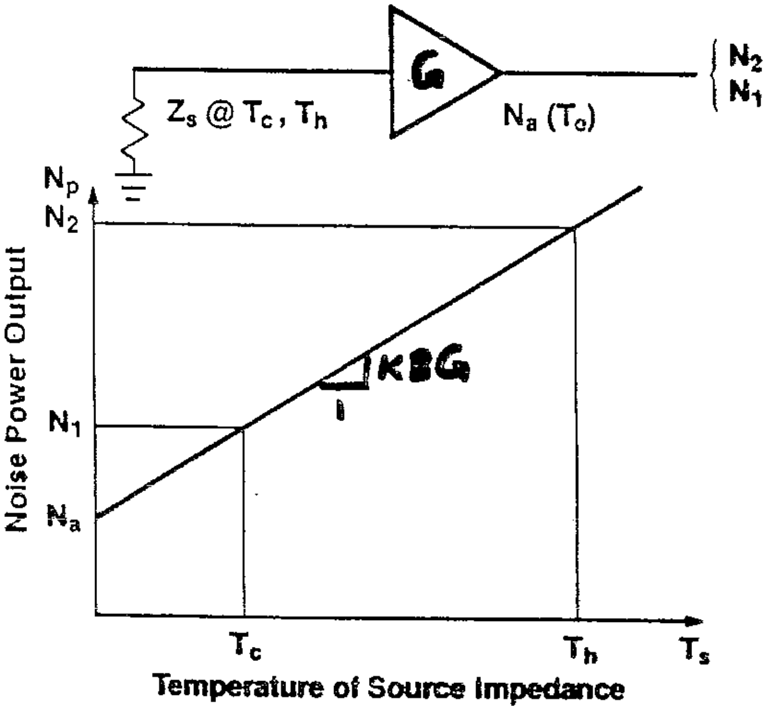
Link Margin: 4 dB

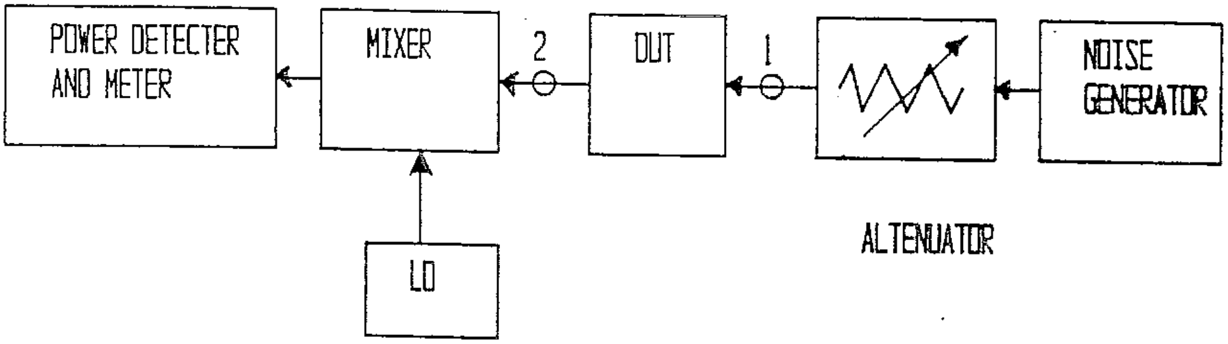


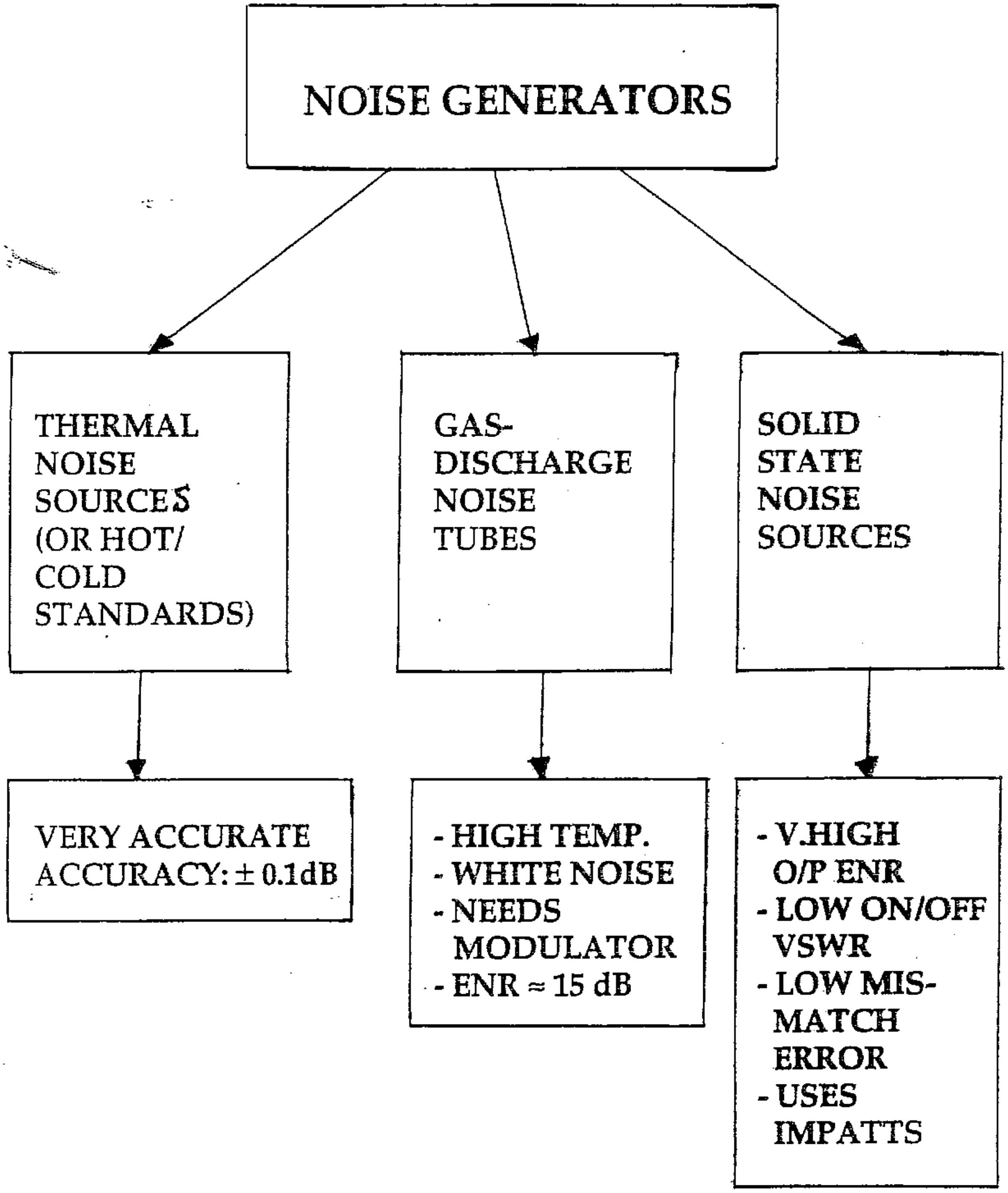
Increase Margin by 3 dB

1. Double transmitter power
2. Increase size of antennas by 3 dB
3. Lower the receiver N.F. by 3 dB

# A BASIC MEASUREMENT SET-UP







# NOISE GENERATORS

THERMAL NOISE SOURCES (OR HOT/ COLD STANDARDS)

VERY ACCURATE
ACCURACY: ± 0.1dB

GAS-DISCHARGE NOISE TUBES

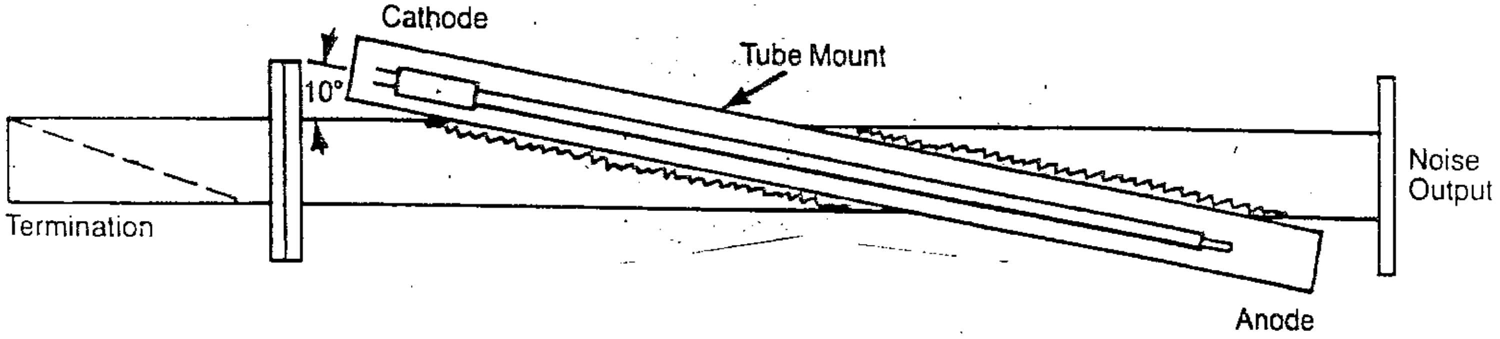
- HIGH TEMP.
- WHITE NOISE
- NEEDS MODULATOR
- ENR ≈ 15 dB

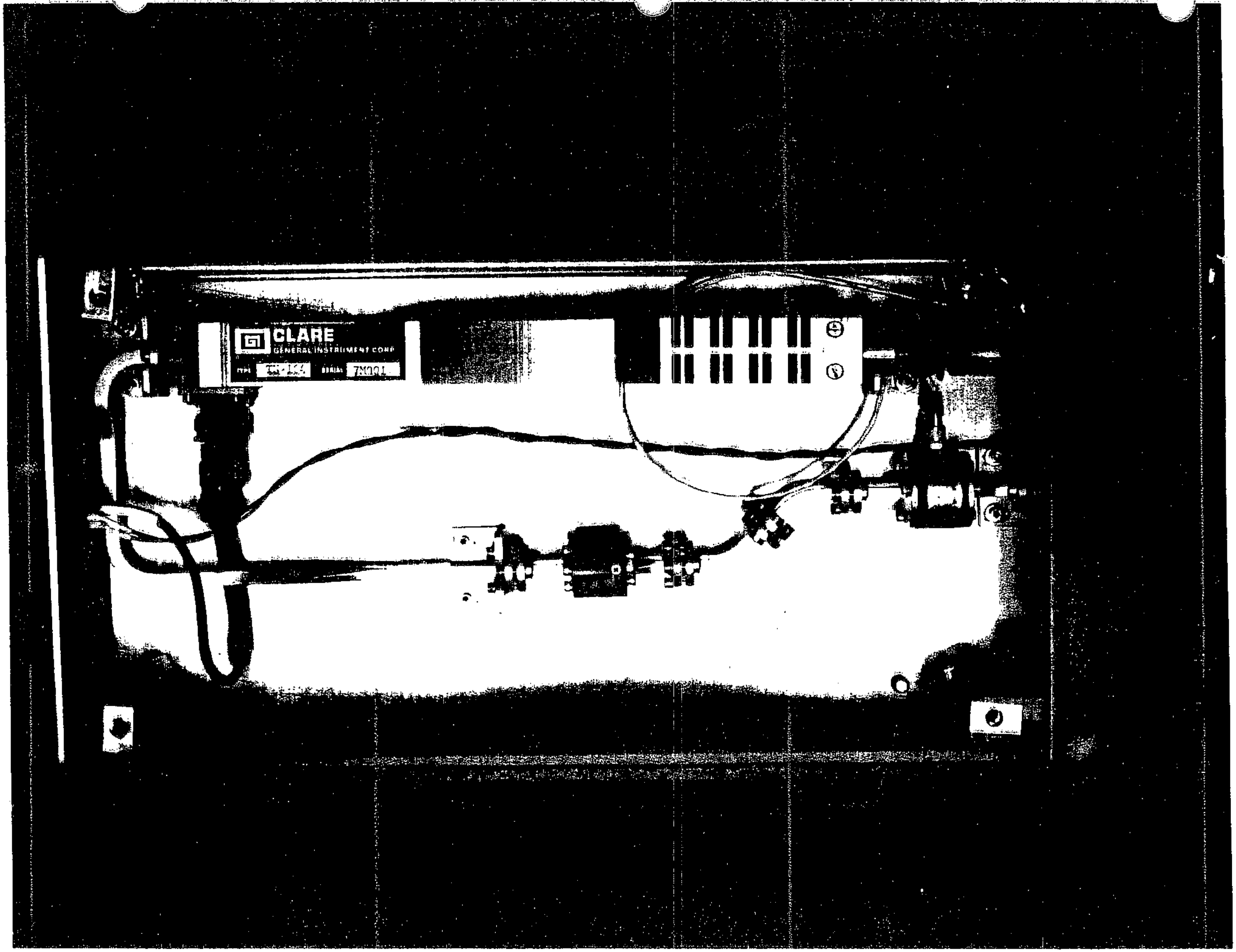
SOLID STATE NOISE SOURCES

- V.HIGH O/P ENR
- LOW ON/OFF VSWR
- LOW MISMATCH ERROR
- USES IMPATTS

# A Waveguide Gas-Discharge Noise Tube

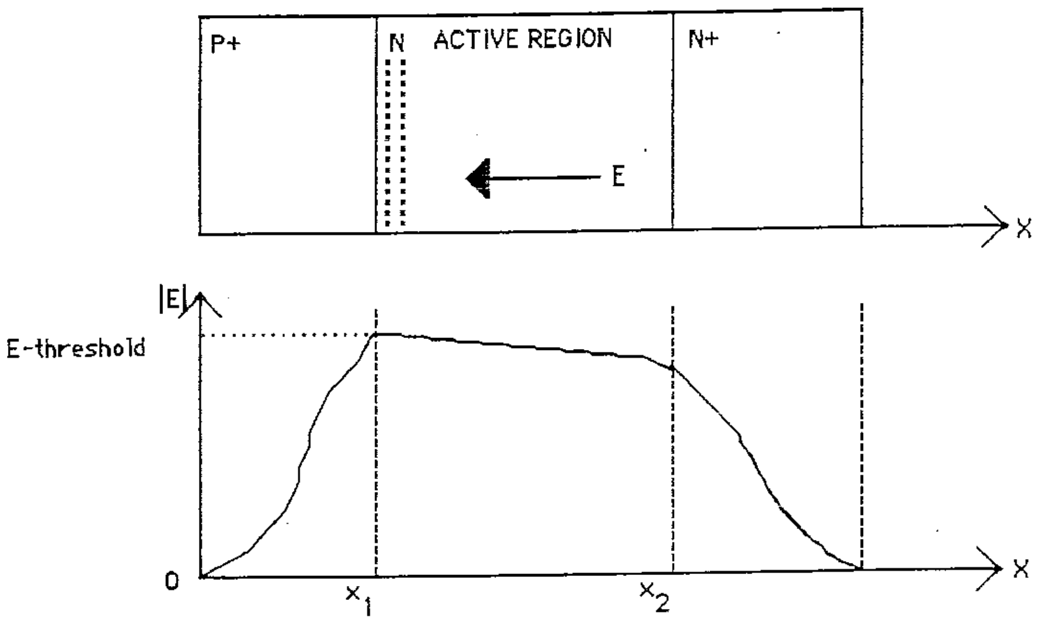
- Waveguide Gas-Discharge
  - Stable with Power Source
  - Flat with Frequency
  - Significant Mismatch Change On to Off
  - High Voltage Power Supply Required
  - Cold Termination Heating




CLARE
GENERAL INSTRUMENT CORP
TYPE
SERIAL
7M001

# SOLID STATE NOISE SOURCES

8. **IMPATT Diode (Impact Avalanche and Transit Time):** a Pn junction diode with a depletion region adjacent to the junction (for carrier drift). The diode is biased to be in Avalanche breakdown.



# II. NOISE THEORY

## Noise Power Spectral Density Function for an IMPATT:

$$W(f) = a^2 \, (V_b/I) \, (R_L/[R_{sc} + R_{sp} + R_L]^2)/(1-f^2/f_a^2)^2$$

where:

$$f_a = [7.6I/(AV_b)]^{1/2}$$

## Assumptions:

1. small transit angle
2. no external reactive element

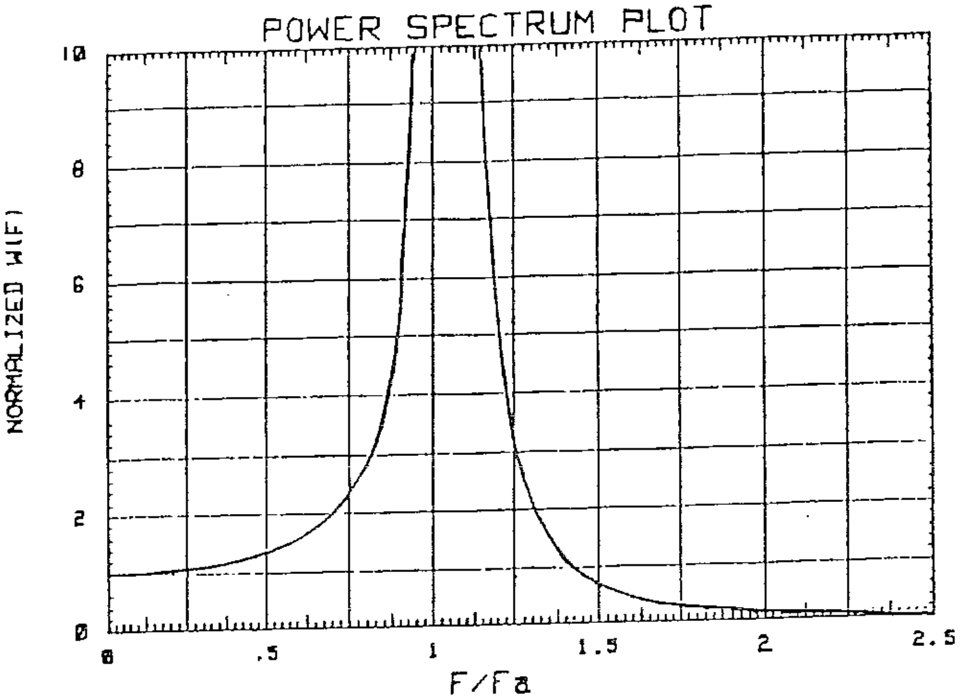


Fig. 1: Plot of W(f) versus $f/f_a$.

# IV. MICROWAVE AND MILLIMETER WAVE IMPATT DIODES

## A-Assembly and proper packaging of IMPATTs:

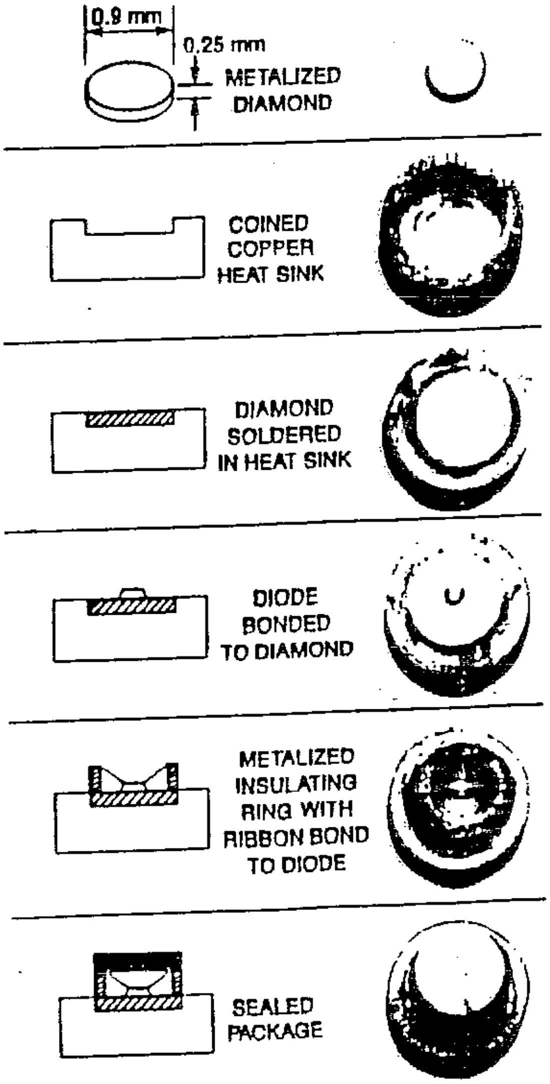


Fig. 3a : Assembly and proper packaging of millimeter-wave diodes.

## C- Variation of total package inductance versus the number of radial connections

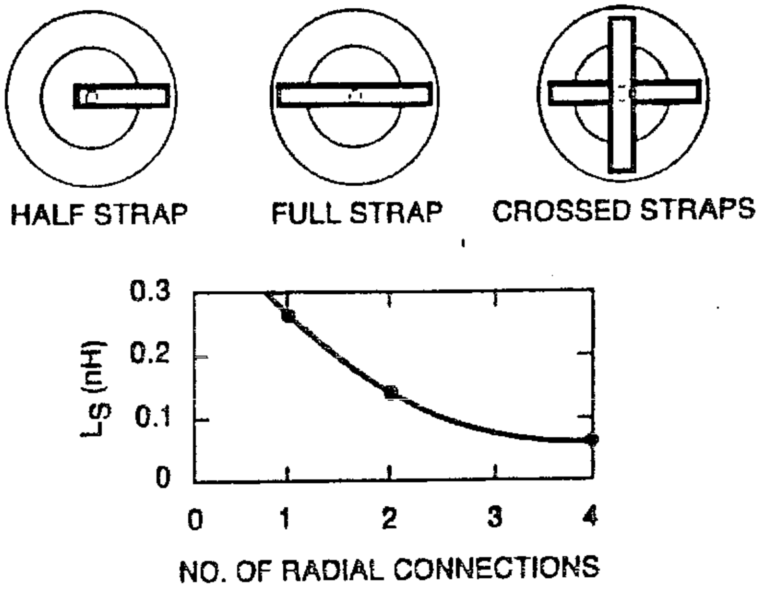


Fig.3c : Variation of total package inductance versus the number of radial connections.

## B- Cross section of the final package for a half-strap IMPATT diode.

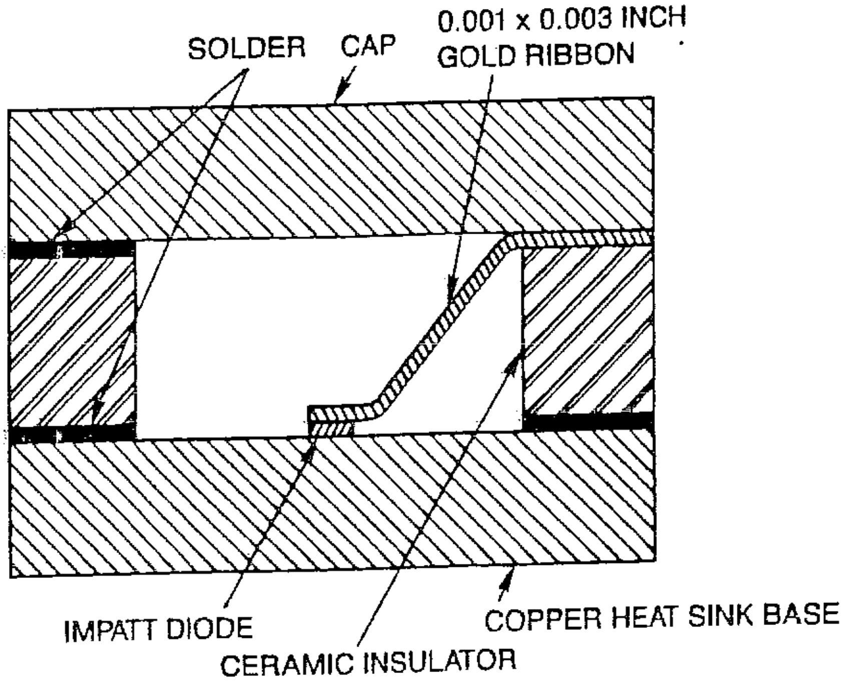
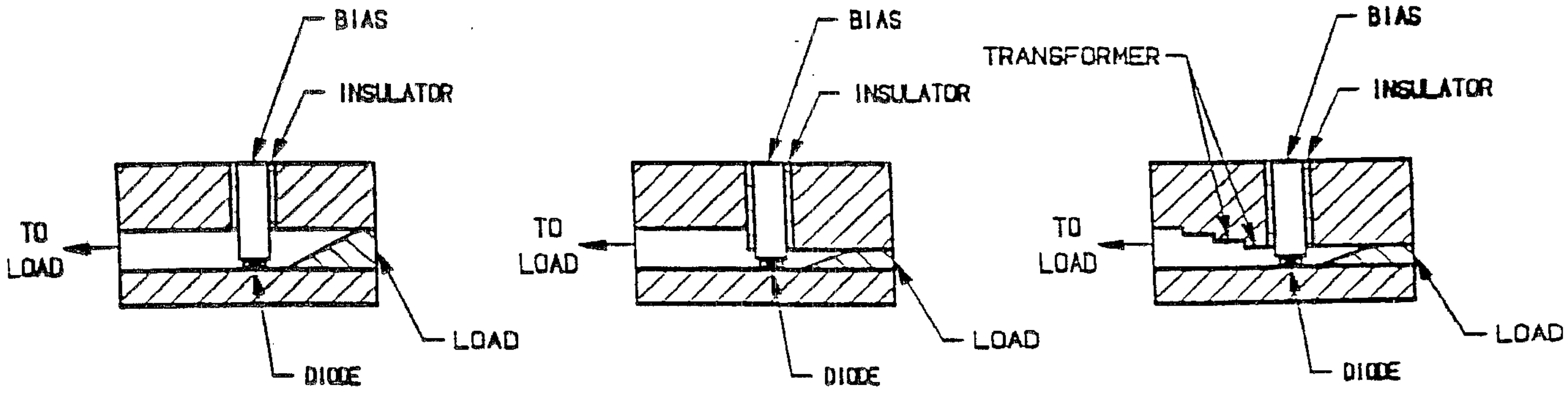


Fig. 3b : Cross section of the final package for a half-strap diode.

# III. WAVEGUIDE CAVITY MOUNTED IMPATT NOISE-SOURCE CONFIGURATIONS



A) FH-FH W/LOAD

B) FH-RH W/LOAD

C) RH-RH W/LOAD

FIG. 2: WAVEGUIDE CONFIGURATIONS

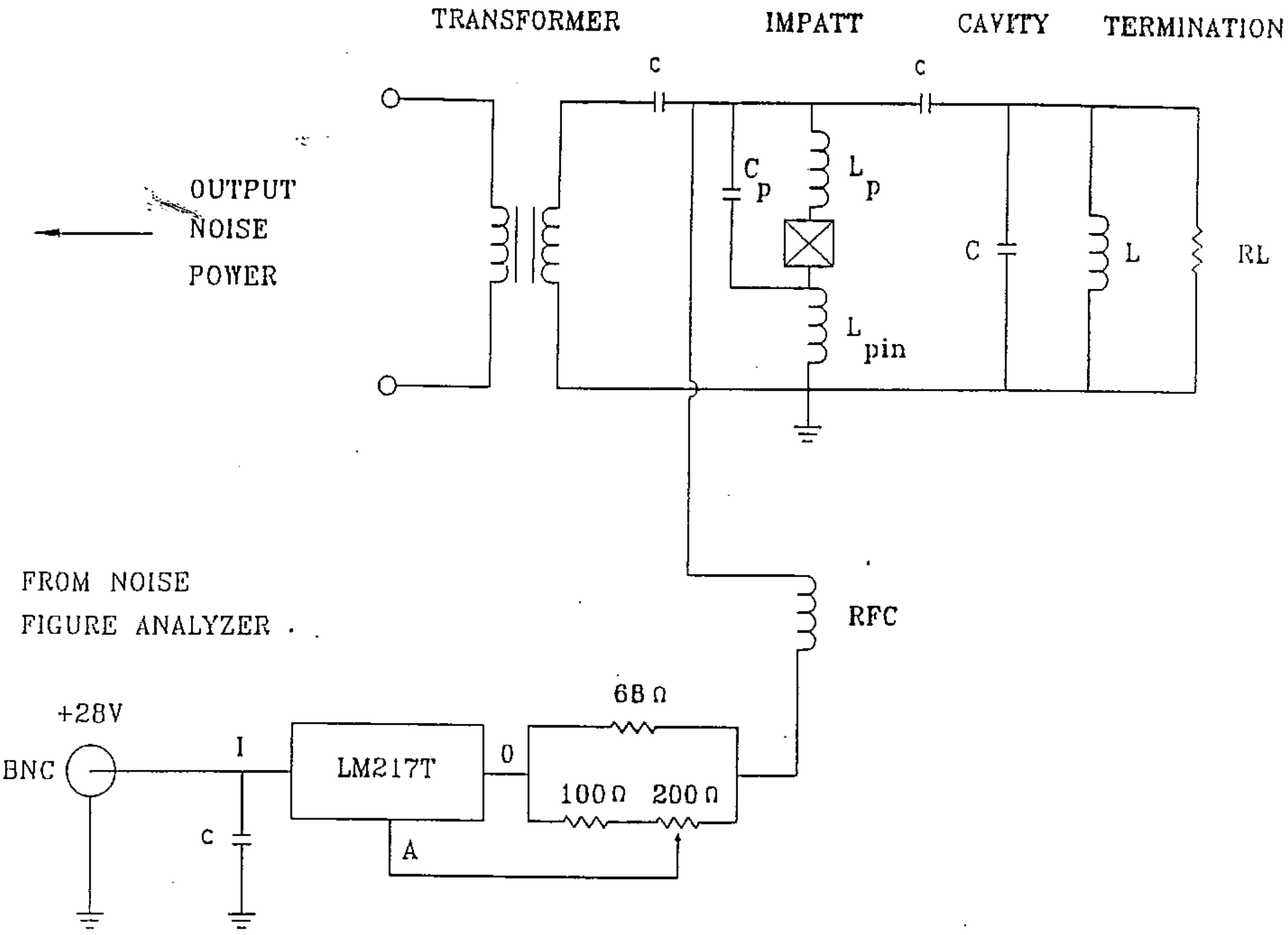


Fig. 3e: noise source equivalent circuit

1 DC current regulator
2 Regulator printed circuit board
3 Side cover
4 IMPATT cavity housing
5 Spring mechanism
6 V-band integral flange

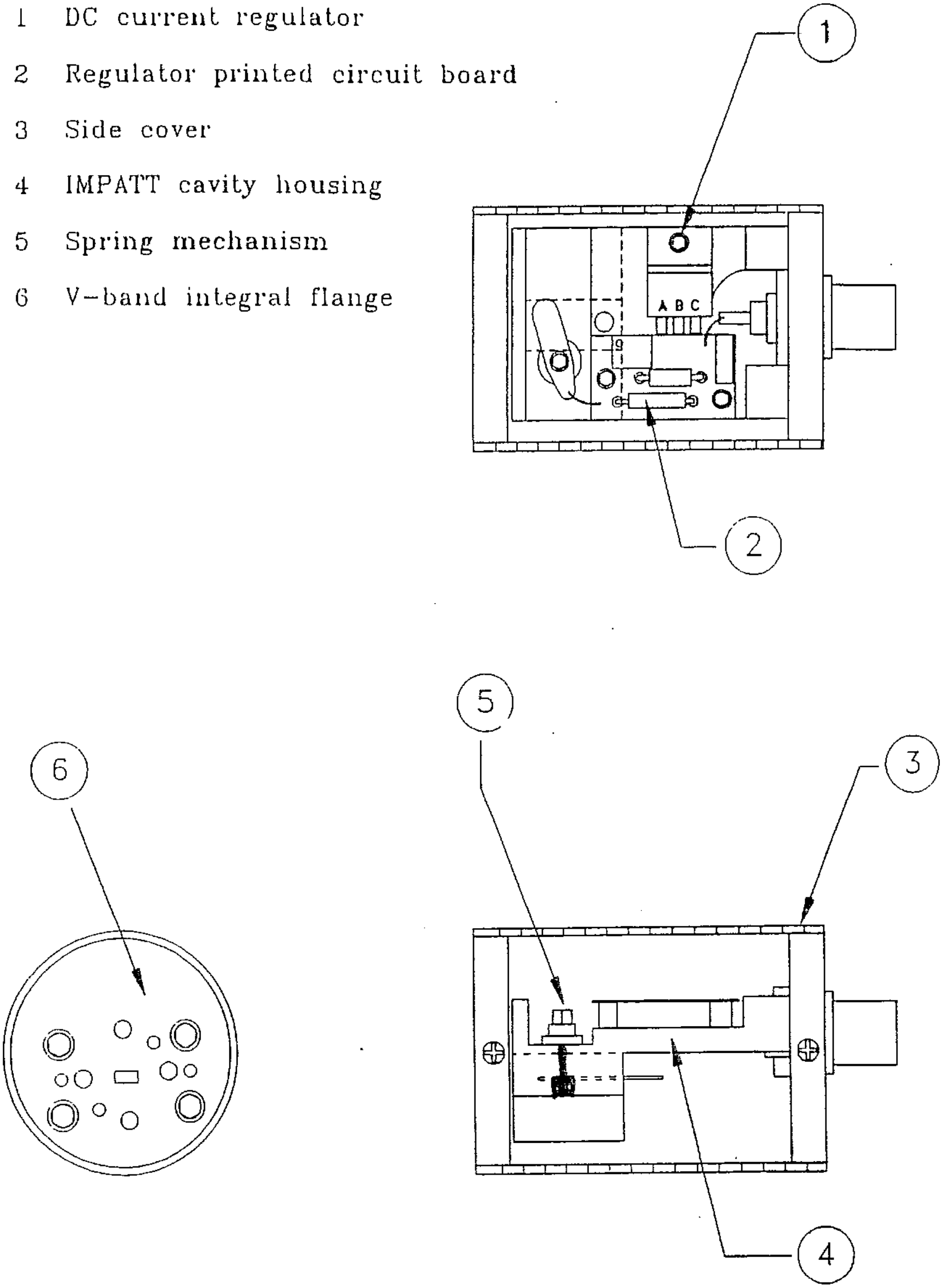


Fig 3d: Prototype of the V-band noise source with build-in DC current regulator.

# VII - CONCLUSIONS

## MAIN CHARACTERISTICS AND IMPORTANT ADVANTAGES:

1 - Large B.W.

2 - Large Operating Temperature Range

3 - Higher Noise Output

4 - Lower power consumption

5 - Pulsed Operation (sub-nsec)

6 - Higher Reliability

7 - Variable Noise Output-ENR 5 to 30 dB

8 - Smaller size and lower weight

9 - Full Waveguide Bands (26.5 to 110 GHz)

10 - Internal Modulator/Output matching (VSWR<1.2)

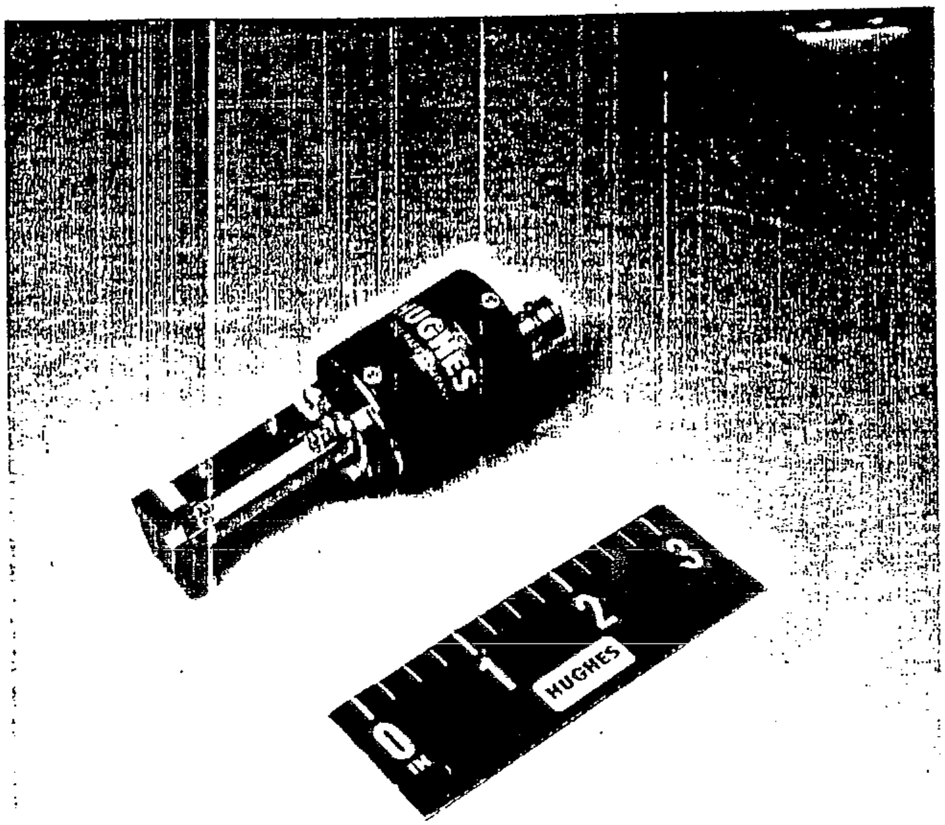
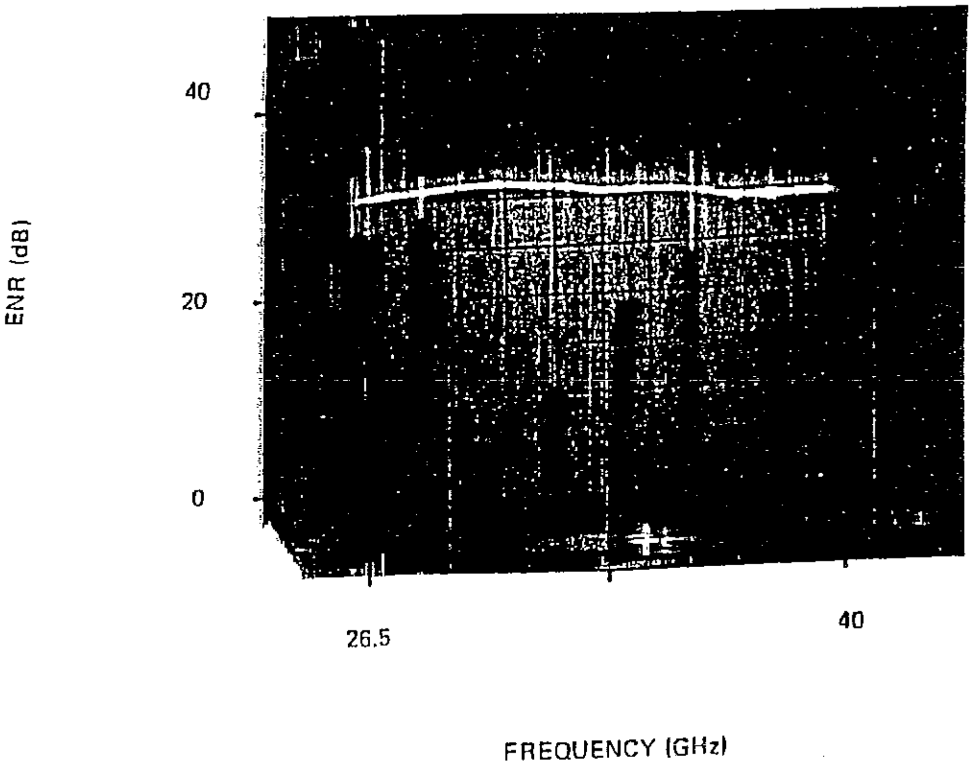


PHOTO OF THE NEWLY DEVELOPED SOLID STATE NOISE SOURCE

# VI. EXPERIMENTAL RESULTS



SPD63

Fig. 7: Photograph of ENR plot in the Ka-Band using a 120 GHz in a RH-RH waveguide cavity mount.

# VI. EXPERIMENTAL RESULTS

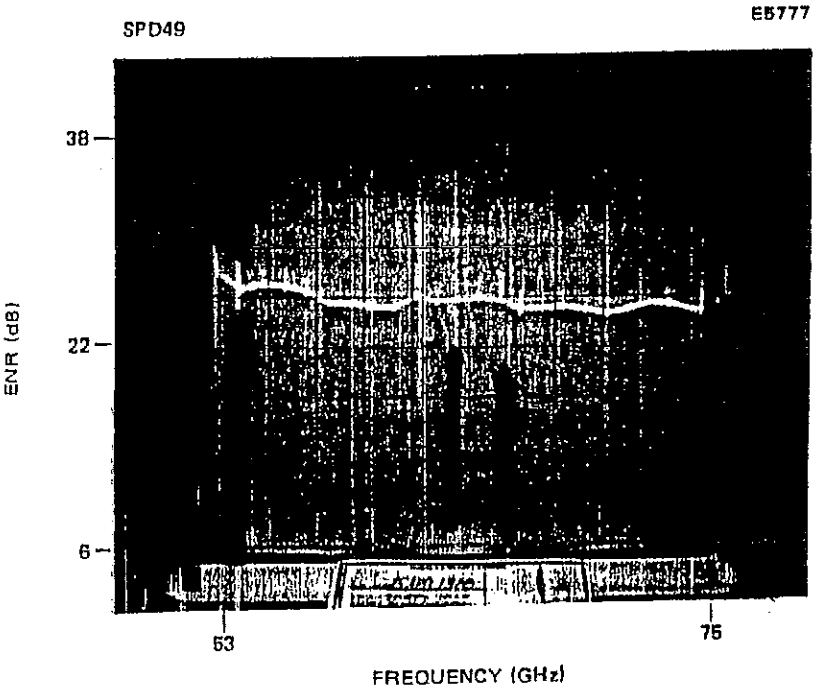


Figure 11 Photograph of ENR plot over the V-band in an RH-RH cavity mount ($I_{DC}$ = 40 mA).

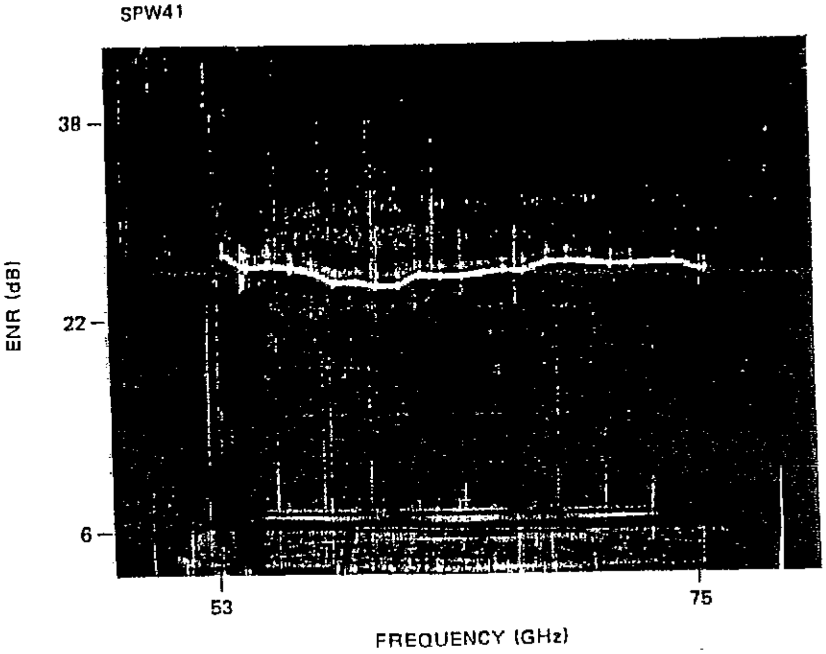


Figure 12 Photograph of ENR plot over the V-band in an RH-RH cavity mount ($I_{DC}$ = 40 mA).

# VI. EXPERIMENTAL RESULTS

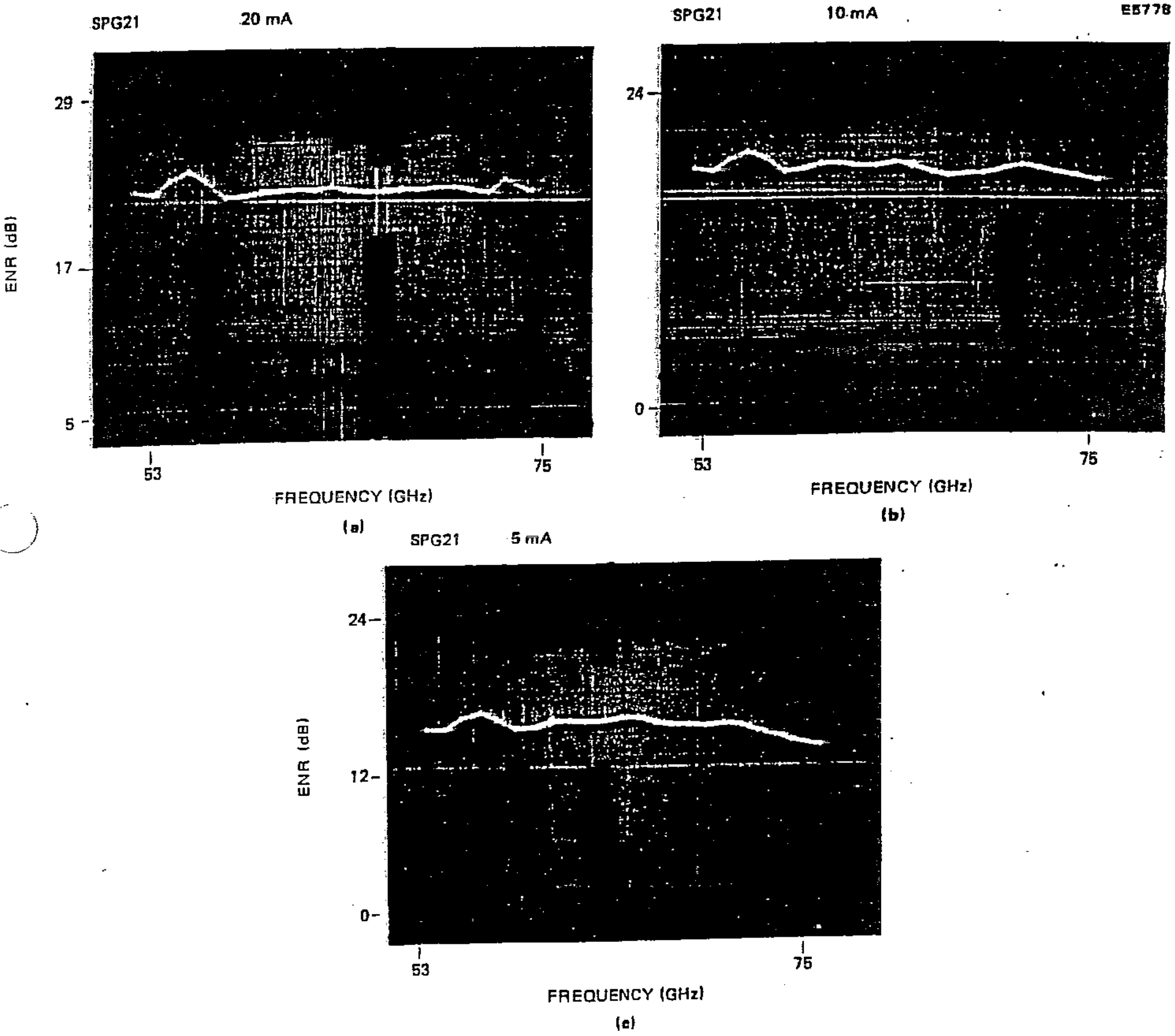
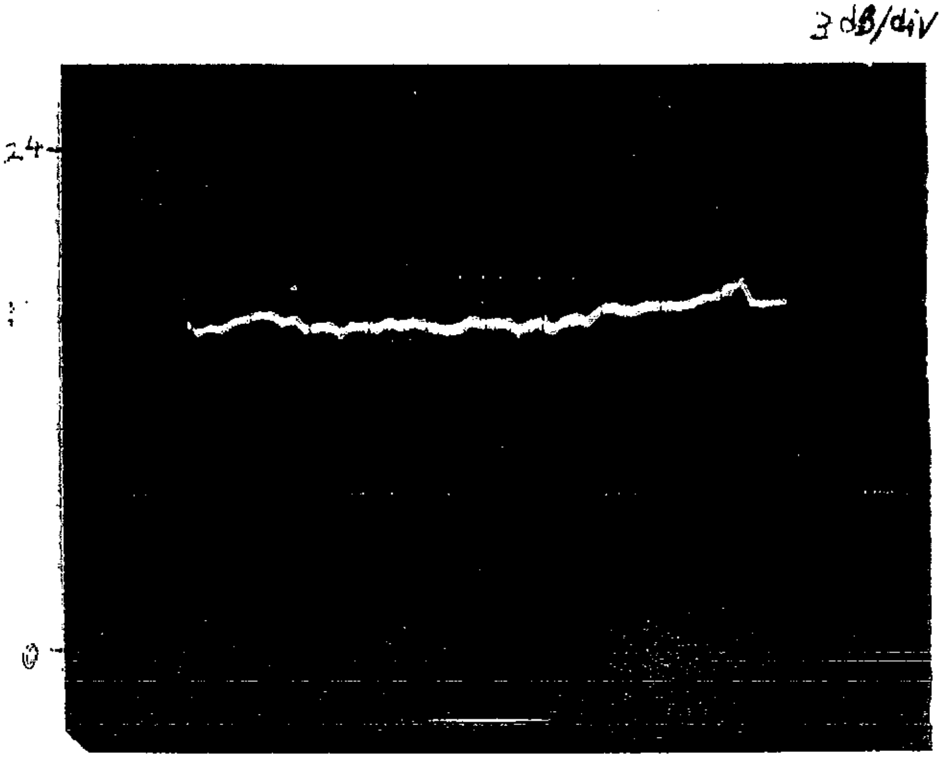
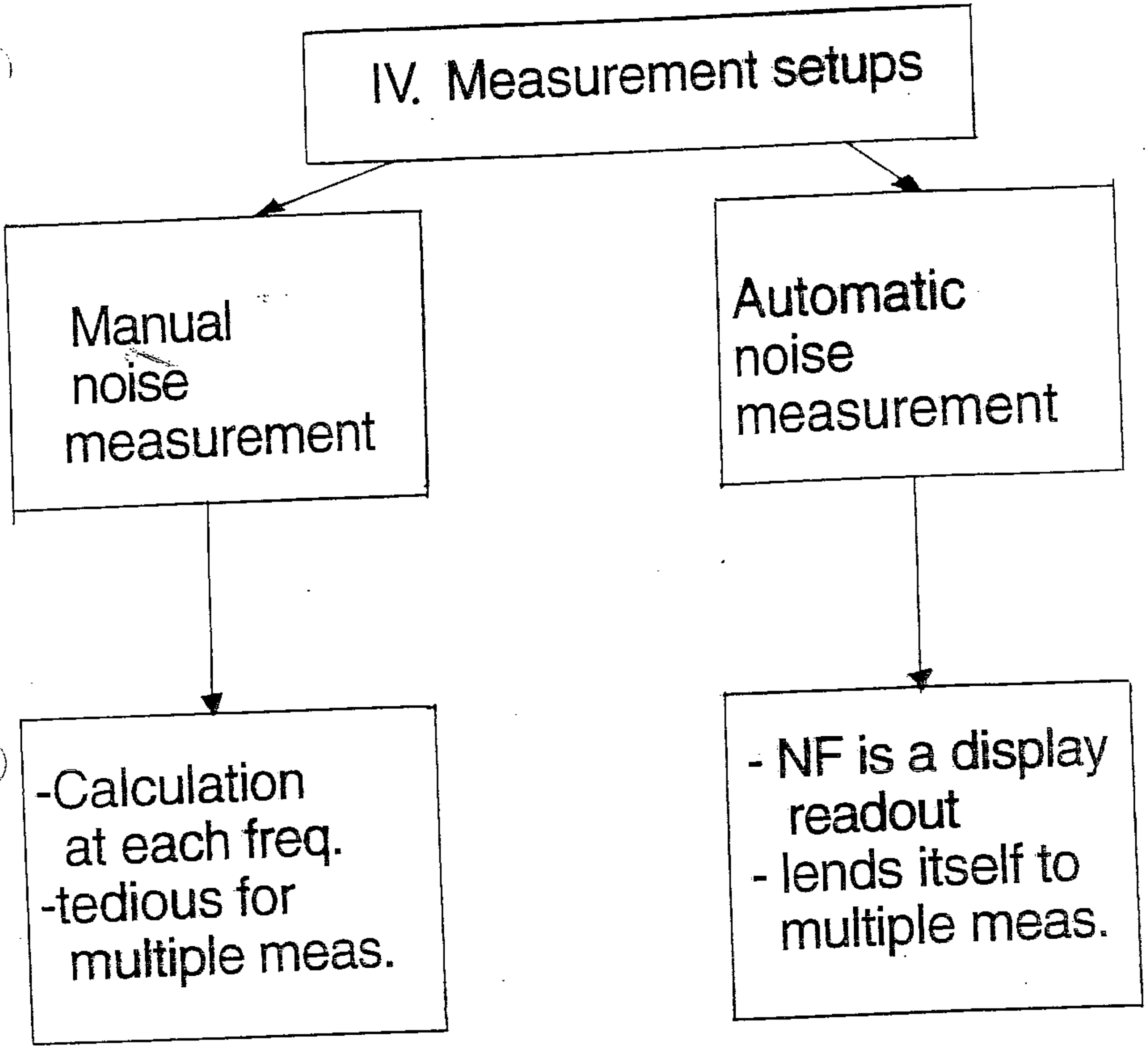


Figure 10 Photograph of ENR plot in the V-band in an RH-RH waveguide cavity mount ($I_{DC}$ = 20, 10, 5 mA).



ENR of The Noise Tube (50-75)

ENR PLOT OF THE NOISE TUBE ( VERT: 3 dB/DIV ; HORZ: 50-75 GHZ)



# IV. Measurement setups

Manual noise measurement

- Calculation at each freq.
- tedious for multiple meas.

Automatic noise measurement

- NF is a display readout
- lends itself to multiple meas.

# Manual measurement

Noise measurement setup #1

In general: $\boxed{NF = ENR - 10 \log (N_2/N_1 - 1)}$

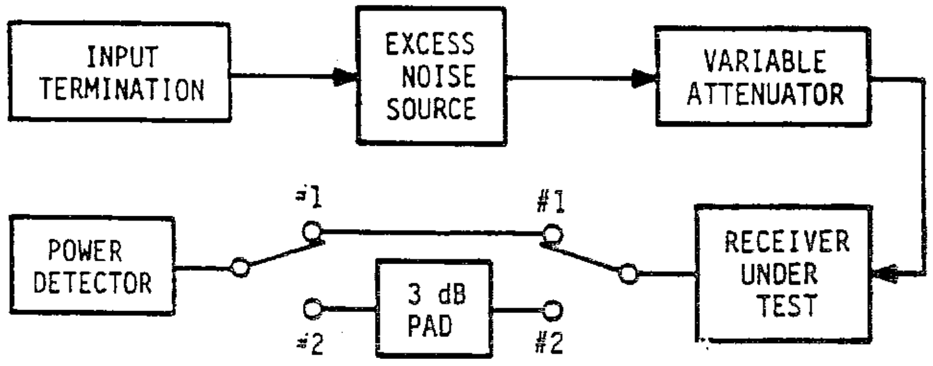
$$ENR = 10 \log \frac{T_N - T_o}{T_o}$$

$T_N$ = equivalent noise temp

$T_o = 290° K$

# Manual measurement: twice-power method

NF = attenuated excess noise ratio



*The "twice power" method of manual noise figure measurement.*

# Noise measurement setup # 2

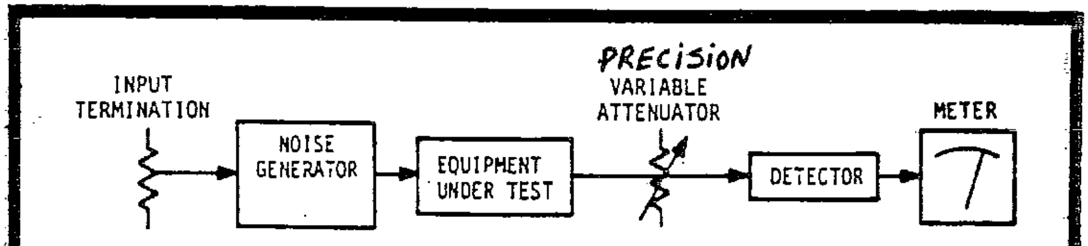
- A more popular method for manual measurement: y - Factor method

1. Noise source off N1

2. Noise source on N2

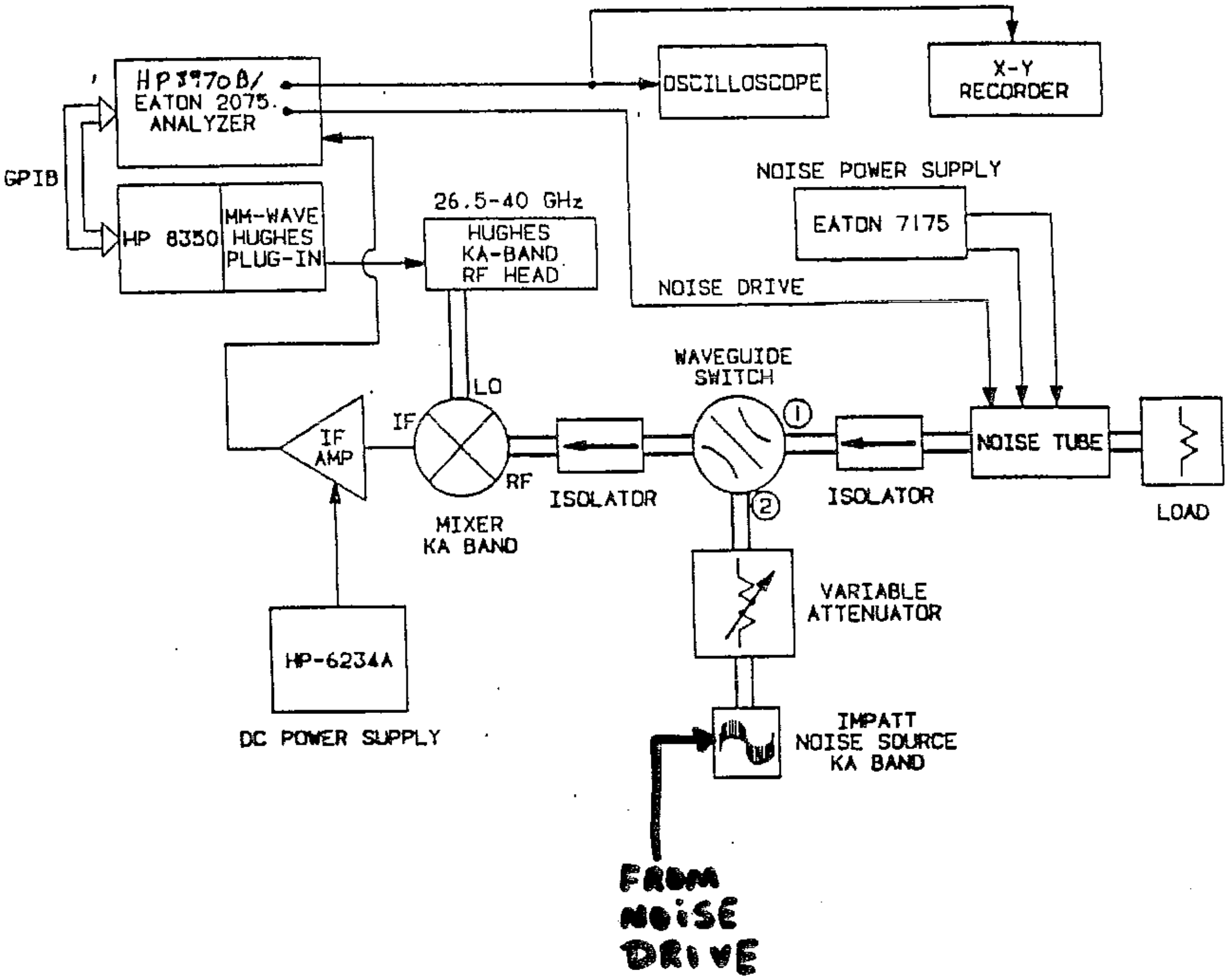
$$NF_{dB} = ENR - 10\log\left(\frac{N_2}{N_1} - 1\right)$$

$Y = N_2/N_1$



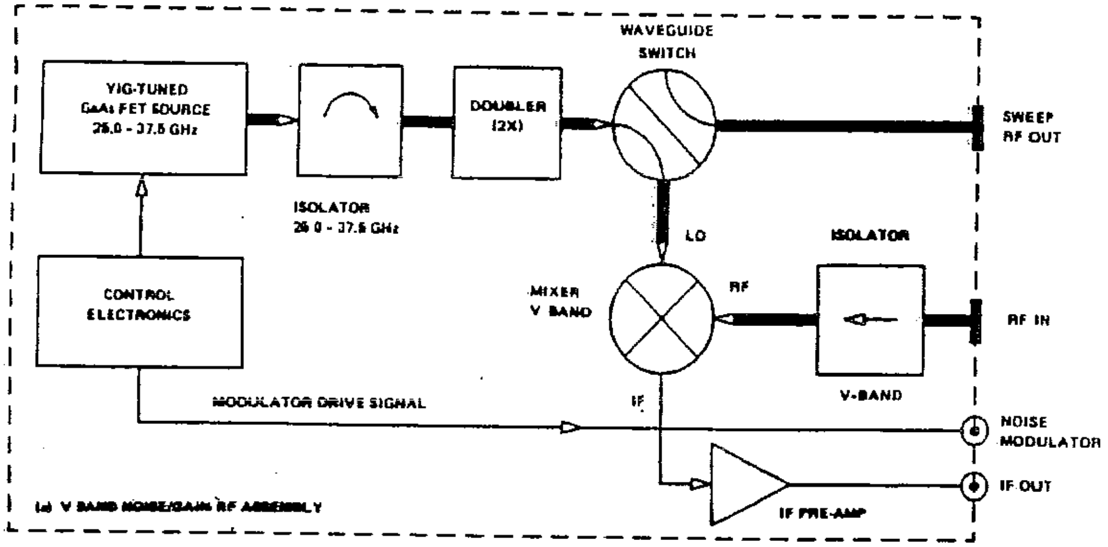
*Block diagram of equipment setup for determining noise figure (Y-factor).*

# AUTOMATIC NOISE MEASUREMENT

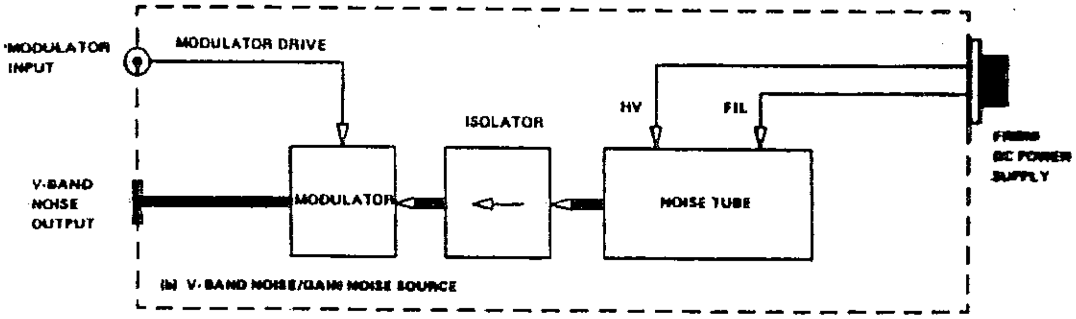


# Automatic Noise measurement

## Modular approach



(a) V BAND NOISE/GAIN RF ASSEMBLY

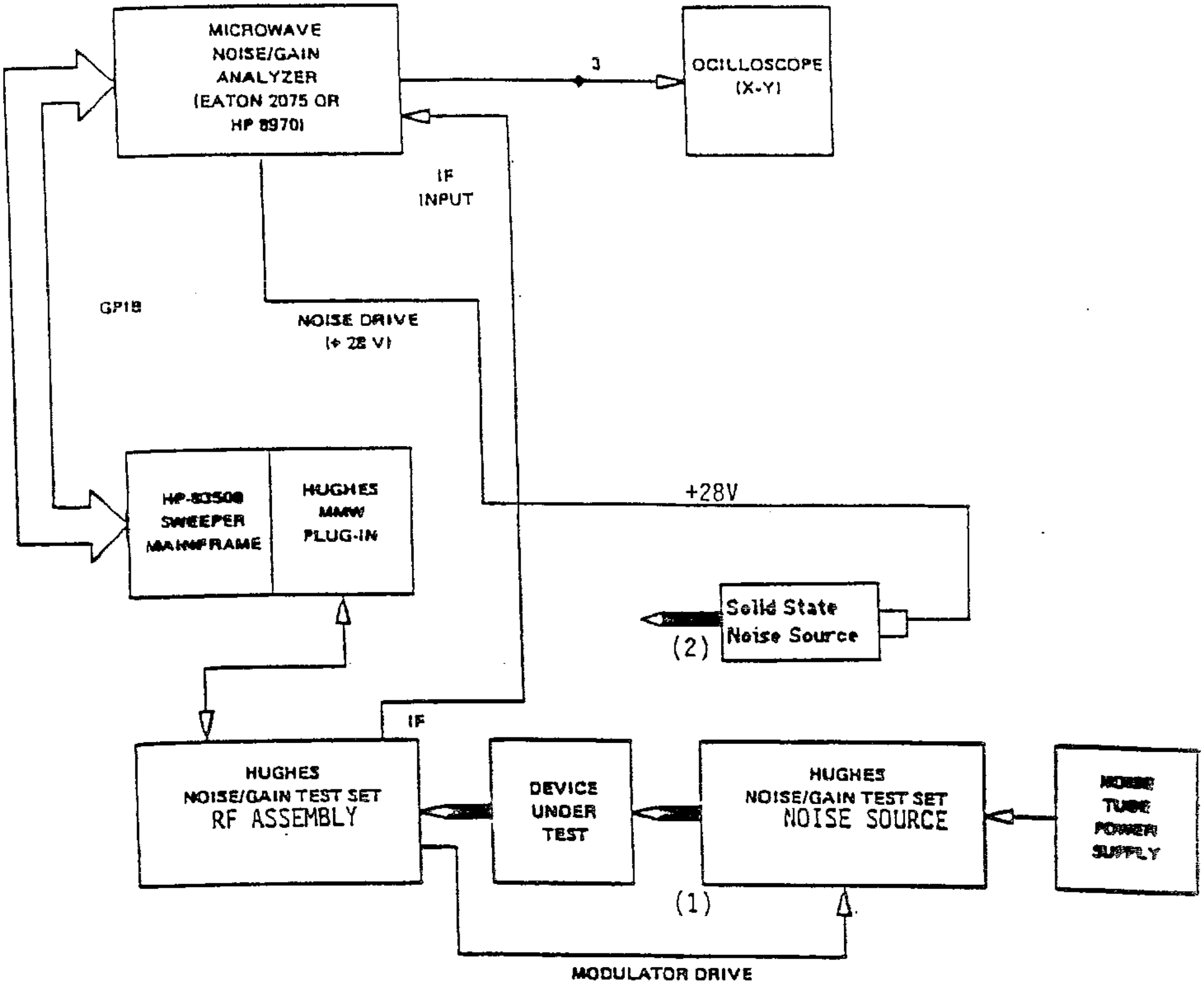


(b) V-BAND NOISE/GAIN NOISE SOURCE

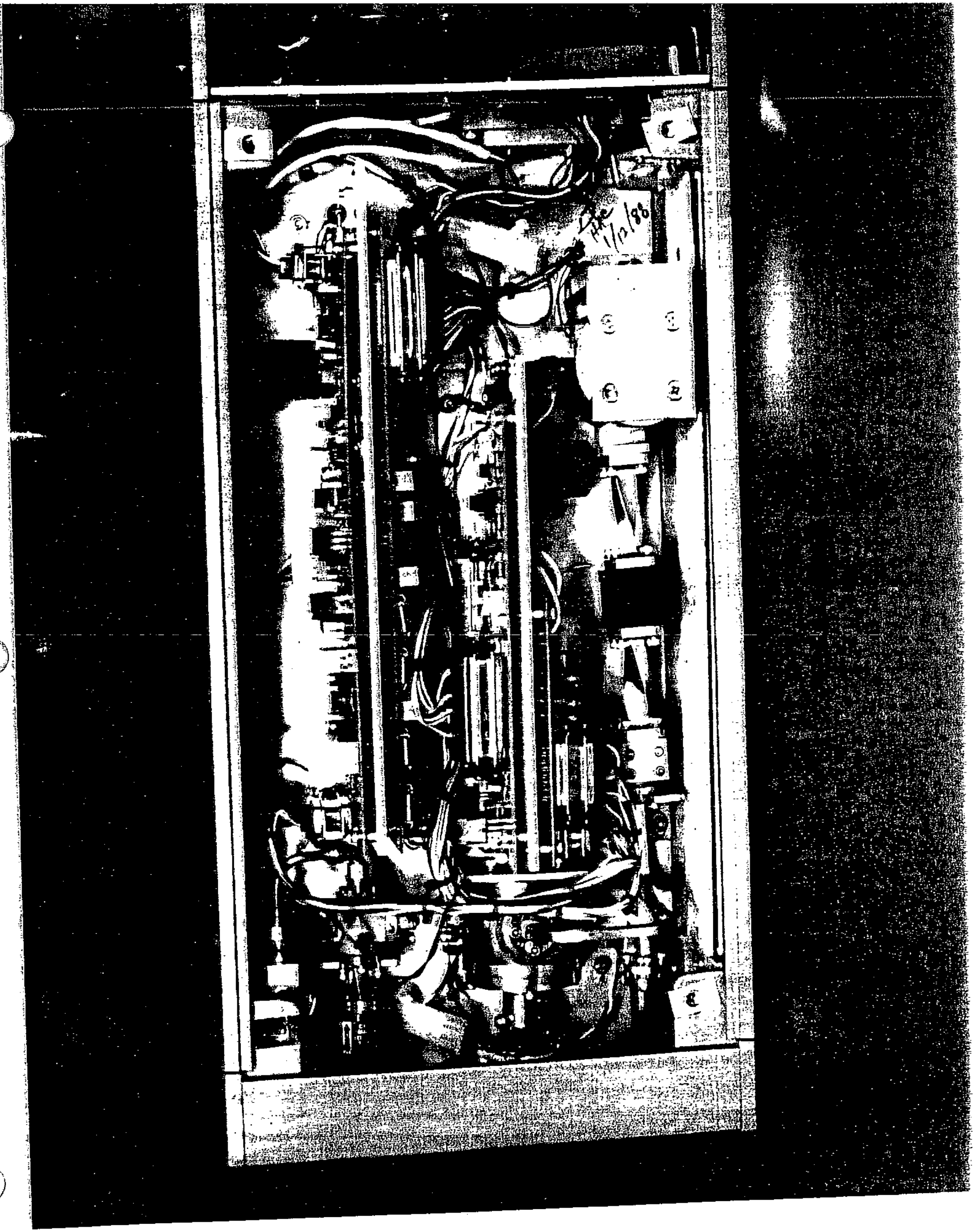
noise/gain test set RF assembly and noise source

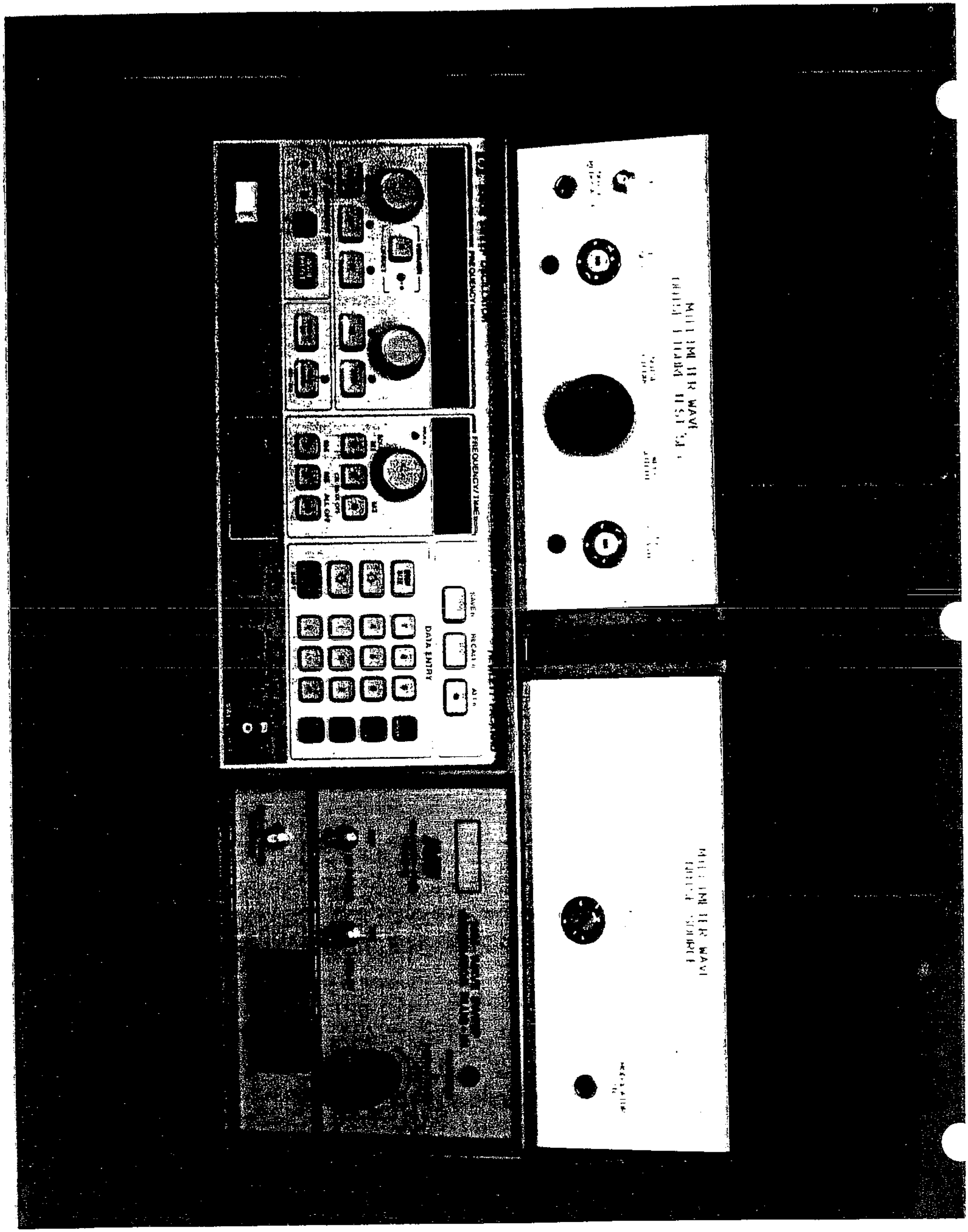
# Automatic Noise measurement

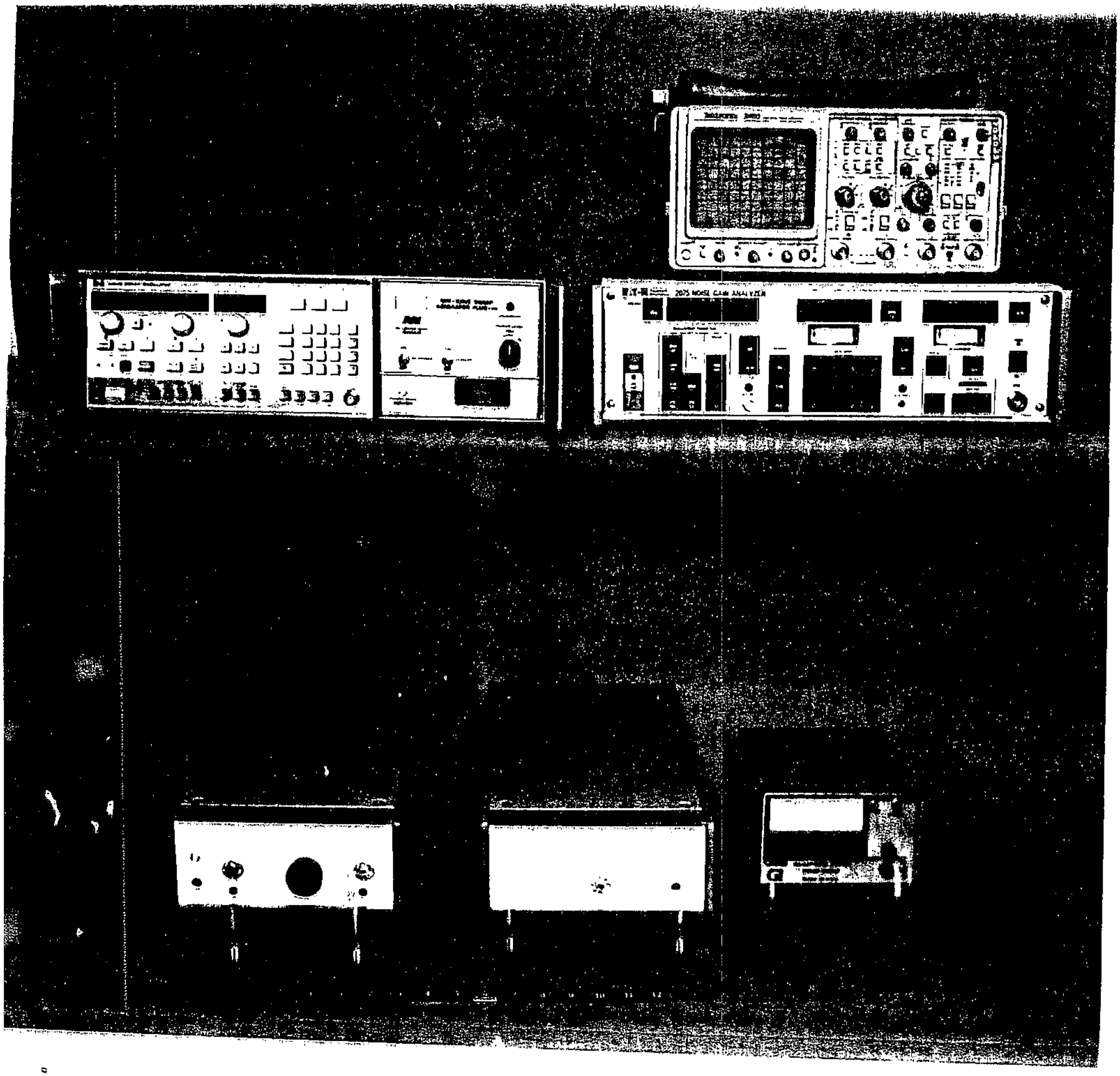
# Modular approach



Noise/gain test set block diagram


1/12/88

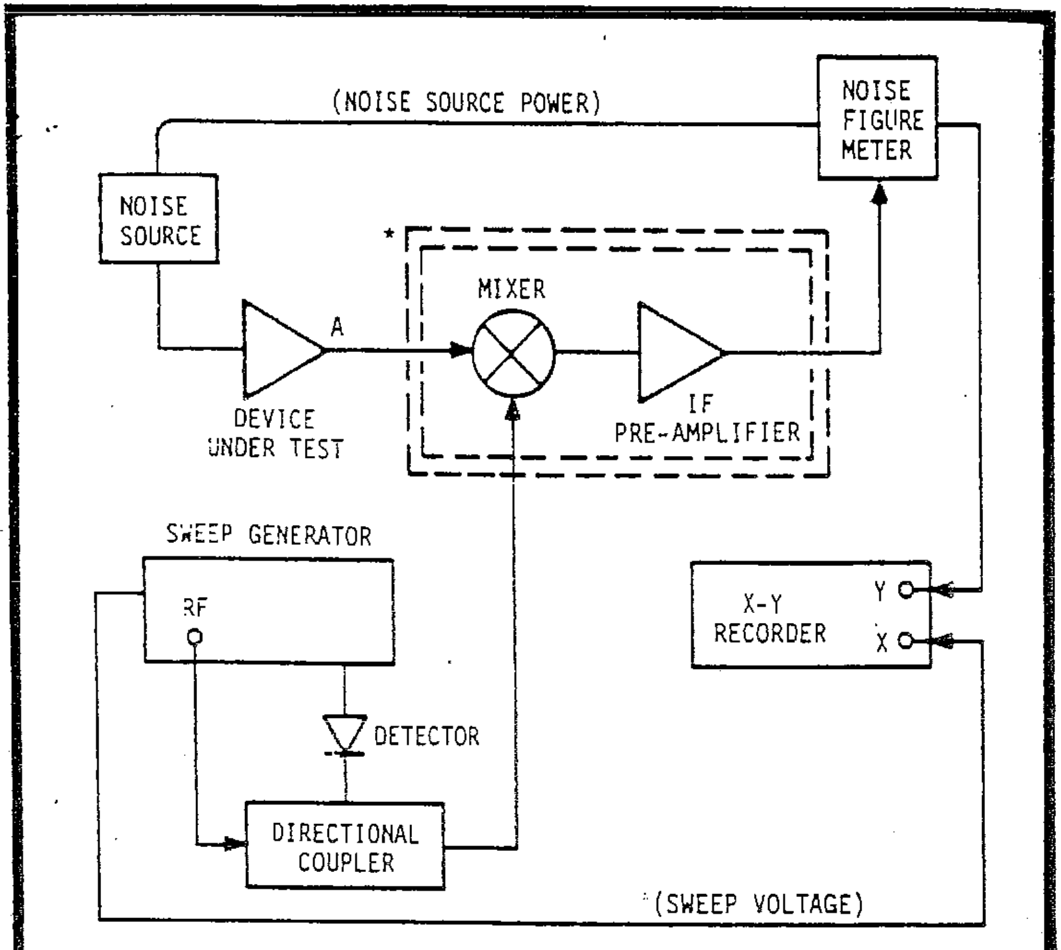

FREQUENCY/TIME
FREQUENCY
DATA ENTRY
SAVE
RECALL
MILLIMETER WAVE
MILLIMETER WAVE
SOURCE


2075 NOISE GAIN ANALYZER

# Measurement uncertainties

1) Instrumentation uncertainty
   - noise generator ENR accuracy
   - noise figure meter reading accuracy

2) mismatch
   - primary (noise generator/DUT)
   - secondary (noise generator/analyser, DUT/analyser)
   - system B.W. mismatch



*Swept automatic noise figure setup*

3) Image & spurious inaccuracy

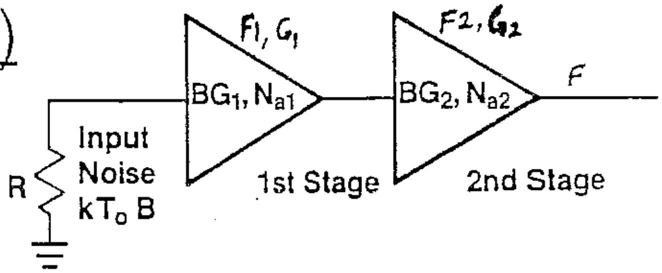
For a broadband noise source:

operating NF = NF (Reading) + lo log ( BT/Bop )

4) correction accuracy

-2nd stage noise contribution

$$F = F1 + \frac{(F2-1)}{G1}$$



5) Poor technique

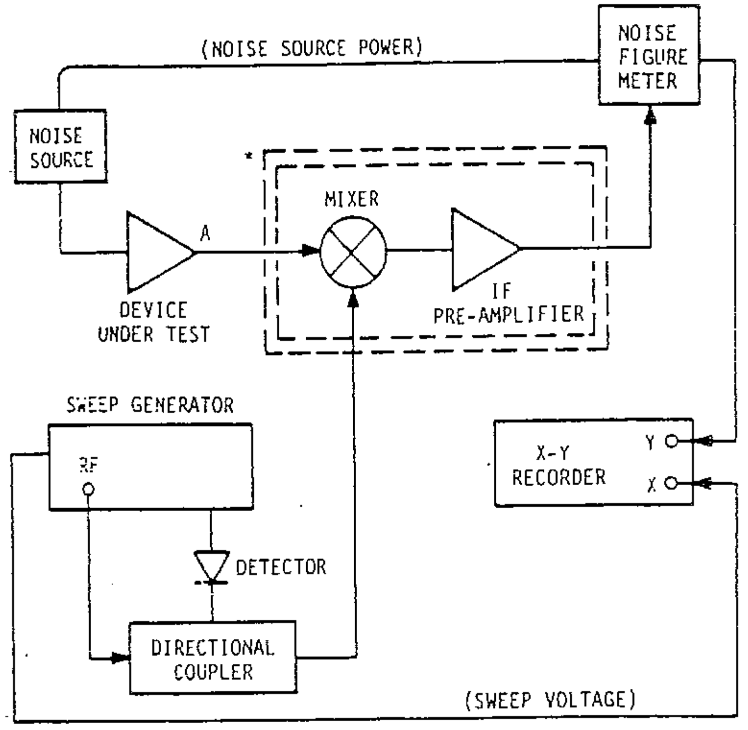
-Interference

-connector integrity

-consistent connection

-cable loss correction

-DUT linearity



# SUMMARY:

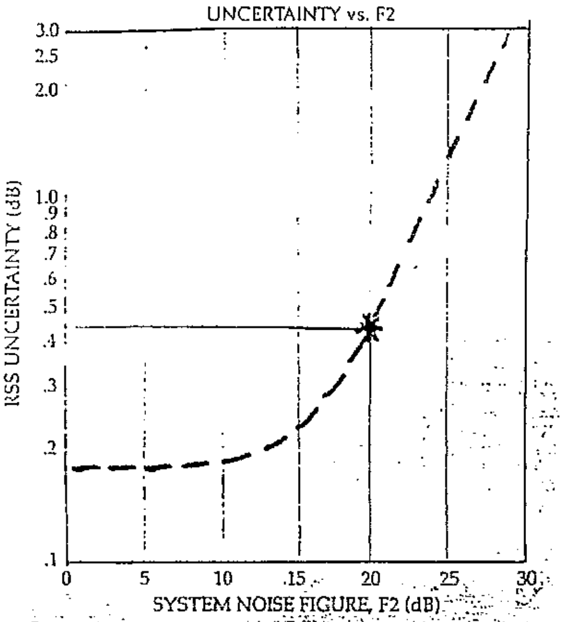


*Figure 1. Noise figure measurement uncertainty (ΔF1) vs. measurement system noise figure (F2).*

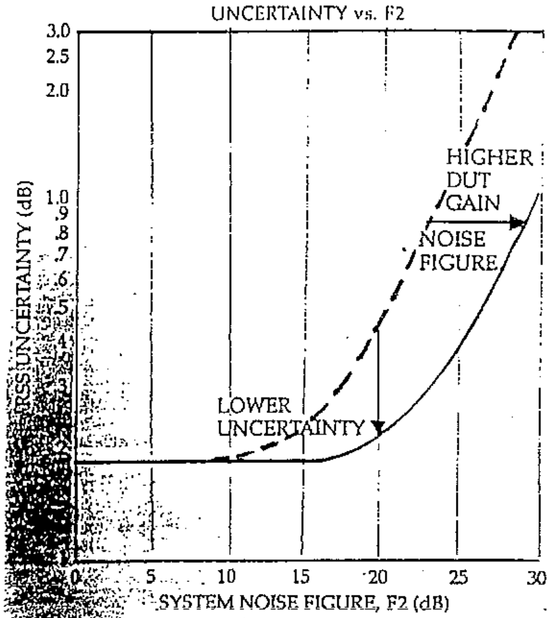


*Figure 2. High gain/noise figure DUT shifts curve to right; lower uncertainty results.*

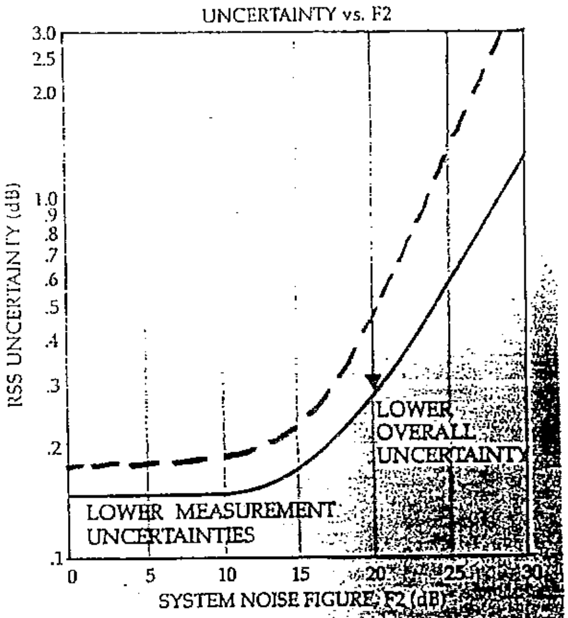


*Figure 3. Lowering ENR, mismatch, and instrumentation uncertainties shifts curve down and decreases upward slope; lower overall uncertainty results.*

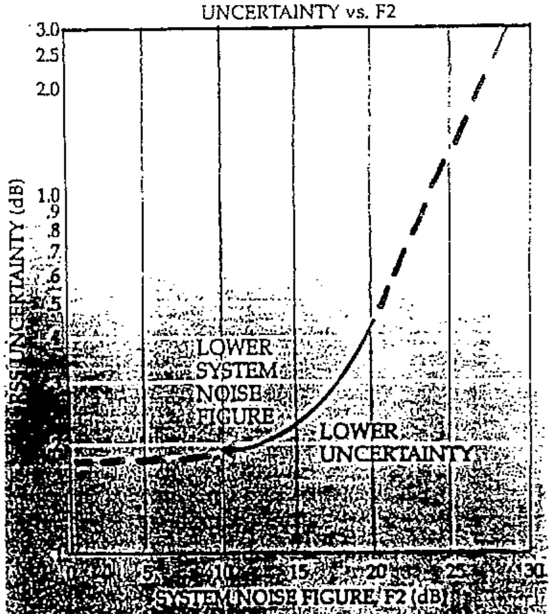


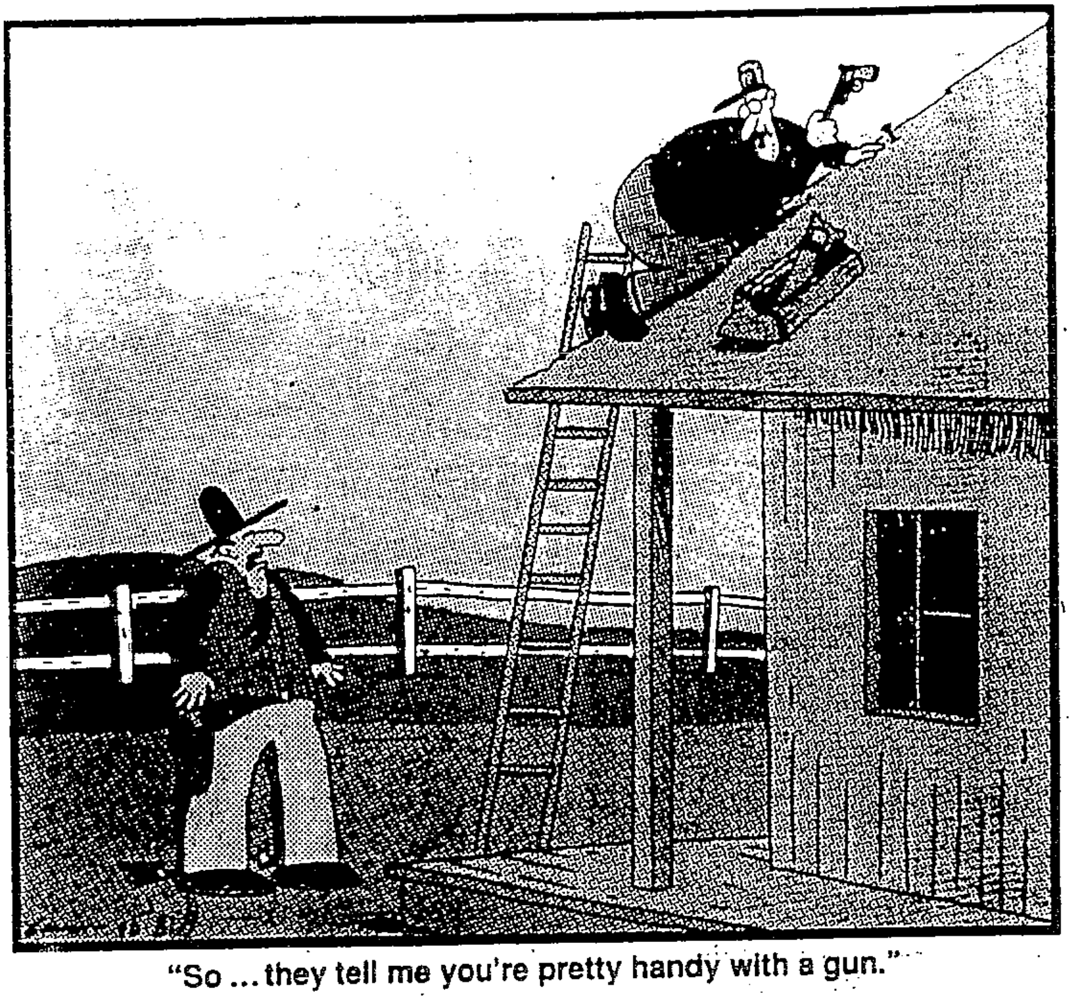
*Figure 4. Lowering measurement system noise figure (F2) moves uncertainty down along curve; lower uncertainty results.*

# SUMMARY:

*Example of Measurement Uncertainties*

| | **RF** | | **Micro-wave** | |
|---|---|---|---|---|
| Second stage correction uncertainty | | 0.01 dB | | 0.10 dB |
| Second stage noise figure | 6 dB | | 10 dB | |
| $T_c$ correction uncertainty | | 0.01 | | 0.01 |
| ENR uncertainty | | 0.10 | | 0.15 |
| Mismatch uncertainty | | 0.15 | | 0.15 |
| Source SWR | <1.10 | | <1.13 | |
| DUT SWR | <1.40 | | <1.5 | |
| Instrumentation uncertainty | | 0.10 | | 0.10 |
| Total uncertainty (Root-sum-of-the-squares) | | 0.21 dB | | 0.25 dB |

# CONCLUSION:



"So ... they tell me you're pretty handy with a gun."