# FIBER OPTIC TECHNOLOGY*
# FOR RADIO ASTRONOMY APPLICATIONS

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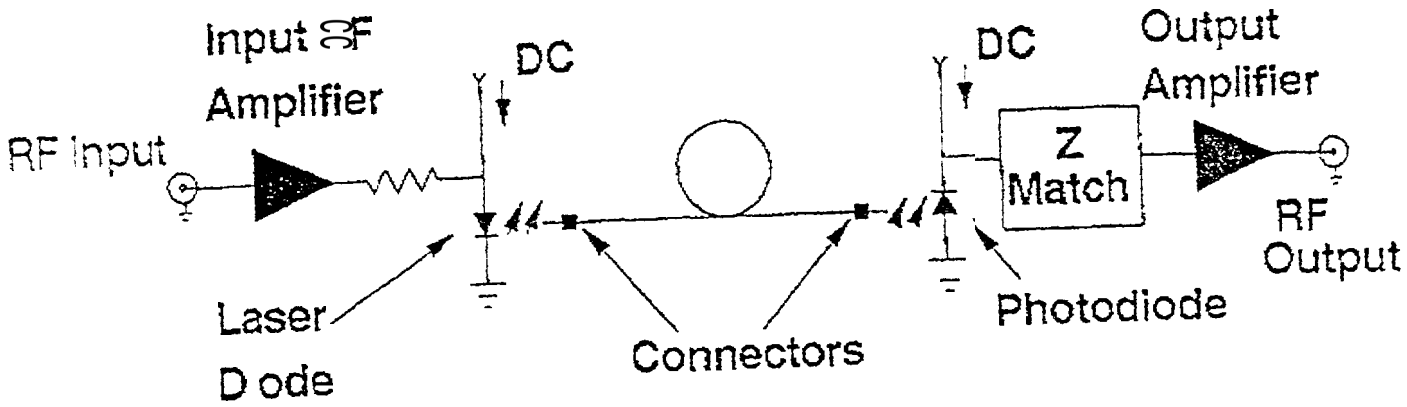
# Analog Link Schematic

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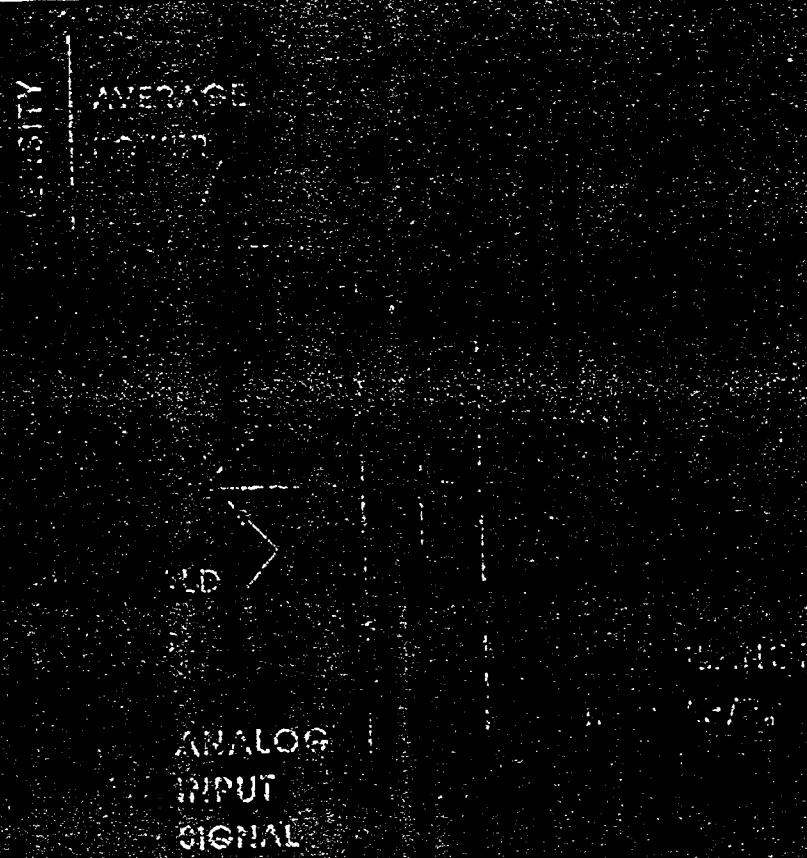
# LASER CHARACTERSITIC
## Slope = M = Modulation Gain

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# PHOTODIODE RESPONSIVITY

Slope = r = responsivity

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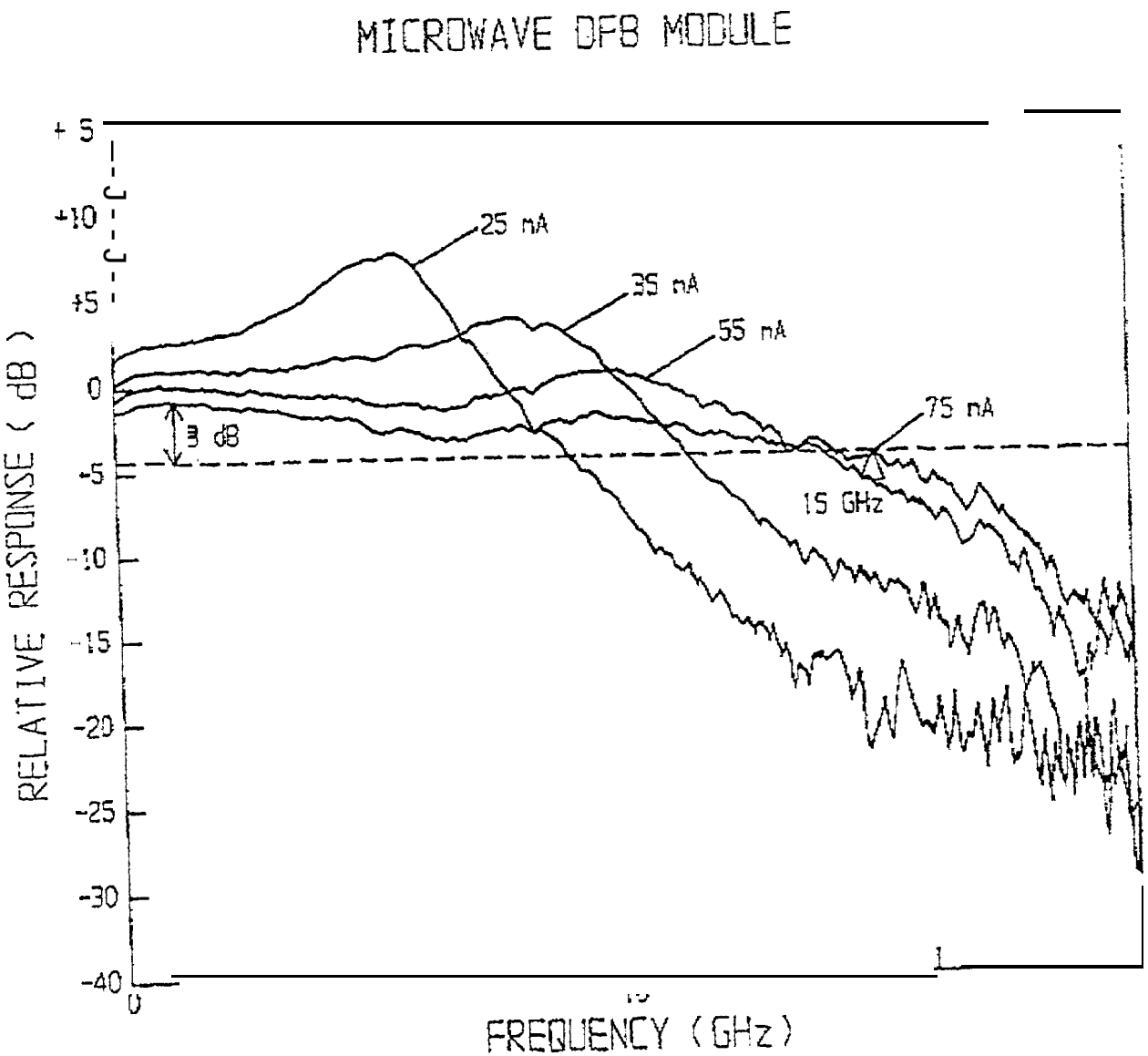
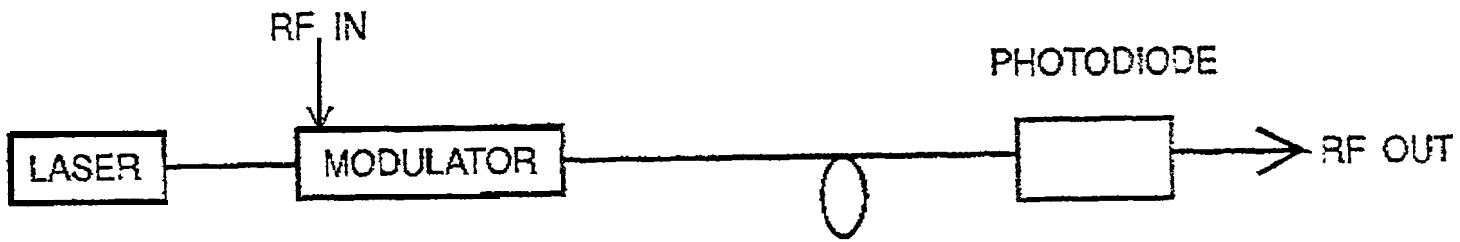



Figure 5. Frequency Response of Microwave DFB Module for Several Values of Bias Current.

# EXTERNAL MODULATION FIBER OPTIC LINK

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# Fiber Optic System Noise

## LASER NOISE :

Relative Intensity Noise (RIN) $= \dfrac{\langle \text{Optical Power Fluctuation} \rangle^2}{\langle \text{Ave Optical Power} \rangle^2}$

Equivalent Input Noise (EIN) $= RF_{in} - S/N$
$= RIN + (I_{Laser})^2 R_{Laser}$

RIN = -140 to -160 dB/Hz, depending upon frequency

## SHOT NOISE :

$N_{Shot} = 2eI_D B R_D$
For 2 mA, $R_D = 50\ \Omega$, $N_{Shot} = -165$ dBm/Hz
For 10 mA, $R_D = 50\ \Omega$, $N_{Shot} = -158$ dBm/Hz

When optical power increases, S/N improves.

## RECEIVER NOISE :

$N_{Rcvr} = kTF$ where F = post amplifier noise figure
For F = 4dB, $N_{Rcvr} = -170$ dBm/Hz

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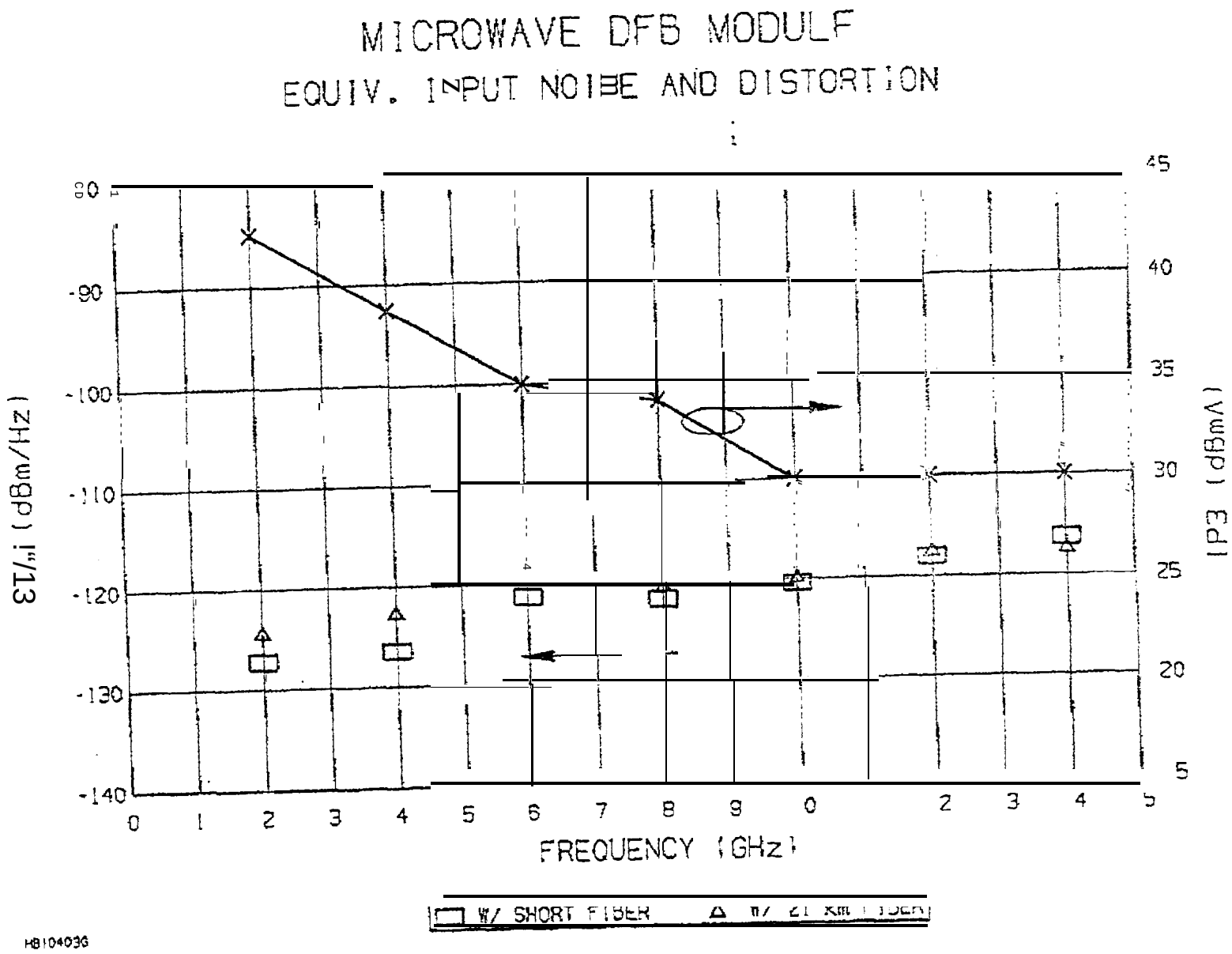
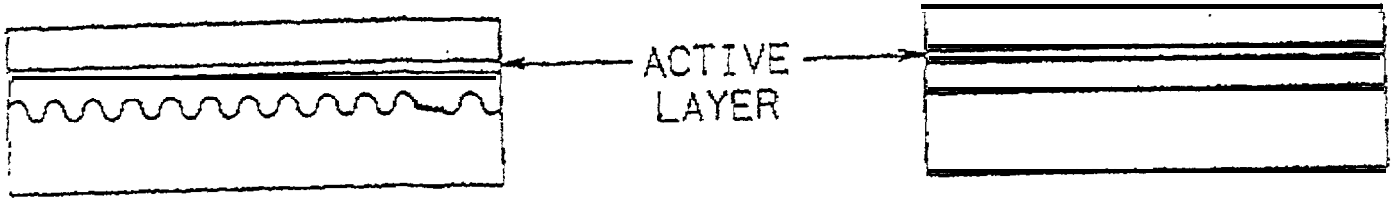
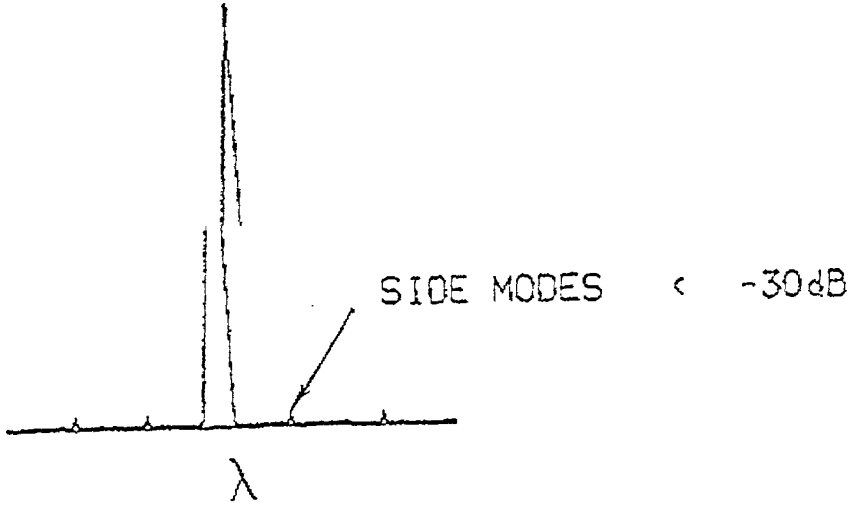


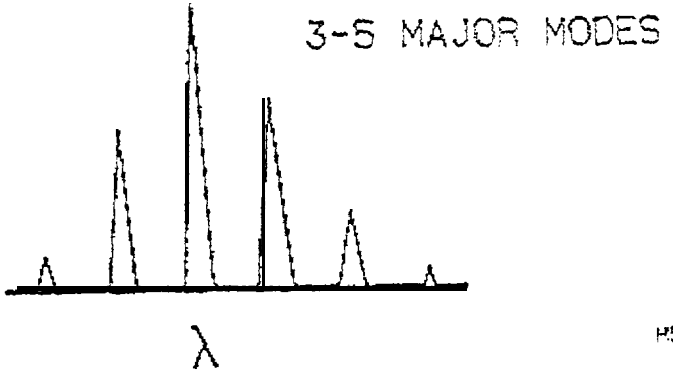

Figure 3. Microwave DFB Module Plots of Equivalent Input Noise and IP3 as a Function of Frequency.

STRIBUTED FEEDBACK LASER

FABRY-PEROT LASER

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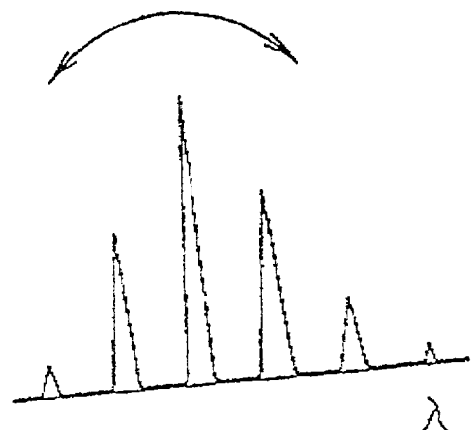
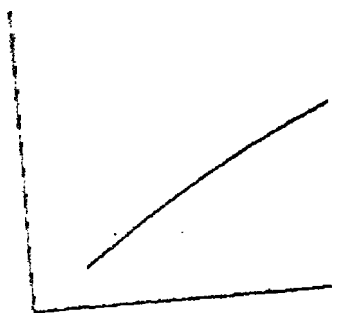
# MODE PARTITION NOIS
# FABRY-PEROT LASER



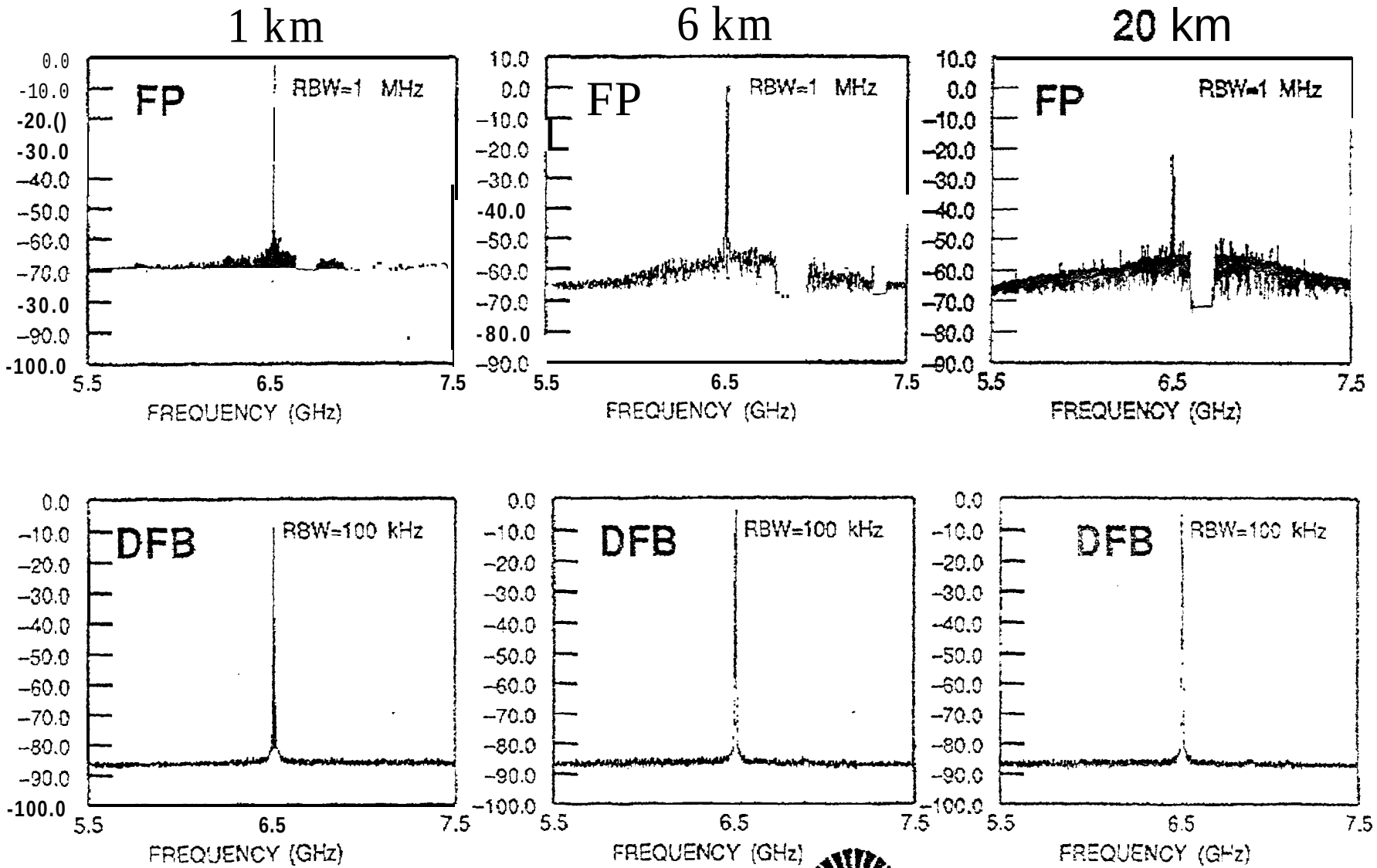

MODE HOPPING

+




DISPERSI

# SIGNAL INDUCED NOISE

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# MINIMIZING MODE PARTITION NOISE

- FABRY-PEROT LASER
  - * Control fiber zero dispersion point (ZDP)
  - * Set laser wavelength at ZDP
  - * Temperature tuning
- USE DFB
  - * No mode hopping
  - * Narrow linewidth
  - * Eliminate effects of dispersion



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# Spur-Free Dynamic Range

SFDR = 2/3 (IP3 - Noise)

<u>DFB LASERS</u>:

At 1 GHz,

$IP_3$ = 40 dBm
Noise = -137 dBm/Hz => SFDR = 118 dB-$Hz^{2/3}$

At 15 GHz,

IP3 = 30 dBm
Noise = -120 dBm/Hz => SFDR = 100 dB-$Hz^{2/3}$

<u>EXTERNAL MODULATOR (Standard Mach-Zehnder)</u>:

For 2 mA,

Output IP3 = -1 dBm
Shot Noise = -165 dBm/Hz
SFDR = -110 dBm - $Hz^{2/3}$

For 10 mA,

Output IP3 = 13 dBm
Shot Noise = -158 dBm/Hz
SFDR = -114 dBm - $Hz^{2/3}$



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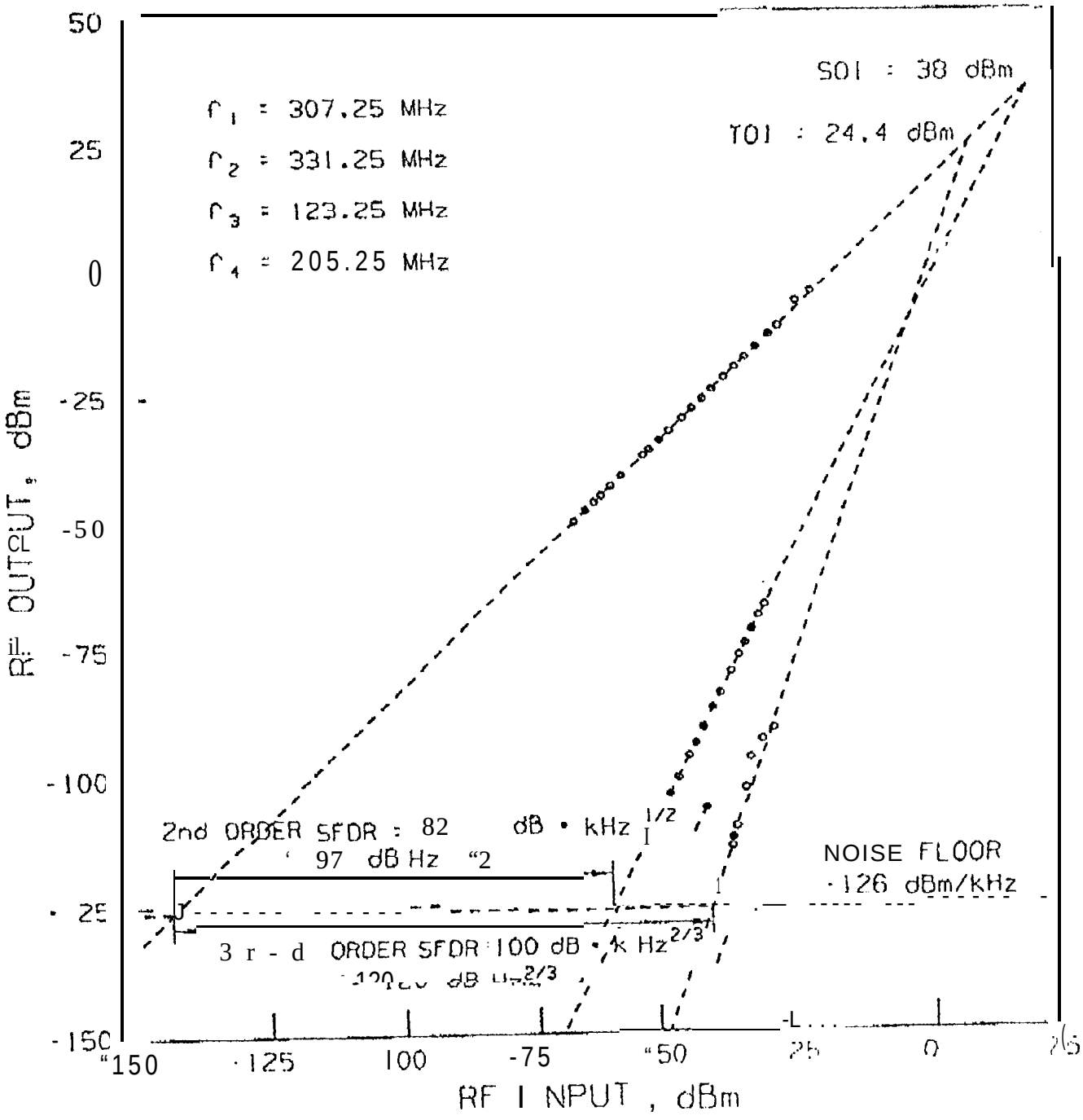
# MICROWAVE DFB LASER FIBEROPTIC LINK
## TWO - TONE INTERMODULATION DISTORTION

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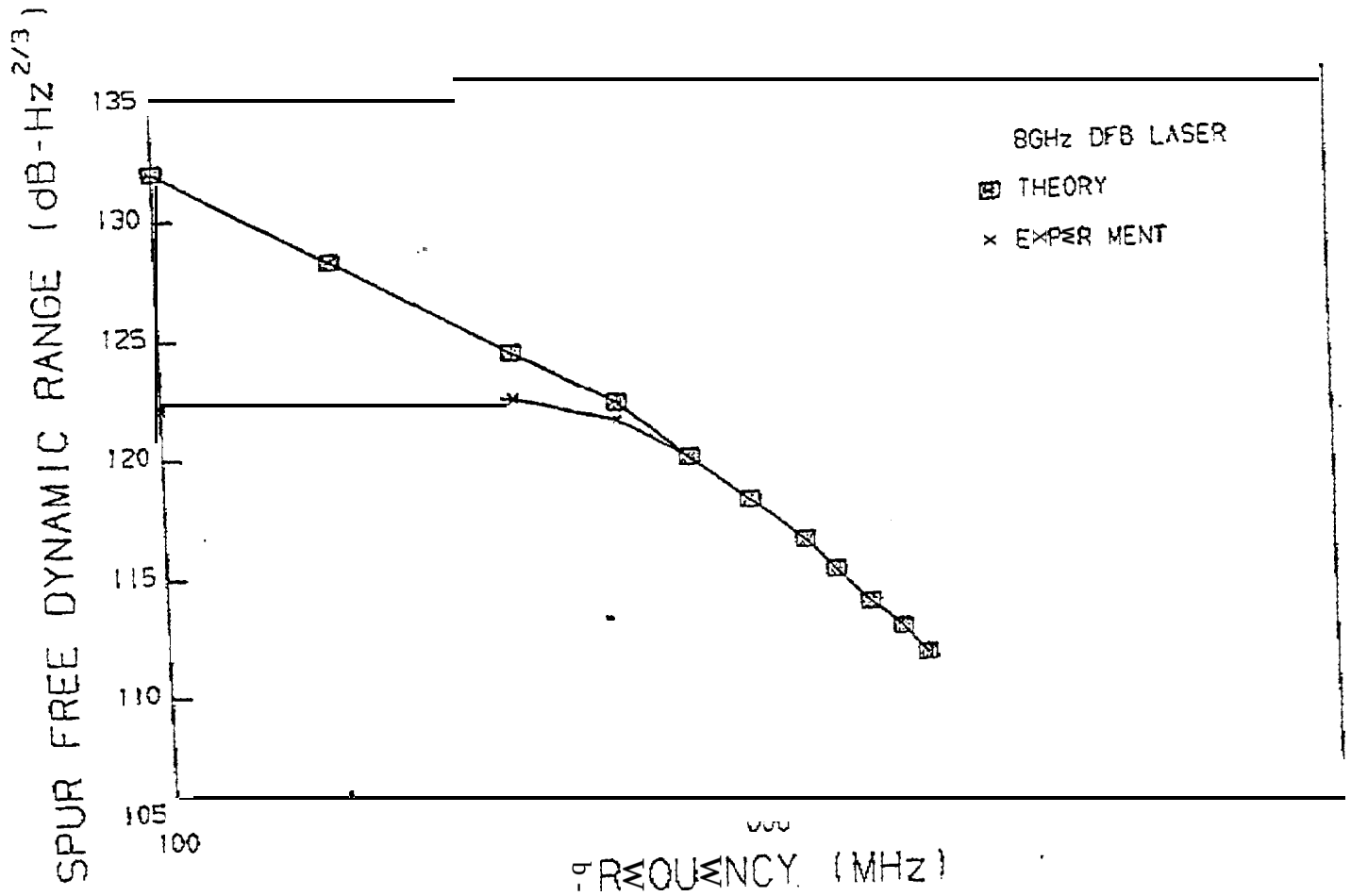


FIG. 2 SPUR-FREE DYNAMIC RANGE OF DIRECTLY MODULATED DFB LASER FIBER OPTIC LINK WITHOUT PREAMPLIFIER

# Link Performance Summary

| 50 MHz -1 GHz | | DFB Laser Link | | FP Laser Link | | External Modulator Link | |
|---|---|---|---|---|---|---|---|
| | | 1 km | 20 km | 1 km | 20 km | 1km | 20 km |
| Output Noise ($I_D$=2mA) | dBm/Hz | -164 | -162 | -155 | -137 | -165 | -165 |
| Output IP3 | dBm | 13 | 13 | 4 | -1 | -1 | -1 |
| SFDR | dBm-Hz$^{2/3}$ | 118 | 117 | 106 | 91 | 110 | 110 |
| Output Noise ($I_D$=10mA) | dBm/Hz | -153 | - | -141 | - | -158 | -158 |
| Output IP3 | dBm | 27 | - | 18 | - | 13 | 13 |
| SFDR | dBm-Hz$^{2/3}$ | 120 | - | 106 | - | 114 | 114 |

| 15 GHz | | DFB Laser Link | | FP Laser Link | | External Modulator Link | |
|---|---|---|---|---|---|---|---|
| | | 1 km | 20 km | 1 km | 20 km | 1km | 20 km |
| Output Noise ($I_D$=2mA) | dBm/Hz | -149 | -144 | -144 | -123 | -165 | -165 |
| Output IP3 | dBm | 1 | 1 | 1 | 1 | -1 | -1 |
| SFDR | dBm-Hz$^{2/3}$ | 100 | 97 | 97 | 83 | 110 | 110 |
| Output Noise ($I_D$=10mA) | dBm/Hz | -135 | - | -130 | - | -158 | -158 |
| Output IP3 | dBm | 15 | - | 15 | - | 13 | 13 |
| SFDR | dBm-Hz$^{2/3}$ | 100 | - | 97 | - | 114 | 114 |

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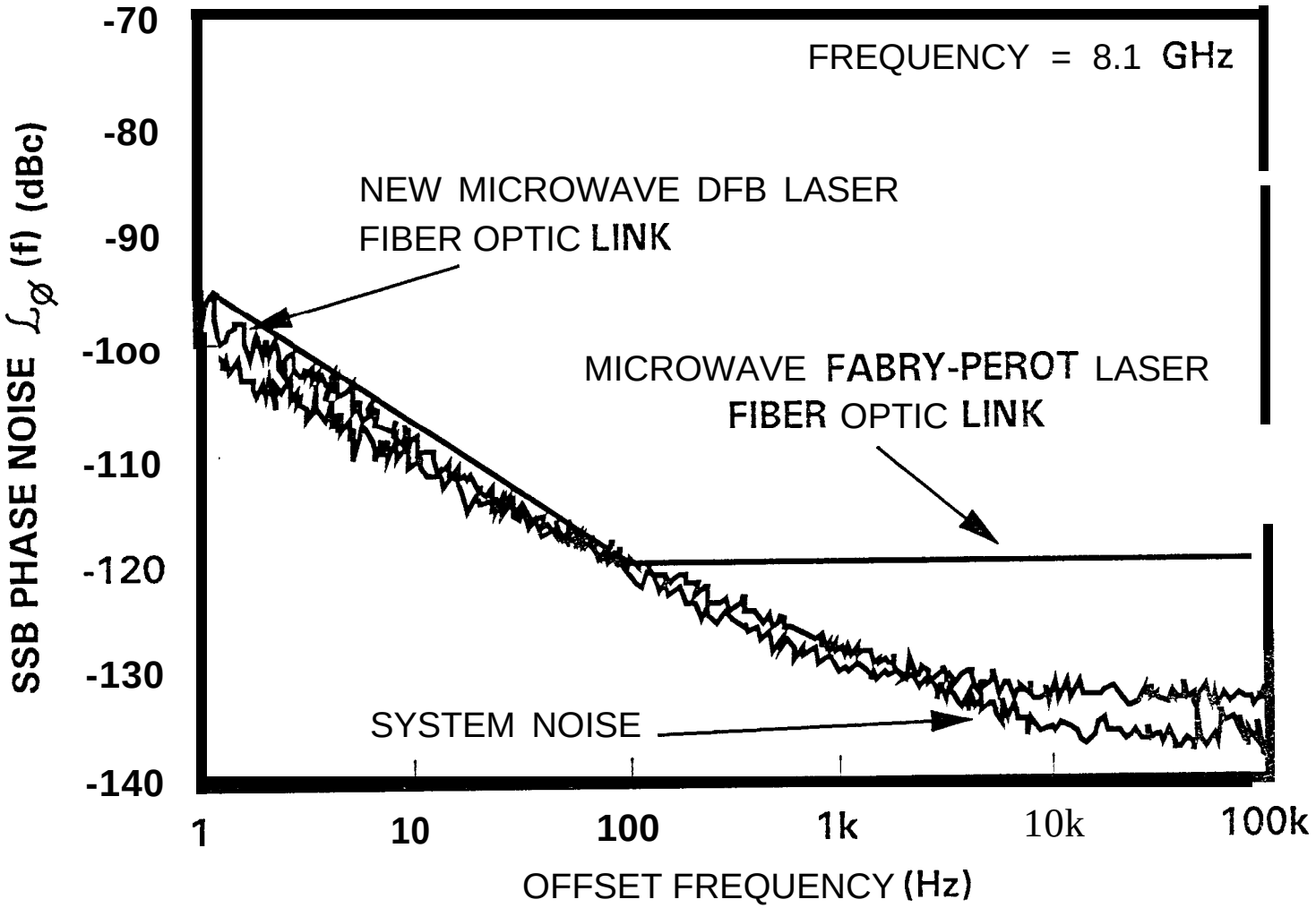
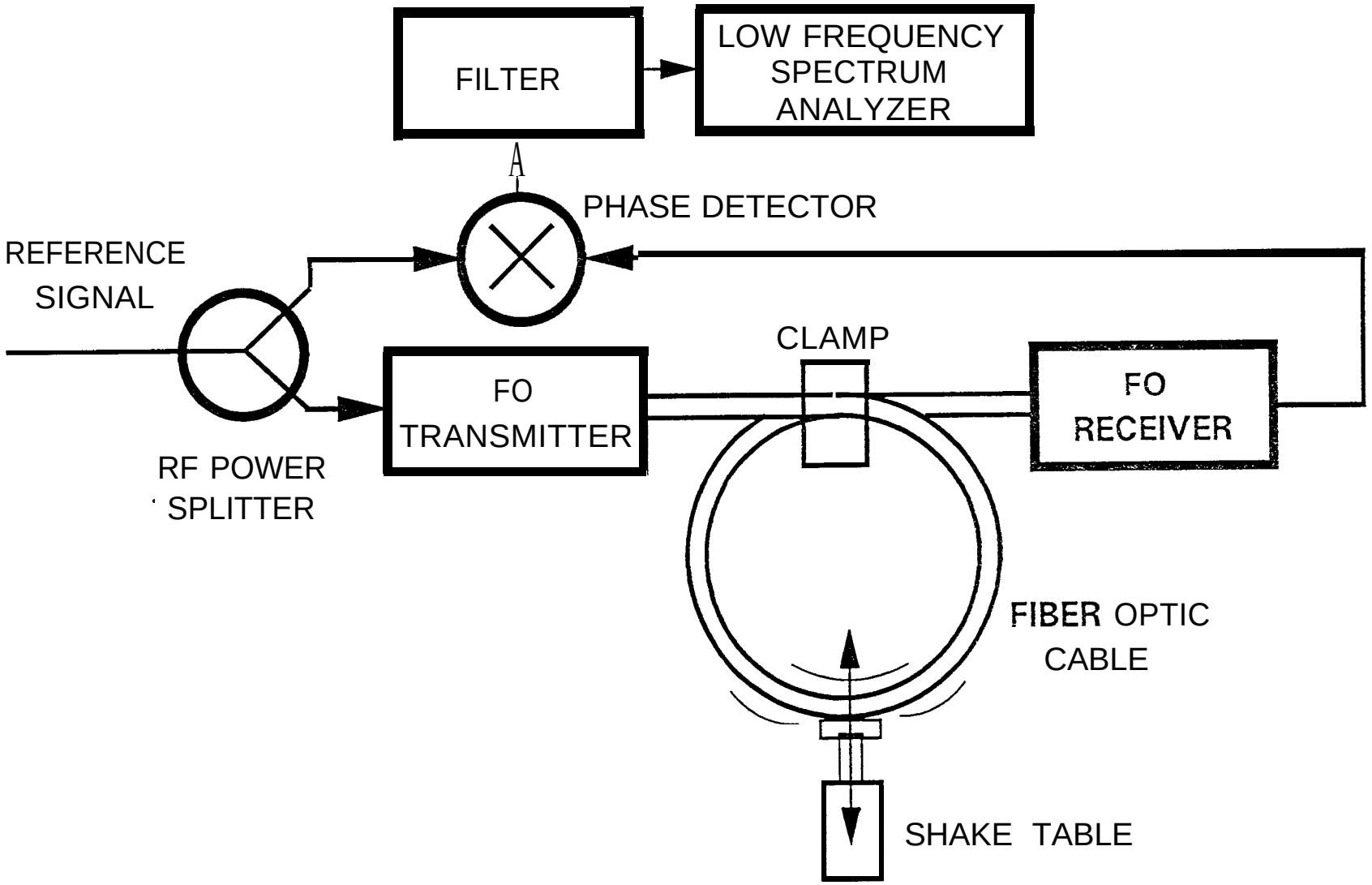
# MICROWAVE FIBER OPTIC LINK WITH DFB LASER

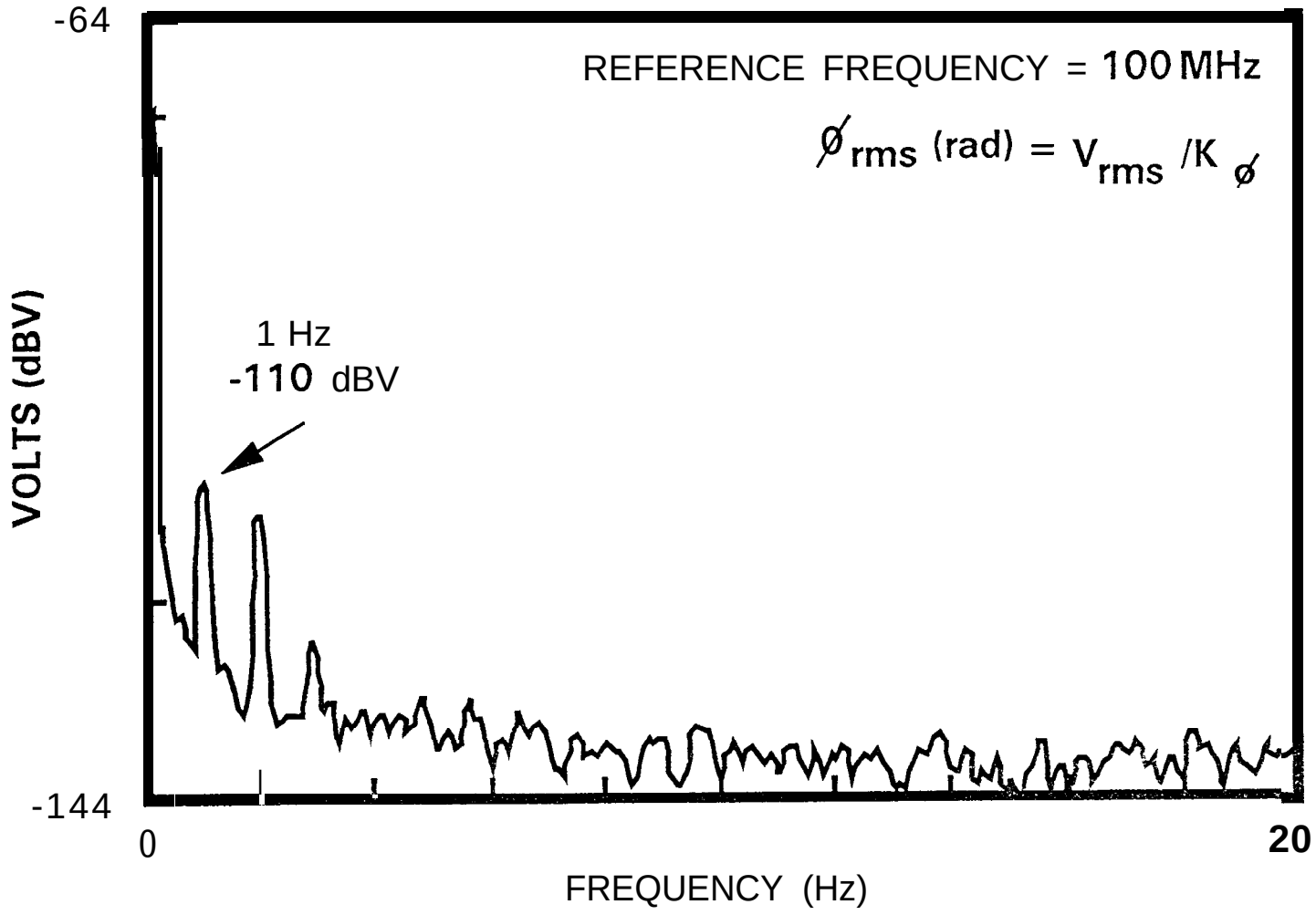


# DELAY CHANGE IN OPTICAL FIBER VERSUS CABLE FLEXURE MEASUREMENT METHOD

. JPL



# PHASE NOISE SPECTRUM DUE TO CABLE FLEXURE



# MINIMIZING PHASE NOISE AND IMPROVING DELAY STABILITY

- STABILIZE LASER TEMPERATURE
- STABILIZE THE RECEIVER TEMPERATURE
- MINIMIZE REFLECTIONS
- INCREASE LASER ISOLATION
- MAXIMIZE SIGNAL TO NOISE RATIO
- USE LOW THERMAL COEFFICIENT OF DELAY (TCD) FIBER
- PROTECT THE CABLE FROM THERMAL VARIATIONS, IWRY IT IN THE GROUND IF POSSIBLE

# THERMAL COEFFICIENTS OF DELAY

- FIBER OPTIC TRANSMITTER 3612B-EO1 — 0.33 ps/$^{o}$C
- FIBER OPTIC RECEIVER 4601A-EO1 — 3.6 ps/$^{o}$C
- STANDARD SINGLE MODE FIBER IN LOOSE CABLE — 7 ppm/$^{o}$C
- LOW THERMAL COEFFICIENT OF DELAY FIBER ($\leq$ 22 $^{o}$C) — $\approx$ 0.1 ppm/$^{o}$C

# CONCLUSION

- DFB LASER LINKS DEMONSTRATE SFDR OF 118 dB-Hz$^{2/3}$ UP TO 1 GHz
- FP LASERS EXHIBIT MODE PARTITION NOISE WHICH INCREASE NOISE BY $\approx$ 20 dB FOR 20 km LENGTHS
- SFRD OF EXTERNAL MODULATOR SYSTEM CAN BE SUPERB IF A HIGH POWER PHOTODIODE DETECTOR IS AVAILABLE
- PHASE NOISE AND DELAY STABILITY PERFORMANCE OF FIBER OPTIC SYSTEMS IS MUCH BETTER THAN CAN BE ACHIEVED WITH COAXIAL CABLES
- DIRECT MODULATION LASER LINK PROVIDES THE LOWEST COST SOLUTION IF IT MEETS PERFORMANCE REQUIREMENTS