GBT MEMO 239

Zspectrometer Installation Options

Steve White

Bob Simon

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Initial Specifications

Three physical location options are considered for the Zspectrometer. The options are:

1) Locate the spectrometer on the receiver room turret.*
2) Locate the spectrometer on the receiver room but off the turret.*
3) Locate the spectrometer in the equipment room.

*The receiver room is located at the secondary focus of the GBT. It houses (NRAO) feeds, receivers, and associated equipment. It also contains (contractor supplied) servo control equipment.

The specifications for the spectrometer are:

Components: 1 controller, 2 Power supplies, 8 correlators,
Size: 48"x54"x28"
Weight: Estimate 800 lbs, including rack, RFI shielding, and mount.
Power: 700 watts
Gain change due to temperature, bias change, vibration, etc: +/- 1.5dB
Differential mode gain change: 0.022 per root Hertz at 3 KHz phase switching, (fractional gain amplitude in $\Delta G_{rms}/G$)
Delay reproducibility: ± 6ps
Differential mode delay amplitude spectral density: <7ps per root hertz at 3 KHz phase switching frequency.
Input RF power level: -10 dBm nominal, -13 dBm to – 3dBm
Band flatness: ± 1.5 dB

1. Maximum rolloff with increasing frequency 0 dB.
2. Maximum rollup with increasing frequency 3 dB.

OPTION: Zspectrometer on Turret

This option reduces the electronic components from the output of the receiver to the input of the spectrometer. Essentially a cable of approximately one or two meters is needed to connect the device.

Weight and size:

The original GBT specification, (GBT specification, Rev B, 08/10/1993, sections 03.6.1.6 and 03.6.1.7) for (NRAO equipment) weight related to the receiver room states "a maximum of 3000 lbs, equally distributed on the turret, and a maximum of 2000 lbs off turret." The total on the turret is currently 5707 lbs, a 90% excess. The total off turret is currently 2716 lbs, a 36% excess. Installing the zspectrometer on the turret would increase the weight to 6507 lbs, a 117% excess. Reducing the on-turret and off-turret weights to the original 3000 lb and 2000 lb specs, would require removal of several receivers and racks. Installing the Zspectrometer while maintaining our current 5707 lbs will require significant equipment removal, such as the L-band and S-band receivers, along with their feed horns.

Receivers are installed on a 112 inch diameter bolt-circle about the center axis of the 14 foot diameter turret. We attempt to balance the turret load by placing receivers of similar weight opposite one another. Mounting the zspectrometer on the turret will offset this load balance, potentially causing pointing errors.

The mount required to secure the RFI equipment rack will require significant modifications to the turret structure. Drilling, welding, etc. on the turret is difficult at best, and must be avoided to prevent damage to existing equipment.

The size of the RFI rack will block access to other components on the turret.

RFI shielding:

Effectively shielding the rack considering a 40 to 50 dB of Rx Room shielding will be a difficult task requiring an expensive, heavy rack with extensive testing for RFI compliance.

Cooling:

Forced air cooling is not available on the turret.

OPTION: Zspectrometer off Turret in Rx Room

This option locates the spectrometer in a rack in the receiver room where there is adequate space and the additional weight is less of a concern. This option requires two 25 meter coax cables that meet the phase and stability requirement through considerable flexing in the cable wrap. Two drums connected with a flexible cable tray make up the receiver room cable wrap. The smaller drum is ~20" diameter, the larger ~40" diameter. During turret movement a cable simultaneously wraps on one drum and off the other.

Weight:

Adding the 800lb RFI equipment rack pushes the total off turret weight to 3516 lbs, or 76% over original specification.

Coax:

With the temperature controlled environment, the phase delay change versus temperature specification for a phase stable cable is achievable, less than 1 picosecond per 10°C delay change for phase stable cable. A recent 7-day plot of temperature vs. time inside the receiver room shows a nominal temp of 25°C +/- 1°C.

Cooling:

Forced air cooling is available if needed in the receiver room.

Andrew FSJ1-50A ¼" Superflex coax cable is commonly used for IF and LO signals on the GBT. The cable is flexible, and capable of numerous reverse bends, a requirement for any cable routed through the receiver room cable wrap. It is designed to operate up to 20.4 GHz. It is constructed with a foam polyethylene dielectric, to minimize phase change due to temperature variation. The following graph shows expected attenuation vs. frequency for a 25 meter cable.

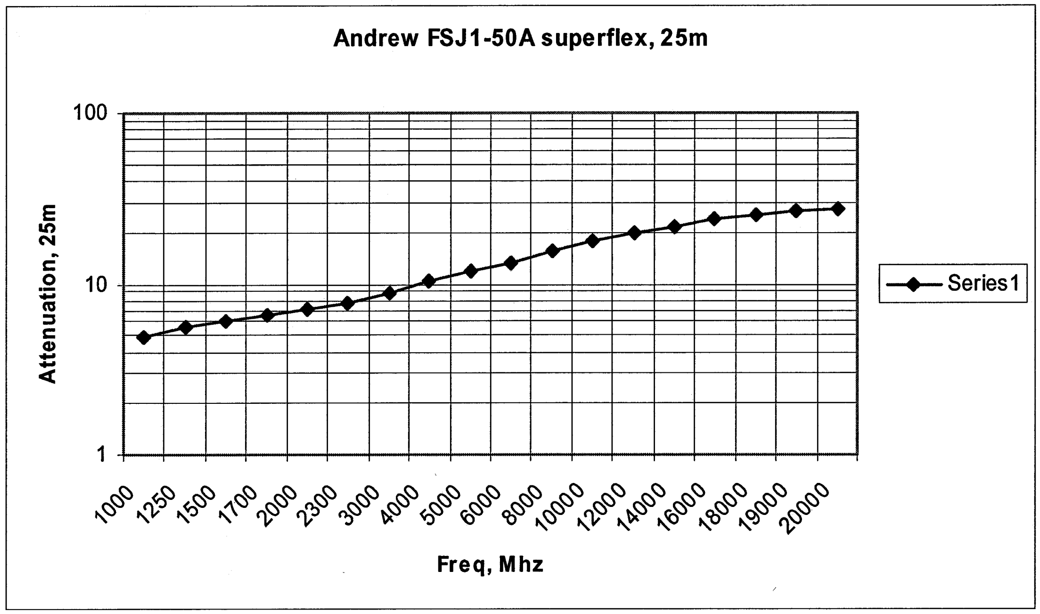

Figure 1 Andrews Cable Attenuation Slope

The considerable negative slope across the band as shown would need to be corrected.

Little is known about amplitude and phase changes under flexing in the cable wrap. Andrew states that "excellent" phase stability is accomplished by adhesively bonding all the cable components together, so that the cable bends on a neutral axis. For a 360° bend around a 1" radius mandrel, at a frequency of 18 GHz, FSJ1-50A heliax has a reported phase change of 3.5°.

The literature goes on to say that phase change with bending is not as repeatable or predictable as phase change with temperature.

Given the slope and phase/amplitude uncertainties of flexed coax cable along with no easement of RFI emissions, this option is not recommended.

OPTION : Zspectrometer in Equipment Room

Weight limitations on the GBT receiver room turret warrant investigating locating the Zspectrometer in the equipment room. Two optical transmitter modules are mounted next to the Ka-band receiver, and the signal send to the equipment room.

Weight and size:

No significant weight is on the turret. Existing turret equipment will not be blocked.

RFI:

Prior testing has indicated that the equipment rack will need to be RFI shielded if the unit is installed in the receiver room (see memo "Zspectrometer RFI Testing" by Carla Beaudet, October 20, 2005). From this memo, it appears that an RFI shielded rack will not be necessary if the unit is installed in the equipment room.

Maintenance/commissioning:

There is typically one 8-hour maintenance period each week, which allows access to the receiver room. If the rack is installed in the equipment room, access for maintenance is much less restrictive.

Cooling:

Forced air cooling is available if needed in the equipment room.

Fiber:

The Ka band 4-18 GHz frequency band would be intensity modulated onto 3 Km of SMF-28 fibers.

The GBT IF links have been thoroughly tested for amplitude stability with a corrective system implemented reducing the gain fluctuations due to polarization changes by 17 DB. The stress induced birefringence effects occur at frequencies less than 10 HZ. The perturbations are not known to cause spectral changes in the pass band. As evident from the Table 1, all photodiodes tested satisfy the amplitude stability spectral density requirement, since the energy density is contained in a 10 HZ bandwidth and the polarization dependent loss is sufficiently low.

Other parameters to consider are gain slope, noise temperature (loss), and linearity of the fiber links. As an example of specifications for a broad band optical link, the specifications for our current system are given; the Mach-Zehnder external modulator frequency response is given in Figure 1, and the New Focus 1414 photodetector is given in Figure 3. The loss of each link is 40 DB with a 45 DB noise figure. In order to reduce the effects of RFI intermodulation, the Mach-Zehnder, which has a raised cosine transfer function, are operated at -5 DBm input. This equates to a SNR of 23 DB for an 8 GHz bandwidth. The Ortel direct modulated laser diode link parameters have similar specifications, with a different transfer function. The Miteq transmitter contains a transimpedance amplifier which lowers the 1 dB compression point and the total noise figure of the link. The trade offs are similar for either method with SNR and integration times versus linearity effects being the primary concern. All the noise contributions are random, and thus integrate away with $1/\sqrt{B}\,\tau$.

Manufacturer	Detector	Bandwidth [GHz]	Polarization Sensitivity ΔG/G +/- σ
Ortel 1990	2510A	3.0	0.0270 0.0038
Ortel 1992	2510A	3.0	0.0069 0.0016
Ortel	2515A	10.0	0.0430 0.0047
Ortel	2516A	20.0	0.0304 0.0005
Ortel	2518A	15.0	0.0123 0.0034
Lasertron	QDMH2	10.0	0.0151 0.0009
New Focus	1414	25.0	0.0019 0.0009
New Focus	1434	25.0	0.0042 0.0037
New Focus	1514	6.0	0.0080
HP	HPDT0412	3.0	0.057 0.0010

Table 1. The photodetectors polarization sensitivity was measured with an 1100 MHz CW signal with the resulting power gain changes recorded. The New Focus 1414 model was chosen for the GBT IF link design.

The specification for phase stability is comparable with state of the art link designs. This was not a consideration for the GBT links, since round trip phase and phase calibration methods are used for correction. The ability of single mode FO links to provide very stable reference signals over many kilometers is well documented. NRA0-GB has not performed phase stability measurements at picoseconds resolution on our systems. We can, however, take the work from other laboratories, along with our LO reference delivery system data, to model the effects of temperature on absolute and differential phase delay.

The RTP measurement system measures the delay in a 500 MHz reference system over the 3 KM link from the equipment room to the receiver room. The GBT monitor records the phase delay and temperature. From this data, the phase delay versus temperature can be modeled by the equations:

$$\Delta t = \gamma\, L / v \;\; \Delta T$$

Comparing the phase delay over temperature from the RTP measurement systems yields the following results with

$\gamma = 7$ ppm/°C
$v = 300e6/1.5$
$\Delta T = 10$°C

The calculated length of exposed fiber is 425 meters with a corresponding diurnal cyclical time delay of 150 picoseconds. This over estimates slightly (~25 meters) the length of the cable on the telescopes since the 2.6 Km of buried cable is not included in the calculation. We can also reasonably expect the temperature never to change more than by 25°C over a 24 hour period.

These results agree with CARMA group paper by A. Navarrini, R. Plambeck and E. Fields entitled. "Thermal and mechanical tests of loose-tube and military tactical fiber-optic cables". Furthermore, these results in the paper indicate the differential phase delay can be reduced by 250 from the absolute delay, or 1 picosecond over a 24 hr period.

With the large bandwidth required by the Zspectrometer, dispersion effects also must be considered. The equation for dispersion is given by

$$D(\lambda)= S_o/4[\lambda- \lambda_o{}^4/ \lambda^3]$$

with constant values of the zero dispersion wavelength of 1310 nm, zero dispersion slope 0.092 ps/(nm*km) and operation wavelength of 1550 nm. With a bandwidth of 14 GHz and length of 3 Km the dispersion effects are 5.6 picoseconds. Dispersion is a deterministic measurable fiber quality; however, random variations must be assumed due to polarization mode dispersion. Since SMF-28 has a PMD of 0.1 ps/$\sqrt{\text{Km}}$, the random effects are negligible.

Conclusion:

The above analysis indicates the Ka band IF passband can be transmitted over a fiber optic link without compromising Zspectrometer technical specifications, while easing overweight conditions on the turret and in the receiver room. Three possible optical transmitters are considered: an Ortel direct modulated laser at 1310 nm; a Miteq direct modulated laser at 1550 nm and a Mach-Zehnder externally modulated link like currently used on the GBT. The Ortel transmitter is near zero dispersion wavelength; however, the input VSWR is near 3:1 at higher frequencies. The S21 appears response is flat to ± 1.5 over the three 4 GHz bandwidth segments. The Miteq transmitter improves the match into the laser diode with a microwave amplifier. In the standard model, this amplifier is a low power device with 1 dB compression point of -14 dBm. According to the applications engineer, the amplifier can be modified to increase the compression point with a corresponding increase in noise temperature. The Mach-Zehnder has VSWR less than 2:1 over the entire band, but with a more negative S21 slope. This technique uses a laser at the 1550 nm where dispersion is an issue. All modulators are comparable in price, $12Kquoted for the Ortel transmitter, $14K quoted for the Miteq, and $10K for the Mach-Zehnder. The MZ option requires an external laser which can be spared for $2k allowing repair in case of failure. The New Focus 1414 photo-detector should be considered even though the price is $3K above other models, since its polarization mode loss is an order of magnitude less than other models and conforms to the existing fiber optic system. Enough laser transmitter options exist to recommend locating the spectrometer in the equipment room with the final selection based upon pass band response, linearity, cost, and dispersion.

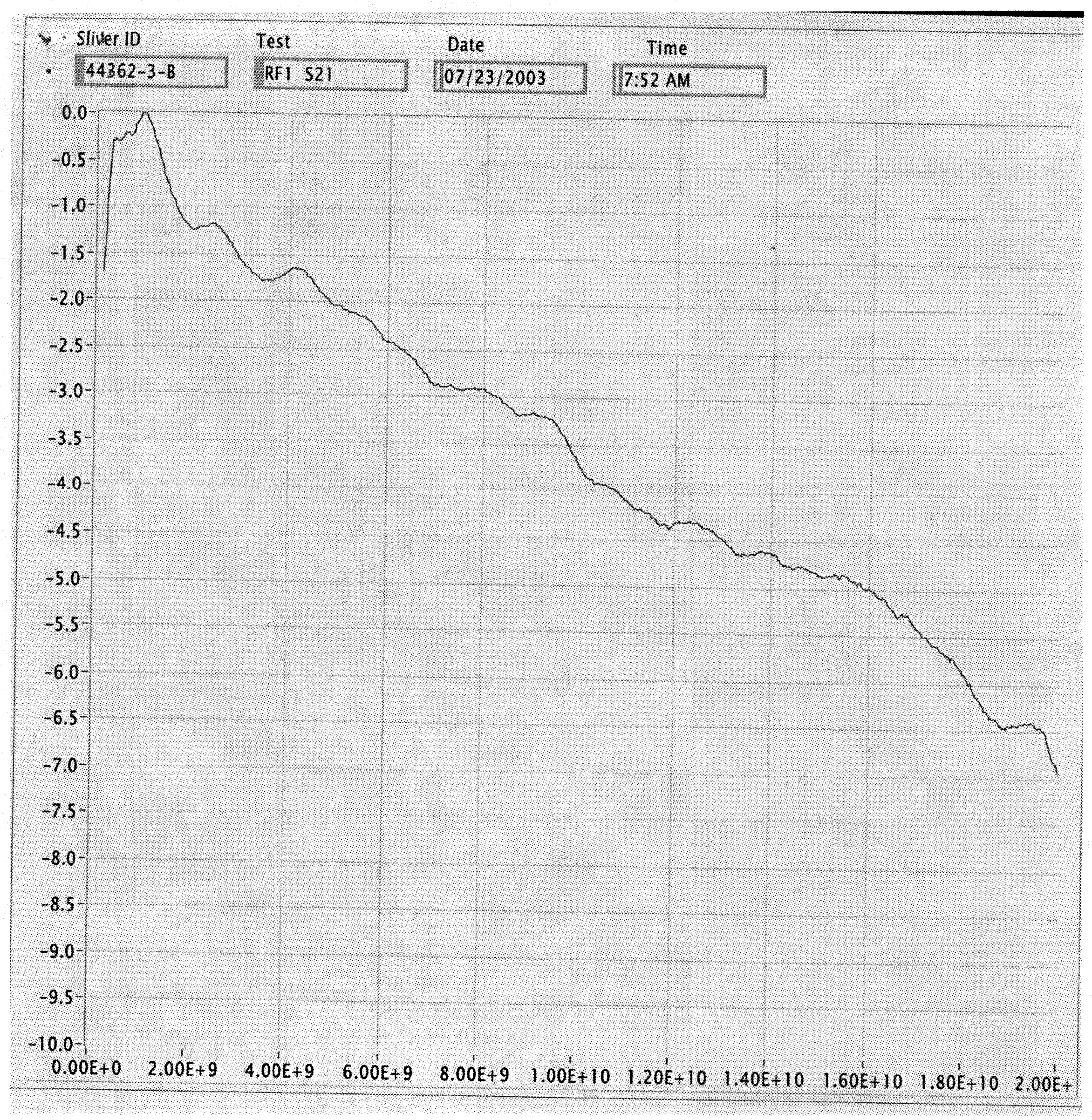

Figure 2 S21 response for MZ modulator. 1550 nm

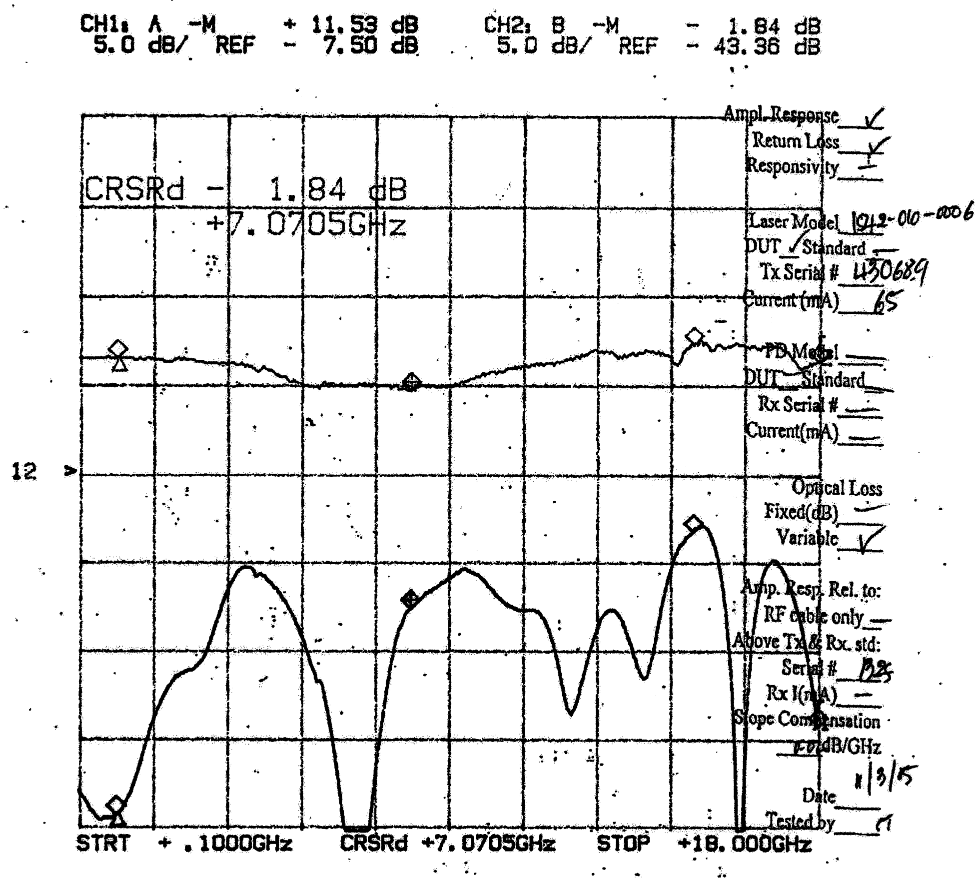

Figure 3 Ortel Laser Transmitter S Parameters. 1310 nm

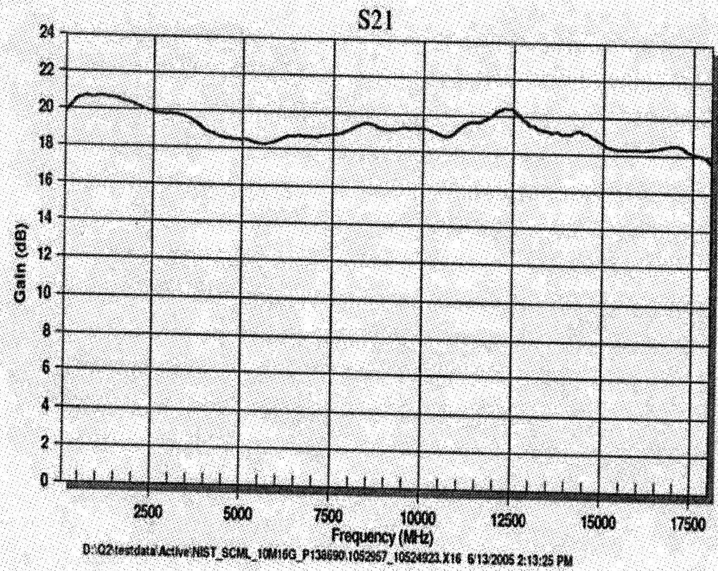

Figure 4 Miteq Laser Transmitter S21 response. 1550 nm

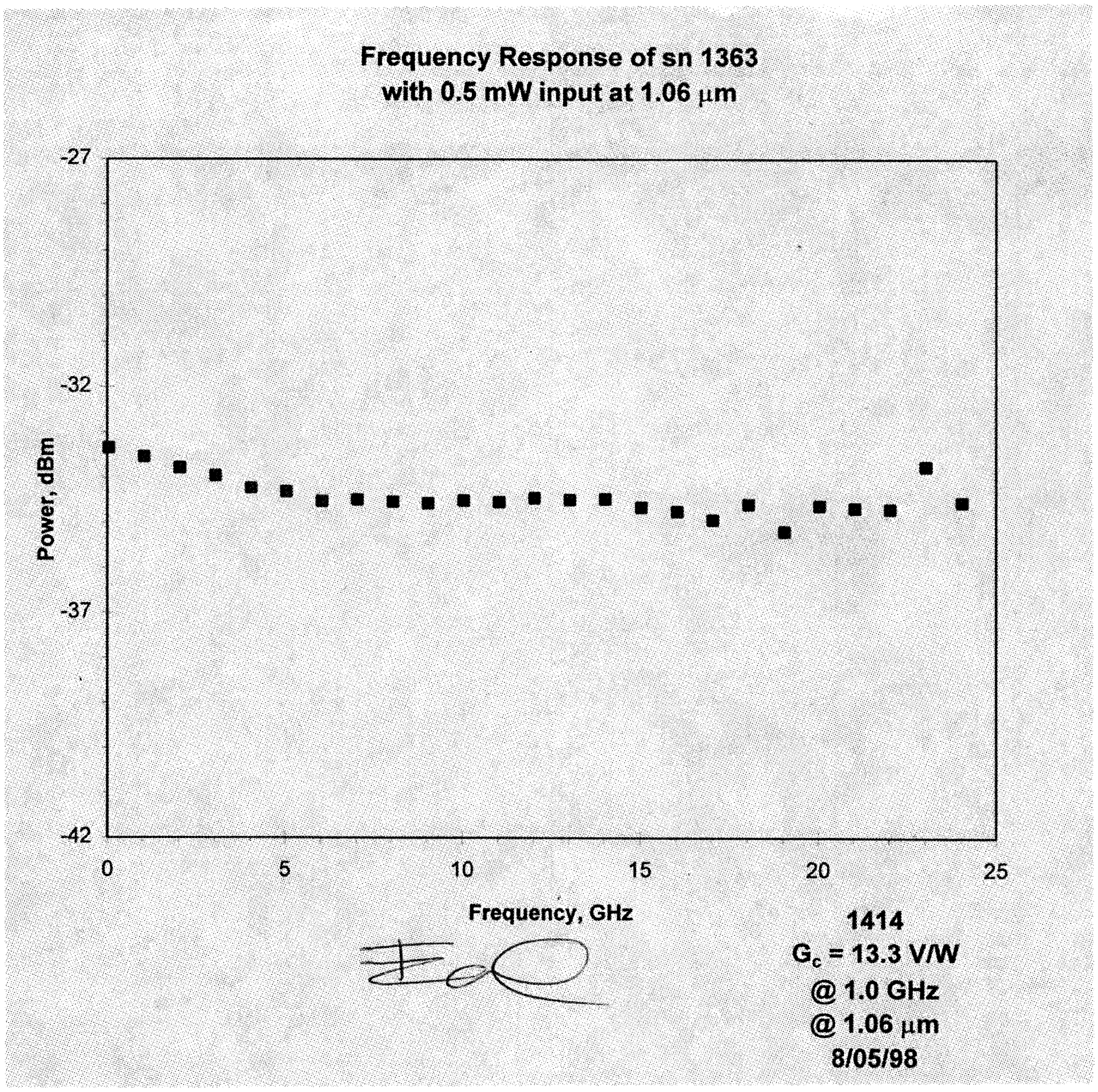

Figure 5 New Focus Photodetector Frequency Response