STATUS OF DEBUNCHER OPTICAL FILTER.

AUGUST 1988.

W. Kells

Comparison measurements, with low intensity $\bar{p}$ beam in the DB, of cooling with the filters on/off now exist. These tests may be judged as best efforts in that they were performed simultaneously with "expert" hand tuning up of the filter depth, dispersion, and machine tune (Q). Relevant comparison is with the detailed simulations of cooling w/wo filter done during the filter design phase with J. Marriner's ~~progr~~ Fokker-Planck program ("FPINT"), and modified ~~for~~ to include the filter effect. Full results of these simulations have already been distributed

as an interim report.

In the measurements, final emittances $\varepsilon_{H,V}(\tau)$ were measured for fixed $\varepsilon_{H,V}(0)$ ~~and~~ fixed initial $\bar{p}$ number and fixed TWT output power. What do we expect ideally? A perfect filter (∞ deep notches; no dispersion; exact $Q = 9.750$ and zero $\Delta p/p$ beam) achieveds, according to the simulations:

$$R(\tau) \equiv \frac{\varepsilon(\tau) - \varepsilon(0)}{\varepsilon(\tau)} \sim 0.3 - 0.5$$

for a <u>thermal noise</u> limited system ($\lesssim 2\times10^7\,\bar{p}$) and for the $1 < \tau < 25$sec of interest. The range of effect depending variously on particle number, PU/K gap and initial $\varepsilon(0)$. For conditions of our best measurement data (winter 1988) at $\tau = 2$sec. ~~$R_H(\tau) = 0.20 - 0.29$ was measured and th~~ The simulation predicts $R(2\text{sec.}) \approx 0.3$. The best measurements (Horizontal cooling system) were $R_H(2\text{sec}) = 0.22 - 0.29$.

The actual performance ought to be worse than the ideal prediction for the following reasons:

1. NOTCHES not ∞ deep due to correlator amplitude imbalance [with frequency]. Our links can ~~have~~ be adjusted to have less than 2db imbalance (2-4 GHz) which corresponds to and agrees with typical notch depths of $\lesssim 25$ db

for well adjusted bench systems (using a variable attenuation trimmer). The operational ~~AB~~ systems show notch depths from 15 – 25db. For 20db notches the filter reduces thermal noise by ~10% less than it ideally should. This effects $R(\tau)$ in the same proportion.

2. Filter dispersion. The ideal filter's periodic transfer function should present zero phase change for the signal from <u>each</u> $\bar{p}$. In a coding model where each band is independent call Δ_i the phase error (band i). Then

$$R_{\Delta}(\tau) \approx R_{\Delta=0}(\tau)\left(1 - \frac{1}{2}\Delta^2_{RMS}\right)$$

Practically Δ_i has two components. First, a <u>zero phase</u> offset, Δ_0; second a true dispersive component which varies band to band. (i.e. the residuals $\Delta_i - \Delta_0$). Consider the case of an ideal <u>linear</u> correlator ($\Delta_i - \Delta_0 = 0$). but with a $\Delta_0 \neq 0$ and with line length τ_L. Clearly adjusting $\tau_L = \tau_0$ (mean $\bar{p}$ revolution period). is <u>not</u> the best choice for minimizing Δ^2_{RMS}. In fact one chooses $\tau_L \ni \Delta_{3GHz} = 0$ and obtains.

$$\Delta^2_{RMS} = \tfrac{1}{9}\Delta_0^2$$

Typical optical fiber link residuals ($\Delta_i - \Delta_0$) are $\pm 5°$ <u>peak</u>. with $\Delta_0 \lesssim 10°$ (w.r.t. 180°)

this gives a reduction in $R(\tau)$ of only 0.3%
Best bench constructed correlators, I have constructed, ~~achie~~ routinely achieve $\Delta_0 \lesssim 10°$ and $(\Delta_i - \Delta_0)_{peak} \lesssim 18°$. This would reduce $R(\tau)$ by 2.5%.

On the other hand the installed DB filters:

$$H: \quad \Delta_0 \simeq 36° \; ; \; (\Delta_i - \Delta_0)_{peak} = 8°$$
$$V: \quad \Delta_0 \simeq 18° \; ; \; (\Delta_i - \Delta_0)_{peak} = 3°$$

So that the offset dominates and reduces $R(\tau)$ in the worst case by 10%

3. Lattice / beam effects. The considerations of 2. apply only to particles of precisely $\Delta Q = 3/4$. If $\bar{Q}_{DB} = 9.750$ exactly there is still an RMS contribution to Δ_{RMS} from beam momentum spread. For a square $\Delta p/p \leq \pm 0.15\%$ this would give $\leq 8\%$ Reduction in $R(\tau)$. This quantitatively agrees with simulations of the same effect in the Fokker-Planck routine.

Potentially more serious is the inevitable departure of $\bar{Q}_{DB}$ from 9.750. <u>Unlike the Δ_0 phase offset affect discussed above</u>, this $\Delta Q \neq 0$ cannot be compensated for by adjusting $\tau_{line} - \tau_0$. Thus the deviation enters Δ_{RMS} as a <u>peak</u>, not an RMS influence. To illustrate, our best filter on/off measurements were taken with

$Q_H = 0.758$; $Q_V = 0.791$. This would reduce $R_H(\tau)$ by 0.5% and $R_V(\tau)$ by >13%. Indeed, the best data was on Horizontal.

Thus it is not suprising that $R_{meas.}(\tau)$ is $\approx 15\%$ worse than ideally predicted. Nothing can be done about the ~8% degredation due to $\Delta p/p$ (larger in future upgrades!). <u>With respect</u> to this benchmark <u>the present optical links</u> are, themselves, ~~perfect!~~ ideal w.r.t. phase errors (dispersion) Improvement can come as follows:

Ⓐ $Q_{H,V.}$ must be kept below $\Delta Q \approx 0.02$ from quarter integer. Should be easy (?).

Ⓑ The trade-off in τ_L v.s. Δ_0 must be carefully implimented. Presumably the <u>best</u> prescription (section 2. above) is automatically accomplished by on line adjustment of the entire system with the NA phasing program (and <u>not</u>, e.g., by setting f_0 of the off line nnotch program to be equal τ_0^{-1}).

Ⓒ The installed correlators have $\Delta_0 >>$ that possible in bench setups. This is not suprising since different components are used; especially <u>in-</u>correlator amplifiers. Thus as much improvement as is meaningfully possible <u>can</u> be had with existing components.

(D) Aside from the $\Delta\rho/\rho$ effect it is possible to reduce degredation as outlined in (A), (B) & (C) such that finite notch depth dominates. Network analyser (nnotch) studies of the correlator indicate an effective notch depth of 20-25db (or a few % $R(\tau)$ degredation). However in real operation low spectral density noise is filtered and optic link dynamic range becomes an issue. Careful bench tests show that our links will carve > 30db deep notches out of broadband noise (no notch less than 22db deep!) The critical adjustment is total RF power into the link. If too high I.M. distortion limits dynamic range. If too low photon statistics noise does. The claim (Optical filter Tech. Spec. note of Oct 12, 1987) has been made that this dynamic range is the major limitation to notch depth. We see that it is actually from correlator component mismatch! (≳ 3.0dbm recommended $P_{IN,TO}$

LONG TERM STABILITY

It was first pointed out by Fritz Caspars that the ultimate problem with optical link delays could be laser diode light output stability since the notch depth critically depends on CONSTANT optical link INSERTION LOSS. ORTEL finds no evidence for laser degredation and our prototyping

as well as early experience bore this out. However we have observed changes in link monitor values over the last 6-9 months:

	V	H	spare
DET. MONITOR	4.0 → 2.94 V	3.1 → 2.76 V	5.5 → 2.2 V
INSERT. LOSS	< 1-2 db higher	< 1-2 db higher	~10 db higher
LASER MONITOR	no chng.	no chng.	no chng.

obviously less light gets to the diode receiver. The (unused!) spare seems worse. Insertion loss of the installed units, as measured by notch depth has not appreciably suffered (this remains to be studied in detail, off line). However the laser's own monitor indicates no change!! Are we seeing Fritz's fears? Perhaps <u>all</u> the receivers are dying?

Extensive bench tests on the "spare" chassis HAVE BEEN CONDUCTED. In all respects (e.g. gain & phase relative response) the link seems the same <u>except</u> for the net <u>increased</u> insertion loss and D.C. light throughput. By testing various laser/receiver combinations (several "old" units exist in the lab) on which good data exists it is possible to show that the light is lost <u>in</u> the laser or its integral pigtail. In particular the necessary joints (splices) in the fiber link are

at most minor contributors. Fig. 119 and consultation with ORTEL tell a consistant story. They admit a <u>mechanical</u> design "fault." The laser chip and fiber end are fixed to separate substrates & epoxed together accross a gap. The alignment can change with time (mostly epoxy "set" effects). On the other hand the laser monitor diode floats <u>on</u> the laser chip: so is not prone to change. Thus, the fact that the laser monitor has <u>not</u> changed, indicates that the laser is still O.K. (no CASPARS effect!). They claim that this is mostly non-thermal none-operating lifetime related: consistant with both installed & spare degrading. Fig 119 shows how it is possible for one unit to show much more <u>insertion</u> loss. When new the light level is sufficient to <u>not</u> effect insertion loss (≈ zero slope). Then the received light can fall-off a lot before insertion loss is greatly affected. Apparently our "spare" is just farther along the curve drawn. It is not possible to determine whether the installed units will stabilize or continue to degrade.

ORTEL no longer makes the TYPE LASER AND RECEIVER (NOTE: SAME DESIGN FLAW LURKS IN THE RECEIVERS AS well!). The chips & substrate MOUNTING HAS BEEN ENTIRELY REENGINEERED TO PRIMARILY ADDRESS THIS problem:

1. NO STABILITY PROBLEMS
2. Thermo ELECTRICALLY cooled ⇒ less "CASPARS" EFFECT
3. Better R.F. μ STRIP CONNECTIONS ⇒ flatter Response. (see NEXT SECTION ON → 10 GHz LINKS).
4. Light matching to fiber is better ⇒ less Reflection / REGENERATIVE gain ripple problems.

The less important difficulties with fiber splices can be remedied by using fusion splicing (which we're successfully used).

Higher FREQUENCY LINKS.

I have been working with ORTEL to pin down the performance of their > 10 GHz LINKS (DP-1501C and DP-2501C). It has been hard (impossible) to get representative DATA. (all I've got my hands on are "prototypes" which are not up to snuff or data whose conditions of taking I cannot vouch for). Their work seems devoted to one large defense CONTRACT which immediately sucks up all good UNITS. However the best data looks excellent (Figures). The gain and phase from 4-8 GHz are only 2 times WORSE IN VARIATION THAN the best Links we've seen already (2-4 GHz). Ripple still dominates the variations. ORTEL claims that the ripple will

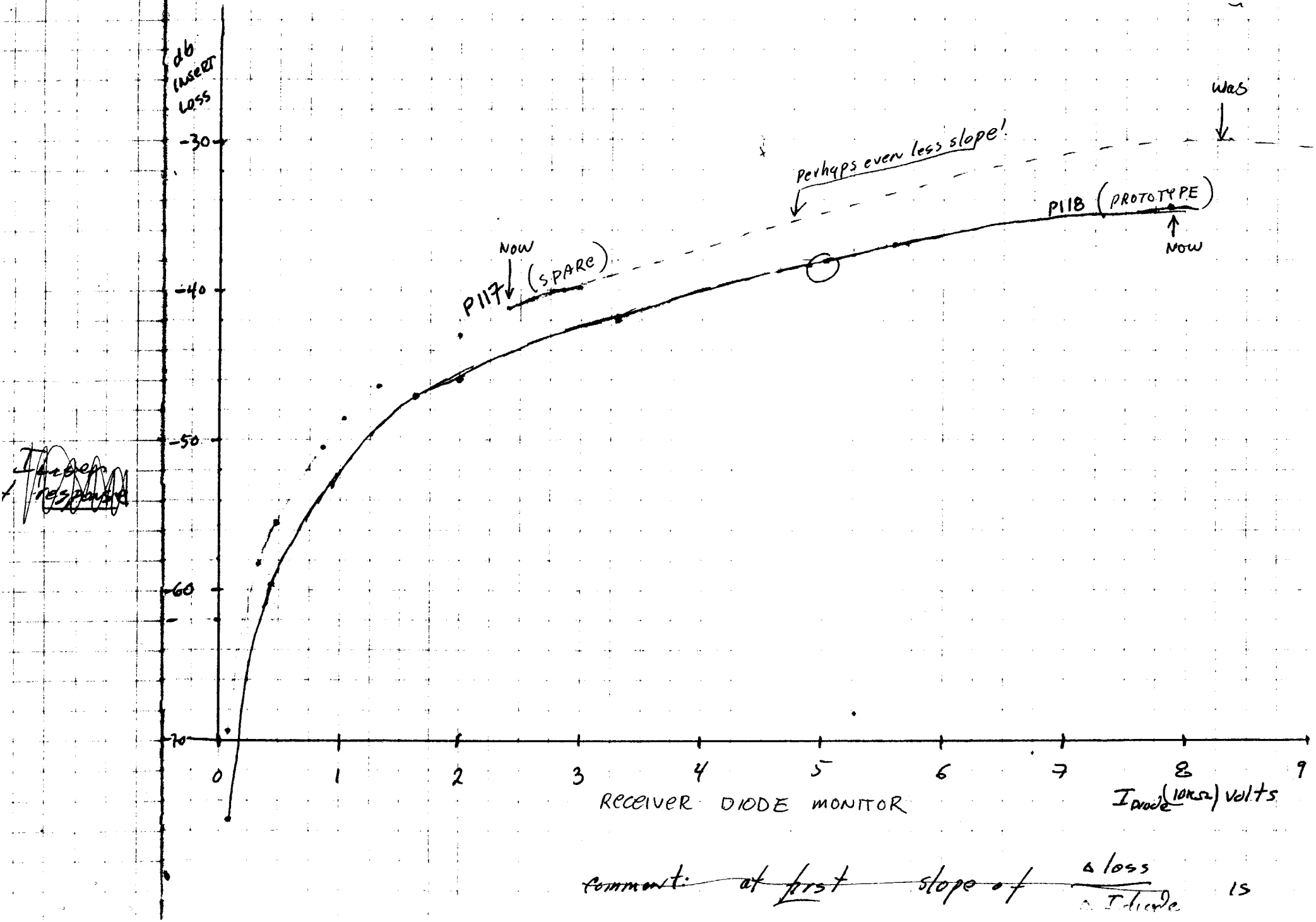
be absent on "delivered" units.

These high frequency units employ all the mechanical & RF circuitry improvements mentioned in the last section. They should be long term stable.

NETWORK ANALYSER PROBLEMS.

It should be emphasized that N.A. measurements involving phase deviations of, e.g. ±5° (with comparable offsets) over 2-4; 4-8 GHz, etc. are subtly and deceptively difficult. I have found that mild bending of the CALIBRATION sma cables from N.A. to D.U.T. can easily give comparable diviations! My final figure illustrates a fault we have found in the 8510B N.A. This fault prevents agreement between measuring a link's length with N.A. "electrical delay" and with the nnotch program. It allows ambiguities in "DISPERSION" of the ~~amounts~~ size we ~~have~~ are attempting to measure.

FIG. 119



~~comment: at first slope of $\frac{\Delta \text{loss}}{\Delta I_{diode}}$ is~~

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360 NETWORK ANALYZER

MODEL: KU_BAND_LINK DATE: 6/30/88 Page 1
DEVICE ID: I_70MA OPERATOR: G_GRIMES

SWEEP DATA

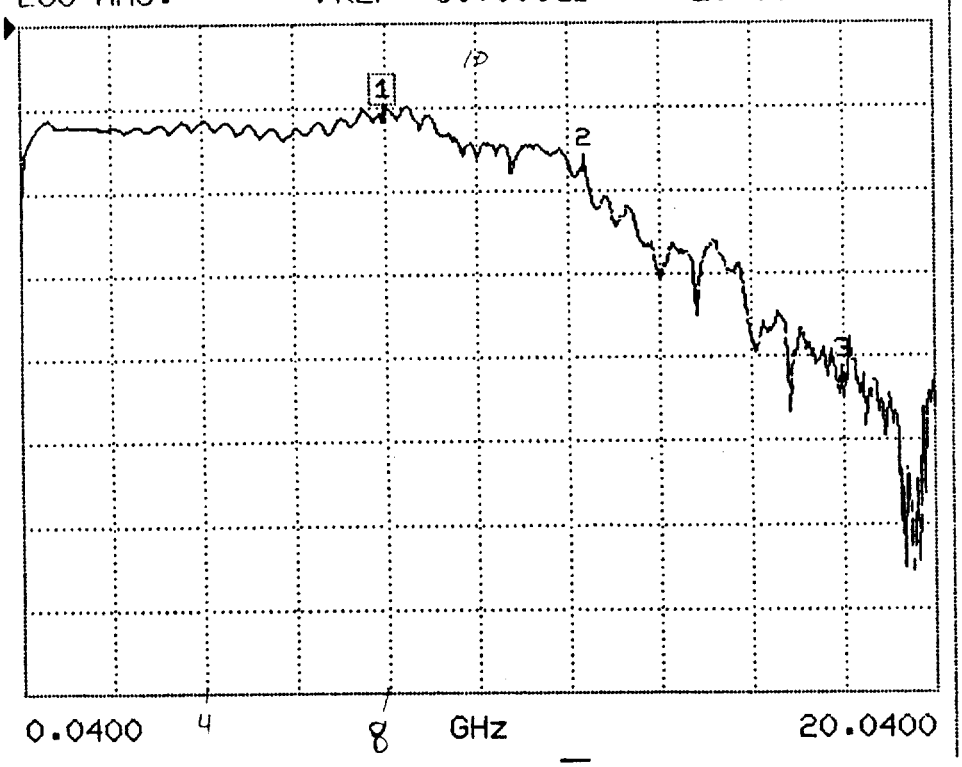
START:	0.0400 GHz	GATE START:	-	ERROR CORR:	12 - TERM
STOP:	20.0400 GHz	GATE STOP:	-	AVERAGING:	1 PTS
STEP:	40.0 MHz	GATE:	-	IF BNDWDTH:	REDUCED
		WINDOW:	-		

----------CH3----------

S-PARAMETER:	S21
NORMALIZATION:	OFF
REF DELAY:	21.166 ns
SMOOTHING:	0.0 PERCENT
DELAY APERTURE:	-

S21 FORWARD TRANSMISSION

LOG MAG. ▶REF=-30.000dB 10.000dB/DIV



CH 3 - S21
21.166 ns div

▶MARKER 1
8.0000 GHz
-41.412 dB

MARKER TO MAX
MARKER TO MIN

2 12.4000 GHz
-47.401 dB

3 18.0000 GHz
-72.840 dB

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360 NETWORK ANALYZER

MODEL: KU_BAND_LINK DATE: 6/30/88 Page 1
DEVICE ID: I_70MA OPERATOR: G_GRIMES

SWEEP DATA

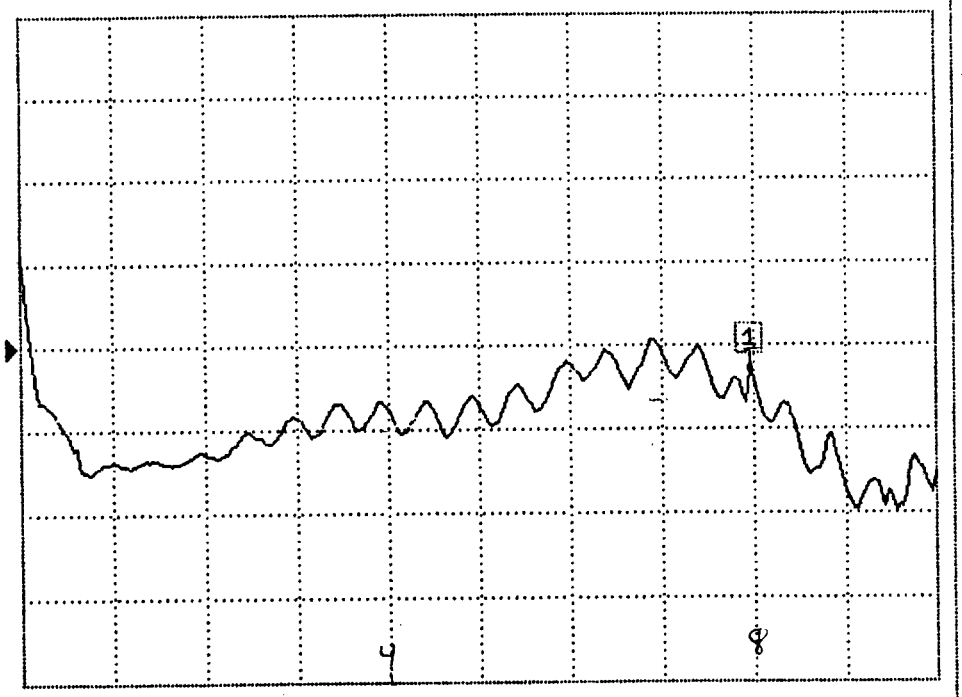
START:	0.0400 GHz	GATE START:	-	ERROR CORR:	12 - TERM
STOP:	10.0400 GHz	GATE STOP:	-	AVERAGING:	1 PTS
STEP:	40.0 MHz	GATE:	-	IF BNDWDTH:	REDUCED
		WINDOW:	-		

----------CH3----------

S-PARAMETER:	S21
NORMALIZATION:	OFF
REF DELAY:	21.155 ns
SMOOTHING:	0.0 PERCENT
DELAY APERTURE:	-

S21 FORWARD TRANSMISSION

PHASE ▶REF=-140.00° 20.00°/DIV



0.0400 GHz 10.0400

SWEEP SETUP

START
0.0400 GHz

▶STOP
10.0400 GHz

251 DATA PTS
USING ABOVE
START AND STOP
40.0 MHz
STEP SIZE

C.W. MODE OFF

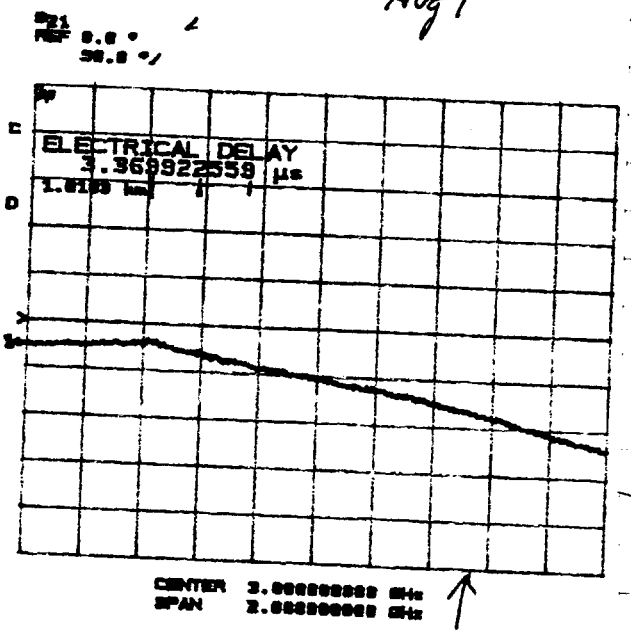
MARKER SWEEP

HOLD BUTTON
FUNCTION

REDUCED TEST
SIGNALS

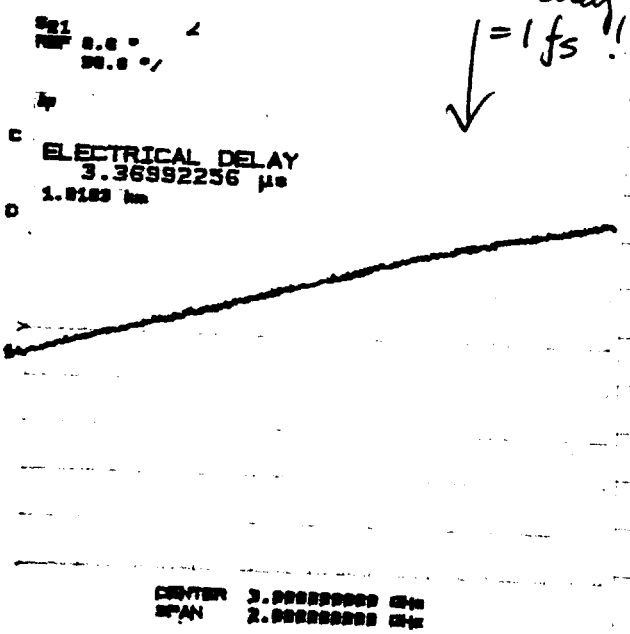
PRESS ◀ENTER▶
TO SELECT
OR TURN ON/OFF

Avg 9



Better pic of NA. problem!

(link alone ⟺ DUT)

$\Delta\tau_{delay} = 1\,fs$!!

only change is knobing of "ELECTRICAL DELAY"