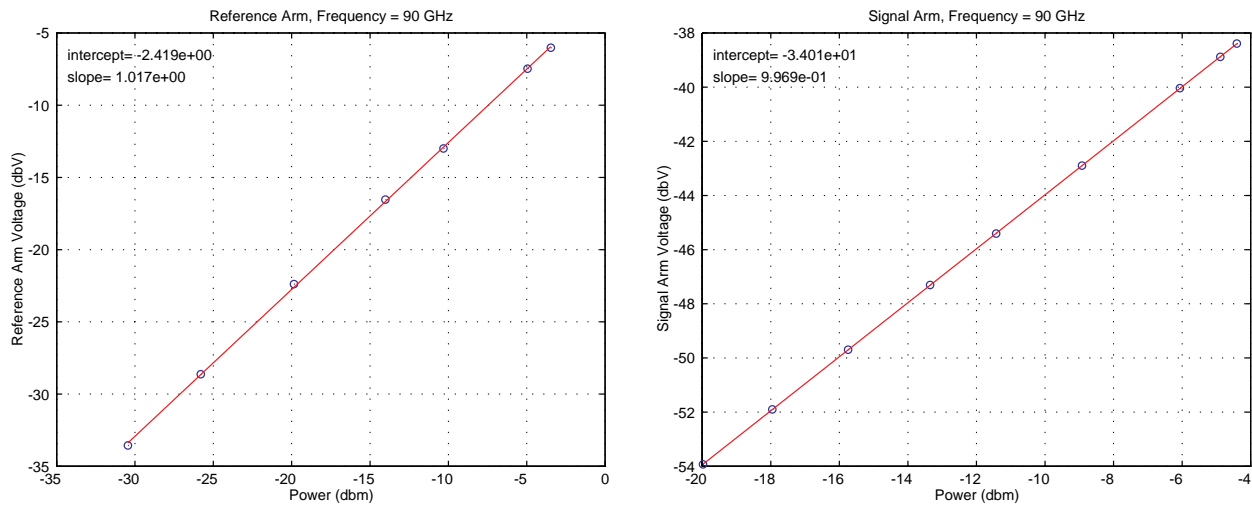


Calibration of W-Band Measurement Apparatus and Results for First Structure

An HP 437B Power Meter and W8486A Power Sensor were purchased for use in calibrating the W-band measurement apparatus. This note documents calibrations and also presents the results for the first W-band structure. A schematic of the apparatus is reproduced on the next page. For the measurements reported here the "reference" and "signal" detectors were

Arm	Mixer	Coupler
Reference	HP 2521A01227	Hughes 45326H-1120 #30 (20 db)
Signal	HP 2521A01274	Hughes 4532641-1320 #021 (20 db)

First, the linearity of the reference and signal with power were measured. The results are in the figure below. The conclusion is that both are linear with power.

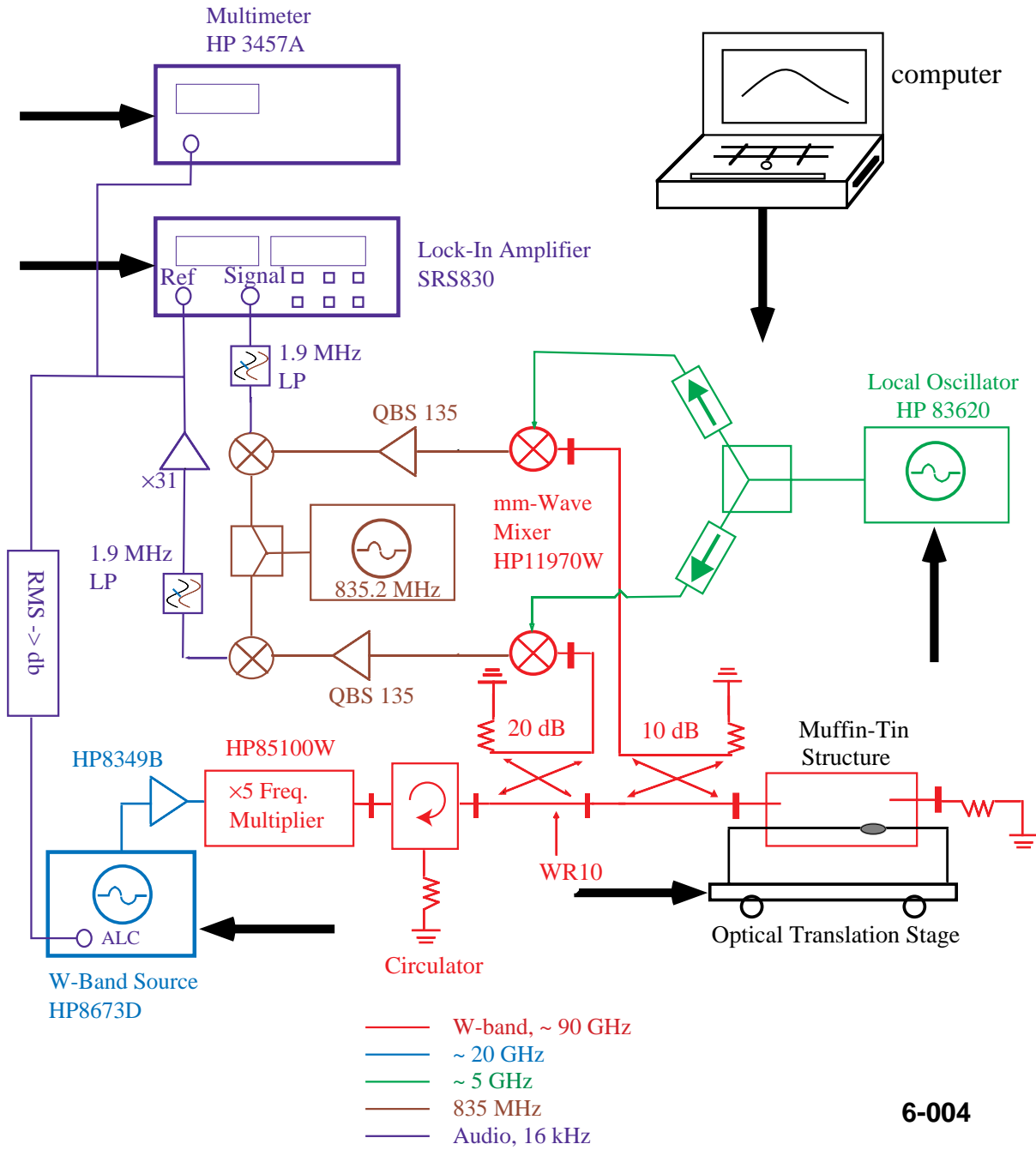


The relationship between the measured voltage and power can be written as

$$\text{Voltage(dbV)} = \text{Power(dbm)} + \text{Intercept} \quad (1)$$

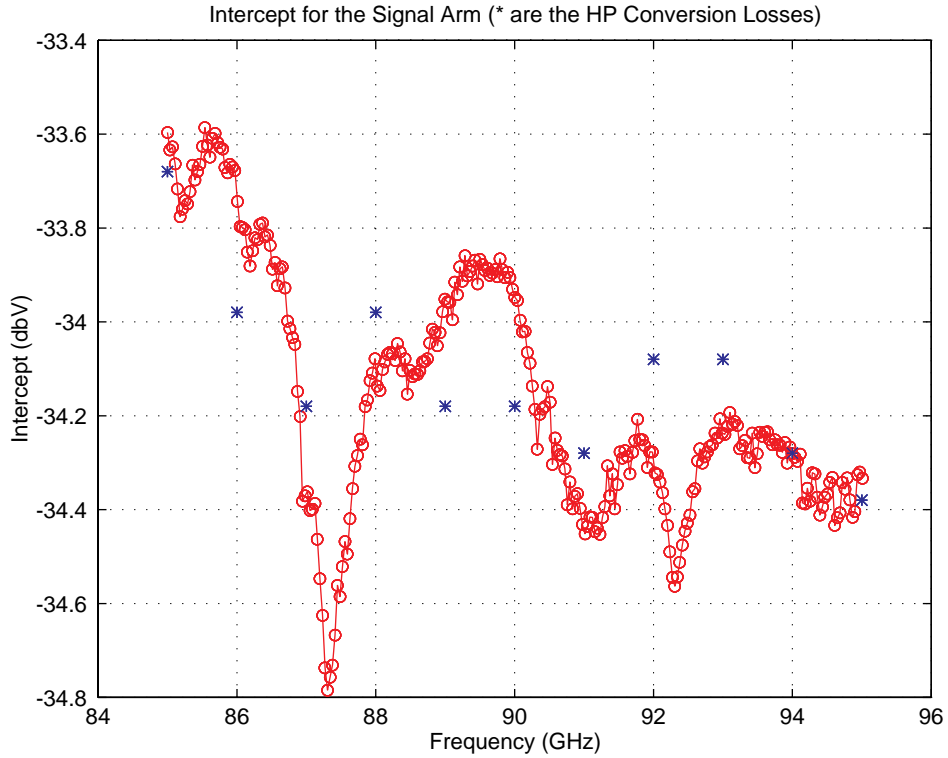
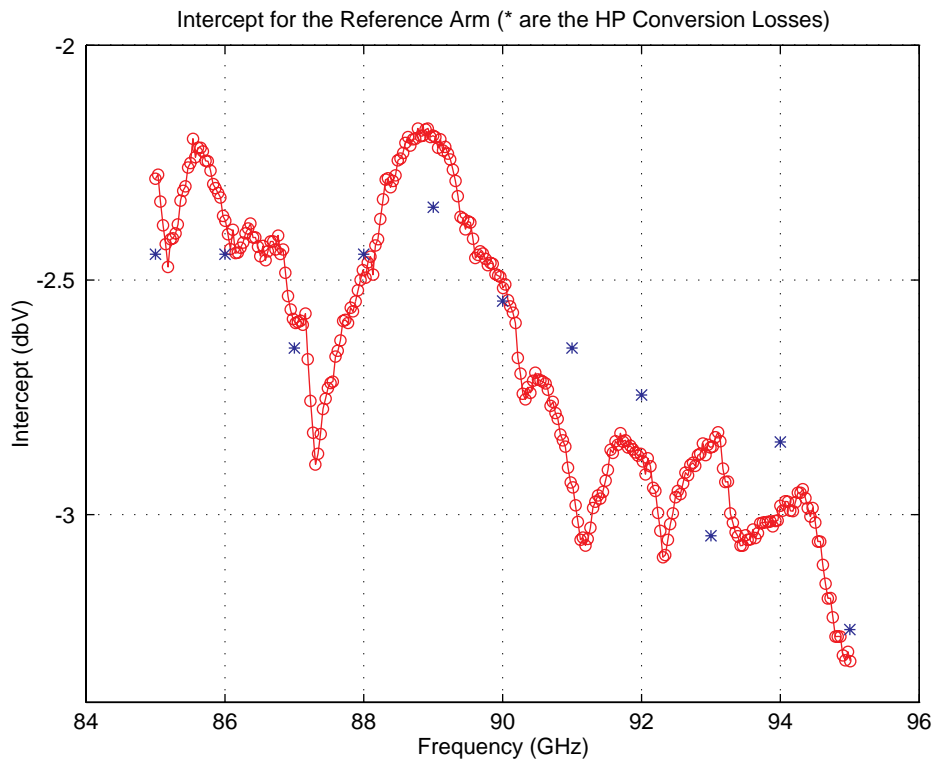
where the intercept can be a function of frequency. The intercepts were determined by measuring the power and either reference or signal at the same time.¹ The results, together with the conversion losses quoted by HP (with constant offsets), follow. The variation in intercepts is roughly 1 db, and there is rough agreement with the HP calibrations of conversion loss. It should be noted that these calibrations were performed for a different LO power, 16 dbm vs 15 dbm for the W-band apparatus, and different IF frequency, 360 MHz vs 835 MHz for the W-band apparatus.

The stability of the intercepts was checked on April 7, 1997 after several weeks and the apparatus having been taken apart and reassembled several times. Plots of those results follow. The signal arm intercepts were stable over that time while the reference arm ones drifted by about 0.25 db. The ×31 audio amplifier will be replaced to improve stability.



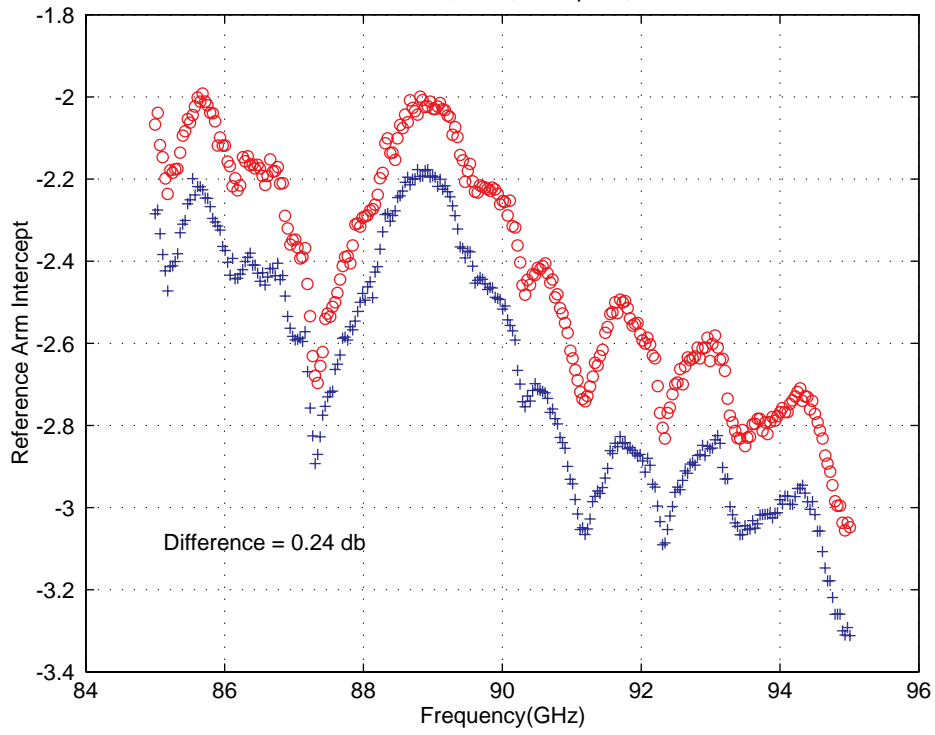
6-004

March 23, 1997 Intercept Measurements¹

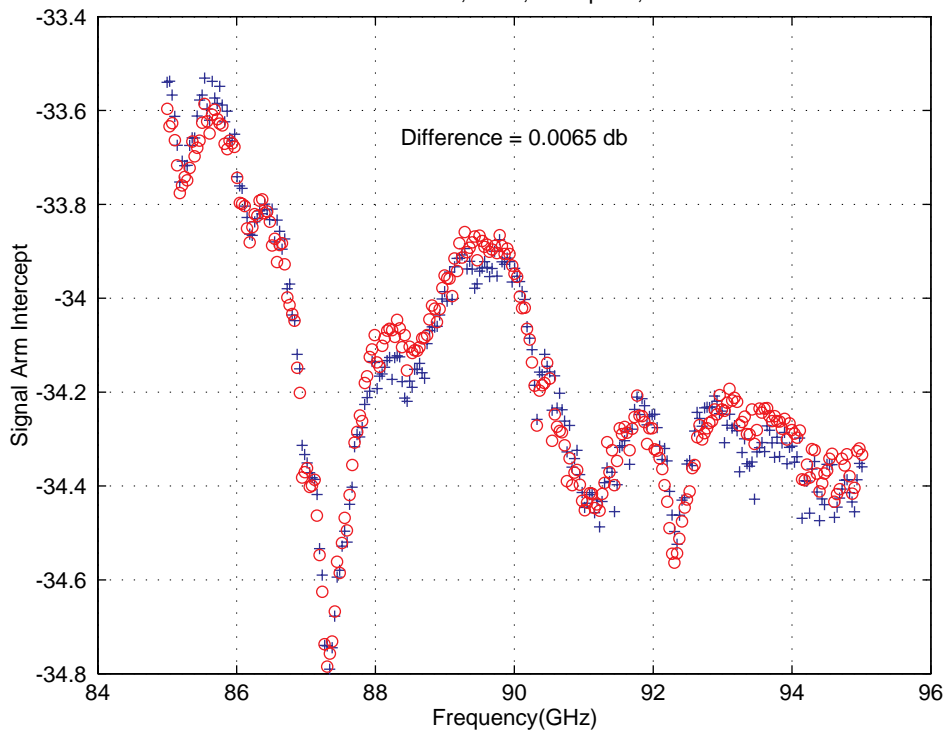


Intercept Drift Measurements

o = March 23, 1997, + = April 7, 1997



o = March 23, 1997, + = April 7, 1997



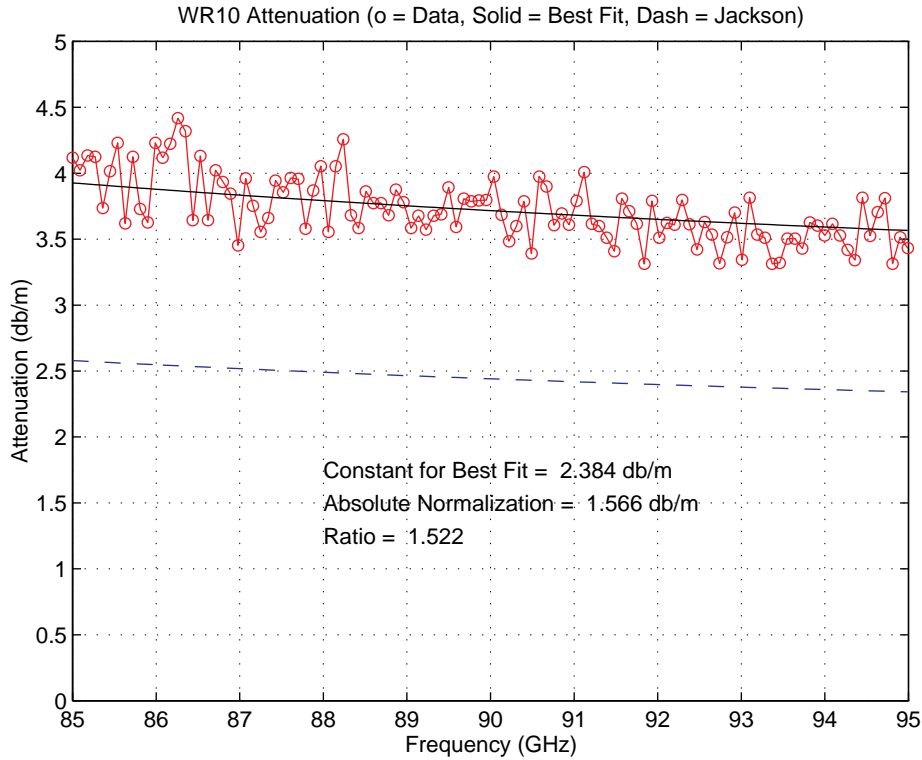
Waveguide element losses

A number of different measurements have been made using these intercepts. The first which are useful for calibration purposes are the losses in various waveguides and waveguide elements. Jackson gives the following expression for the loss in a waveguide vs frequency (eq. 8.63 in the first edition)

$$\beta = \frac{20}{\ln 10} \sqrt{\frac{\epsilon_0}{\mu_0}} \frac{1}{\sigma \delta_\lambda} \frac{C}{2A} \frac{(f/f_\lambda)^{1/2}}{(1 - f_\lambda^2/f^2)^{1/2}} \left[\xi + \eta \left(\frac{f_\lambda}{f} \right)^2 \right] \quad (2)$$

where β is in db/m; C and A are the waveguide circumference and cross sectional area, respectively; f_λ is the cutoff frequency; σ is the conductivity; δ_λ is the skin depth at the cutoff frequency; and ξ and η are dimensionless geometrical parameters. The leading constant converts Jackson's equation to db/m. For WR10: $C = 7.62$ mm, $A = 3.23 \times 10^{-6}$ m², $f_\lambda = 59$ GHz. For the TE₀₁ mode $\xi = \eta = 2/3$, and for copper $\sigma = 5.99 \times 10^7$ W/m giving $\delta_\lambda = 0.29$ μ .

Data were taken for a 4" long piece of WR10. The results are below. The frequency dependence agrees well with that expected from Jackson, and the losses are 1.5 times higher than they would be for copper.



Other devices were measured and fit to the functional form

$$\beta = \Lambda \frac{(f/f_\lambda)^{1/2}}{(1 - f_\lambda^2/f^2)^{1/2}} \left[1 + \left(\frac{f_\lambda}{f} \right)^2 \right] \quad (3)$$

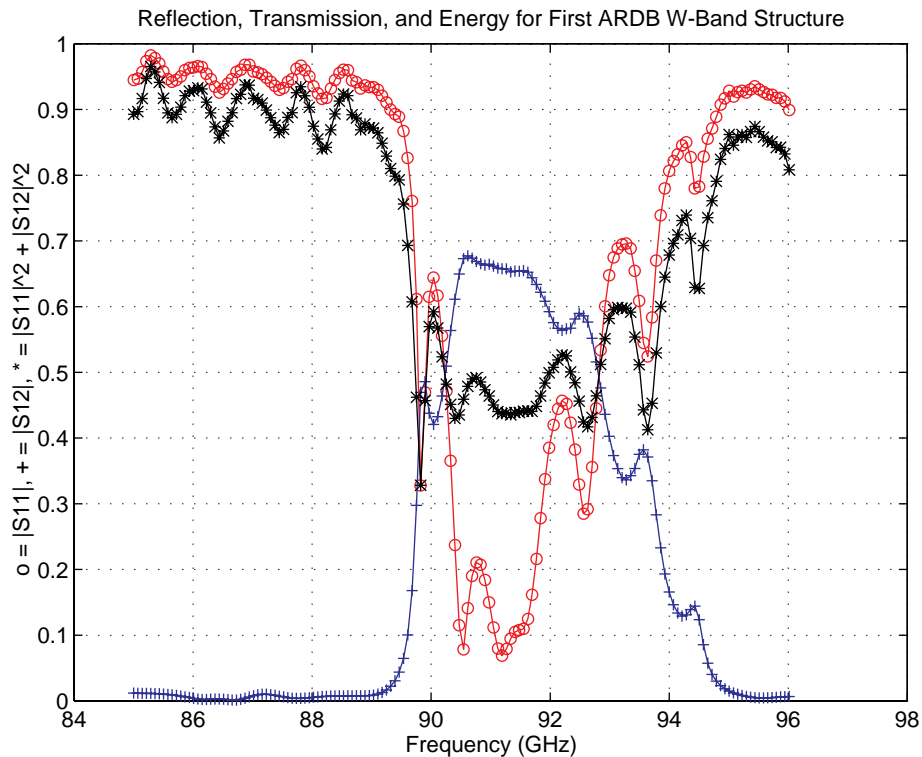
where β is the loss for the object and Λ is a constant. The values of Λ measured for different objects are

Object	Λ
Hughes split plan coupler 4532641-1320 #021 (20 db)	0.685 db
Aerowave H-Bend	0.0682 db
Aerowave E-Bend	0.0739 db
Aerowave Twist	0.0606 db

Equation 2, with a correction factor of 1.522, and eq. 3 are used to correct for losses when calculating transmission and loss.²

S₁₁ and S₁₂ Measurements for the First W-Band Structure

Transmission and reflection for the first 7-cell W-band structure (assembly drawing SA-700-918-31) were measured using the intercepts and losses discussed above. The results are plotted below.



The transmission passband is about 1 GHz wide which is roughly what was expected. Analysis of the data is underway. There is approximately 50% energy loss in the middle of the passband. Three possible explanations are: i) losses due to the surface condition of the structure; ii) conversion into modes that do not propagate through the structure and iii) radiation of energy through the beam or vacuum ports. The last possibility has been checked by shorting those ports.

Small changes in transmitted signals were seen (~ 0.5%), but this does not explain the large energy loss. The first possibility will be tested with a 2" long waveguide section made by the same EDM process as the structure.

Waveguide Length and Phase Measurements

In addition to correcting for attenuation, it is possible to make corrections for the phase shift due to path length. For a guide of length L the phase shift is

$$\Delta\phi = 360^\circ \frac{Lf}{c} \sqrt{1 - (f_\lambda/f)^2} . \quad (4)$$

This equation can be used directly for a waveguide of length L. For other devices the lengths were determined by fitting phase shift vs frequency. The resultant lengths are

Object	L
Hughes split plan coupler 4532641-1320 #021 (20 db)	8.557 cm
Aerowave H-Bend	4.445 cm
Aerowave E-Bend	4.428 cm
Aerowave Twist	3.788 cm

There is a residual phase shift, probably associated with details of the mixers, that must be taken into account. The fit to the coupler data together with the residual of the fit is plotted on the next page. The lengths together with the residuals from this fit can be used to correct phase measurements.³

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1. These intercepts are used in the LabView program ABSOLUTE.VI that gives calibrated outputs. They are saved on the W-Band PC as d:\matlab\toolbox\rhsfun\w-band\ref32397.txt for the reference intercepts and d:\matlab\toolbox\rhsfun\w-band\sig32397.txt for the signal intercepts.
 2. These calculations are done in the LabView program ABSOLUTE.VI.
 3. The residuals are used in the LabView program ABSOLUTE.VI. They are saved on the W-Band PC as d:\matlab\toolbox\rhsfun\w-band\fphs4797.txt.

Hughes Split Plane, 20 db Coupler³

