Measurement Results of Sandwich FSS

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1 General

In OVLBI memo #18 [1], initial test results for a frequency-selective-surface (FSS) were presented. The test results indicated that the reflection band of the FSS was not constant as the angle of plane-wave incidence on the FSS was varied. Also, the reflection response was different depending on whether the incident field was transverse-electric (TE) or transverse magnetic (TM). Also in memo #18, a new tri-layer FSS was described and was being fabricated. The tri-layer FSS has been renamed the "Sandwich FSS" here, both names describing the layered construction, which is depicted in Figure 1. This memo contains measurement results for this new FSS.

2 Requirements

The detailed frequency requirements of the OVLBI Earth Station are given in OVLBI memo #18; the resulting minimum requirements for the FSS are:

Band	Frequency (GHz)	Loss
Transmission	7.2–8.5 GHz	$< 0.10 - 0.20$dB
Reflection	14.2–15.3 GHz	$< 0.10 - 0.20$dB

The earth station will operate in circular polarization, and the FSS will be tilted at approximately a 25° angle to the X-band feed horn and the reflected ray-path from the Ku-band horn. Thus, the above specifications need be met for both TE- and TM-incident linear polarizations, and for a range of incident angles from approximately 10° to 40°. The latter requirement is due to the fact that the subreflector subtends ±13° of the horn pattern, so if the central ray crosses the FSS at 25°, then the range of incident angles is approximately $25 \pm 13 = 12^\circ\ to 38^\circ$.

3 Sandwich FSS Construction

The sandwich FSS is depicted in Figure 1. It consists of two 30-mil thick Teflon dielectric slabs[2], one unmetallized, the other with a copper pattern etched on one side. The two dielectric slabs, approximately 18" by 14", are bonded together using a 1-mil thick adhesive bonding film under thermal compression. The result was a much sturdier and damage-proof FSS than the initial Kapton single-layer design. The pattern mask was made in-house, and the etch and bond process done by Precision Prototypes.[3]

4 Measurement Results of Sandwich FSS

The measurements were taken using a new computer-controlled swept-frequency antenna range setup, for which a block diagram is shown in Figure 2. Previously, the Scientific-Atlanta receiver resident on the Green

[1]Bill Shillue, "A Frequency-Selective Surface for the OVLBI Earth Station: Initial Design and Test Results," November 20, 1991

[2]602 dielectric material, B600 Bonding Film, Norplex Oak, P.O. Box 1448, LaCrosse, WI 54602-1448

[3]Precision Prototypes, 55 Midland Ave., Garfield, NJ 07026.

Bank Antenna Range had to be phase-locked at each frequency, which limited the amount of data which could be taken in a reasonable time.

A computer program was written in Pascal, which controlled the synthesizer and the power meter through a Capital Equipment Corp. IEEE-488 interface on the PC, consisting of software drivers and a hardware card. The control software was straightforward, with a swept measurement performed by repeatedly setting the synthesizer to the desired CW frequency, and triggering the power meter for a measurement. The transmission phase of the FSS is not measured with this setup. Although it is critical that the phase delay of the FSS be relatively flat versus frequency due to the two-way timing links of the Earth Station, simulation results indicated very little phase fluctuation.

The measurement technique consisted of sweeping the frequency over the desired range with no FSS present, measuring and recording the received power at each frequency. The FSS was then inserted at 0° incidence, and the swept frequency measurement was repeated. Again it was repeated for 15°,30°, and 40°. The FSS was then removed and the free-space transmission measurement was repeated. This measurement was compared to the first measurement to assure that there was no change over the approximately ten intervening minutes. With this condition fulfilled, the data was considered legitimate, and the transmission loss for the FSS was calculated as the difference between the free-space measurement and the measurement with the FSS in place. The measurements were done for both TE and TM incidence by rotating both of the feed horns by 90° degrees.

A possible source of measurement error is spurious power generated as harmonics of the desired signal. The Sci-Atlanta 2180 signal source specification for harmonic generation is $\leq -10dBc$. At X-band, harmonics generated by the signal source would be reflected by the FSS, and thus appear as a loss that did not really exist. If the harmonic was only 10 dB below the carrier, then this loss might appear as high as 0.45 dB. At Ku-band, the situation is less clear because the harmonics exceed the frequency range specified for the power meter head. However, if spurious harmonic energy is received, it would make the measured results appear worse than they actually were. For both X- and Ku-band, the measurement results presented here should represent a worst case. For now, we are assuming that this error was negligible, but we will run a test to see if it was significant.

The results of the transmission measurements are shown in Figures 3–6. Figures 3 and 4 are the transmission loss for the FSS over the entire frequency range for TE and TM incidence. It will be noticed that the transmission loss is low from 7.2–8.5 GHz and high for 14-15.5 GHz, as expected. The important thing to note in Figures 3 and 4 are the uniformity of the response for all angles, and the nearly identical reflection bandwidth for TE- and TM-incidence.

The transmission loss at X-band is shown with better resolution in Figures 5 and 6, for TE- and TM-incidence, respectively. Recognizing the desired bandwidth as 7.2–8.5 GHz, it is plain that the transmission loss at the band edges is higher than we would like, ranging from 0.0–1.0 dB. The mid-band loss is about 0.2-0.4 dB, so some performance gain could be had at 8.5 GHz by scaling the design so that the response shifts upward by 100-200 MHz, which will sacrifice some performance at the Radioastron 7.2 GHz uplink while degrading only very slightly the VSOP 14.2 GHz data downlinks.

Table 1 compares the measurement results of the Sandwich FSS with those of the single-layer Kapton FSS given in OVLBI memo #18.

It should be pointed out that all the measurements were made in transmission, so that the 20 dB reflection bandwidth refers to bandwidth over which the received power was 20 dB less than the transmitted power. This is equivalent to -.044 dB reflection loss *in the absence of scattering and material loss.* The 0.5 dB transmission bandwidth was used in the table simply because it was difficult to estimate the 0.1 dB bandwidth for the Kapton FSS due to measurement uncertainties. One sees from the table that the bandwidth, especially at Ku-band, is markedly better for the Sandwich FSS than the Kapton FSS.

5 Reflection and Crosspolarization Measurement Results

Several attempts were made to measure the reflection loss directly. As mentioned above, energy which does not pass through the FSS is not necessarily reflected as we would hope. It can also be lost to the dielectric material or to scattering. The former effect can be approximated by assuming we had a dielectric layer the same thickness as the FSS, but with no metal. The dielectric loss is given by:

$$\mathrm{Loss(dB)} = 27.3\sqrt{\epsilon_r}\,\delta\frac{t}{\lambda}$$

0.5dBTransmissionBandwidth

	Kapton FSS		Sandwich FSS	
Angle	TE	TM	TE	TM
0°	7.2–8.5	7.2–8.5	7.2–8.6	7.2–8.4
15°	7.3–8.5	7.3–8.5	7.2–8.6	7.3–8.7
30°	7.4–8.9	7.2–8.7	7.2–8.4	7.2–8.4
40°	7.6–8.9	7.3–9.0	7.2–8.4	7.1–8.8
	Common BW : 7.6–8.5		Common BW : 7.3–8.4	

20dBReflectionBandwidth

	Kapton FSS		Sandwich FSS	
Angle	TE	TM	TE	TM
0°	13.8–15.5	13.8-15.5	13.9–15.7	14.0–15.8
15°	13.7–15.3	13.8-15.1	14.0–15.6	14.0–15.6
30°	13.5–15.0	13.3-14.5	13.8-15.5	13.9–15.3
40°	13.4–14.7	13.1–14.0	13.7–15.5	13.9-15.1
	Common BW : 13.8–14.0		Common BW : 14.0–15.1	

Table 1: Comparison of Bandwidth: Kapton FSS and Sandwich FSS

where ϵ_r, δ, t, and λ are the dielectric constant, loss tangent, thickness of material, and wavelength, respectively. At 15 GHz, ϵ_r=2.5, δ=.0023, and t=.060" and λ= .79". The result is only .007 dB of material loss.

However, scattering caused by the elements and dielectric surface is energy being reradiated in other directions, and this effect may be significant. Unfortunately, reflection measurements that were made failed to distinguish between scattering loss and reflection loss that was inherent in the test setup, such as reflections from the tower structure and the FSS frame. Due to the limi¡ted size of the FSS, a reflection measurement requires a small beam size, which is only possible by using a focussing mirror or lens. A truly reliable measurement of the FSS reflection loss may be postponed until after we procure the offset ellipsoid.

A cross-polarization measurement was done in which the FSS was operated in reflection mode at 15 GHZ and about 25° incidence angle for TE incidence. The source antenna was rotated 90° for TM incidence, and the cross-polarized pattern measured. On-axis, the FSS-reflected field looked just like the free-space transmission measurement, with no appreciable crosspol. Off axis, there were cross polarized sidelobes at -32 dB from the copolar peak power. Since the test horn had -33 dB cross-polarized sidelobes, and after reflection from the FSS this had increased to -32 dB, the added crosspolarization from FSS reflection is small. It should be noted that this measurement takes no account of phase, which can also be detrimental to crosspol performance.

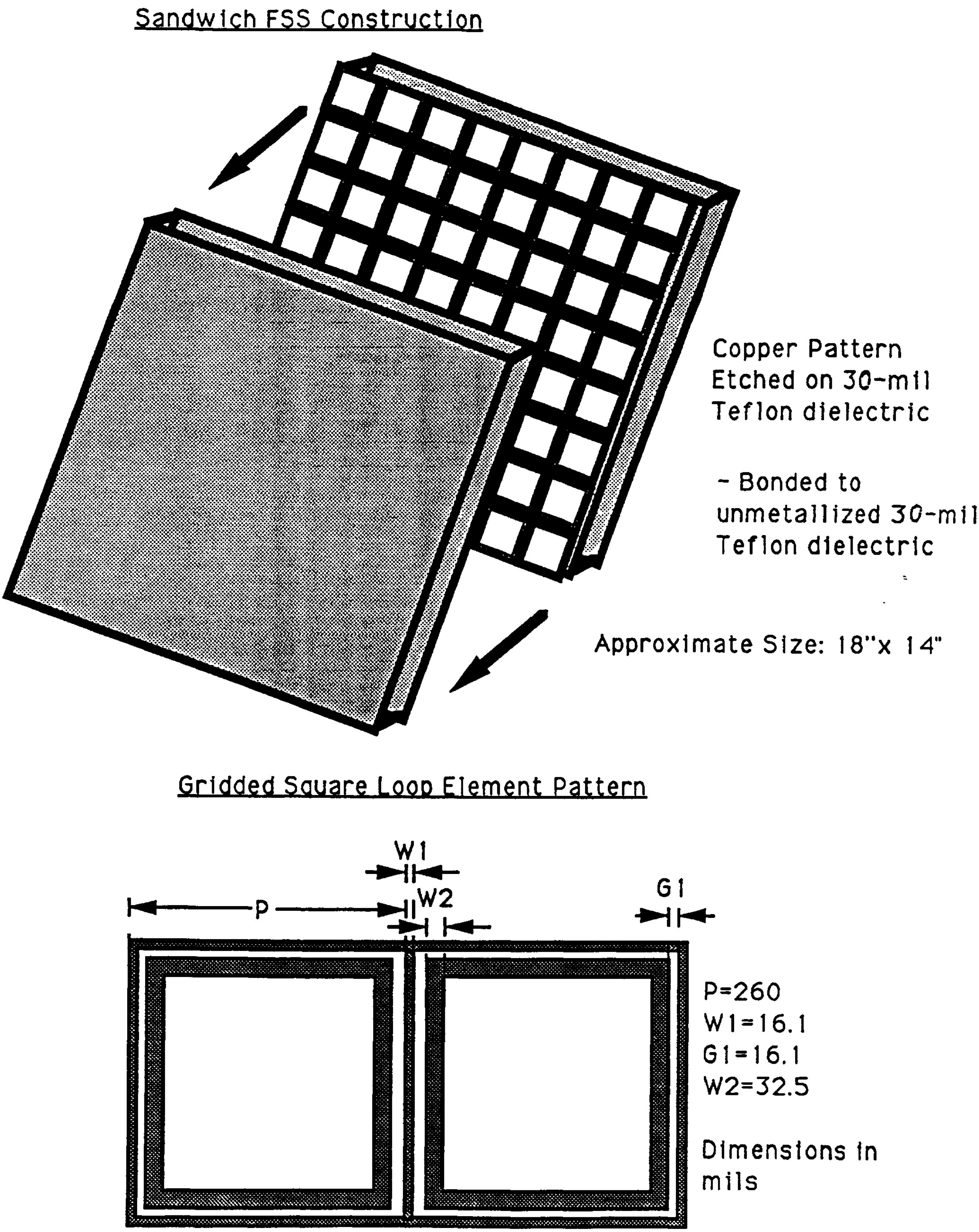

Fig. 1: Sandwich FSS Construction and element geometry

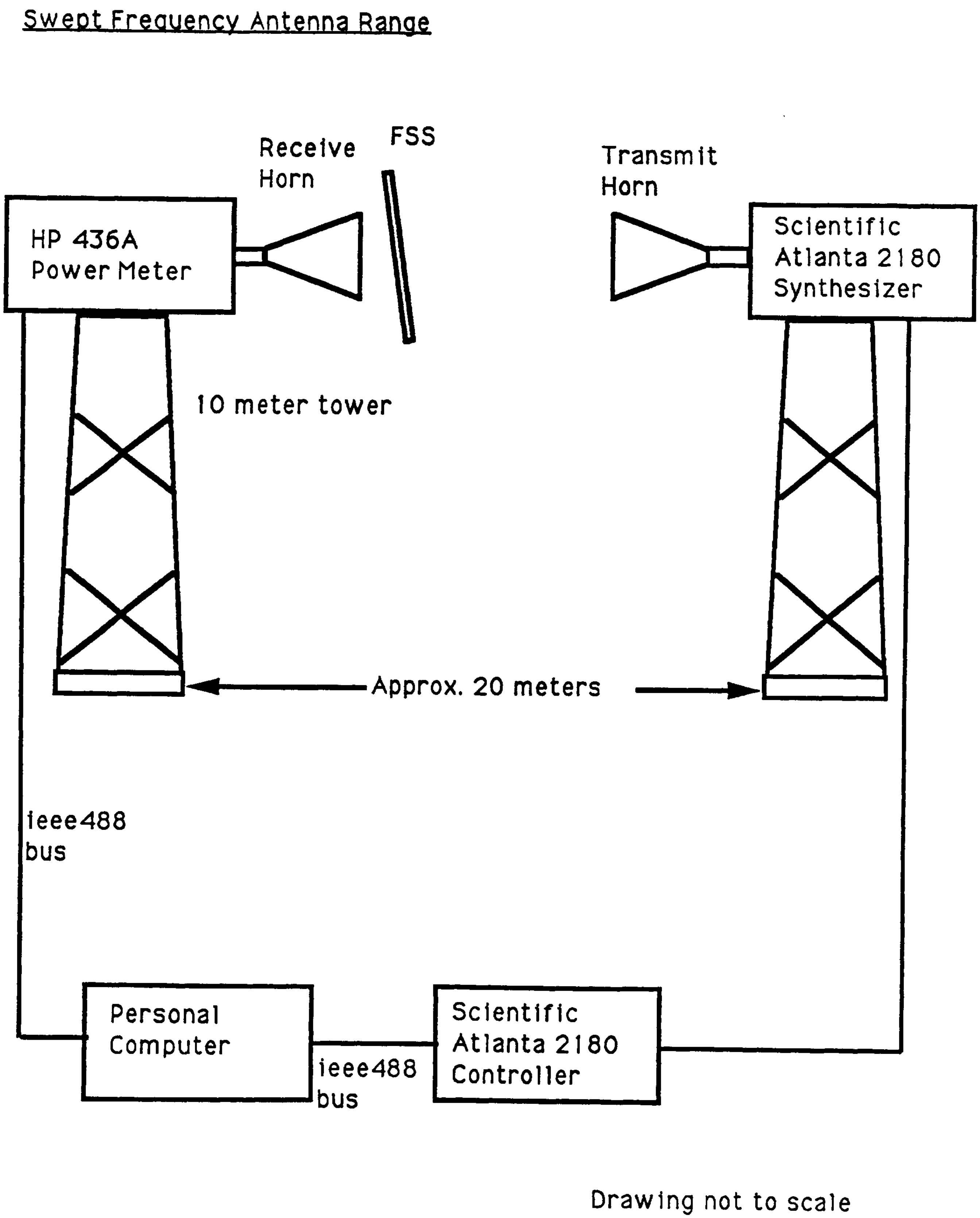

Fig. 2: Swept Frequncy Antenna Range

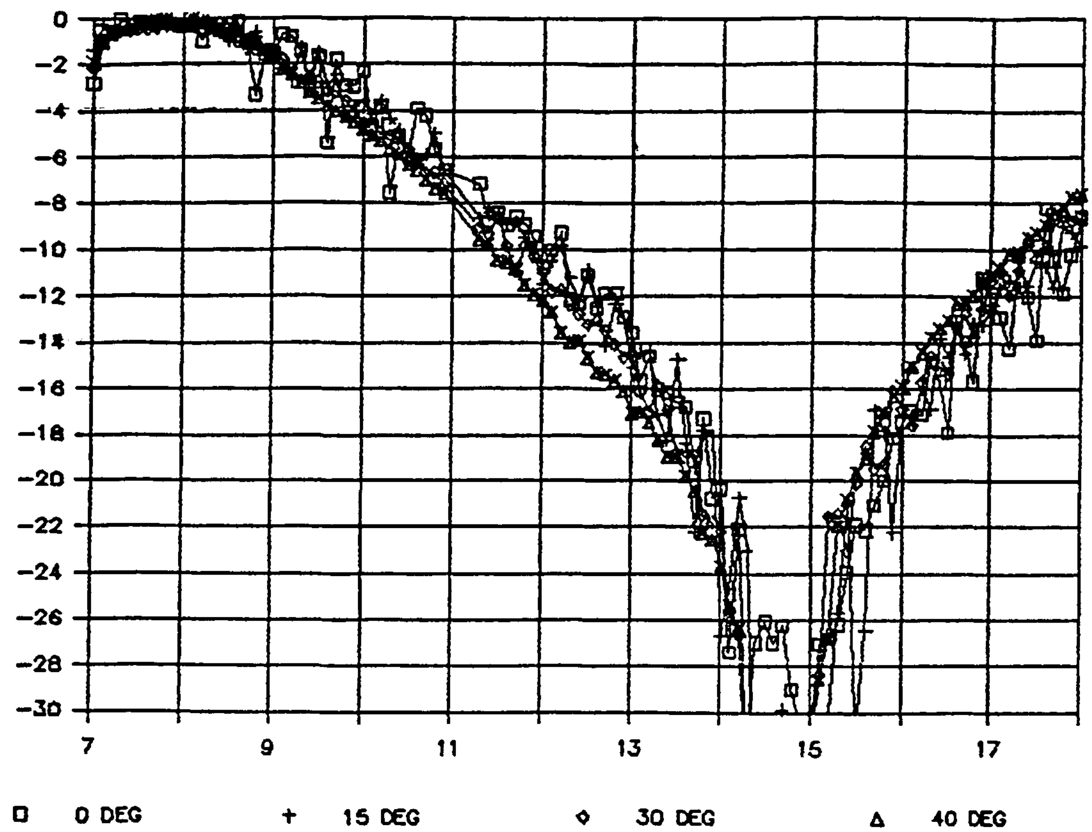

Fig. 3: Sandwich FSS measurement results for TE incidence

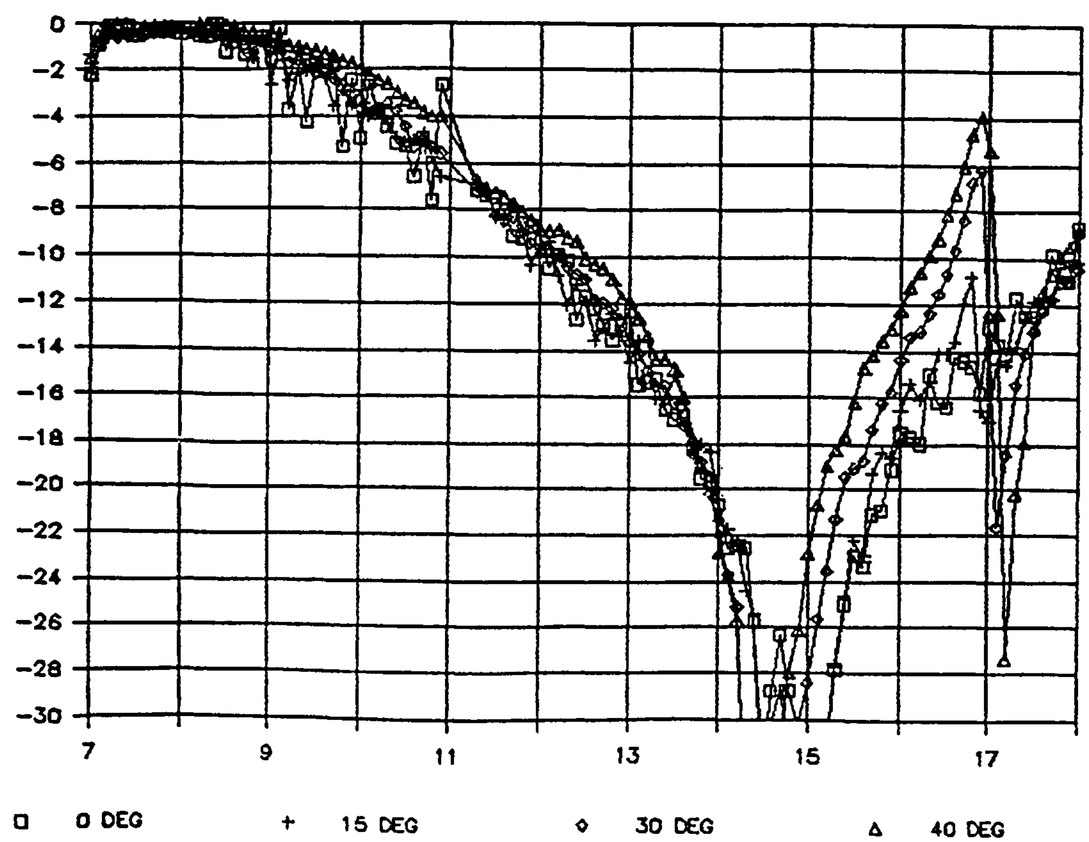

Fig. 4: Sandwich FSS measurement results for TM incidence

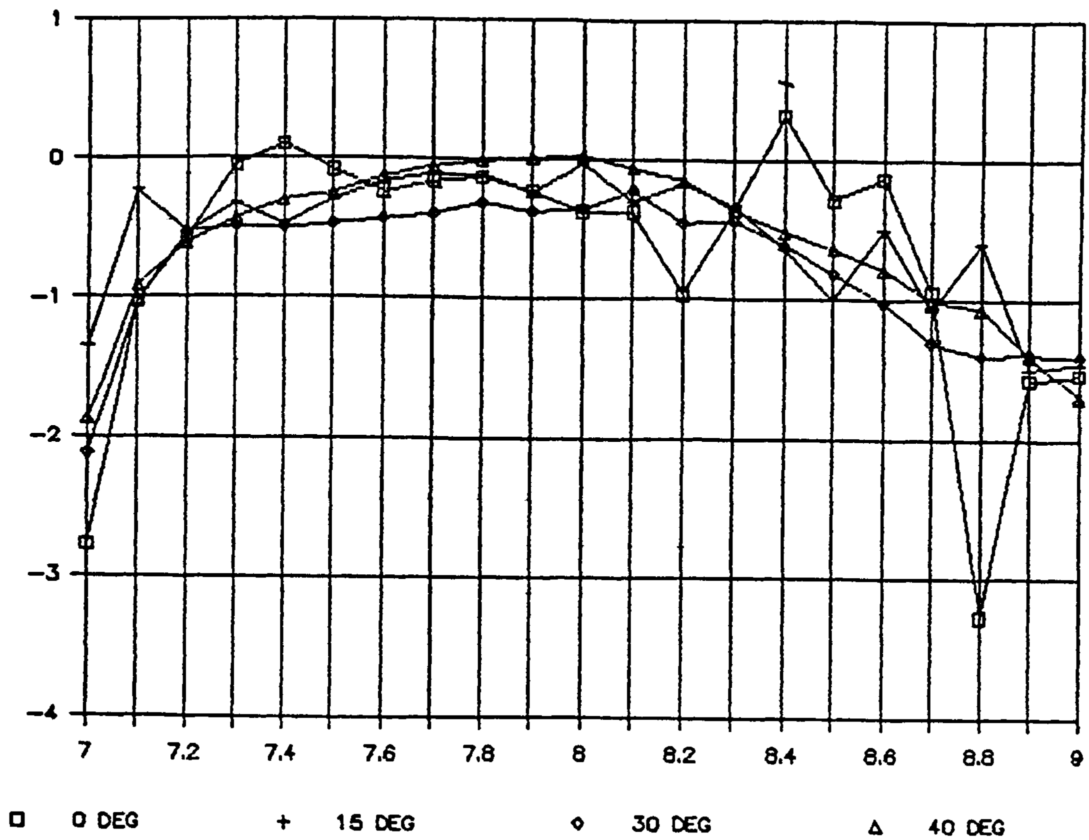

Fig. 5: Sandwich FSS X-band measurement results for TE incidence

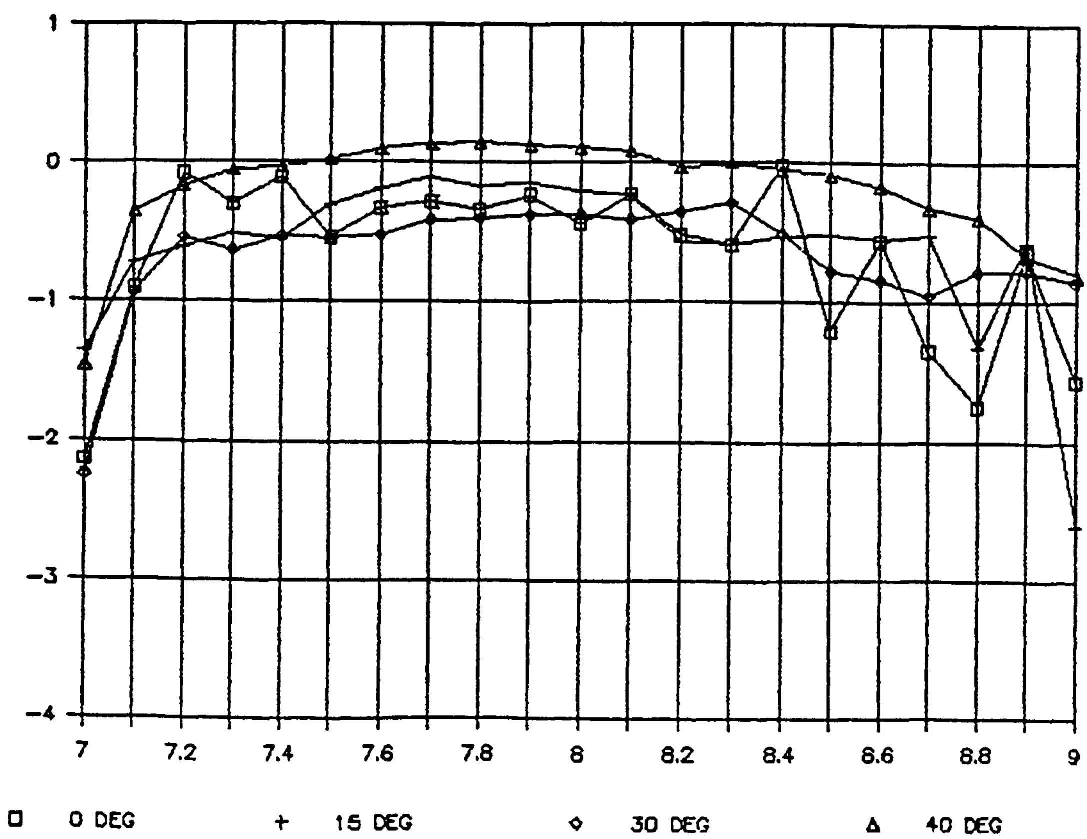

Fig. 6: Sandwich FSS X-band measurement results for TM incidence