Design Considerations for a Reflector Antenna for
Good Spectral Baselines
from Rick Fisher

An important criterion in the design of a large reflector antenna for astronomical spectroscopy is that it must not produce significant structure in the received noise spectrum over bandwidths less than about 100 MHz. In observers' language, the telescope must not have bad baselines. The causes of bad baselines are numurous, - receiver filter drifts, front-end gain and noise temperature changes, unstable reflections in telescope cables, and multiple reflections of signals in the antenna structure - but this note deals only with the last cause.

Relatively narrow band fluctuations in an antenna's response can be looked upon as ripples in the gain of the antenna as a function of frequency or as multi-path interference of received noise. Any spectral features that cannot be accurately duplicated in a reference spectrum of some sort will cause trouble. The biggest source of bad baselines on the 300-ft telescope was radio noise from the sun getting into the feed via more than one path. Sources in the main beam with significant continuum radiation (~> 1 Jy) caused baseline ripples because of reflections between the feed and the reflector surface. Ground and atmospheric radiation and other radio sources in near sidelobes may also be sources of trouble, but these have not been conclusively identified. There may be a few more tricks we can play in data reduction techniques to reduce the effects of unwanted noise, but eliminating the original source of error is much more desirable.

A goal for baseline purity is less than 1 milli-Kelvin peak-to-peak ripple over 50 MHz. This noise level is the rms fluctuation in a spectrum integrated for one hour with a 20 K system temperature and a single channel bandwidth of 100 kHz. Typical baseline ripples on the 300-ft were a few tens of milli-Kelvins any time during the day, and they could be as bad as a few tenths of a Kelvin or more around noon and, strangely enough, around sunrise and sunset.

At 21 cm the quiet sun adds about 0.5 K to the system temperature in a sidelobe with isotropic gain or about 50 mK in a -10 dBi sidelobe which is typical for far sidelobes on the 300-ft. Low-level far sidelobes are the interference of several scattering paths on the structure, so it is not surprising that we sometimes see nearly full modulation of the solar radiation in the spectral baselines. The active sun can be about 100 times stronger. By far the best solution to bad baselines due to the sun is the reduction of far sidelobe levels. [This was not as obvious to me as it now is. Adding the spoiler to the surface of the 300-ft did not help daytime observations as much as I might have expected, although it probably did reduce the baseline ripple due to receiver noise radiation and noise received in the main beam. The feed-surface resonance may not play a dominant role in the frequency structure of the far sidelobes.]

A continuum radio source in the main beam has most of its intercepted enery focused near the feed. About 30% of this energy is scattered by the feed back into the dish. (That's why the taper efficiency is typically 70%.) If any of the scattered energy returns to the feed, it will interfere with itself, and the frequency dependence of the interference will depend on the length of the scatter-return path. The baseline ripple "wavelength" has been correlated with the distance between the feed and the dish surface or other reflecting surfaces on many radio telescopes. If 10e-6 (-60 dB) of the feed-scattered power from a continuum source with an antenna temperature of one Kelvin is returned to the feed, its spectrum will have a ripple of about one milli-Kelvin. Note that noise interference is a voltage addition problem. Return losses for a signal trnsmitted from the feed in the range of -50 to -60 dB have been measured on the 300-ft and 140-ft telescopes (EDIR #184). The receiver itself can radiate from a few to many tens of Kelvins of noise, and this can interfere with itself via the same paths, but, since it is usually the same in the signal and reference spectra (no frequency switching), it is usually subtracted out in the data reduction.

The reflector surface under the feed is not the only important mode of returned noise. The three attached figures show the results of swept-frequency return-loss measurements from the focal points of the 300-ft and 140-ft antennas at about 3 GHz. The top diagram in each figure shows the return loss as a function of distance from the feed that results from the Fourier transformation of the interference pattern between the outgoing and return waves (bottom diagram). From the distance of each peak we can usually determine the important sources of reflection.

Figure 1 is from the 140-ft measurements. Peaks A an B are from the top of the cassegrain house. Peak C is from the waveguide cutoff point at 3 GHz of the higher frequency feeds in the cassegrain system. Peak D is from the reflector surface just outside the cassegrain house. Probably peak E and certainly peak F are due to the circumferential gaps between the surface panels. Peak G corresponds to the distance to the attachment points of the feed support stiffening cables. Peaks H, I, J, and K have not been identified. A tilted reflecting plate was installed on top of the cassegrain house and produced the strong reduction in the reflection from the top of the house (A, B, and C). The outer panel gap was covered with aluminum tape which reduced reflection F and confirmed its source. The gap itself may not be as important as a phase discontinuity because of slight adjacent panel misalignment.

Figures 2 and 3 show similar measurements on the 300-ft. The power-vs-distance spectrum is much simpler here because there is no cassegrain house. The shortest distance peak is directly from the surface under the feed. The two harmonics of this reflection are due to the fact that there was a traveling feed track attached to the underside of the feed cabin. This track was parallel to the plane wave front and allowed waves to reflect between it and the dish surface several times. Adding a 7 x 14-meter spoiler to the center of the antenna reduced the primary reflection by about 14 dB and put the multiple reflections below the detection level. Elimination of the multiple reflections was a big improvement because the amplitude of these reflections were very sensitive to the lateral position of the feed. An expansion of the main reflection in figure 3 shows that there are at least two distances involved that are slightly greater than the distance to the antenna center. These could be either two-reflection paths involving the feed support legs or returns from discontinuities in the surface. Dave Morris, John Bieging, and others at Effelsberg have demonstrated that feed-to-leg-to-surface-to-feed paths are significant.

Fourier transforms of composite 128-MHz wide, 3.4 GHz, radiometer spectra taken on the 140-ft show characteristic distances that agree with the reflectometer distances. This indicates that the reflectometer data have at least some validity in connection with the baseline problem. The distance resolution and sensitivity are poorer on the radiometer measurements, however.

One final comment is to note that the exact form of a wavy spectrometer baseline is very sensitive to the precise position of a contunuum radio source in the main beam or sidelobes. This is because the scattering amplitudes and phases change rapidly with source position. For this reason, the baseline is different for a slightly extended source than it is for a point source. This sensitivity to continuum source position has thwarted most attempts to calibrate baseline ripples. In particular, the sun, one of the worst sources of bad baselines, is continually moving in the sidelobes during an observation of a sidereal object.

In rough order of importance, the design guidelines for a reflector antenna with good spectroscopic-baseline characteristics are as follows:

1. Reduce far sidelobes as much as possible. A sidelobe envelope between 15 and 20 dB below the CCIR standard curve would make a great improvement in daytime spectroscopy at 21 cm over what was done on the 300-ft. This sidelobe level would approximately meet the 1-mK baseline ripple spec for quiet-sun radiation when the sun is more than about 30 degrees from the main beam.

2. Avoid or eliminate specular reflections of waves emitted or scattered from the feed from anywhere on the reflector surface. An unblocked aperture meets this criterion naturally, but a symmetrical design will have to include a spoiler at the center of the antenna. This spoiler will need to be between 10 and 15 meters across in a 100-meter antenna, depending on the degree of reflection reduction required. Care must taken to redirect the reflection to a harmless area of the sky.

A symmetrical cassegrain or gregorian design is a rather more difficult case to deal with in terms of spoiling specular reflections. Because of defraction limits, a larger relative area would have to be covered by a spoiler on the subreflector than on the main reflector. The specular reflection spot on the subreflector is smaller, but this is offset by the higher secondary feed gain.

3. Strive for a clean structure and feed support system. This includes no surfaces which are parallel to the wavefronts from the feed or reflector (thinking of the transmitting case). Carefully break up feed support surfaces that might allow a feed-to-leg-to-surface-to-feed specular path. Don't put a lot of clutter around the feed.

4. If possible, avoid gaps between surface panels that travel along lines of constant phase as seen by the signal wavefront. This might mean a zig-zag circumferential panel gap. If this is not feasible, then keep the gaps and panel edge misalignments to an absolute minimum. Even a perfectly concentric circle for the edge of the dish might be avoided.

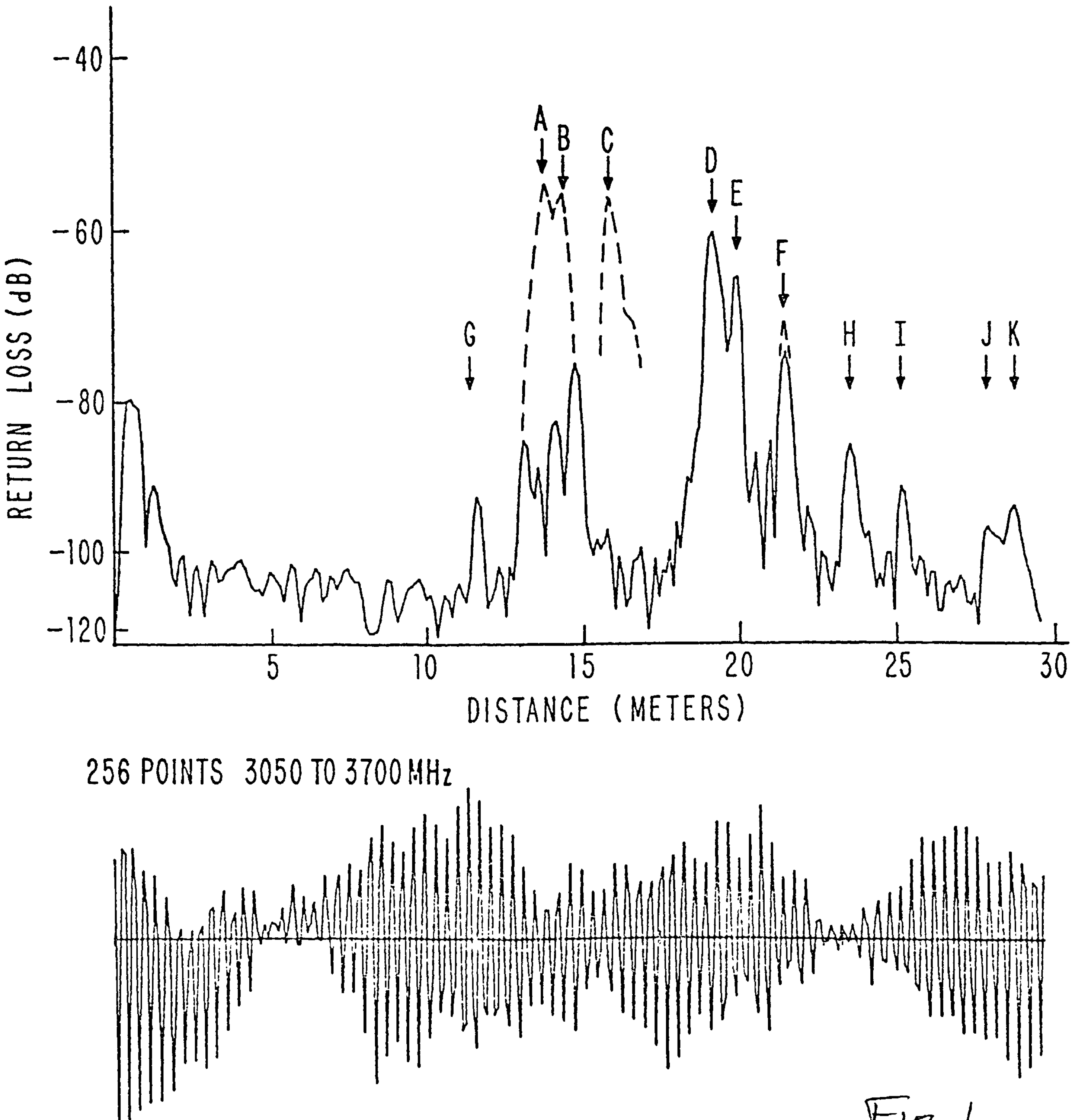

Fig. 1

140-ft reflection spectrum before (---) and after (—) addition of spoiler to the top of the cassegrain house.

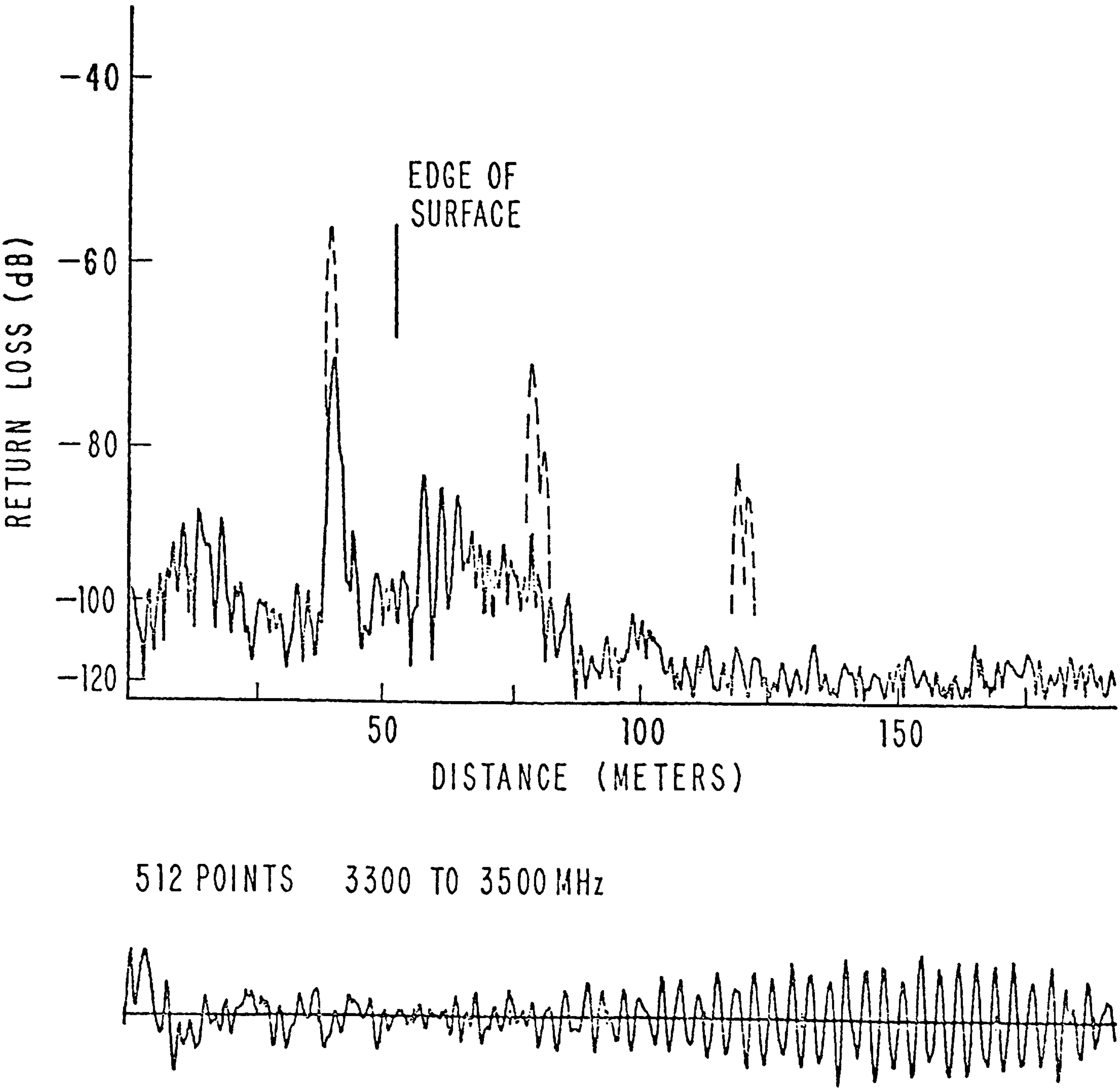

Fig. 2

300-ft reflection spectrum before (---) and after (—) the addition of a spoiler at the center of the surface.

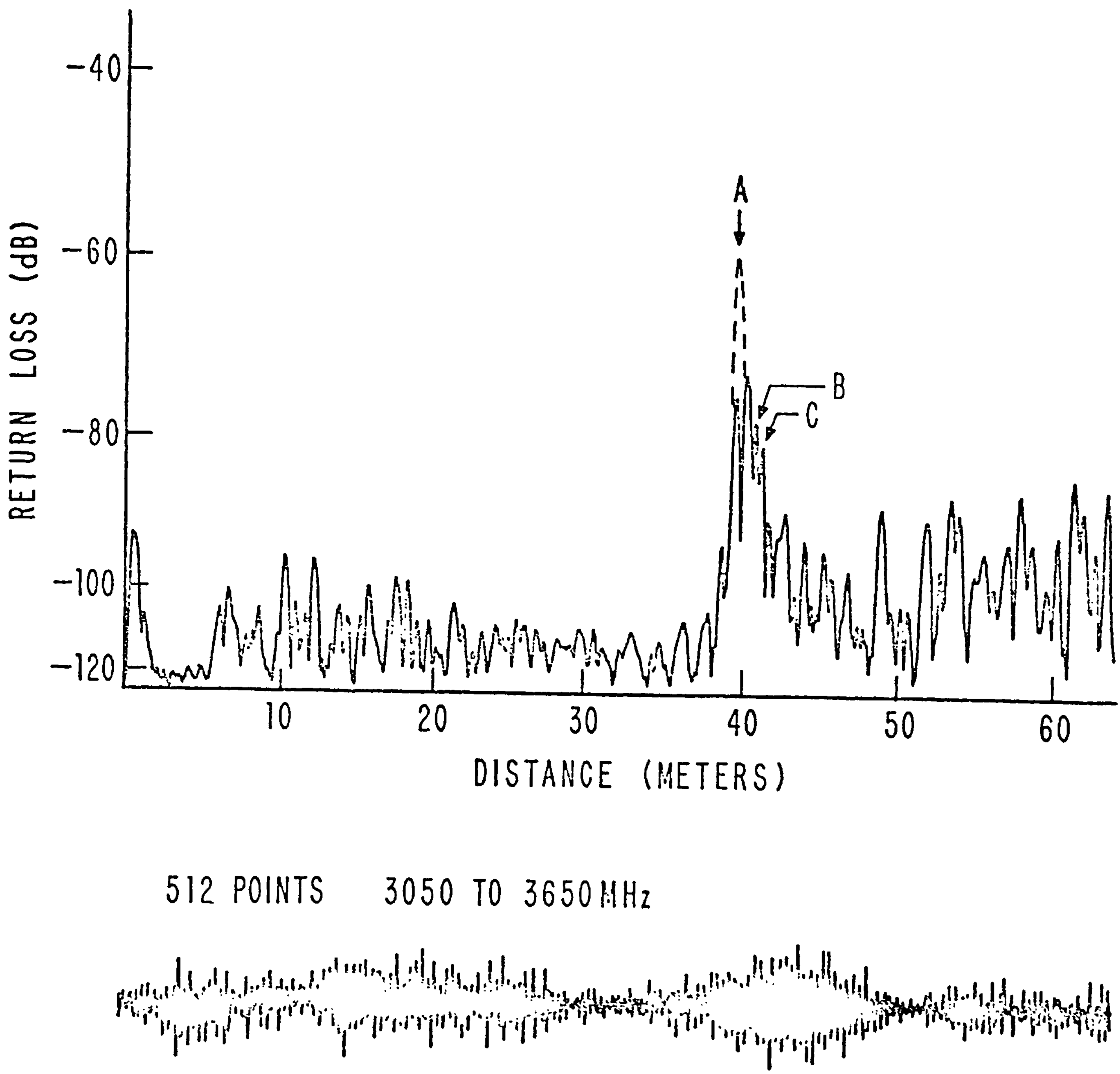

Fig. 3

Same as figure 2 except with higher distance resolution over a shorter distance range.