Generation of Unwanted EM Modes in the ATA Feed Dewar

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1 Introduction

The Low Noise Amplifier(LNA) for the ATA will be located in a vacuum dewar which allows it to be cooled to 80K. It connects to the feed with a passive balun which transforms the balanced signal from the feed into an unbalanced signal for the LNA. The shape of the dewar is planned to be conical to fit inside the feed pyramid. In addition, there will be a conical radiation shield at 80K, coaxial with the dewar wall. This will keep the temperature of the balun on the axis of the dewar at 80K, protecting it from the 300K black body radiation of the dewar wall.

The balun is of the gradual transition type for wide bandwidth now in common use (Duncan and Minerva, 1958). The unbalanced end begins as 100 ohm microstrip with the ground plane gradually becoming smaller until it is 200 ohm twin line (Rumsey et al, 1965). This structure lies on the axis of the dewar, and there is a potential for coupling to the ordinary coaxial mode in the dewar. Such a coupling can be expected to create losses in the balun circuit. Since the outer wall of the coaxial line is the heat shield, those losses would be at 80K and could raise the noise temperature of the system. Even if the coupling were weak, there is another effect which could be a nuisance. The coaxial mode will be badly matched at the ends of the dewar, and so it will act as a resonant cavity. Even if it were very weakly coupled, it could show up as sharp resonances in the main mode at frequencies where there are standing wave resonances. At resonant frequencies, the effective coupling is increased by the Q of the resonant cavity. Such effects are frequently a problem in boxes with amplifiers.

The first question addressed here is: "Is there coupling to the coaxial mode along the line of the balun?". If the balun transition is sufficiently gradual, such coupling would not be expected. But is it gradual enough in the present application? Measurements on a test circuit consisting of two back-to-back gradual baluns (like the one designed for the present application) show that the balun coupling to the coaxial mode is negligible.

The second question is: Given that the coaxial mode will be excited at the discontinuity corresponding to the connection to the LNA, how can it be avoided or rendered harmless? Some of the tests suggest ways in which the effects of the coaxial mode can be reduced.

2 The Test Fixtures

Two test fixtures were built early in the planning stages to verify that the balun design works. Both are back-to-back. That means that each consists of two baluns connected at their balanced ends, where the impedance is 200 ohms. This provides a single structure with a 50 ohm coax connector at each end, suitable for test with a network analyzer. The baluns are on a substrate called "cuflon', a version of teflon. For one of the structures the twin leads were inverted where the two baluns were connected. A comparison of the transmission between the two structures shows that over the designed bandwidth, 1 - 12 GHz, amplitude transmissions are identical within 1% and the phase transmissions are also identical, except for a shift of 180^o, as expected. This comparison shows that the balun design works as expected.

The fixtures both use a narrow (1.25 inch)metal plate to hold the end coaxial connector plates. Each double balun is 22.5 inches between the two end connector plates. Each balun is about 11 inches long, and the width of the microstrip board is 1.1 inch. The separation between the microstrip and the narrow metal plate is 0.5 inch. These baluns are nearly in free space, except for the metal plate. There exists a weakly excited TEM mode propagating along the fixture with the field between the baluns and the supporting plate described above. The presence of this mode is detected by a few weak sharp resonances whose separations in frequency are consistent with a standing wave between the end connector plates in free space, not in the cuflon. Replacing the 1.25 inch plate with a piece of wood eliminates the resonances and shows a negligible change in transmission amplitude. The disappearance of the sharp transmission resonances shows that they were correctly identified, and the negligible overall change in transmission shows that the TEM mode had been only weakly excited.

3 Coupling Tests

As an analog to the heat shield in the dewar, a curved semi-cylindrical shield with a U-shaped crossecion and a length of 14 inches was prepared. It's diameter where it is circular is 1.25 inches so that it can be placed over the balun microstrip and nearly touch it. Then the parallel U part is 0.5 inch to extend down to the mounting plate. It is open at the bottom so that it can be easily put in place or removed. It makes a good coaxial transmission line with the balun as its center conductor. Over the region that is mostly parallel line it makes a coaxial line with a characteristic impedance of about 300 ohms, as compared with the 200 ohm impedance of the twin line or 50 ohms for the impedance of the microstrip at its input.

Figures 1 to 4 are a sequence of transmission measurements made on the fixture with the wooden base using an Agilent Network Analyzer, model 7522ES. The full two port calibration has been applied. Figure 1 shows the transmission of just the fixture with its double balun. The scale is 1 db/cm to show the fine detail. The total range is just 50 MHz to 5 GHz with 801 points to provide enough resolution to permit detecting any sharp coupled resonances, 6.2 MHz. The visible small amplitude structure is presumably small imperfections in the end connectors and the balun board. The subsequent figures all show transmission, with the figure 0 plot superposed, as well, for comparison. In Figure 2, the curved shield has been added so that it is approximately in the middle part of the fixture with one end about 2.5 inches from one of the connectors. There is very little difference between the transmissions. A maximum difference of about .05db at 2.7 GHz corresponding to 1% is about all that can be seen. In Figure 3, the cover has been moved to within 1 inch of the end connector. A maximum difference of about 0.1 db may now be seen near 1.5 GHz. In Figure 4, the cover is now touching the end connector, and up to 0.2 db differences may be seen in a few places. The trend is clear. Coupling from the balun to the coaxial mode along the transmission line is essentially negligible. Coupling only becomes significant when the coaxial line is brought up to the connector. This agrees with the expectation that the mode coupling occurs at the discontinuity of the input connector and not along the line. The balun transition is sufficiently gradual not to generate a significant amount of other modes, despite its close proximity to the shield.

4 Eliminating the Dropouts Due to the Weakly Coupled Coaxial Mode

The coupling into the coaxial mode due to discontinuities may be weak, but if there are high Q resonances at various frequencies in that mode, the coupling is enhanced by the Q, and sharp absorptions may appear in the regular mode. For Figure 5, a rectangular cover has been added that extends past the ends of the fixture. Its cross section just matches those of the end connector plates. Here there are now sharp transmission dropouts of as much as 1db, corresponding to standing wave resonances in the coaxial mode. The separations between the resonances correspond to free space standing waves between the end plates, showing that they are in the coaxial mode. Except at the resonances, there is no more than 1% absorption in the regular mode, showing that the coupling is otherwise weak.

It will be difficult to reduce the coupling below the level of about 1% at all frequencies, and that fact requires that the coaxial mode Q must be kept low to avoid the sharp drop outs. A number of experiments with the rectangular box coaxial cover show that lowering the Q is not easy for the standing mode between the end plates. Unlike the field in the desired mode that is confined to the central structure, the coaxial mode extends out to the cover. It would seem that putting absorber on the cover surface should increase losses in the coaxial mode without affecting the main mode. However, various attempts to carry this out were not very successful. Making the cover out of stainless steel, a very poor conductor, had a surprisingly small effect. Covering the surface with the of kind of black rubberized absorbing material that is conventionally used inside of amplifier boxes only reduced the sharp dropouts by a factor of about two. Putting in longitudinal vanes of absorber such as are used as waveguide absorbers (thin metal deposited on mica) only reduced the resonances by a little. Unfortunately, most of the losses in coax with a small center conductor occur on that inner conductor and not on the outside wall. A familiar example is that one can obtain coaxial cable with a stainless steel outer conductor that has almost the same loss whether or not the outer wall is copper plated. Thus, the approach of introducing loss on the outer conductor is not very effective. Even worse, when the inner balun structure is cooled down for low loss in the desired mode, the coaxial mode problem will be even worse.

The clue to a possible solution is in Figure 3. With the curved cover touching one end plate, losses of up to 0.2db could be seen at a few frequencies, but no large sharp dropouts. Also, placing the rectangular cover on but with it only covering one end plate eliminates the sharp dropouts. Evidently, the standing wave between one end plate and the open end of the cover has a low Q resonance. The open end of the coaxial waveguide must radiate sufficiently to lower the Q. There is a way to use this circumstance in the ATA dewar. The heat shield will act as the coaxial line. Thus, if it comes to an (open) end before the glass seal end of the dewar is reached, it can serve as the open waveguide. It will be important that the end of the shield can radiate well into the outer part of the dewar, and absorbing charcoal can be embedded in the layers of insulating material that will be placed between the dewar wall and the heat shield. The other important point is that the glass seal in the end of the dewar is matched for TEM waves by two pieces of teflon in the ambient pressure section between the tip circuit board and the glass seal. This should also produce a good match for that part of the coaxial mode that continues on along the wires.

5 Bibliography

1. Duncan, J.W., and V. P. Minerva, 1960, Proc IRE 48, 156.

2. Gans, M.J., D. Kajfez, and V. H. Rumsey, 1965, Proc. IEEE, 53, 647.

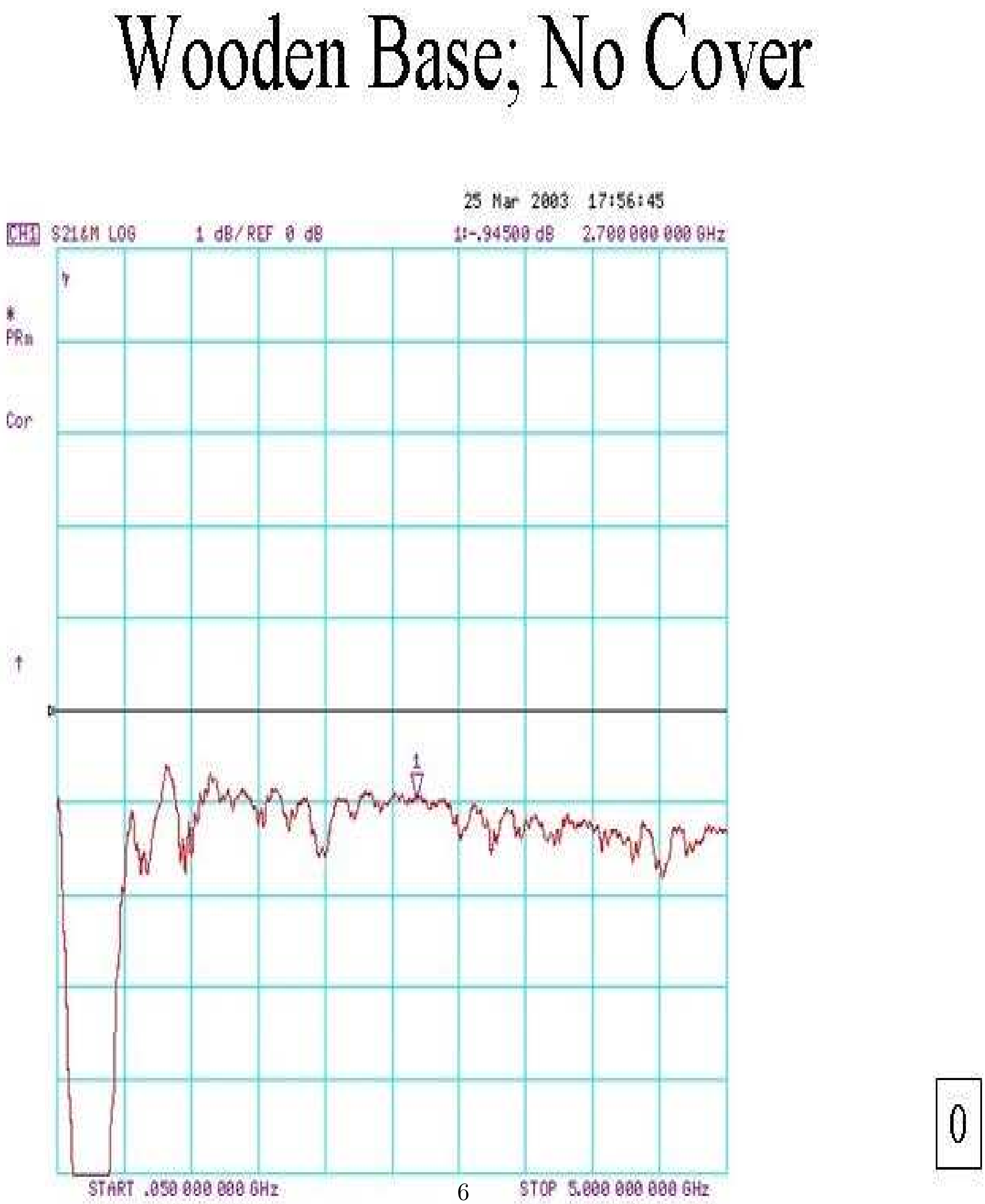

Figure 1: Transmission through the double balun mounted on the wooden block

Wooden Base; Cover On, 2.5” From End

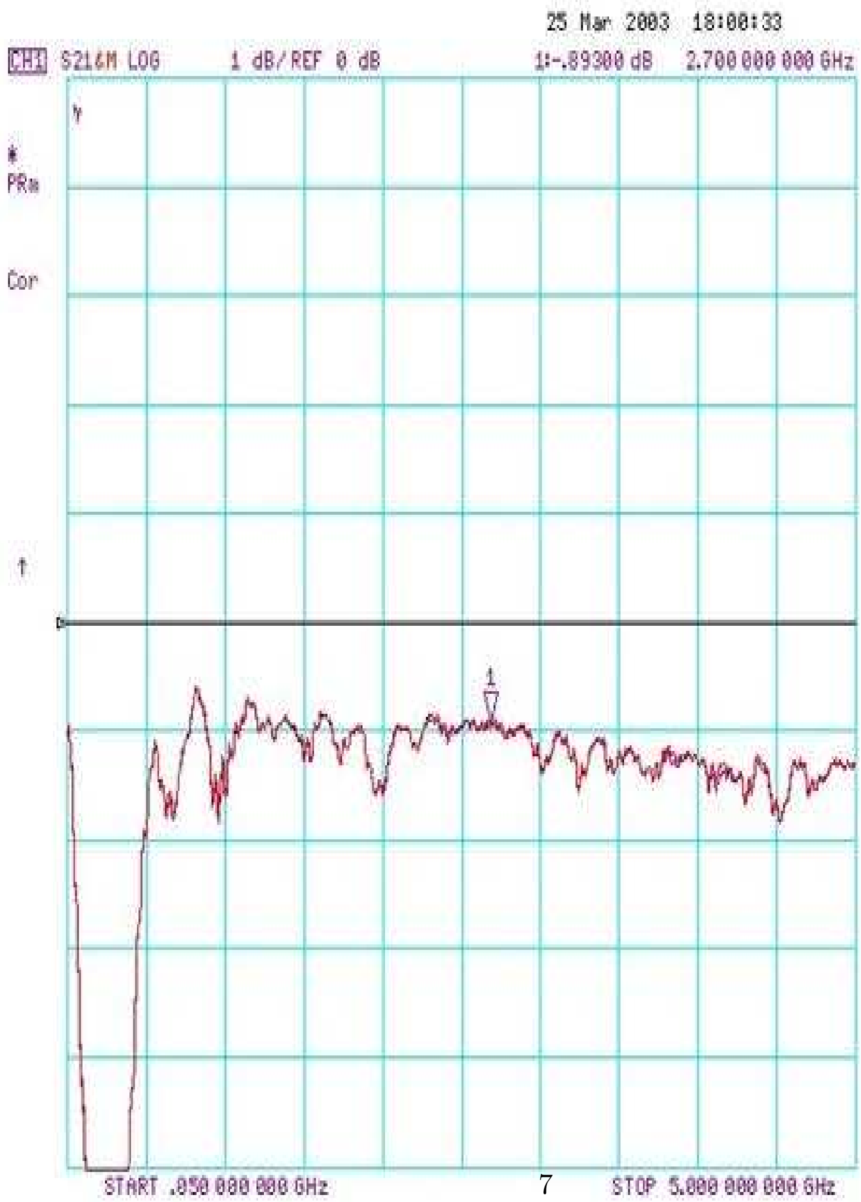

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Figure 2: Two traces. One is the trace of Figure 0, the other is the trace with the copper u-shaped cover placed over the middle of the double balun fixture. It fits tightly with the fixture.

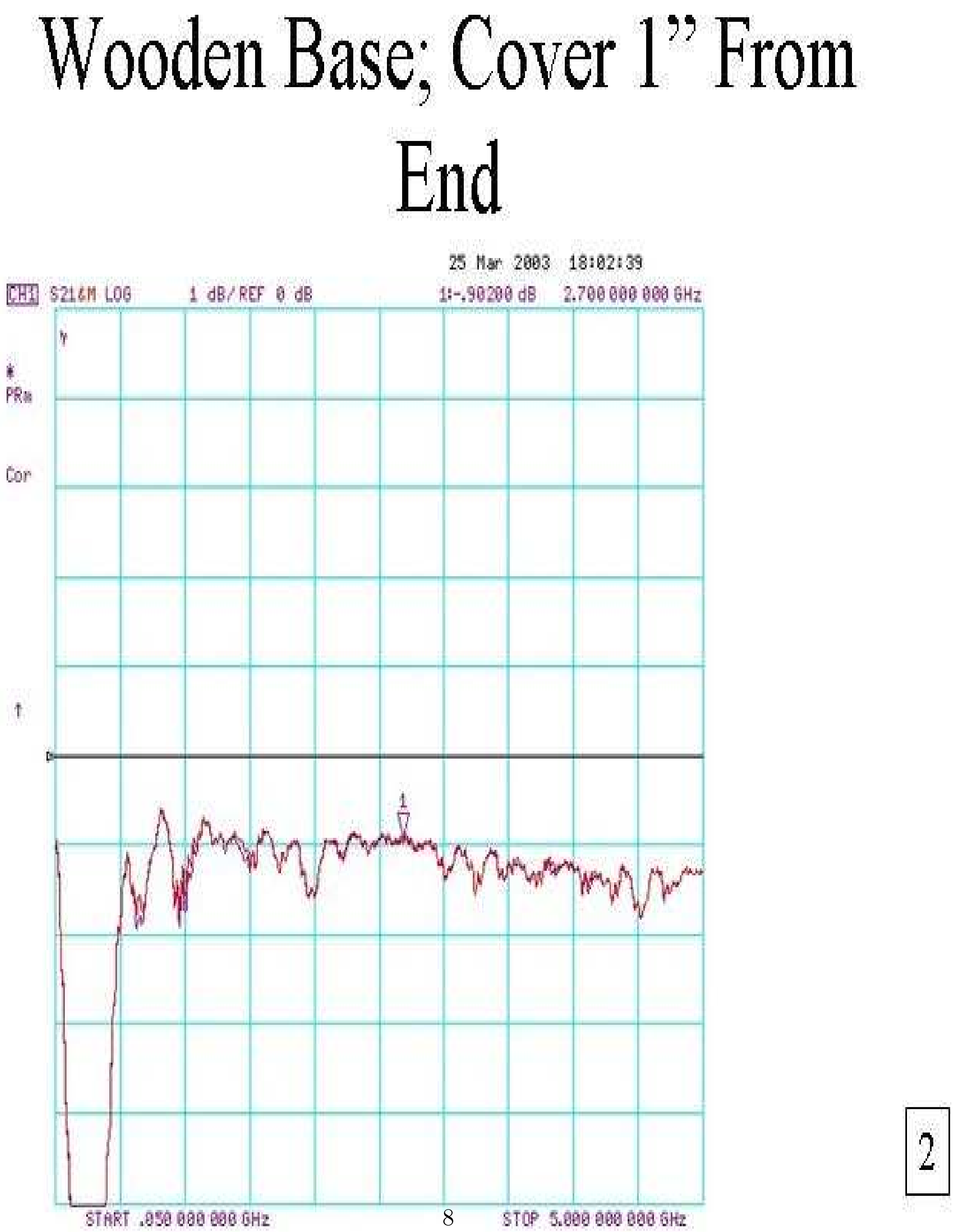

Figure 3: Two traces. One is the trace of Figure 0, the other has the u-shaped cover in place with one of its ends just one inch from the fixture end plate.

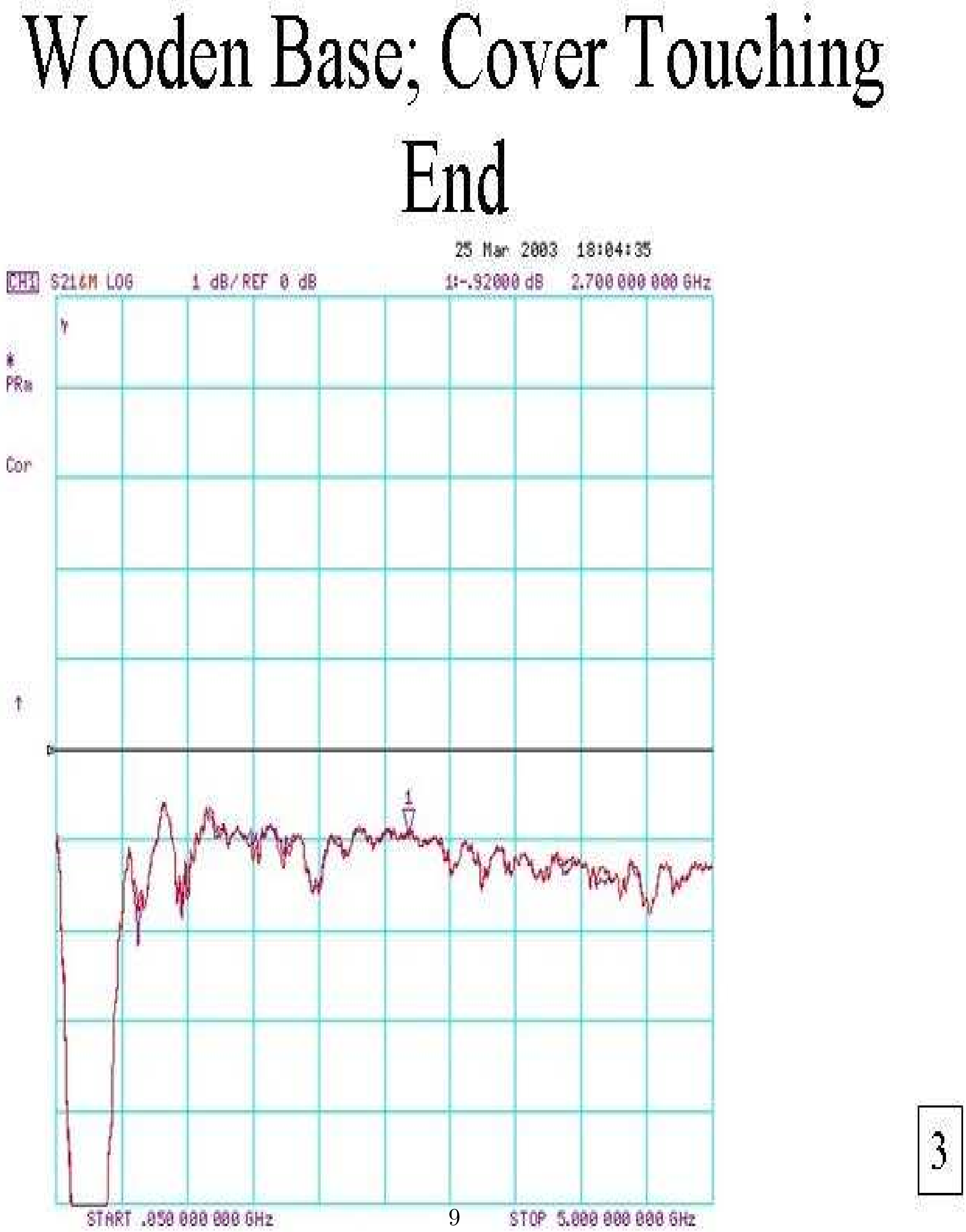

Figure 4: The trace of figure 0 plus a second trace with the u-shaped cover placed on and with its end touching the end plate.

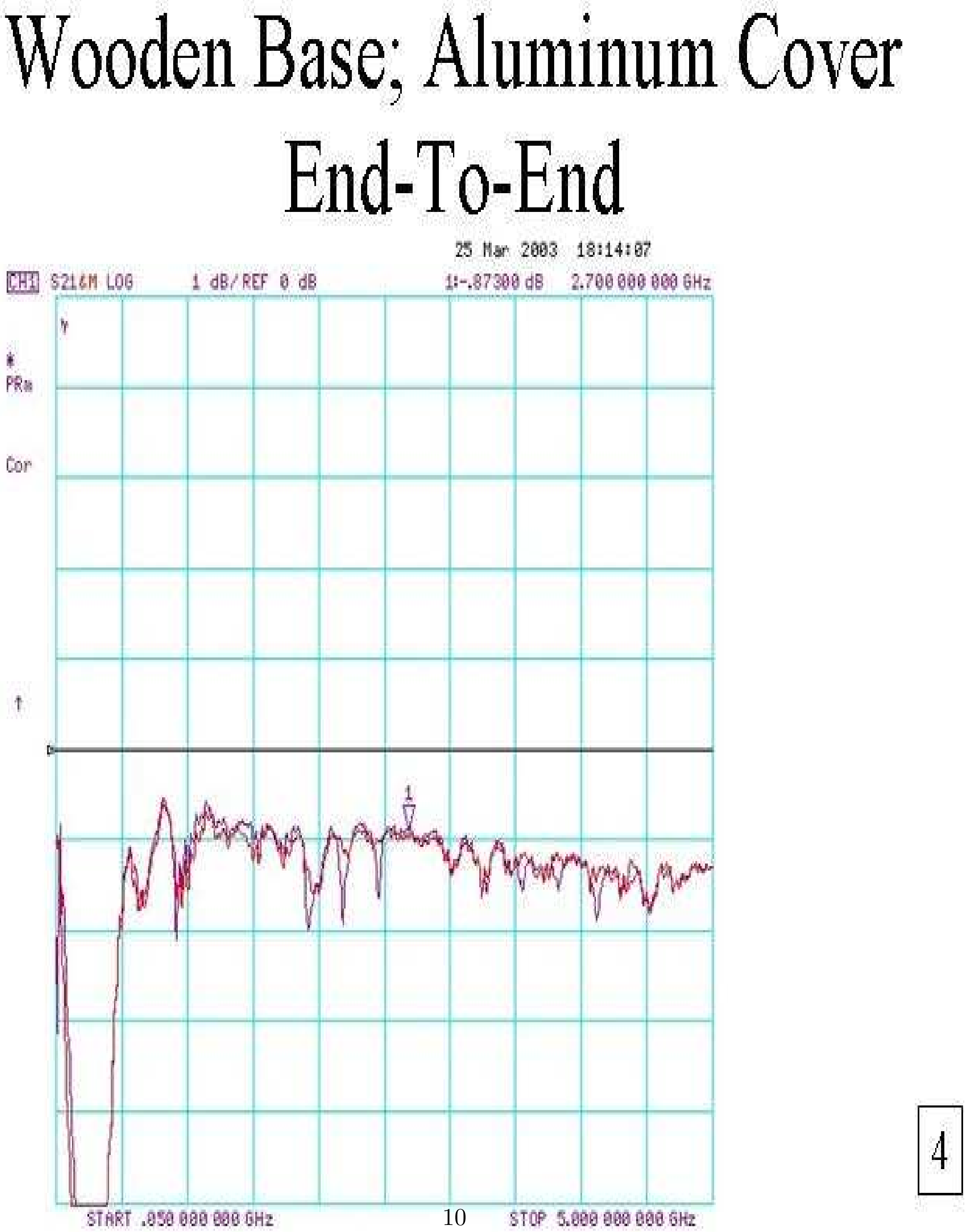

Figure 5: Two traces. The first from Figure 0, for the second the rectangular box cover is in place with both of its end covering the two end fixtures. The sharp resonances are evident at several frequencies.