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To: EDGES Group

From: Alan E.E. Rogers

Subject: Tests of prototype Fourpoint antenna with modified Roberts balun.

Memo 87 proposed to eliminate the need to use a lossy balun as part of the EDGES system by building the balun into the antenna. Including the balun as part of the antenna eliminates the need to make separate measurements of the balun provided the balun loss is low enough to be incorporated in the estimate of the resistive losses in the antenna and ground screen. This way all the measurements of the antenna can be made to the highest accuracy via a single standard unbalanced SMA port.

The design proposed in memo 87 was based only on simulation of the antenna S11 using FEKO and simulation of the balun based on transmission line theory. The Fourpoint dimensions were as follows:

The Fourpoint dimensions (for 102 to 192 MHz) are

Panel side length	0.375 m
Panel diagonal length	0.685 m
Panel lip width	0.017 m
Panel separation	0.01778 m
Panel height	0.525 m
Panel thickness	0.0625"
Plastic baseplate	24" × 24" × 0.25"

Outer coupling between panels is formed by a sandwich of aluminum, Teflon and aluminum with 0.25" hole in center.

Aluminum	2 × 0.75 × 0.25"
Teflon	2 × 0.75 × 0.1875" nominal (measured 0.2" thick)
Estimated capacitance	3.8 <i>pf</i>

The Robert's balun parameters and dimensions were as follows:

A. Input line

length	0.53 m
Brass tube inner dimension	0.37"

Copper rod outer dimension	0.15625"
3 equispaced Teflon spaces	0.5" Long
Nominal impedance	50 Ω
Estimated impedance with Teflon spacers	49.5 \pm 0.5 Ω

B. Balanced line

Length	0.525 m
Tube diameter	0.5"
Nominal impedance	238 Ω
Length from panel to short	0.49 m
Capacitance	0.28 m

C. Compensation capacitor

Nominal capacitance	~ 3 pf
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D. Connection to panels

A "top-plate" is used to connect from the inner conductor of the input line to the opposite panel.

Figure 1 Summarizes the materials used in the prototype. Figure 2 gives the details of the "compensation capacitance" on the balun and Figure 3 shows the details of the "top plate" connection. Figure 4, 5, 6, and 7 show the prototype under test on a large ground screen.

1] Simplified Roberts balun

The balun has a center conductor of the input 50 Ω transmission line going to the opposite panel via a low inductance top plate as shown in schematic drawing of Figure 8. The balun differs from the original Roberts balun described in memo 87 in the following ways.

- a) Input coax impedance Z_a is 50 ohms
- b) Balanced line has a compensation capacitance not present Z_b for the Roberts balun
- c) The series impedance Z_c is zero

As shown in memo 87 these modifications lead to an even wider bandwidth in the case of the Fourpoint antenna.

2] Sensitivity of return loss to balun and antenna parameters.

The antenna has 6 parameters but in practice on the panel separation and the added capacitance at the outer connection between panels are critical. Both of these parameters need to be within 10% to avoid a 3 dB increase in return loss.

The balun has the following 4 parameters:

- a) Position of short on balanced line
- b) Position of compensation capacitance
- c) Value of compensation capacitance
- d) Input line impedance

Of these 4 parameters the input line impedance is most critical and needs to be within 1 ohm of 50 to avoid a 3 dB increase in return loss. Originally it was thought that the widest bandwidth for a return loss under -15 dB might be obtained by changing the antenna dimensions to obtain a nominal 100 Ω of bandcenter and making the input line impedance $(5000)^{1/2}$. However for an almost 2:1 bandwidth this approach was found not to work and it was determined that for a wide bandwidth at the standard 50 Ω impedance the input line impedance Z_a needs to be 50 Ω so that in effect the balun only presents a frequency dependent reactance in parallel with the antenna. In this case the position of the short should be near the ground plane to present the largest reactance around 100 MHz. The position of the short is not very critical. There is a high correlation between the position of the compensation capacitance and its value. If we fix the position then its value needs to be within about 20% of the nominal 3 *pf* to avoid 3 dB increase in return loss about 150 MHz.

3] Comparison of theory with measurements

The theory suggests that achieving a return loss under -15 dB over a bandwidth of about 1.9:1 should be possible but only after considerable adjustment of the panel separations, the capacitance between panels at the outer edges and the balun compensation capacitance were we able to achieve about -15 dB from 102 to 192 MHz.

The difficulty arose, primarily because of small differences between the optimal values predicted by the simulations and those found in practice. The difference which presented greatest difficulty was that the simulation predicted an optimal separation of 0.016 m while in practice the best separation was found to be 0.0175 m. This difference is not yet understood and the wider separation is currently not properly incorporated in the prototype and the separation of the tubes of the balanced line is wider at the top. While the effect non uniform separation is probably negligible this needs to be corrected.

4] Balun shield

A shield has been built for the balun and initial tests show that the reflection coefficient is not significantly changed with the shield in place so that any adjustments to the position of the compensation capacitance can be made without the shield. It is not clear if a shield is

needed as the effect of radiation from the balanced line without the shield is to produce some vertical polarization in the pattern more than 30 dB below the horizontal.

5] Estimate of environmental stability of the Fourpoint with modified Roberts balun.

If the antenna is extremely stable it might be possible to measure the antenna impedance (or equivalently S11 magnitude and phase) under ideal conditions during installation and then assume the measured values in conjunction with an estimated temperature coefficient. If the stability is poor then it might be necessary to incorporate a means of frequent automated S11 measurements within the EDGES System.

Table 1 shows the rms change in S11 amplitude and phase over the 102-192 MHz range by a 1% change in a given parameter.

Parameter	Ampl. (dB)	Phase (radians)
Input line impedance	0.37	0.05
Balanced line impedance	0.10	0.008
Compensation capacitance	0.17	0.01
Top plate capacitance	0.04	0.004
Capacitance at antenna	0.15	0.02
Antenna size	0.03	0.09
Antenna height	0.18	0.03

If we now consider the material of the antenna and assume temperature coefficients for aluminum, PVC and Teflon of 3×10^{-5} , 5×10^{-5} , 9×10^{-5} respectively a 20 K change in temperature is estimated to make a change of about 0.02 dB and 0.005 radians. There is some concern over the stability and variable expansion coefficient of Teflon and consideration is being given to replacing the Teflon with Quartz glass ($E_r = 3.8$) appropriately changed in size or thickness to obtain the same capacitance. Also if the antenna and balun were made of precisely machined parts, it should be possible to measure S11 at one place, take the antenna apart, move it to another location, reassemble the antenna and have the reflection coefficient be unchanged following a small correction for any change in temperature.

Estimated effect antenna reflection on sky spectrum

The original goal was to achieve a reflection coefficient under -20 dB over a 2:1 bandwidth while this prototype falls significantly short of the goal it may still be possible to set a significant limit on the hydrogen line in the early universe. The -20 dB goal was primarily driven by the assumption that the VNA accuracy is limited to 0.1 dB in amplitude and 0.1 radians in phase. However it may be possible to improve the VNA accuracy over the 50-200 MHz range with “custom” calibration. With a reflection coefficient of -15 dB and a sky temperature of 500 K an accuracy of 0.01 dB in reflection magnitude is needed to reach the 30 mK level.

Preliminary S11 measurement

Figure 9 shows preliminary S11 measurements made manually with an old VNA. The thick line are the measurements and thin line is the FEKO model.

Added Notes: To reduce the sensitivity to temperature the Teflon spacers have been replaced with

Quartz	1×0.75×0.2”	in middle (tempCo 0.5 ppm/°C
Aluminum	1×0.75×0.25”	on either side (tempCo 24 ppm/°C

For an estimated capacitance of 3.16 *pf*

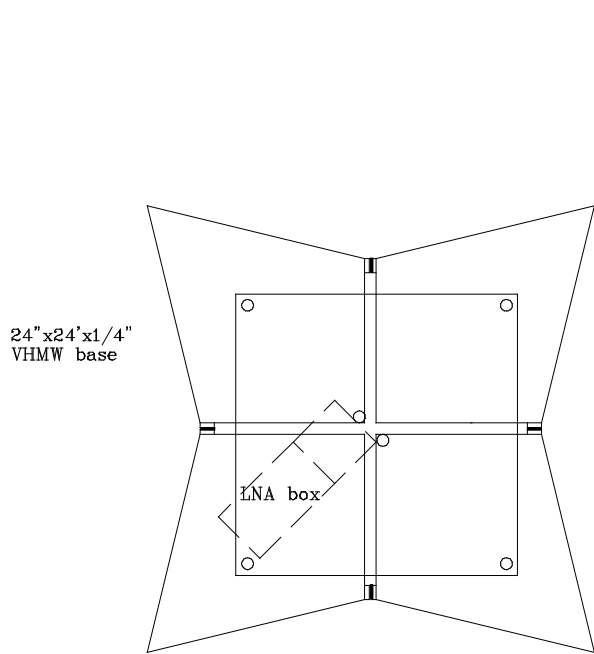
The tuner capacitance on the balun is now

Quartz	1×0.75×0.2”
Teflon	1×0.75×0.035”

The inner spacers on the panels are now

0.7” ×0.5” diameter G10/FR4 TempCo 12 ppm/°C and the PVC supports have been replaced with Fiberglass (TempCo 18 ppm/°C).

For a constant atmosphere the temperature dependence of S11 is expected to be about 3×10^{-4} dB/°C (at -15 dB) so that S11 should hold to within 0.01 dB over a 30 °C range.



EDGES-2 "test antenna with built-in balun"

Dimensions:

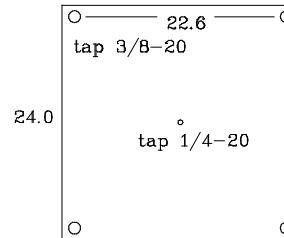
half-gap 0.0087 0.6875"
diag 0.66 26.77"
height 0.52 20.47"

side 0.3713 14.6181"
lip 0.015435 0.6077"
S11 < -15 dB 102 - 192 MHz
beam 8.36 - 6.96 dBi

Misc. parts:

- 9] Brass nuts 1/2-28 Qty 4
- 10] Teflon threaded rod Qty 4
3/8-20 x 21
- 11] Stainless nuts 3/8-20 Qty 4
- 12] SMA male
- 13] Sched.40 PVC 1/2x20.2 Qty 4
- 14] Nylon nuts+bolts 1/4-20 Qty 12
- 15] Teflon spacers
with 1/4 clearance Qty 4
- 16] 4x4x1/8 shield with 3.75x5 cutout
- 17] rt.angles Qty 3

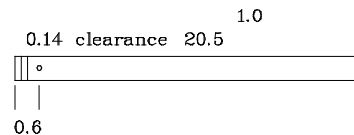
- Parts: 1] VHMW base 24"x24"x0.25" 24.0



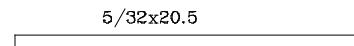
- 2] Panels Qty 4 - see separate drawing template
- 3] Teflon 1x0.75x0.1875 Qty 4



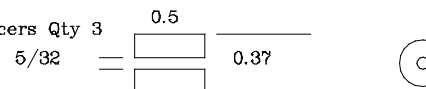
- 4] tubes Qty 2
1/2x20.5
1/2-28 thread
on each end
for 0.5"



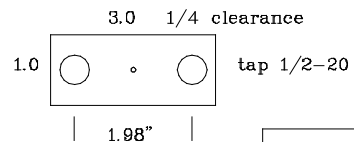
- 5] copper rod



- 6] Teflon spacers Qty 3

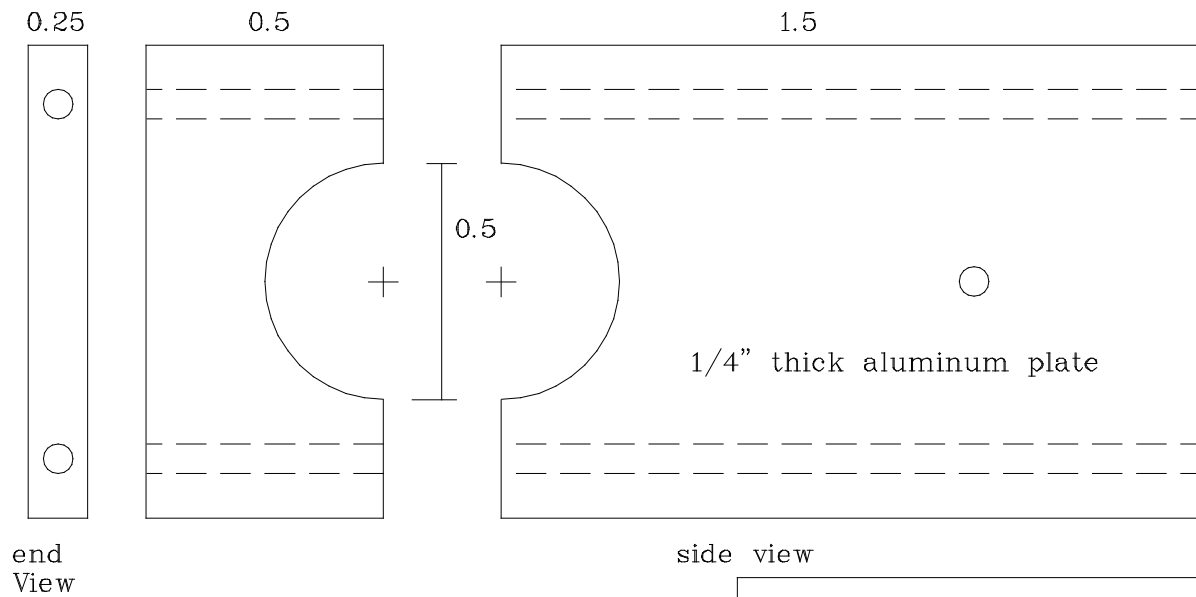


- 7] Brass plate
3x1x1/8



EDGES antenna
prototype using
Roberts balun
Parts aeer 25Jul12

Figure 1 Parts



Tuning for antenna

robertstune 25July12

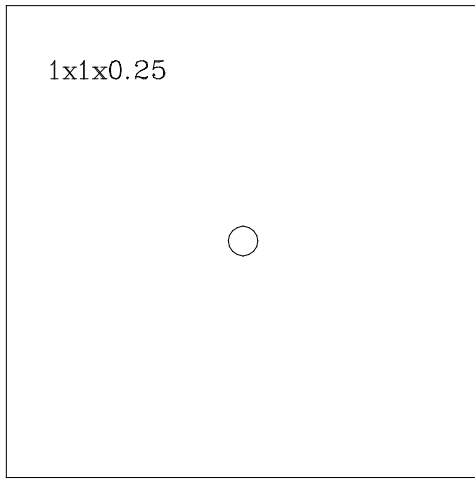
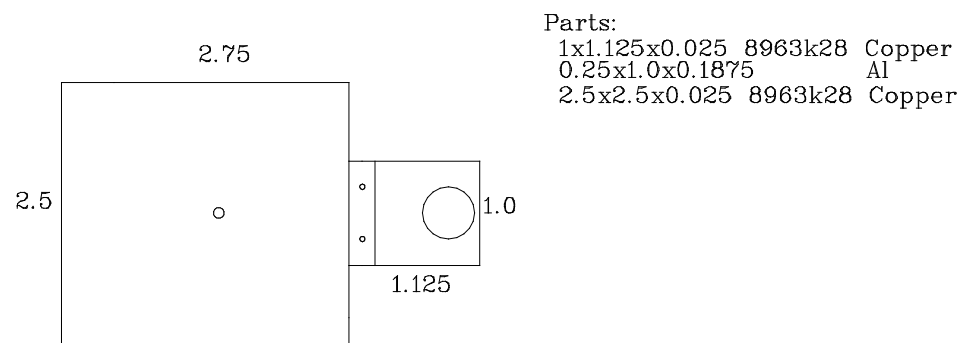


Figure 2 Compensation capacitance



Top plate
 balun

robertplate 15june12

Figure 3

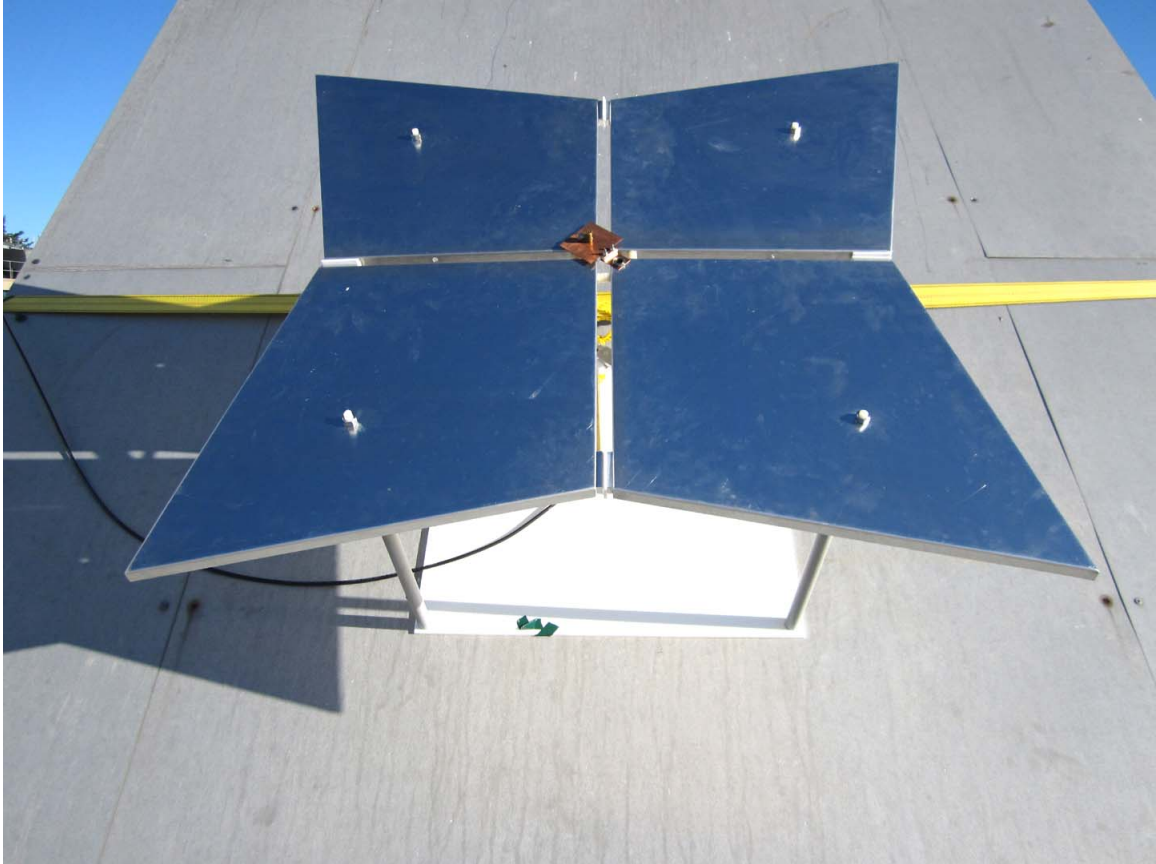


Figure 4. Antenna and ground screen.

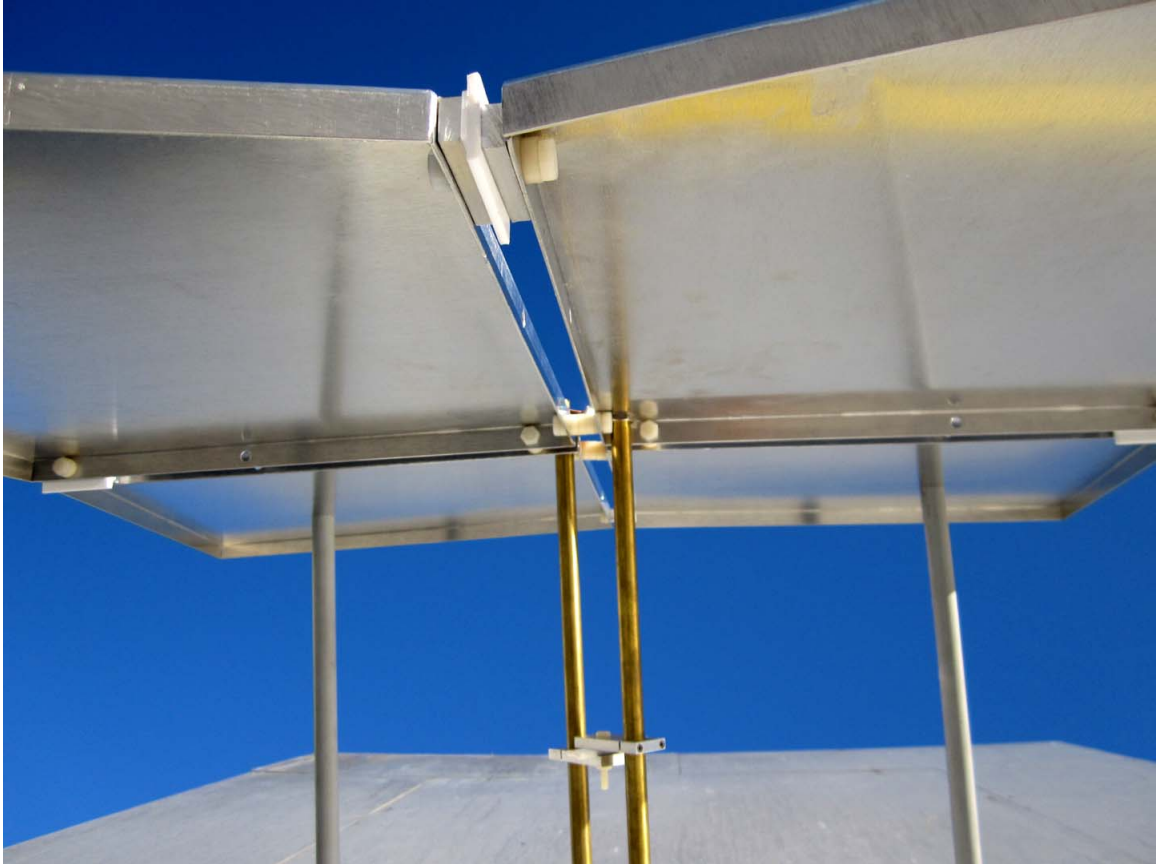


Figure 5. Antenna from below

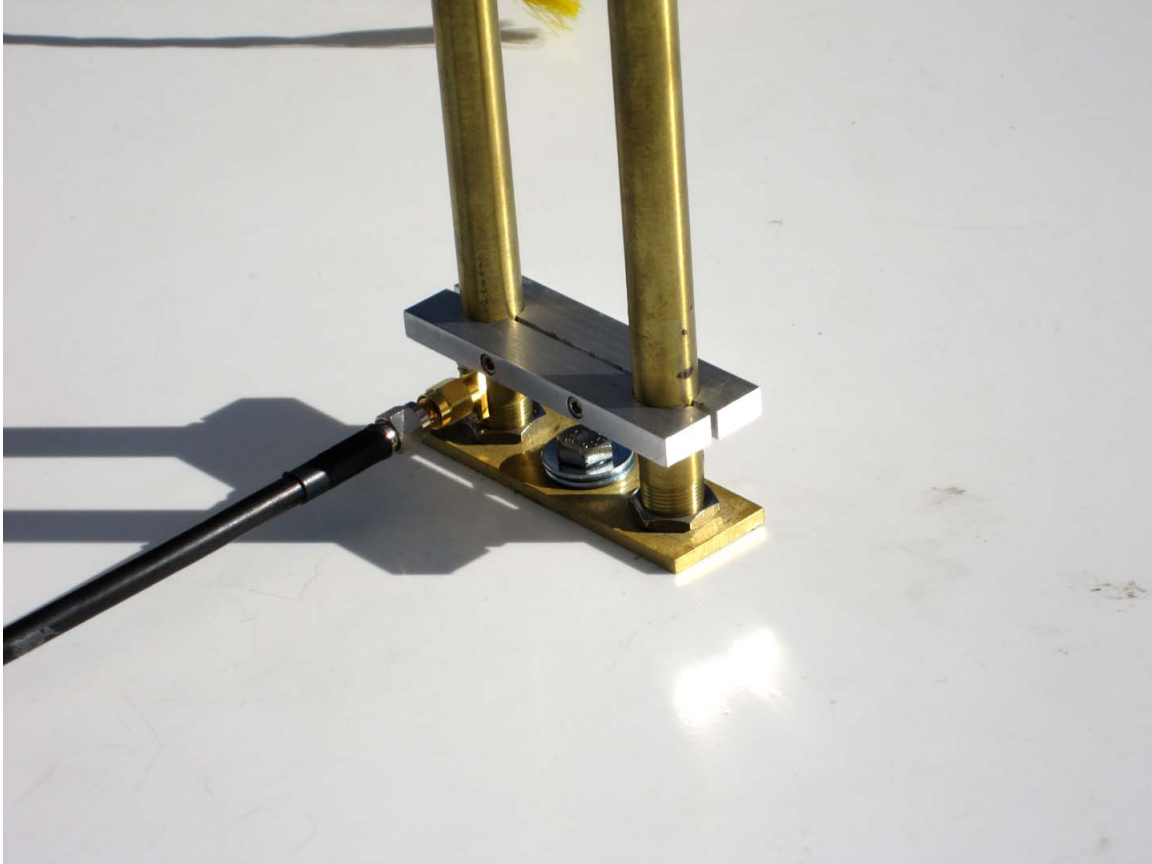


Figure 6. Close-up of antenna port

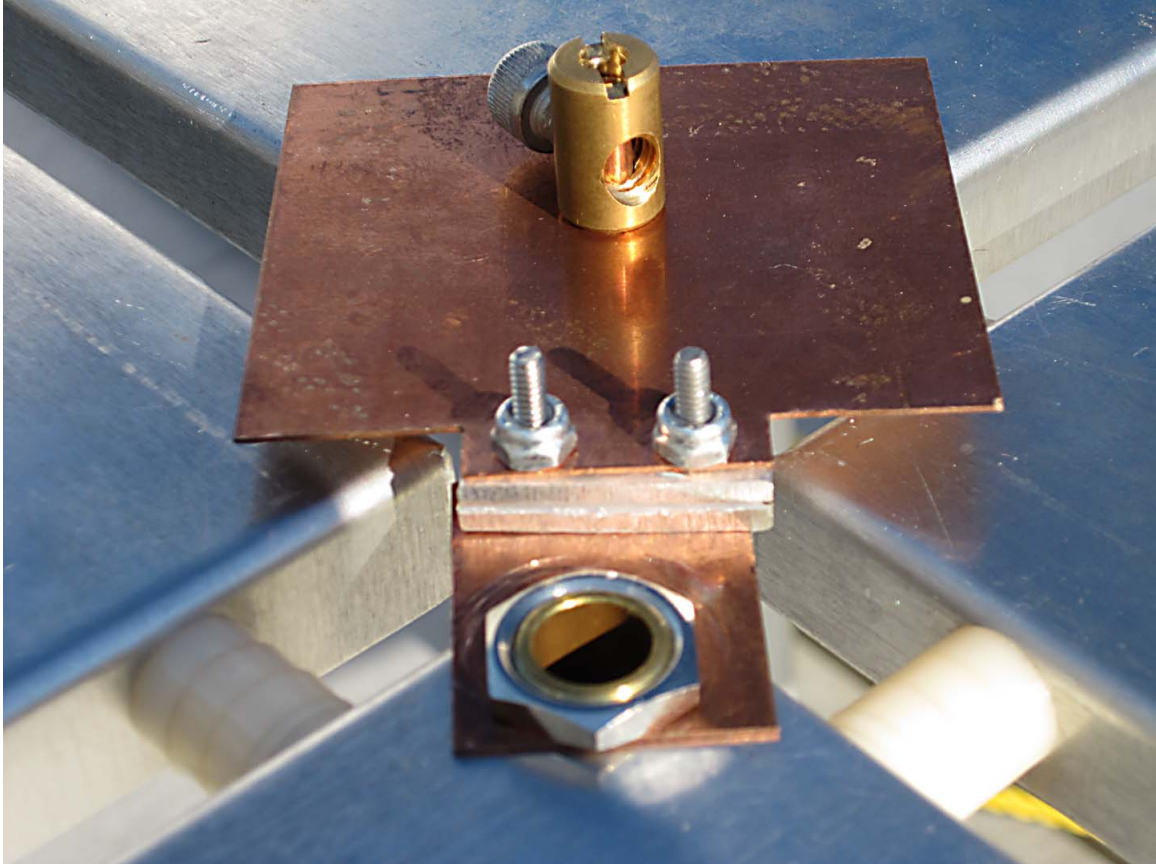


Figure 7. Close-up of connection from balun to antenna panels.

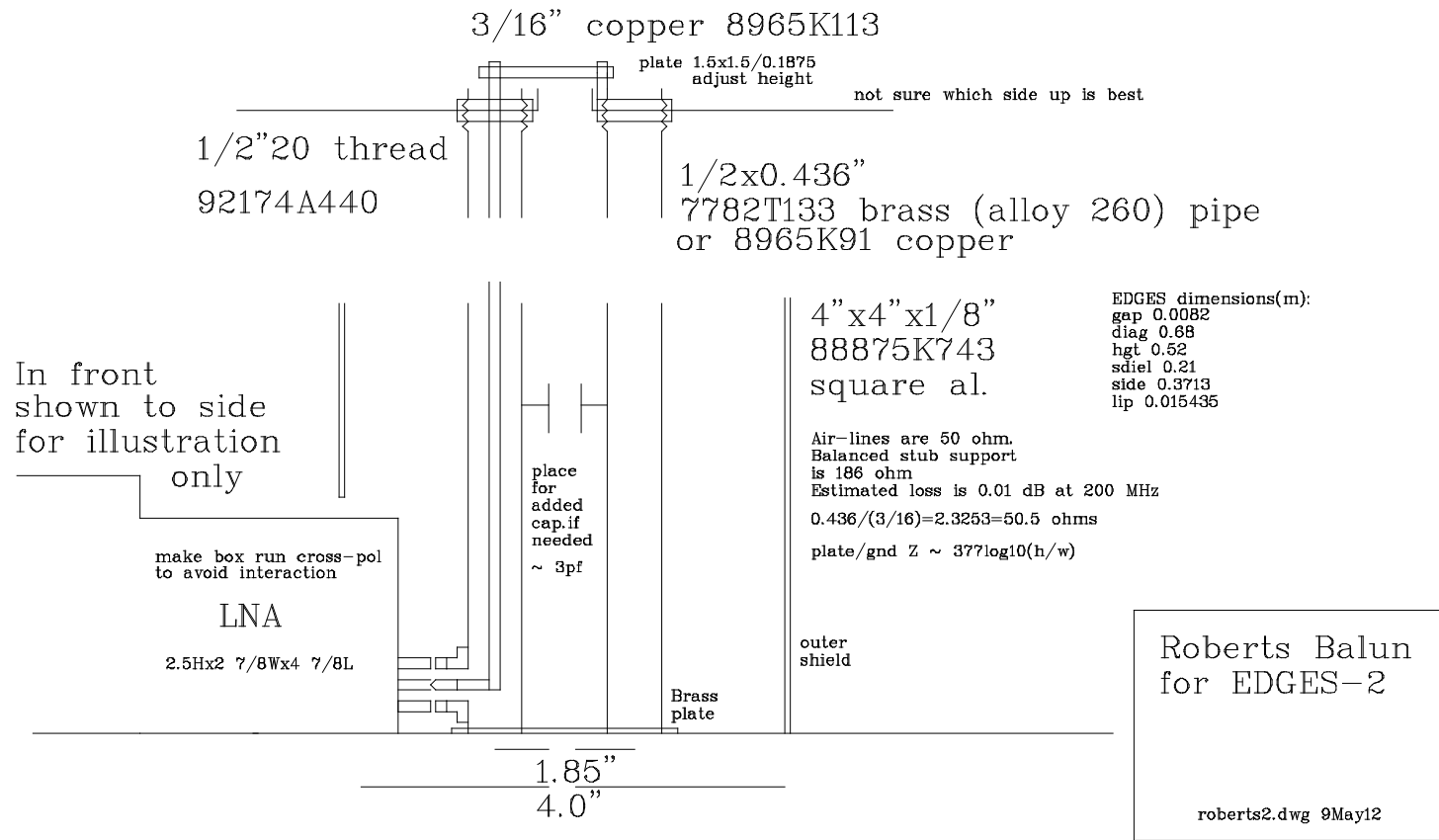


Figure 8. Schematic of Roberts balun.

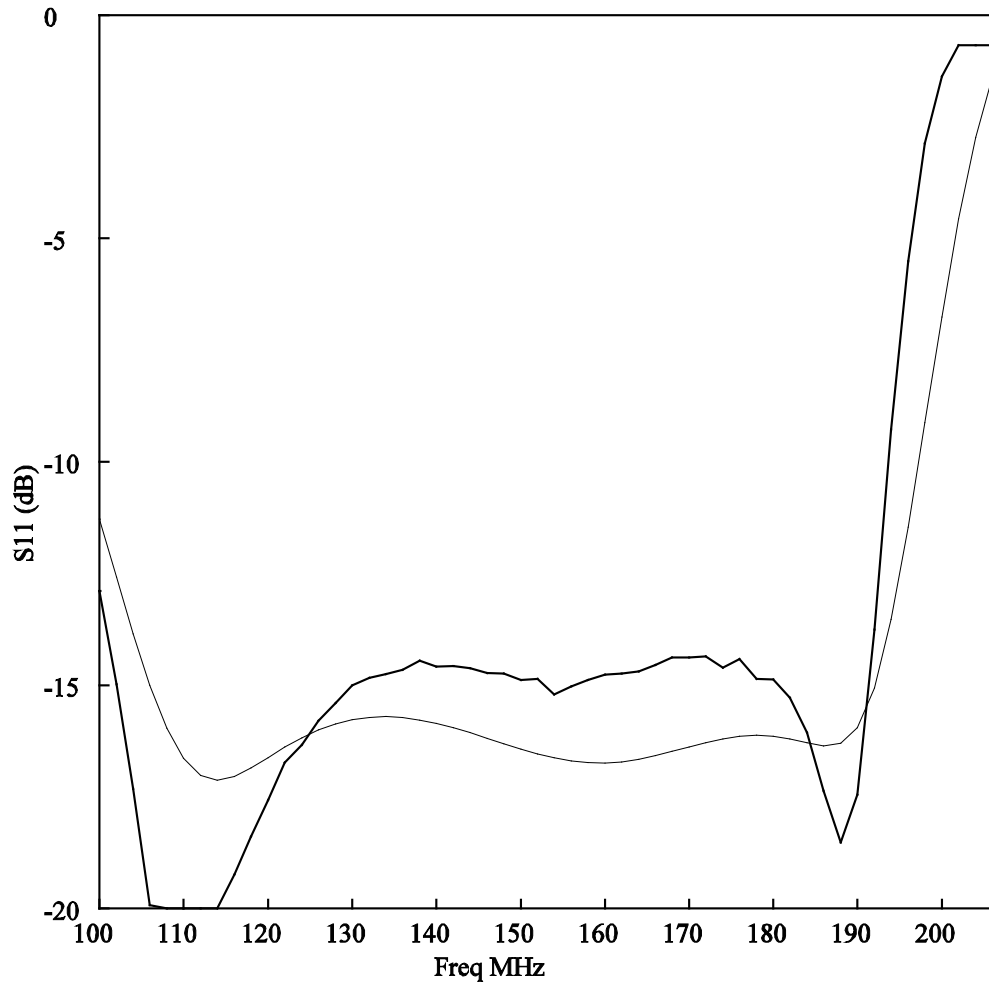


Figure 9. Preliminary measurements (thick line) of prototype