

AN ADJUSTABLE SHORT SLOT HYBRID FOR PRECISE RF POWER DIVIDER SYSTEM FOR CORNELL ERL INJECTOR CAVITIES

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INTRODUCTION

In Cornell Energy Recovery Linac (ERL) project [1], each of the five injector cavities will have a twin input coupler, consisting of two identical antenna type coaxial couplers [2]. Each cavity will be driven by a 1300 MHz 150 MW CW klystron through a power dividing system. A difference of field magnitudes on individual coupler antennae must not exceed 1-2%, and a phase difference must not exceed 1°. This imposes very strict requirements on the power dividing system.

A possible scheme of the power dividing system for ERL injector cavities is shown in Figure 1 [3]. We propose to use an adjustable short slot hybrid as a power divider for this precise RF power dividing system. This type of hybrids seems to have better electrical properties compared with other four-port hybrid designs: low sensitivity to mismatch, a wide frequency band, and the best high power handling [4]. A similar device is used, for instance, in the 324 MHz RF system of JAERI/KEK high-intensity proton linac, which has similar requirements [5].

For power balance between the two sides of a twin coupler, a movable stub in the middle point of the short slot hybrid can be used. A schematic view of this hybrid is presented in Figure 2. By varying the stub penetration into the waveguide, one can adjust the power splitting between output arms of the hybrid. The terminating ports of the hybrid will be the standard WR650 waveguide ports.

SHORT SLOT HYBRID: GENERAL CONSIDERATIONS

The coupling region of a short slot hybrid is wide enough for both the TE_{10} (even) and the TE_{20} (odd) modes to propagate. The fields of the input port excite these two modes with equal amplitudes and a relative phase such that their fields add constructively on the side nearest to the input port and destructively on the other side. As the guide wave numbers of these two modes are different, their relative phase changes as they propagate along the guide. To get equal split between output ports of the hybrid (−3 dB relative to the input port), the total phase lengths for these two modes through the connecting guide must differ by 90°. It results in the length of the slot region [6]

$$L = \frac{1}{4} \frac{A_2 A_1}{A_2 - A_1},$$

where A_1 is the guide wave length of the mode TE_{10} and A_2 is the guide wave length of the mode TE_{20} . In our case, $L = 260.5$ mm.

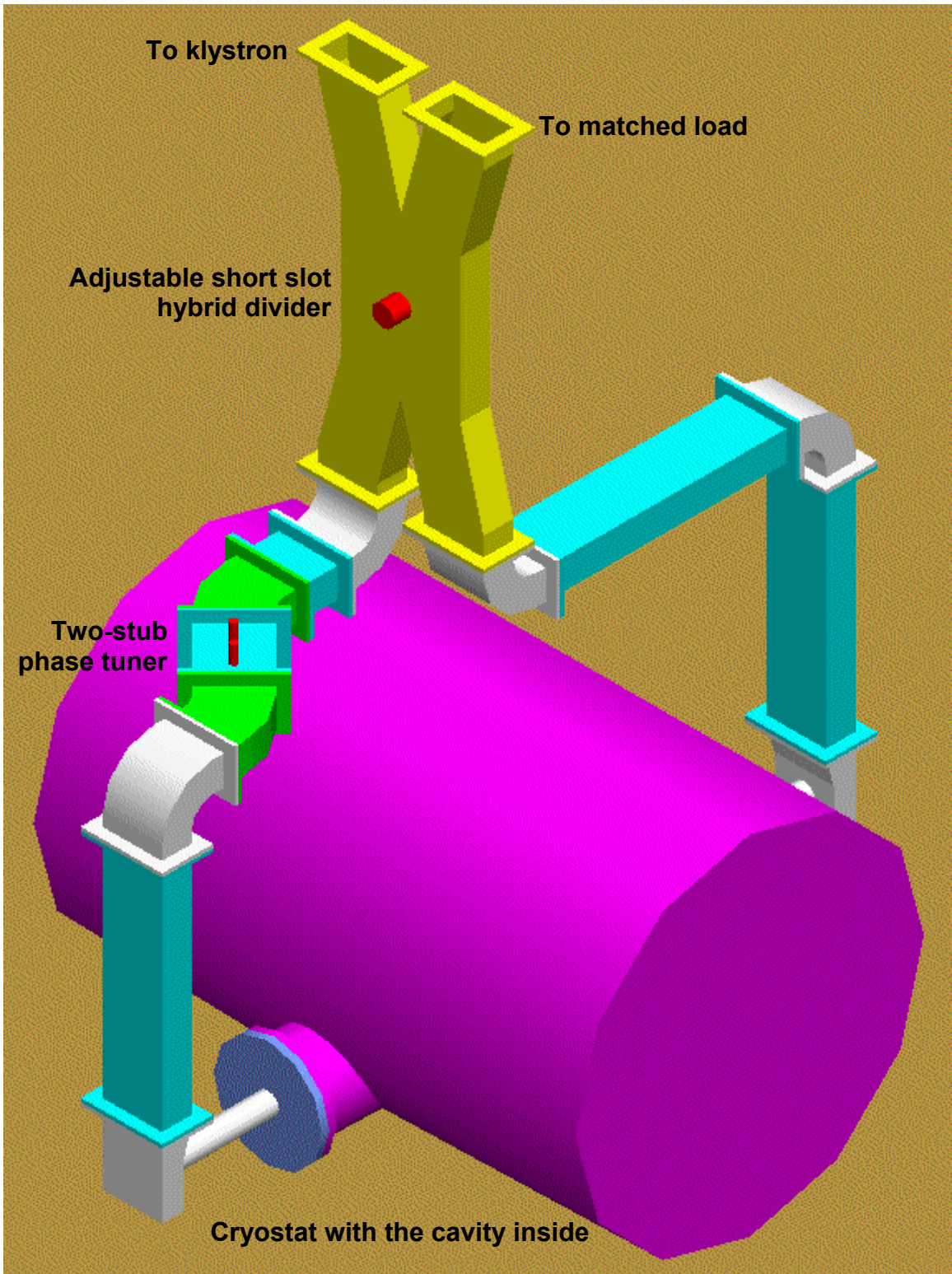


Figure 1: 3D view of power splitting scheme for an ERL injector cavity.

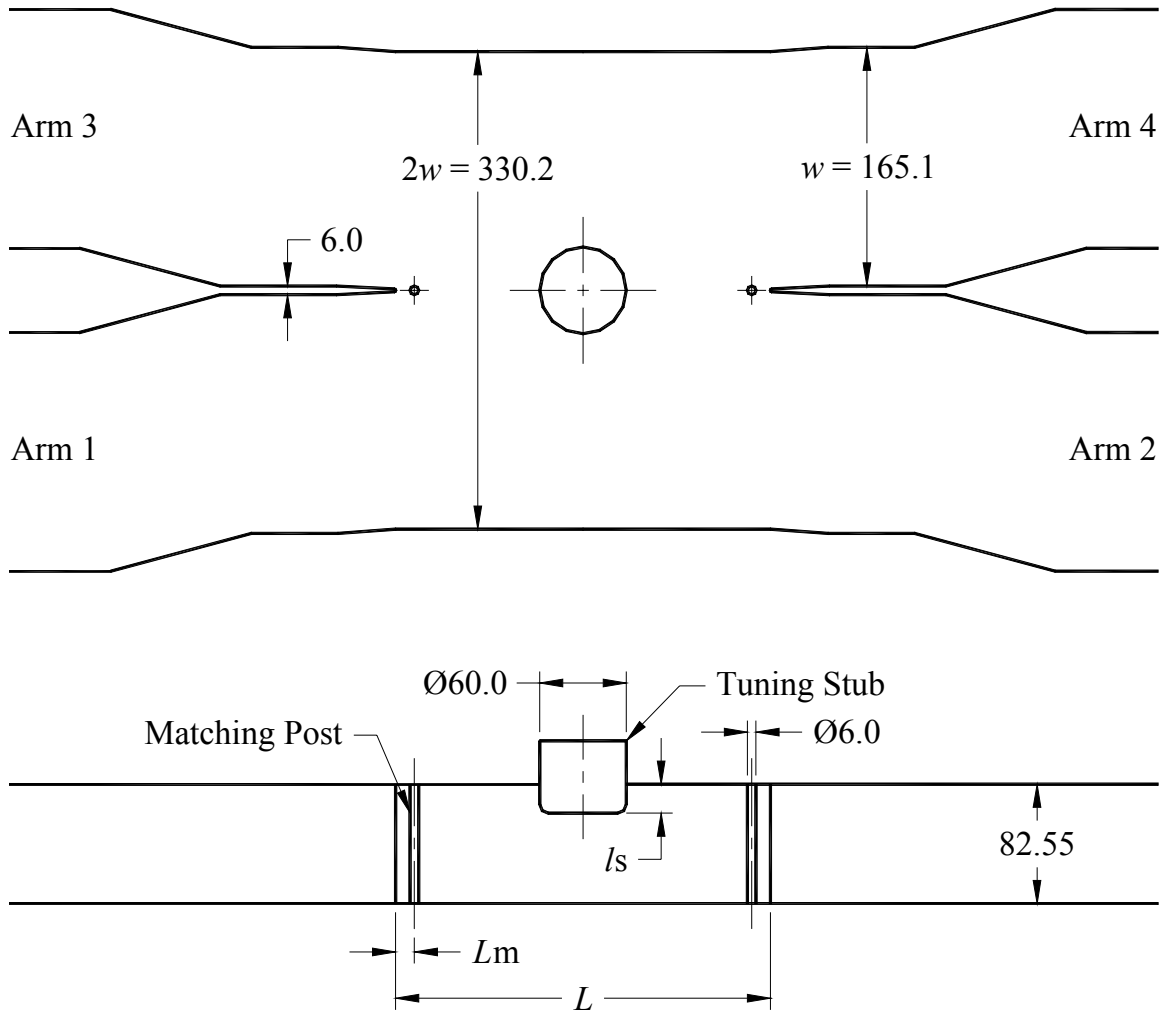


Figure 2: Schematic view of an adjustable short slot hybrid.

It is important to keep the TE_{30} mode cut off in the slot region for the whole operating frequency band. To this end, the width of the slot region is often being made narrower than twice the standard guide width. It is particularly important for broadband applications. In our case, the cut-off frequency of the TE_{30} mode is 1.36 GHz, and this seems to be close to the operating frequency of 1.3 GHz. However, the ERL RF system is very narrowband, and 60 MHz is quite a good margin. Therefore, we can use guides with standard width ($w = 165.1$ mm) and eliminate additional transition parts required between narrowed guides in the hybrid and the regular WR650 terminating ports.

In the hybrid design, we need to achieve high directivity and equal power division. For this purpose, we need to control simultaneously the phase advance and match of both the TE_{10} and TE_{20} modes in the slot region. As the width of the slot region is twice the width of the arm waveguides, the wave number of the odd mode is equal to the wave number of the single mode (TE_{10}) in the arm waveguides. Therefore, the odd mode is easy to match.

On the contrary, the even mode has a different wave number and, due to that, reflections appear on the end planes of the slot region. For compensating these reflections, matching elements should be included in the hybrid design. The tuning stub can be used for this purpose. However, for having extra freedom to achieve precise hybrid properties, we include additional matching elements in our design. Two posts near each end of the slot are these matching elements.

RESULTS OF COMPUTER SIMULATIONS

The hybrid parameters depend both on the positions of matching posts and insertion value of the tuning stub, as it is shown in Figures 3 to 5 for the nominal ERL frequency f of 1.3 GHz. These, as well the other results, were obtained by a 3D computer code CST Microwave Studio® [7], which was used extensively in the hybrid design process.

The short slot hybrid has its best properties at $L_m = 10-12$ mm. By varying the insertion value l_s of the tuning stub around a value of 15 mm, it is possible to adjust the coupling to output ports at a rate of 0.12 dB/mm with a rather small change of the phase advance ($0.2^\circ/\text{mm}$).

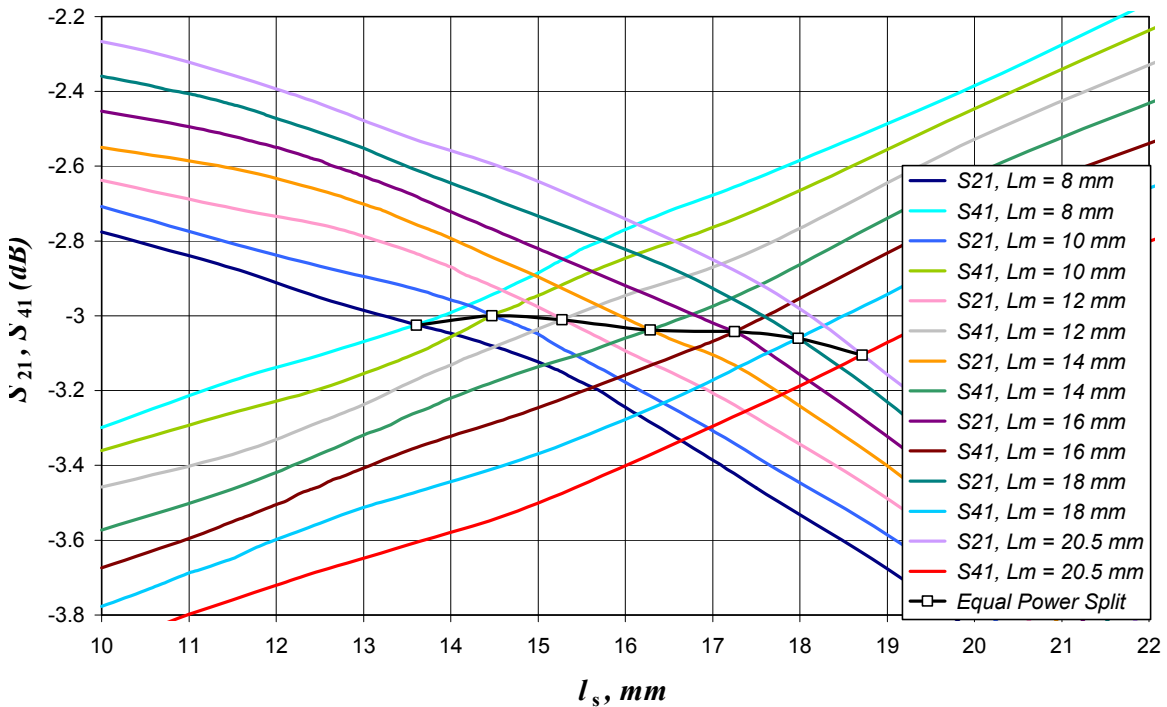


Figure 3: Couplings to the output ports as functions of stub insertion l_s for different locations of matching posts (hybrid with standard width, $w = 165.1$ mm).

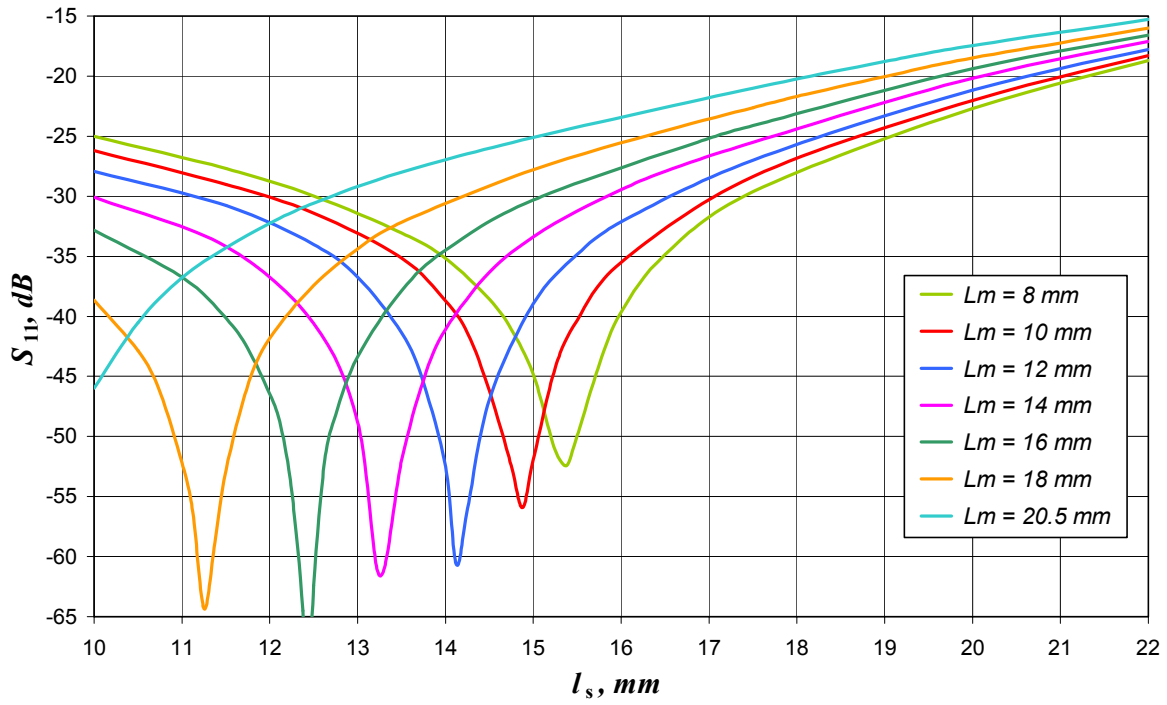


Figure 4: Reflection from the hybrid as a function of stub insertion l_s for different locations of matching posts (hybrid with standard width, $w = 165.1$ mm).

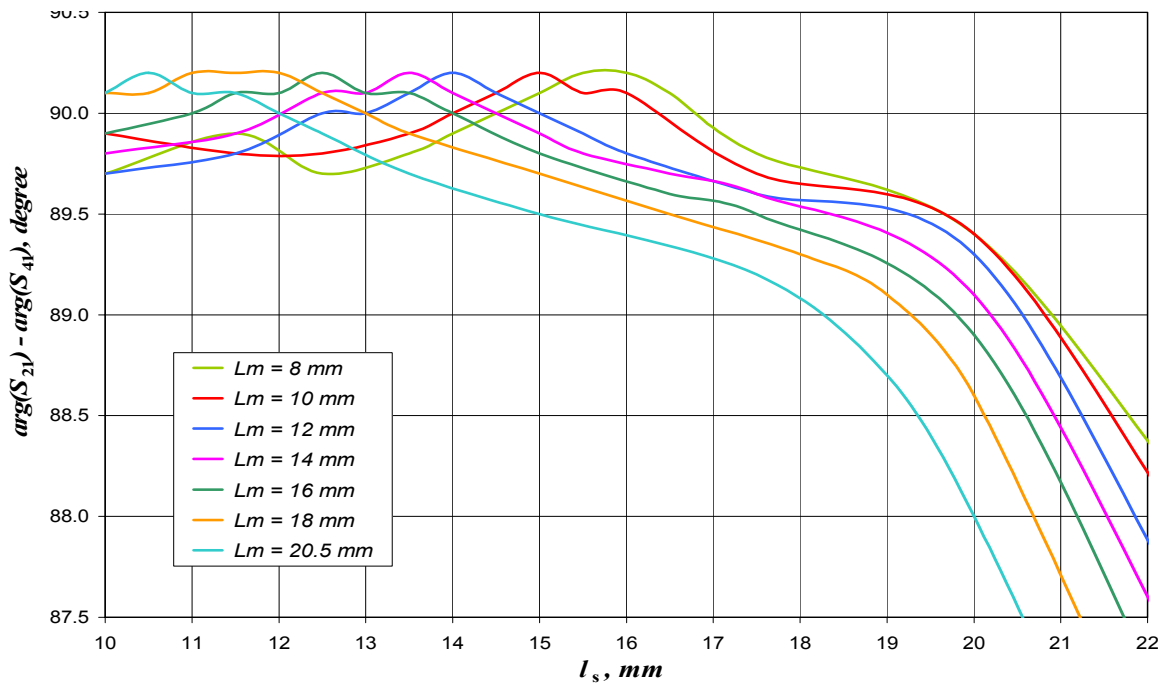


Figure 5: Phase difference at the output ports of the hybrid as a function of stub insertion l_s for different locations of matching posts L_m (hybrid with standard width, $w = 165.1$ mm).

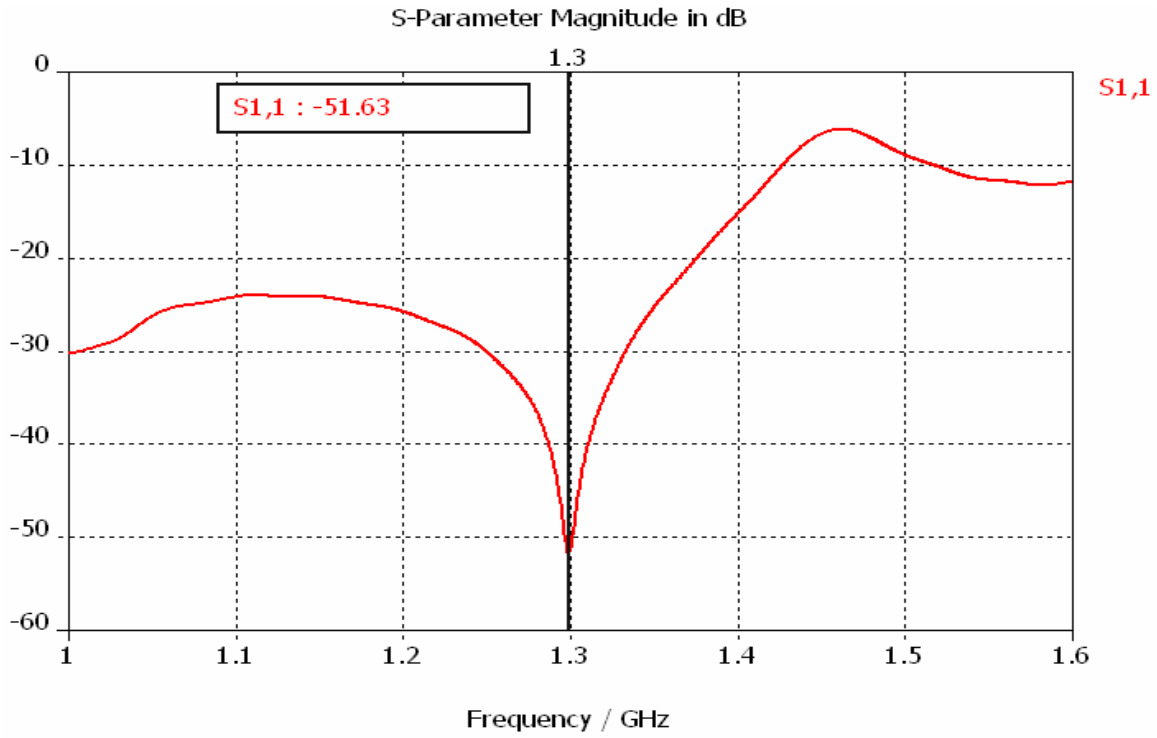


Figure 6: Reflection from the hybrid with $w = 165.1$ mm, $L_m = 10.5$ mm, $l_s = 14.65$ mm.

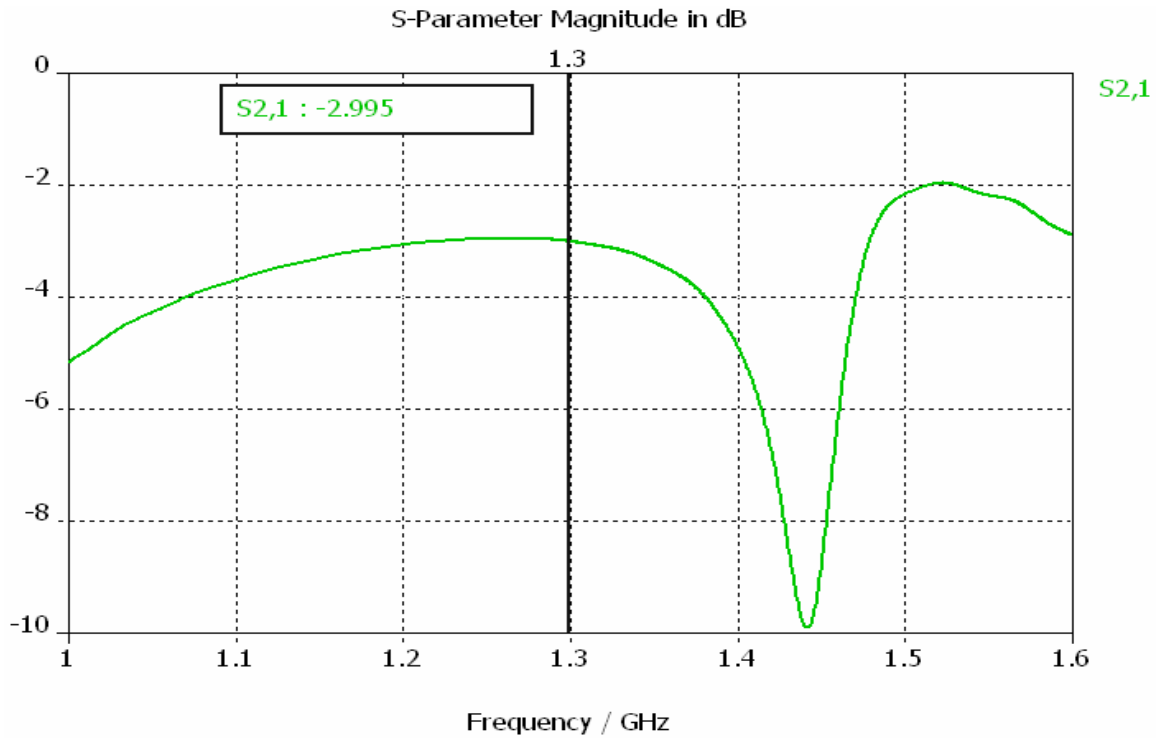


Figure 7: Coupling to the output port 2 for the hybrid with $w = 165.1$ mm, $L_m = 10.5$ mm, $l_s = 14.65$ mm.

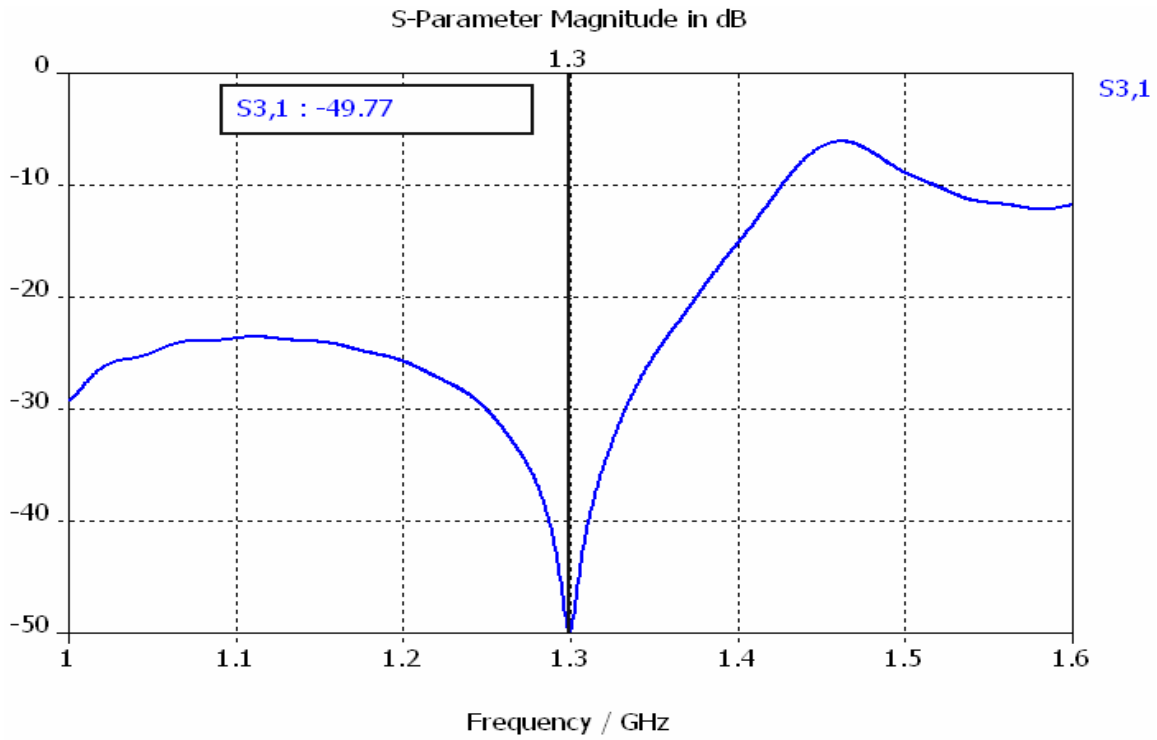


Figure 8: Return loss for the hybrid with $w = 165.1$ mm, $L_m = 10.5$ mm, $l_s = 14.65$ mm.

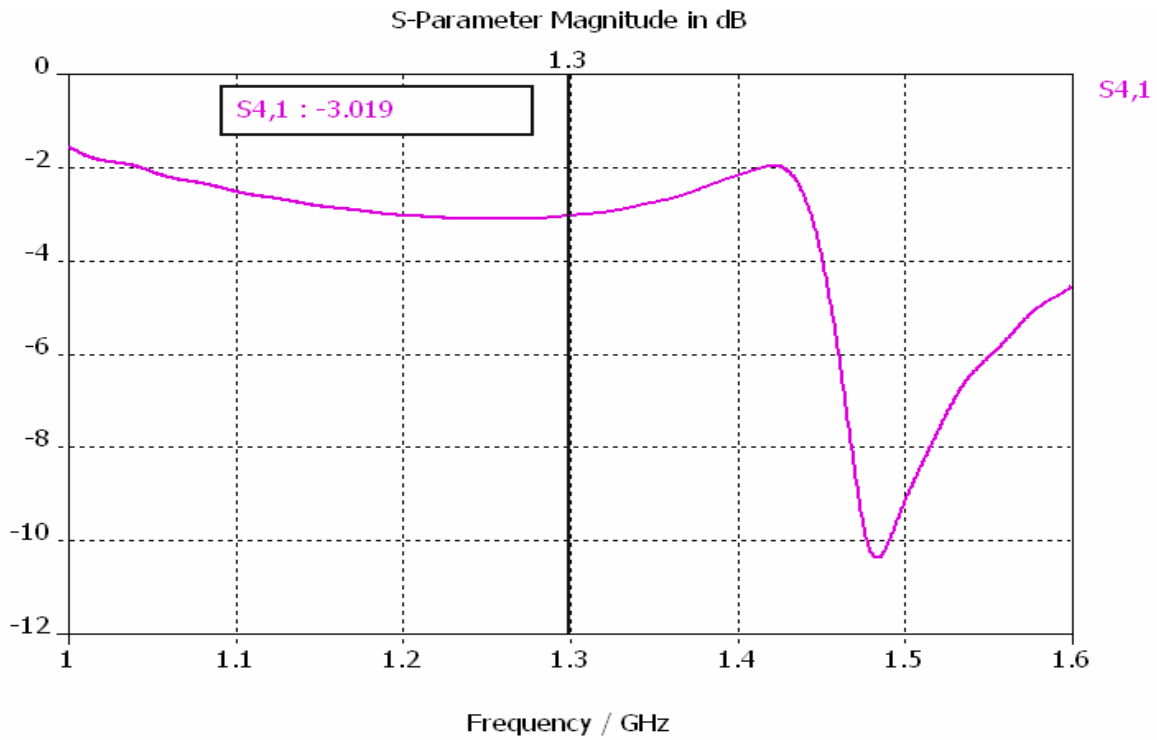


Figure 9: Coupling to the output port 4 for the hybrid with $w = 165.1$ mm, $L_m = 10.5$ mm, $l_s = 14.65$ mm.

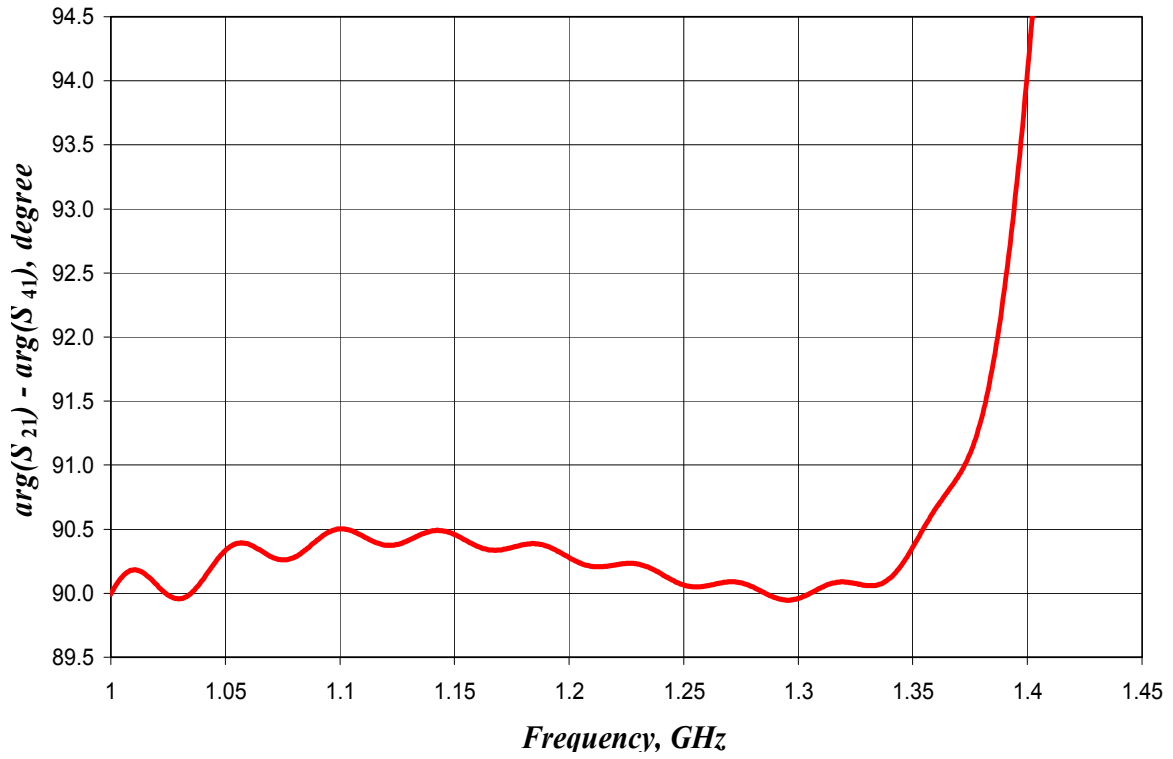


Figure 10: Phase difference of output signals for the hybrid with $w = 165.1$ mm, $L_m = 10.5$ mm, $l_s = 14.65$ mm.

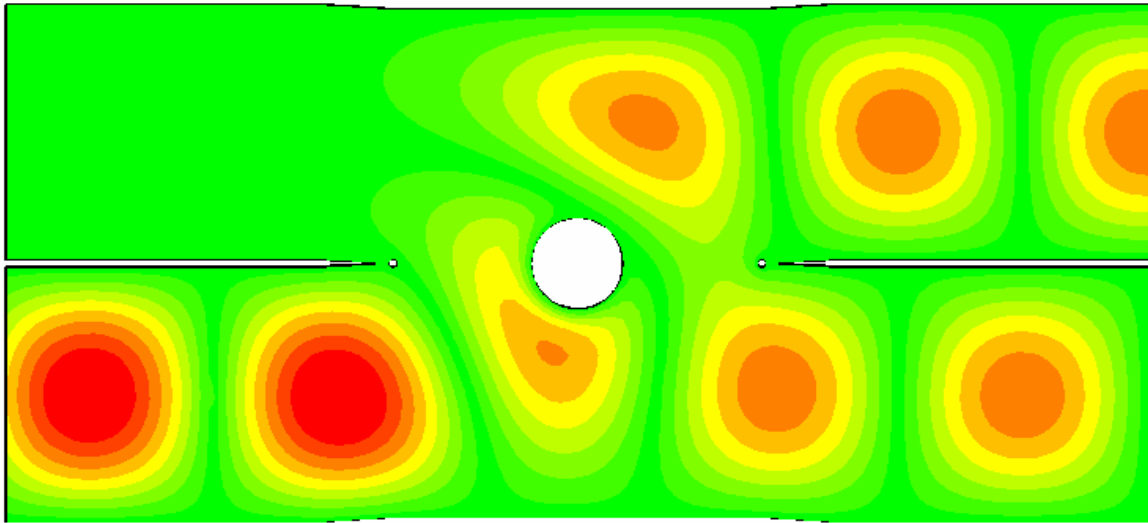


Figure 11: Pattern of electric field for the hybrid with $w = 165.1$ mm, $L_m = 10.5$ mm, $l_s = 14.65$ mm at $f = 1.3$ GHz.

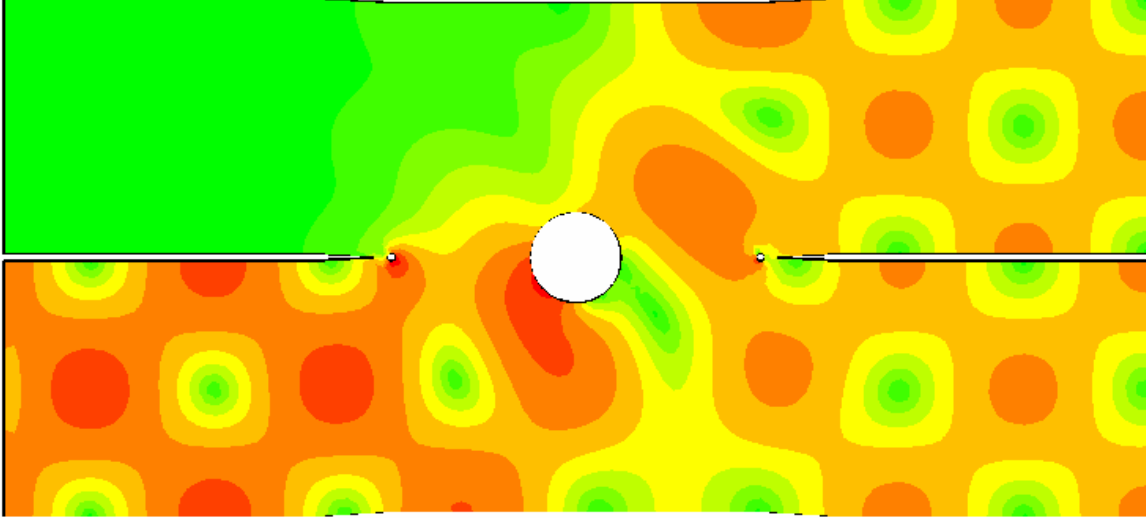


Figure 12: Pattern of magnetic field for the hybrid with $w = 165.1$ mm, $L_m = 10.5$ mm, $l_s = 14.65$ mm at $f = 1.3$ GHz.

Figures 6 to 10 present scattering parameters of the optimized hybrid in a wide frequency range. As apparent, the properties of the hybrid degenerate at frequencies around 1.4 GHz and above. This happens because the TE_{30} mode starts to propagate in the coupling region of the hybrid. Figures 11 and 12 show the plots of electric and magnetic fields in the hybrid at the nominal frequency of 1.3 GHz and illustrate a nice splitting function of the hybrid.

HYBRID WITH A WIDER FREQUENCY BAND

It is easy to improve the properties of the hybrid at higher frequencies by narrowing the coupling region. As an alternative design, on the subsequent graphs (Figures 13 to 20) the properties of the hybrid with the value of $w = 155$ mm are presented. For this design, the cut-off frequency of the TE_{30} mode is equal to 1.45 GHz. Figures 13 to 15 show dependences of the hybrid properties at $f = 1.3$ GHz on the positions of matching posts and insertion value of the tuning stub. One can see that the hybrid has the best properties with L_m around 16 mm and l_s also around 16 mm. Adjusting rate of the coupling to output ports is 0.075 dB/mm, and the rate of the phase advance is 0.1°/mm. These numbers are twice as low compared with the numbers for the hybrid with $w = 165.1$ mm. It is possibly due to a bigger margin to the cut-off of the TE_{30} mode. Figures 16 to 20 illustrate the properties of the optimized hybrid in a frequency range of 1-1.6 GHz.

The properties of this narrowed hybrid are, to some extent, better than those of the hybrid with a standard width. However, it requires additional transition parts between narrowed guides in the hybrid and the WR650 terminating ports. The hybrid becomes longer and might be less convenient when mounted near the ERL cryostat.

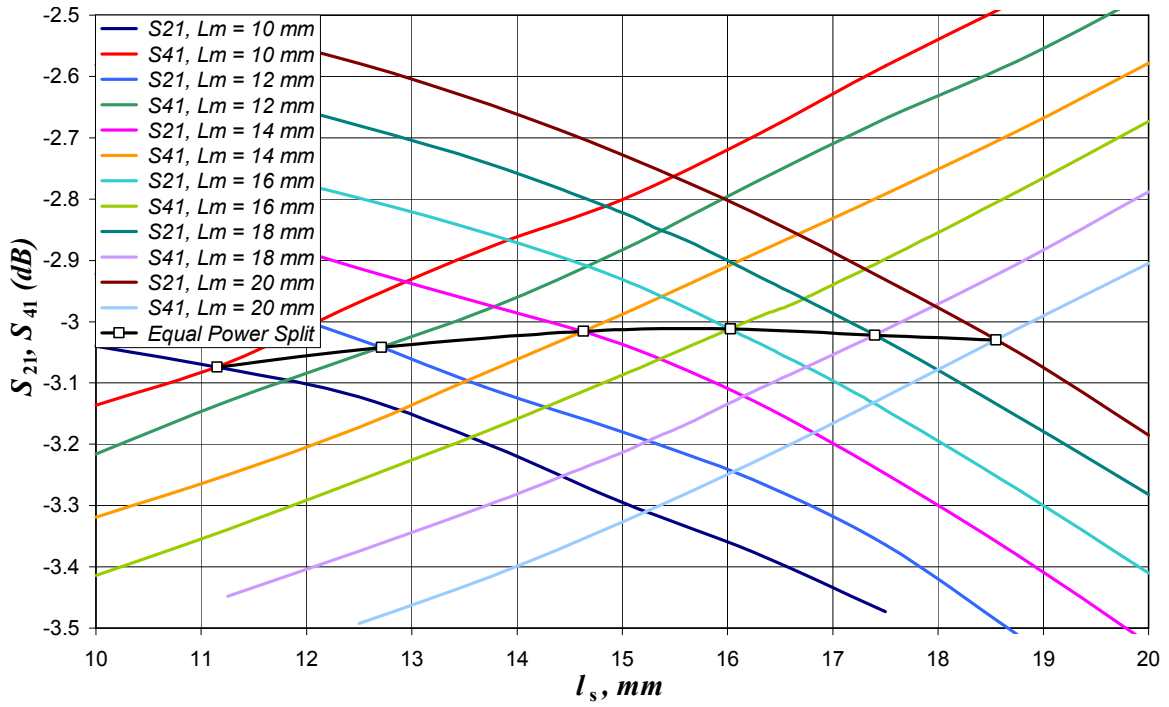


Figure 13: Couplings to the output ports as functions of stub insertion l_s for different locations of matching posts (hybrid with $w = 155$ mm).

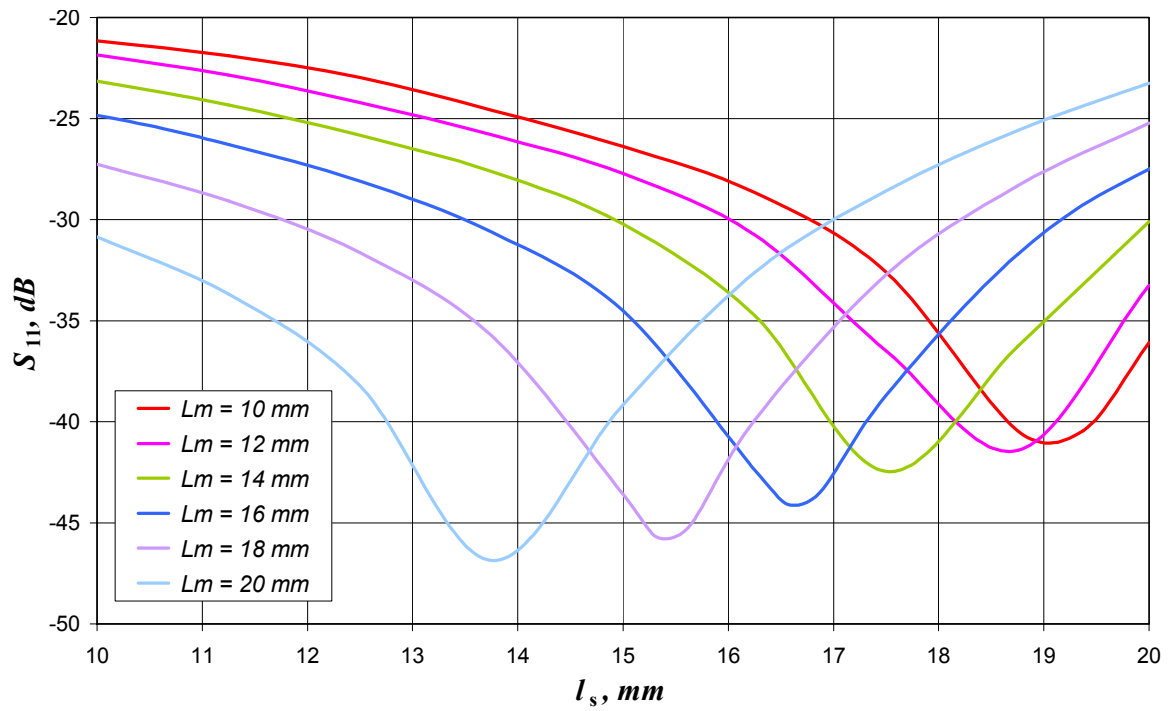


Figure 14: Reflection from the hybrid as a function of stub insertion l_s for different locations of matching posts (hybrid $w = 155$ mm).

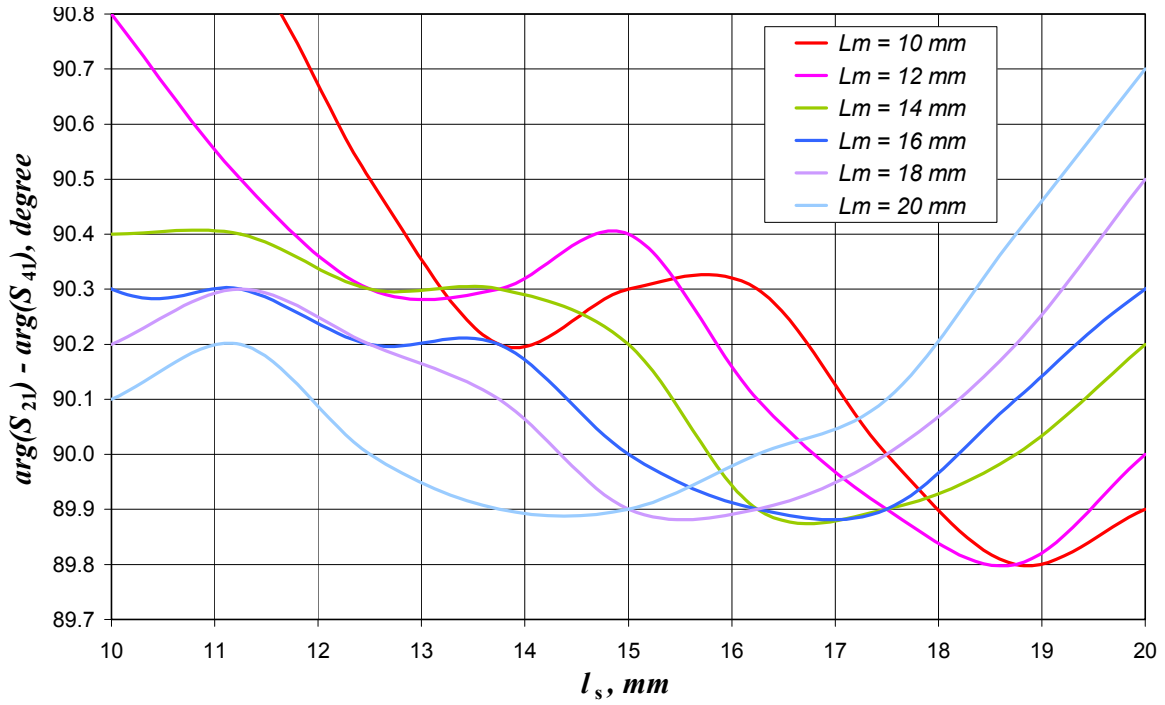


Figure 15: Phase difference at the output ports of the hybrid as a function of stub insertion l_s for different locations of matching posts L_m (hybrid with $w = 155$ mm).

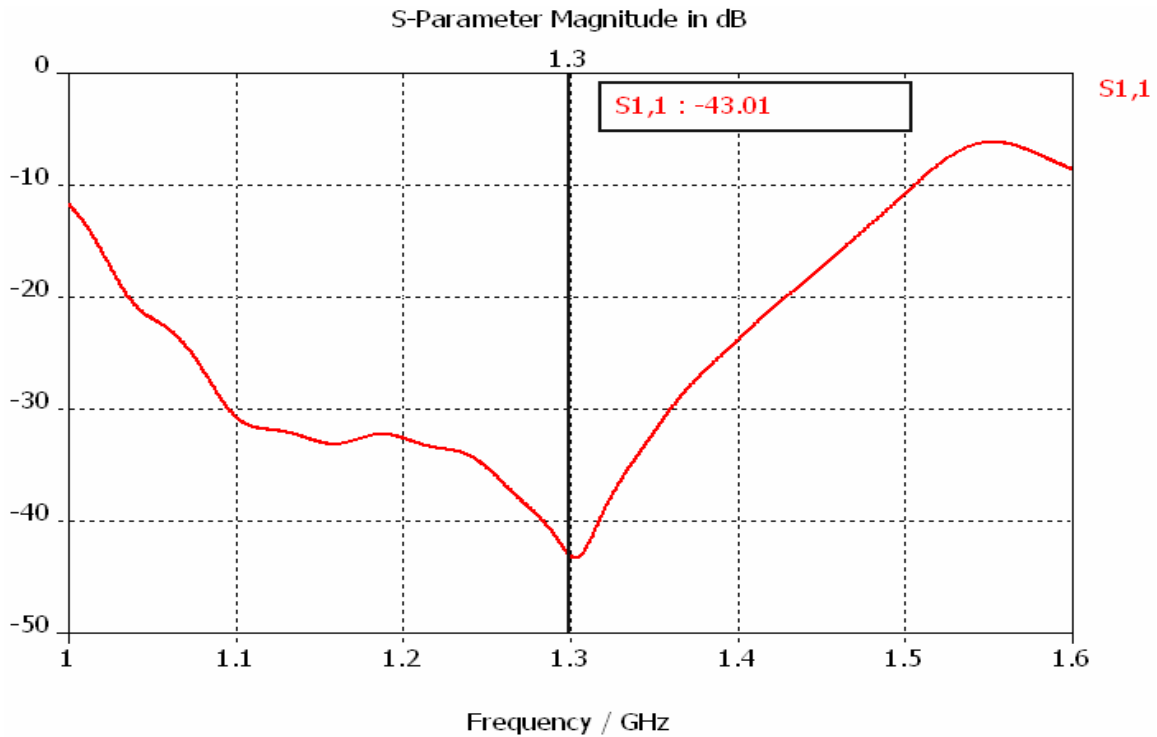


Figure 16: Reflection from the hybrid with $w = 155$ mm, $L_m = 16.6$ mm, $l_s = 16.4$ mm.

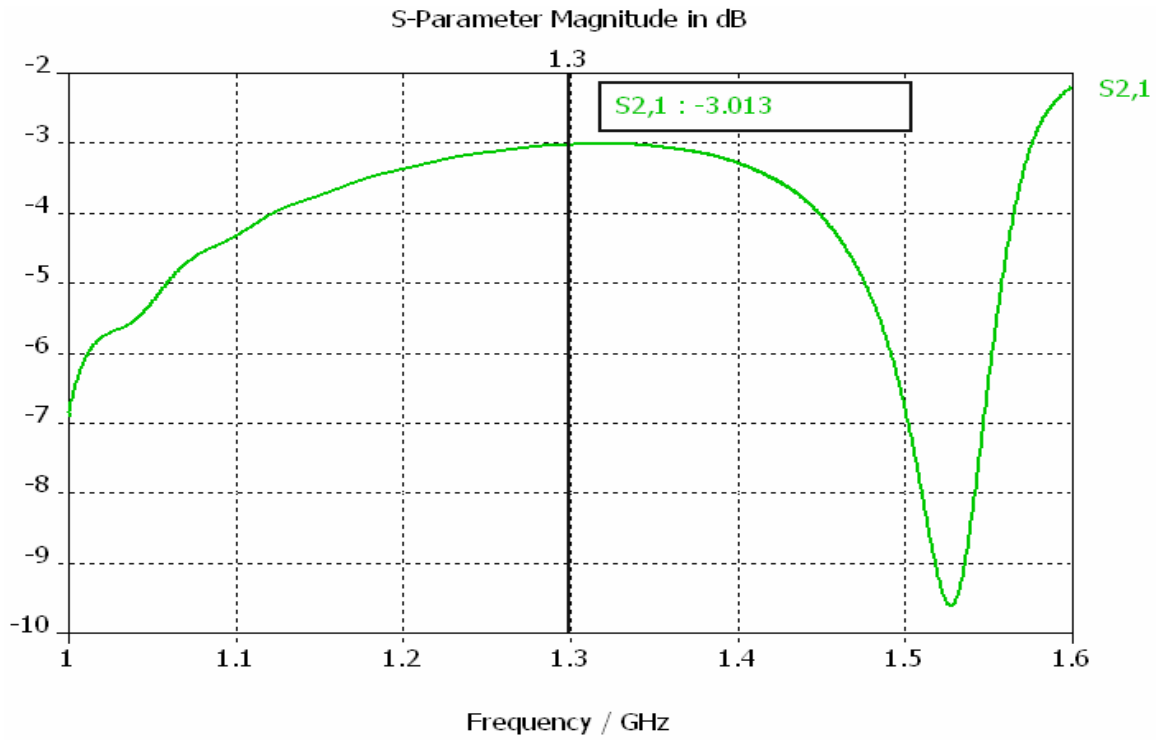


Figure 17: Coupling to the output port 2 for the hybrid with $w = 155$ mm, $L_m = 16.6$ mm, $l_s = 16.4$ mm.

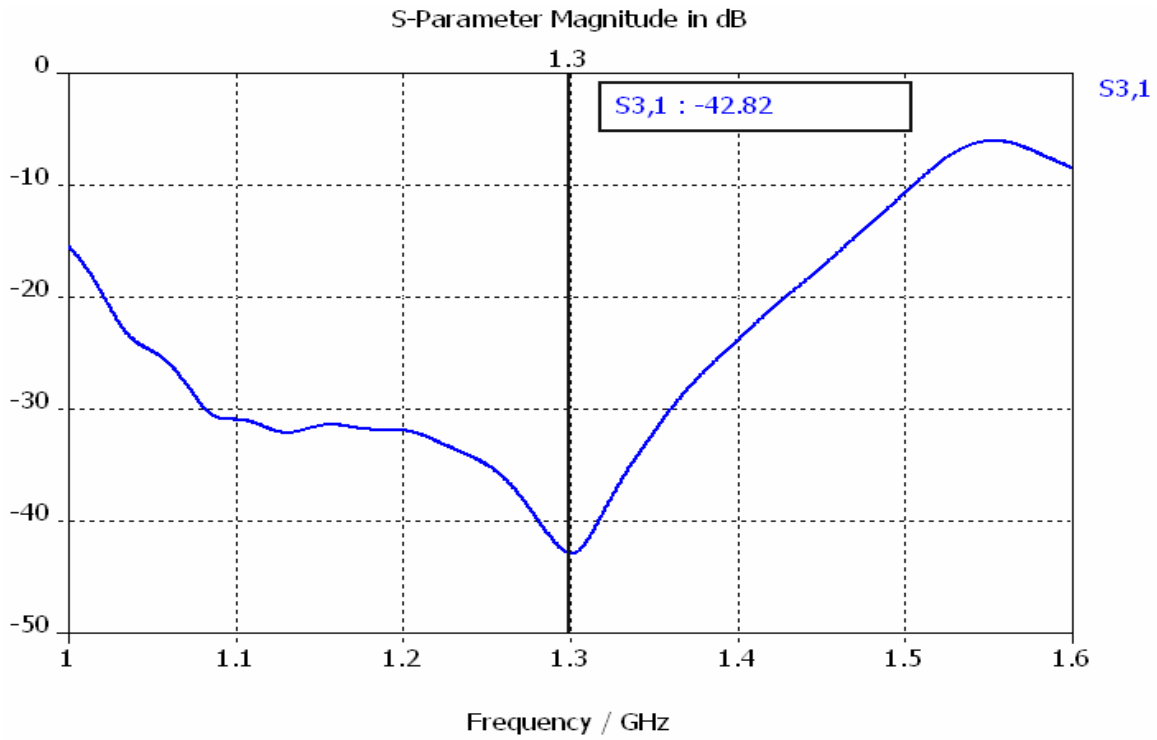


Figure 18: Return loss for the hybrid with $w = 155$ mm, $L_m = 16.6$ mm, $l_s = 16.4$ mm.

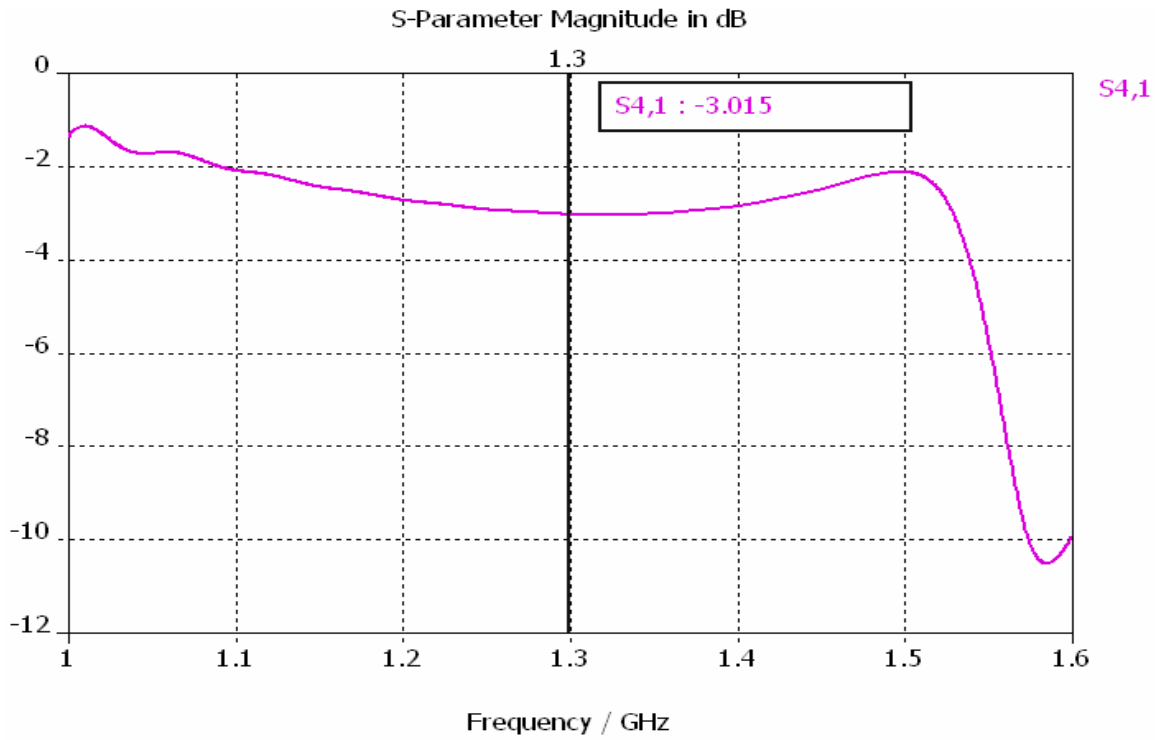


Figure 19: Coupling to the output port 4 for the hybrid with $w = 155$ mm, $L_m = 16.6$ mm, $l_s = 16.4$ mm.

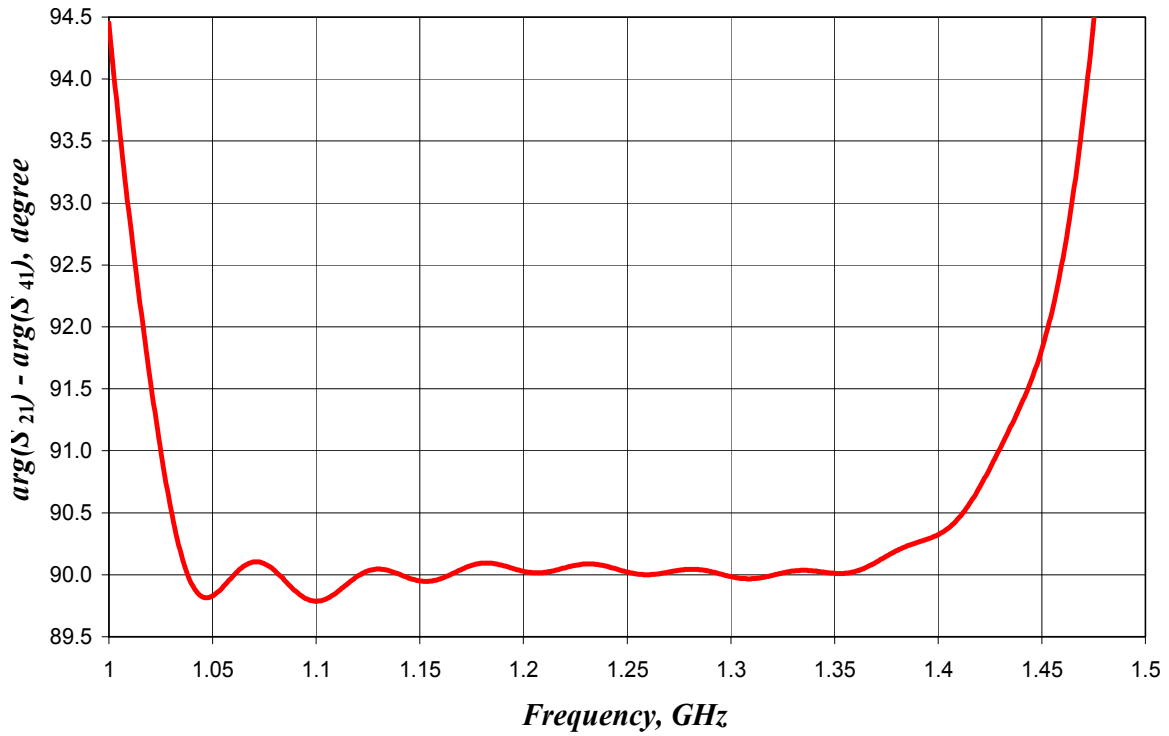


Figure 20: Phase difference of output signals for the hybrid with $w = 155$ mm, $L_m = 16.6$ mm, $l_s = 16.4$ mm.

CONCLUSION

Two versions of an adjustable short slot hybrid design are presented. The first one uses uniform standard waveguide arms of the WR650 type and has a narrower frequency band. The second one uses narrower waveguide arms and needs additional transition pieces for connection to standard waveguides. On the other hand, it has a wider frequency band. As to their properties, both types seem to be adequate to the Cornell ERL RF system.

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