

**Report on the cryogenic performance
of 3dB 90° coaxial hybrid couplers for
the 1-4.4 GHz, 2-8 GHz and 4-12 GHz
bands developed in Yebes for VLBI
2010 antenna feeds.**

I. Malo, J.D. Gallego.

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*Centro Astronómico de Yebes
Apdo. 148 19080 Guadalajara
SPAIN
Phone: +34 949 29 03 11 ext.208
Fax: +34 949 29 00 63*



Change Record

Revision	Date	Affected Paragraphs(s)	Reason/Initiation/Remarks
A	2012-05-29	All	First Issue



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1 Introduction

The future receivers to be built for the new Yebes VLBI 2010 antenna should allow simultaneous operation (with the two orthogonal circular polarizations) in S, X and Ka band. This will be achieved using three in-focus coaxial horns. The present design is based on using a septum polarizer for Ka band in the inner horn, and two outer coaxial horns with four probes each for X and S band. Achieving the adequate field configuration to generate the circular polarization will involve the use of a combination of 180° and 90° coaxial 3 dB hybrid couplers. The minimum bandwidth required is 2.2-2.7 GHz in S band, 7.5-9 GHz in X band and 28-33 GHz in Ka band.

Modern cryogenic amplifiers obtain noise temperatures below 5 K in S and X band. Taking full advantage of this extreme sensitivity requires a very careful design of the feed. In particular, losses in horns, probes, input cables and hybrids couplers can severely degrade the performance and could very easily become the dominant contribution to the total receiver noise. In order to minimize the noise, the design of the VLBI 2010 receiver assumes that the hybrids will be cooled to cryogenic temperature.

YebeS has developed¹ special designs for 3 dB 90° hybrids in several bands optimized for cryogenic operation. There are devices commercially available covering this band with good ambient temperature characteristics, but their cryogenic performance degrades to unacceptable levels. Thereby, three different designs have been made for the bands 1-4.4 GHz, 2-8 GHz and 4-12 GHz. The performance obtained by several demonstration units for each band is presented in this report. A photo with one hybrid of each type is shown in Figure 1.

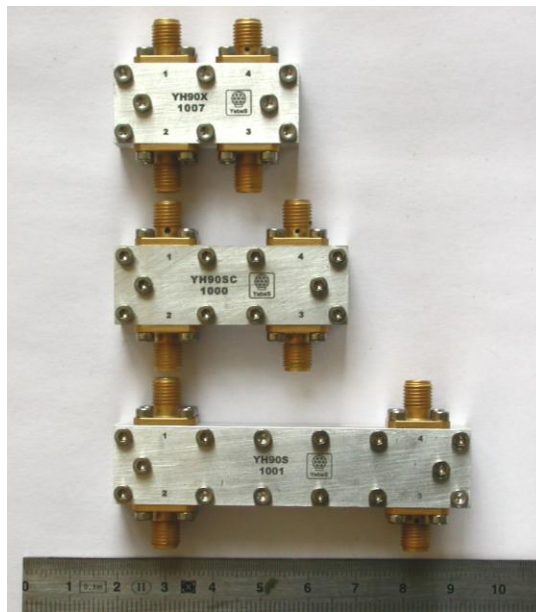


Figure 1. This photo shows one hybrid of each type for easy comparison of their relative sizes. Top: 4-12 GHz, middle: 2-8 GHz and bottom: 1-4.4 GHz.

¹ *Cryogenic Hybrid Coupler for Ultra Low Noise Radio Astronomy Balanced Amplifiers*, Inmaculada Malo-Gómez, J. Daniel Gallego-Puyol, Carmen Diez-González, Isaac López-Fernández, and César Briso-Rodríguez, IEEE Transactions on Microwave Theory and Techniques, vol. 57, no. 12, December 2009.



2 Measurements

The 3 dB 90° hybrid couplers built in Yebes and reported in this work are presented in Table 1. Next, a table is presented for each unit evaluated with a summary of the performance measured in the total band of the design as well as in the sub-band to be used in the VLBI receiver. The graphics of the most relevant parameters measured at ambient and cryogenic temperature as a function of frequency are presented side by side for easy comparison.

<i>1-4.4 GHz</i>	<i>2-8 GHz</i>	<i>4-12 GHz</i>
YH90S 1001	YH90SC 1000	YH90X 1007
YH90S 1002	YH90SC 1001	YH90X 1018
YH90S 1003	YH90SC 1002	YH90X 1019
YH90S 1004		

Table 1. 3 dB 90° hybrid couplers evaluated. The selected hybrids for Yebes VLBI 2010 are in bold: YH90SC 1000 for S band and YH90X 1007 for X band.

MEASURED PERFORMANCE

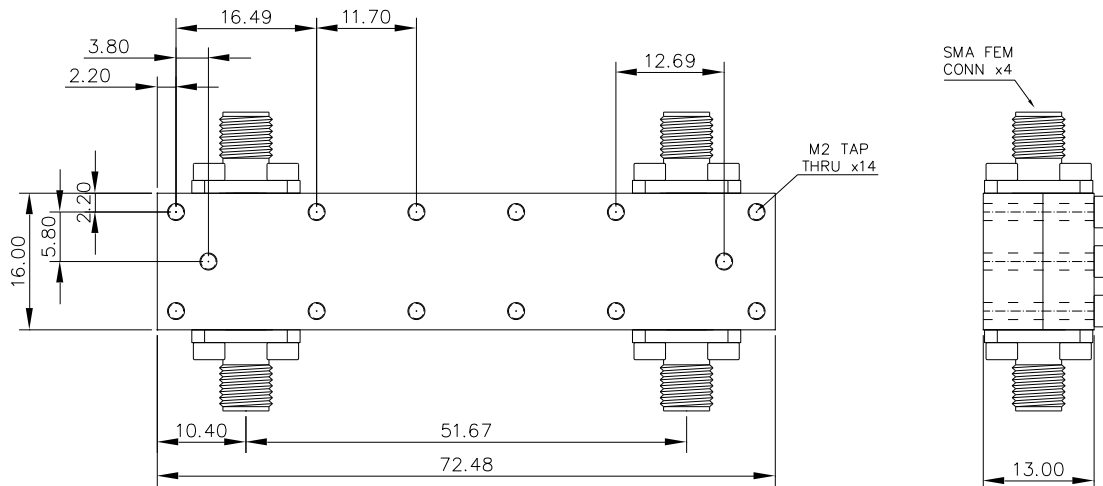
Serial Number	YH90S 1001	
Description	3dB 90° cryogenic hybrid	
Frequency Band	1.05 – 4.4 GHz	
Nominal Coupling	3 dB	
Connector	SMA female, sliding pin	
Weight (typ.)	56 g (1.97 oz)	
<i>Temperature</i>	297 K	20 K
A. E. Insertion Loss dB (max.) ^{*1}	0.49 dB	0.21 dB
Return Loss (max. any port)	-23.7 dB	-19.5 dB
Amplitude Unbalance (max.)	± 0.32 dB	± 0.35 dB
Phase Unbalance (max.)	± 3.6°	± 4.8°

*1: Average Equivalent Insertion Loss (dB), $L_{eq} = 10 \log_{10} (|s_{11}|^2 + |s_{12}|^2 + |s_{13}|^2 + |s_{14}|^2)$

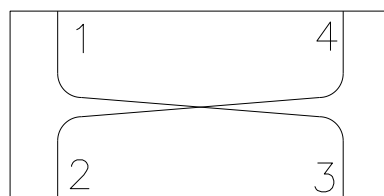
Frequency Sub-band	2.2 – 2.7 GHz	
<i>Temperature</i>	297 K	20 K
A. E. Insertion Loss dB (max.) ^{*1}	0.39 dB	0.19 dB
Return Loss (max. any port)	-25 dB	-21.9 dB
Amplitude Unbalance (max.)	± 0.23 dB	± 0.24 dB
Phase Unbalance (max.)	± 3.2°	± 3.5°

OUTLINE DRAWING

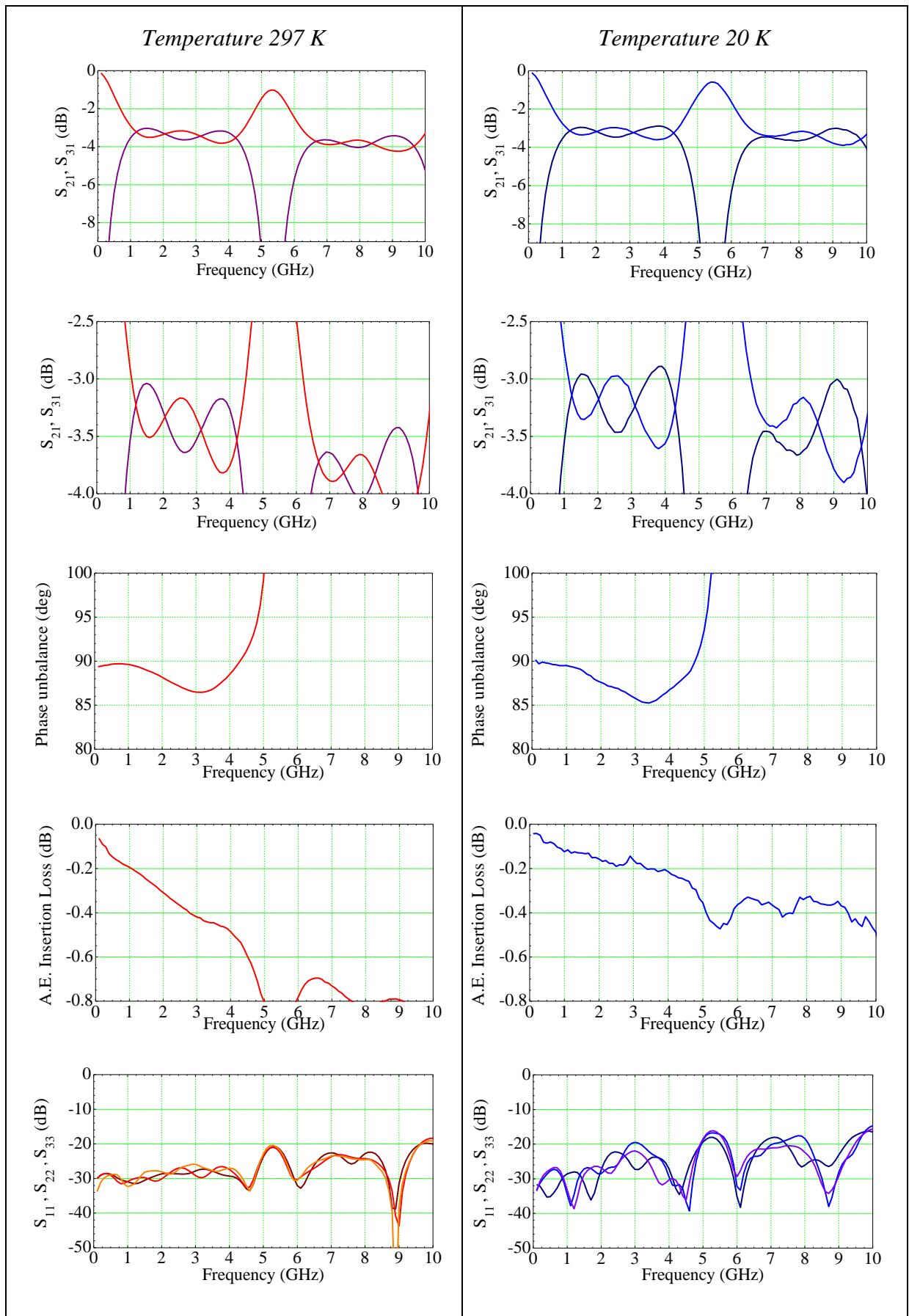
Dimensions in mm.



ELECTRICAL SCHEMATIC



MEASUREMENTS



MEASURED PERFORMANCE

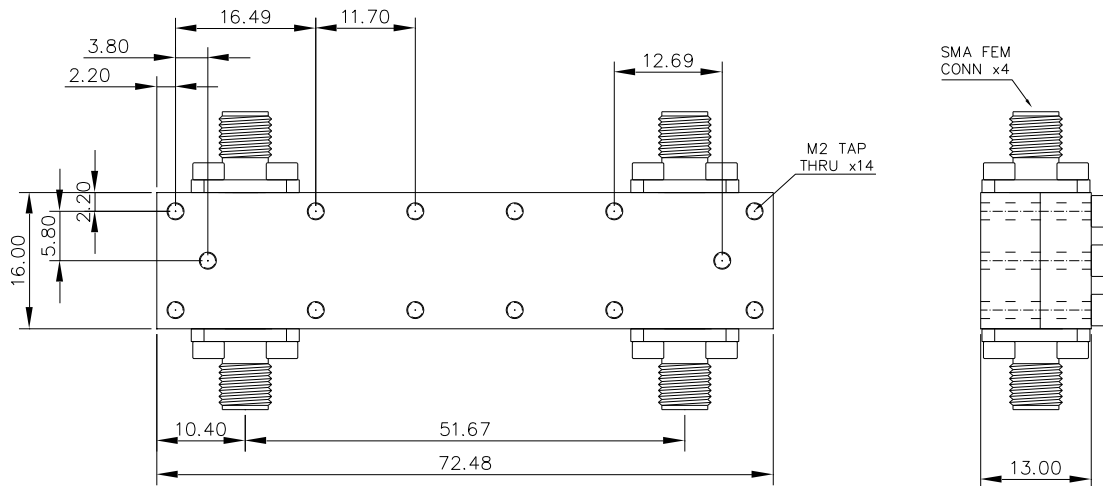
Serial Number	YH90S 1002	
Description	3dB 90° cryogenic hybrid	
Frequency Band	1.1 – 4.5 GHz	
Nominal Coupling	3 dB	
Connector	SMA female, sliding pin	
Weight (typ.)	56 g (1.97 oz)	
<i>Temperature</i>	297 K	20 K
A. E. Insertion Loss dB (max.) ^{*1}	0.50 dB	0.23 dB
Return Loss (max. any port)	-21.1 dB	-18.4 dB
Amplitude Unbalance (max.)	± 0.3 dB	± 0.35 dB
Phase Unbalance (max.)	± 4°	± 1.7°

*1: Average Equivalent Insertion Loss (dB), $L_{eq} = 10 \log_{10} (|s_{11}|^2 + |s_{12}|^2 + |s_{13}|^2 + |s_{14}|^2)$

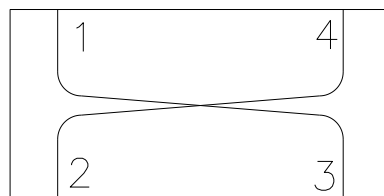
Frequency Sub-band	2.2 – 2.7 GHz	
<i>Temperature</i>	297 K	20 K
A. E. Insertion Loss dB (max.) ^{*1}	0.39 dB	0.18 dB
Return Loss (max. any port)	-23.7 dB	-21 dB
Amplitude Unbalance (max.)	± 0.3 dB	± 0.3 dB
Phase Unbalance (max.)	± 1.7°	± 1.2°

OUTLINE DRAWING

Dimensions in mm.

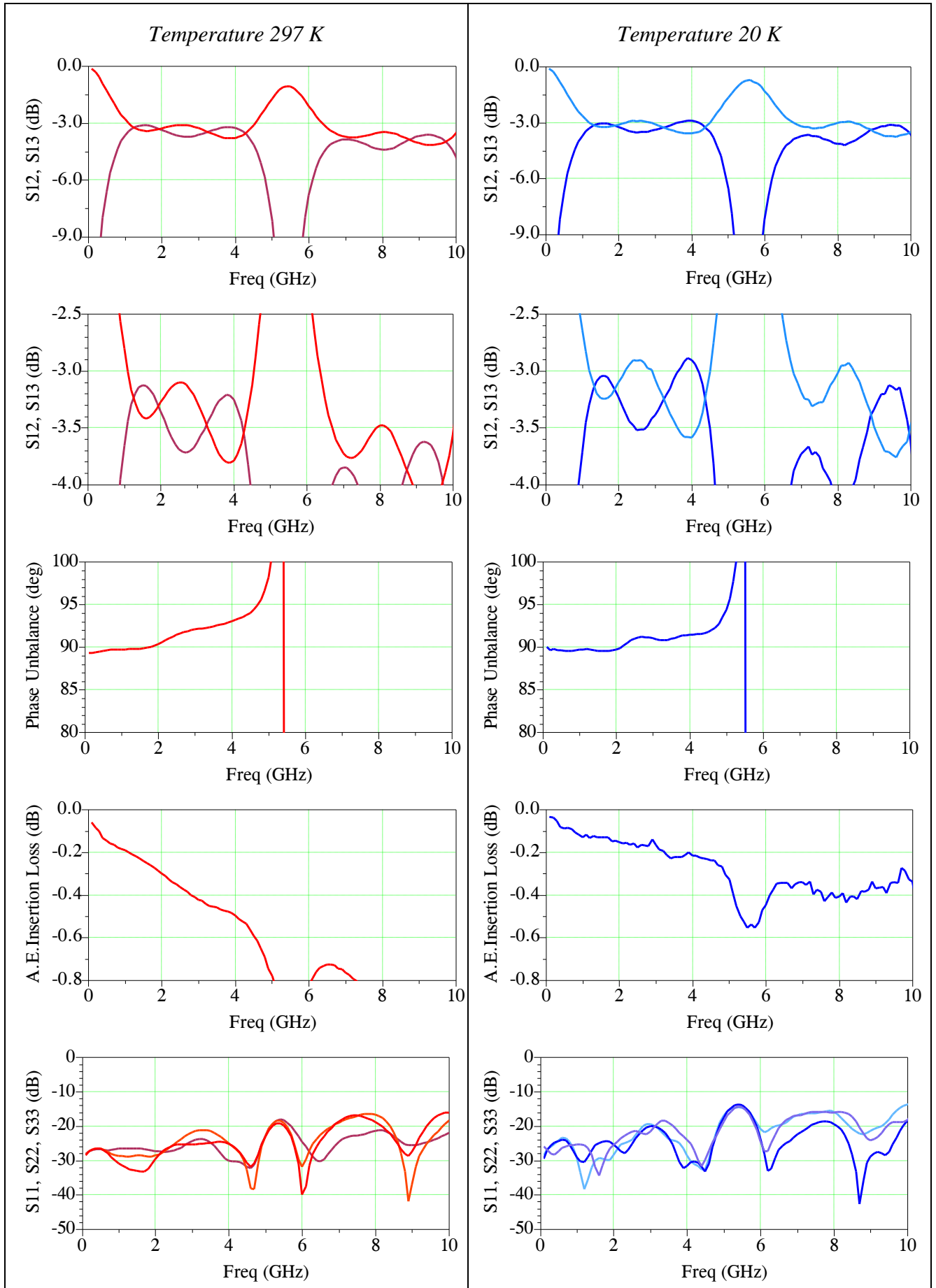


ELECTRICAL SCHEMATIC





MEASUREMENTS



MEASURED PERFORMANCE

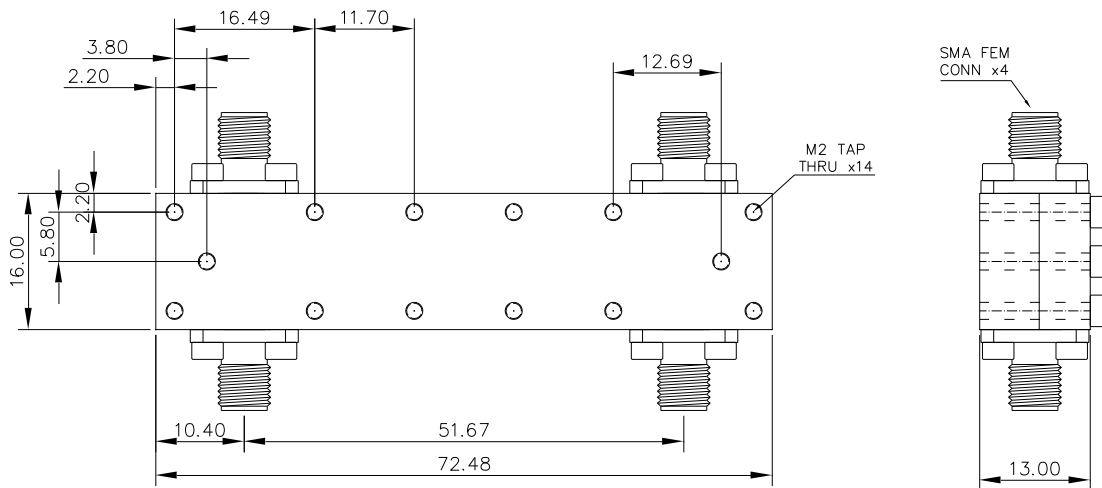
Serial Number	YH90S 1003	
Description	3dB 90° cryogenic hybrid	
Frequency Band	1.1 – 4.5 GHz	
Nominal Coupling	3 dB	
Connector	SMA female, sliding pin	
Weight (typ.)	56 g (1.97 oz)	
<i>Temperature</i>	297 K	20 K
A. E. Insertion Loss dB (max.) ^{*1}	0.53 dB	0.26 dB
Return Loss (max. any port)	-21.2 dB	-19.2 dB
Amplitude Unbalance (max.)	± 0.3 dB	± 0.35 dB
Phase Unbalance (max.)	± 3.7°	± 4°

*1: Average Equivalent Insertion Loss (dB), $L_{eq} = 10 \log_{10} (|S_{11}|^2 + |S_{12}|^2 + |S_{13}|^2 + |S_{14}|^2)$

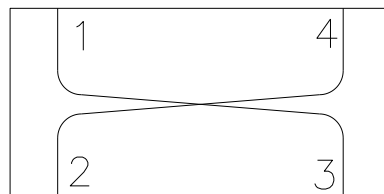
Frequency Sub-band	2.2 – 2.7 GHz	
<i>Temperature</i>	297 K	20 K
A. E. Insertion Loss dB (max.) ^{*1}	0.4 dB	0.2 dB
Return Loss (max. any port)	-24.2 dB	-21.2 dB
Amplitude Unbalance (max.)	± 0.29 dB	± 0.28 dB
Phase Unbalance (max.)	± 3.5°	± 3.9°

OUTLINE DRAWING

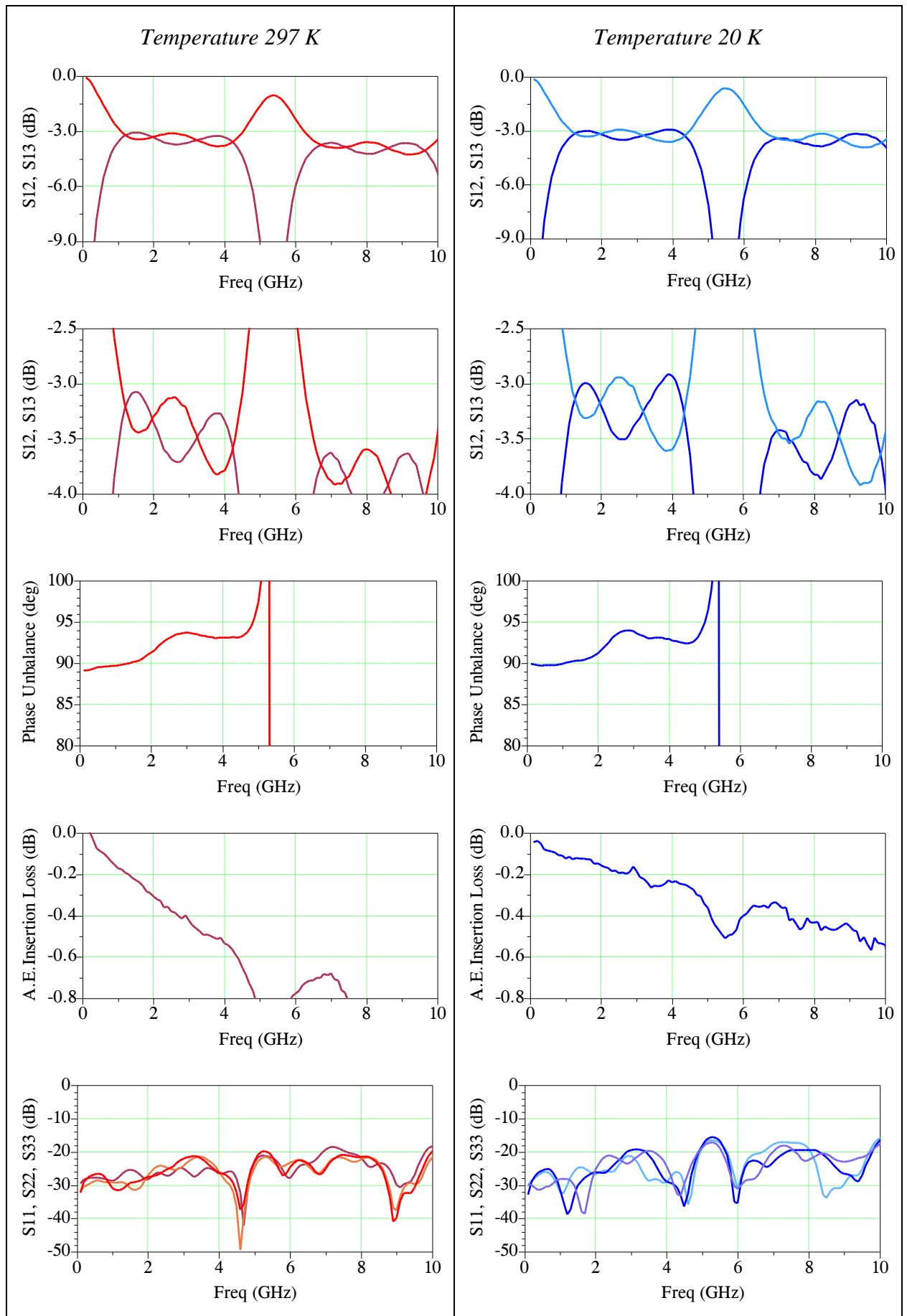
Dimensions in mm.



ELECTRICAL SCHEMATIC



MEASUREMENTS



MEASURED PERFORMANCE

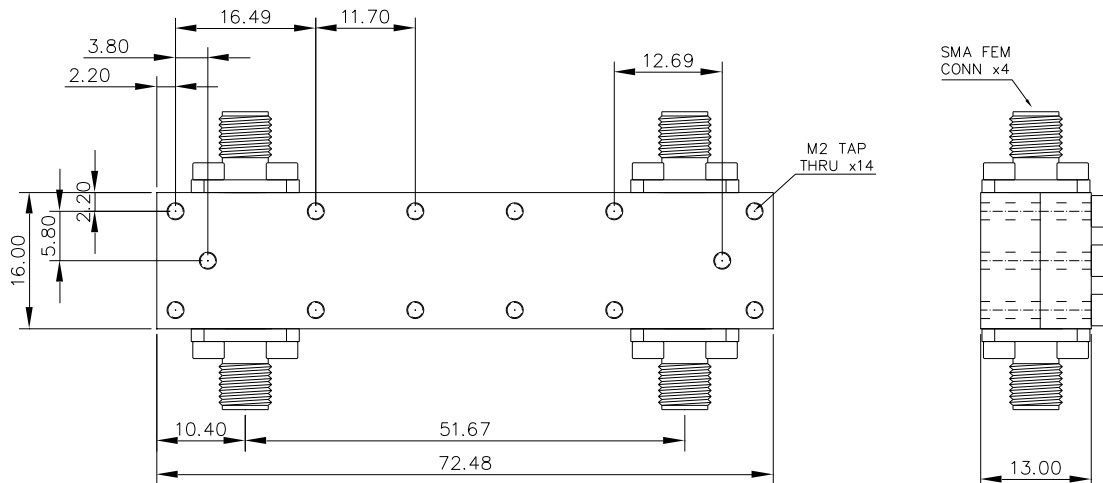
Serial Number	YH90S 1004	
Description	3dB 90° cryogenic hybrid	
Frequency Band	1 – 4.4 GHz	
Nominal Coupling	3 dB	
Connector	SMA female, sliding pin	
Weight (typ.)	56 g (1.97 oz)	
<i>Temperature</i>	<i>297 K</i>	<i>20 K</i>
A. E. Insertion Loss dB (max.) ^{*1}	0.52 dB	0.23 dB
Return Loss (max. any port)	-24 dB	-20.4 dB
Amplitude Unbalance (max.)	± 0.3 dB	± 0.36 dB
Phase Unbalance (max.)	± 3.5°	± 4.5°

*1: Average Equivalent Insertion Loss (dB), $L_{eq} = 10 \log_{10} (|s_{11}|^2 + |s_{12}|^2 + |s_{13}|^2 + |s_{14}|^2)$

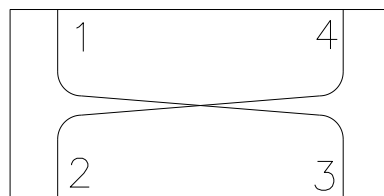
Frequency Sub-band	2.2 – 2.7 GHz	
<i>Temperature</i>	<i>297 K</i>	<i>20 K</i>
A. E. Insertion Loss dB (max.) ^{*1}	0.32 dB	0.19 dB
Return Loss (max. any port)	-27 dB	-22 dB
Amplitude Unbalance (max.)	± 0.3 dB	± 0.25 dB
Phase Unbalance (max.)	± 3.2°	± 3.5°

OUTLINE DRAWING

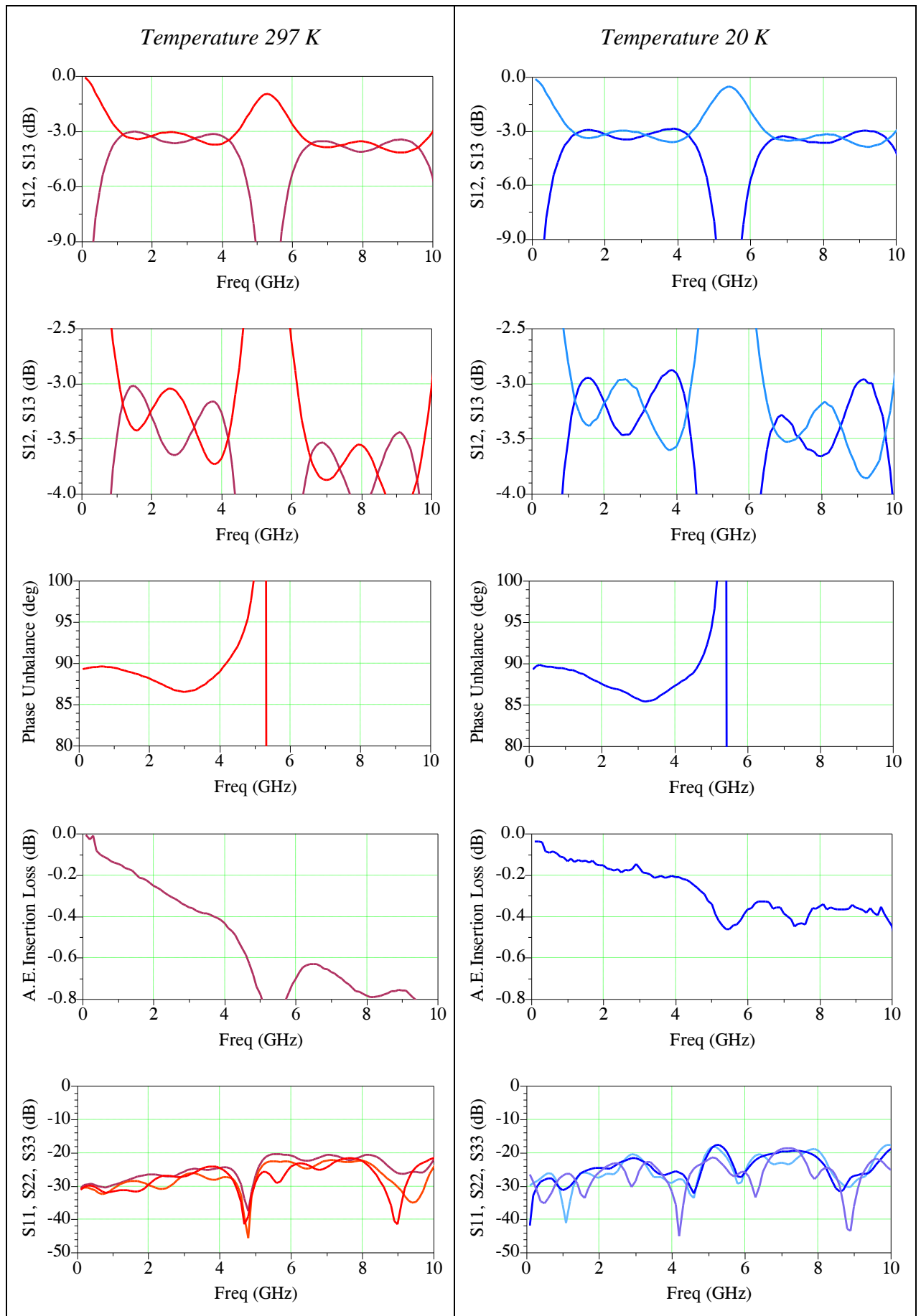
Dimensions in mm.



ELECTRICAL SCHEMATIC



MEASUREMENTS



MEASURED PERFORMANCE

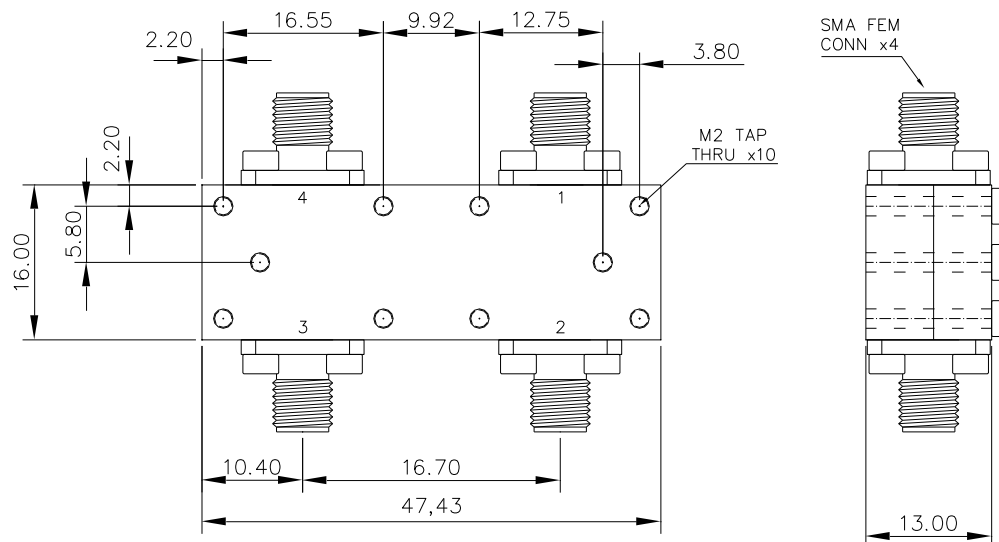
Serial Number	YH90SC 1000	
Description	3dB 90° cryogenic hybrid	
Frequency Band	2 - 8 GHz	
Nominal Coupling	3 dB	
Connector	SMA female, sliding pin	
Weight (typ.)	40.5 g (1.43 oz)	
<i>Temperature</i>	297 K	20 K
A. E. Insertion Loss dB (max.) ^{*1}	0.55 dB	0.16 dB
Return Loss (max. any port)	-20.8 dB	-23 dB
Amplitude Unbalance (max.)	± 0.3 dB	± 0.33 dB
Phase Unbalance (max.)	± 2.4°	± 3.4°

*1: Average Equivalent Insertion Loss (dB), $L_{eq} = 10 \log_{10} (|S_{11}|^2 + |S_{12}|^2 + |S_{13}|^2 + |S_{14}|^2)$

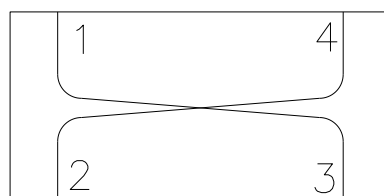
Frequency Sub-band	2.2 – 2.7 GHz	
<i>Temperature</i>	297 K	20 K
A. E. Insertion Loss dB (max.) ^{*1}	0.23 dB	0.07 dB
Return Loss (max. any port)	-28 dB	-27 dB
Amplitude Unbalance (max.)	± 0.29 dB	± 0.26 dB
Phase Unbalance (max.)	± 1.3°	± 0.8°

OUTLINE DRAWING

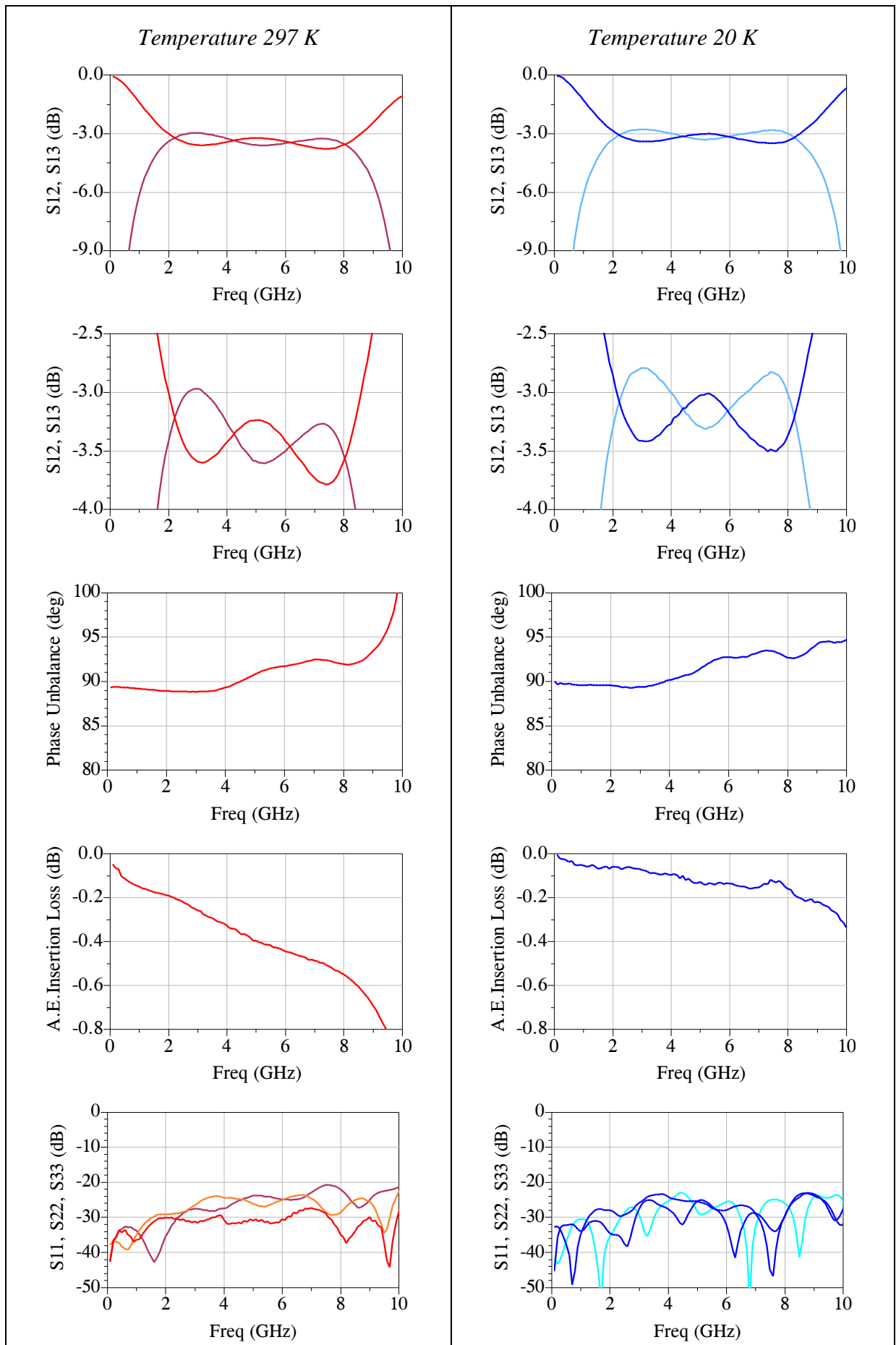
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ELECTRICAL SCHEMATIC



MEASUREMENTS



MEASURED PERFORMANCE

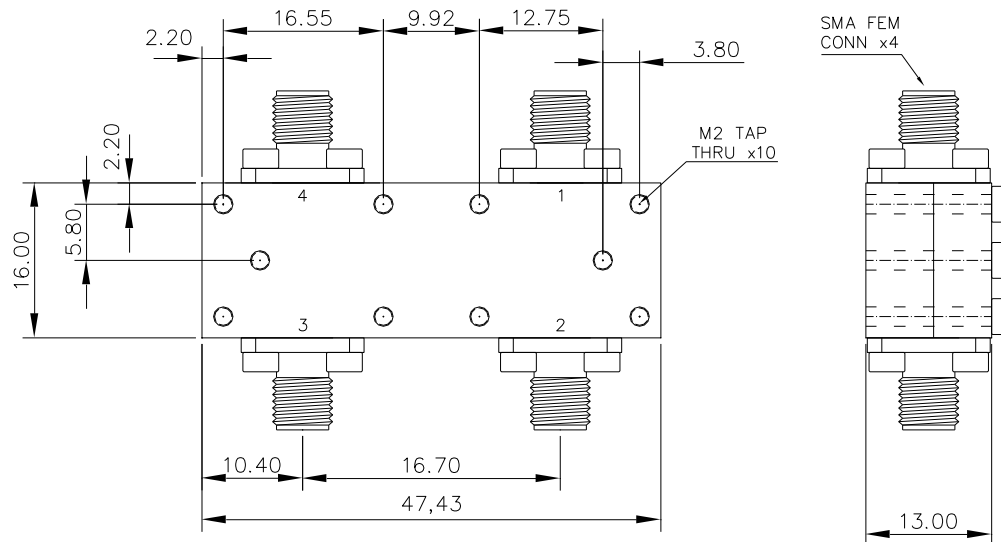
Serial Number	YH90SC 1001	
Description	3dB 90° cryogenic hybrid	
Frequency Band	2 - 8 GHz	
Nominal Coupling	3 dB	
Connector	SMA female, sliding pin	
Weight (typ.)	40.5 g (1.43 oz)	
<i>Temperature</i>	297 K	20 K
A. E. Insertion Loss dB (max.) ^{*1}	0.55 dB	0.18 dB
Return Loss (max. any port)	-23.7 dB	-21.4 dB
Amplitude Unbalance (max.)	± 0.3 dB	± 0.35 dB
Phase Unbalance (max.)	± 2.2°	± 1.3°

*1: Average Equivalent Insertion Loss (dB), $L_{eq} = 10 \log_{10} (|S_{11}|^2 + |S_{12}|^2 + |S_{13}|^2 + |S_{14}|^2)$

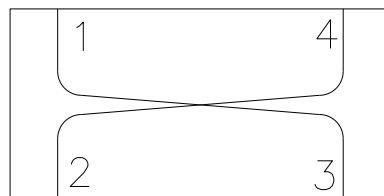
Frequency Sub-band	2.2 – 2.7 GHz	
<i>Temperature</i>	297 K	20 K
A. E. Insertion Loss dB (max.) ^{*1}	0.23 dB	0.08 dB
Return Loss (max. any port)	-28.8 dB	-30 dB
Amplitude Unbalance (max.)	± 0.22 dB	± 0.28 dB
Phase Unbalance (max.)	± 1°	± 0.6°

OUTLINE DRAWING

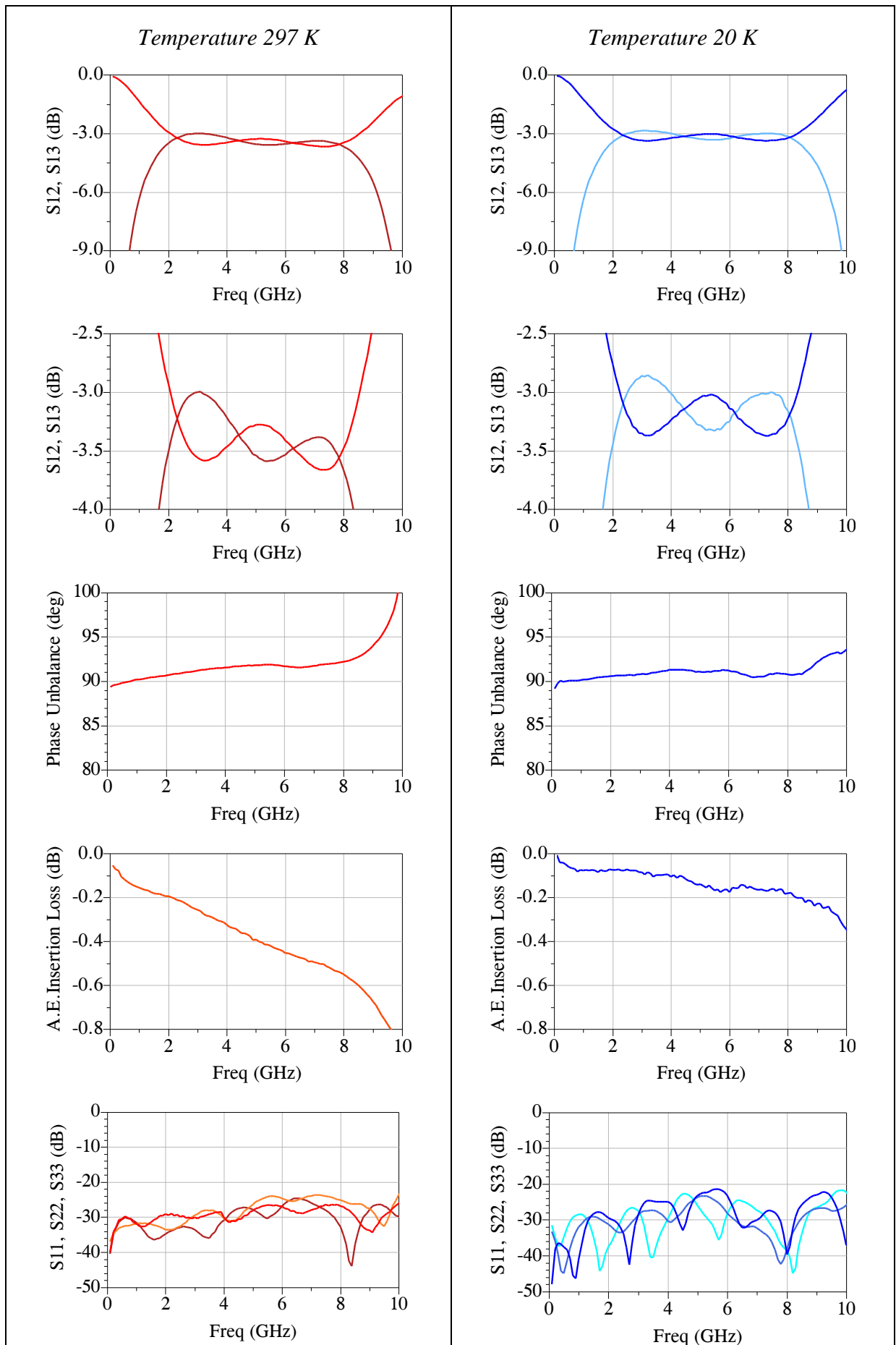
Dimensions in mm.



ELECTRICAL SCHEMATIC



MEASUREMENTS



MEASURED PERFORMANCE

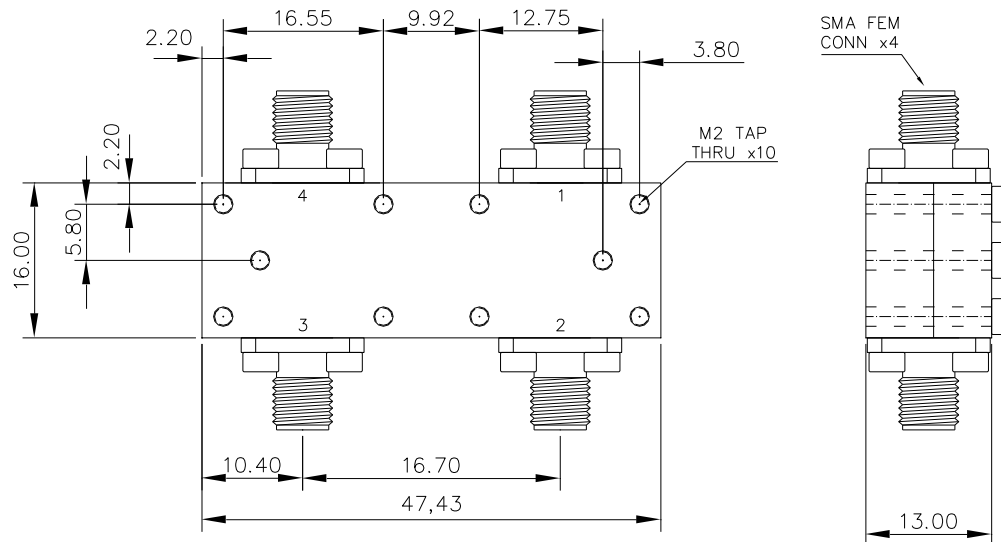
Serial Number	YH90SC 1002	
Description	3dB 90° cryogenic hybrid	
Frequency Band	2 - 8 GHz	
Nominal Coupling	3 dB	
Connector	SMA female, sliding pin	
Weight (typ.)	40.5 g (1.43 oz)	
<i>Temperature</i>	297 K	20 K
A. E. Insertion Loss dB (max.) ^{*1}	0.54 dB	0.18 dB
Return Loss (max. any port)	-22.2 dB	-25.3 dB
Amplitude Unbalance (max.)	± 0.28 dB	± 0.28 dB
Phase Unbalance (max.)	± 1.3°	± 1°

*1: Average Equivalent Insertion Loss (dB), $L_{eq} = 10 \log_{10} (|S_{11}|^2 + |S_{12}|^2 + |S_{13}|^2 + |S_{14}|^2)$

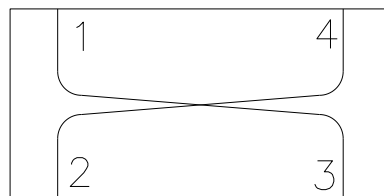
Frequency Sub-band	2.2 – 2.7 GHz	
<i>Temperature</i>	297 K	20 K
A. E. Insertion Loss dB (max.) ^{*1}	0.23 dB	0.09 dB
Return Loss (max. any port)	-28.8 dB	-28 dB
Amplitude Unbalance (max.)	± 0.23 dB	± 0.22 dB
Phase Unbalance (max.)	± 0.2°	± 0.5°

OUTLINE DRAWING

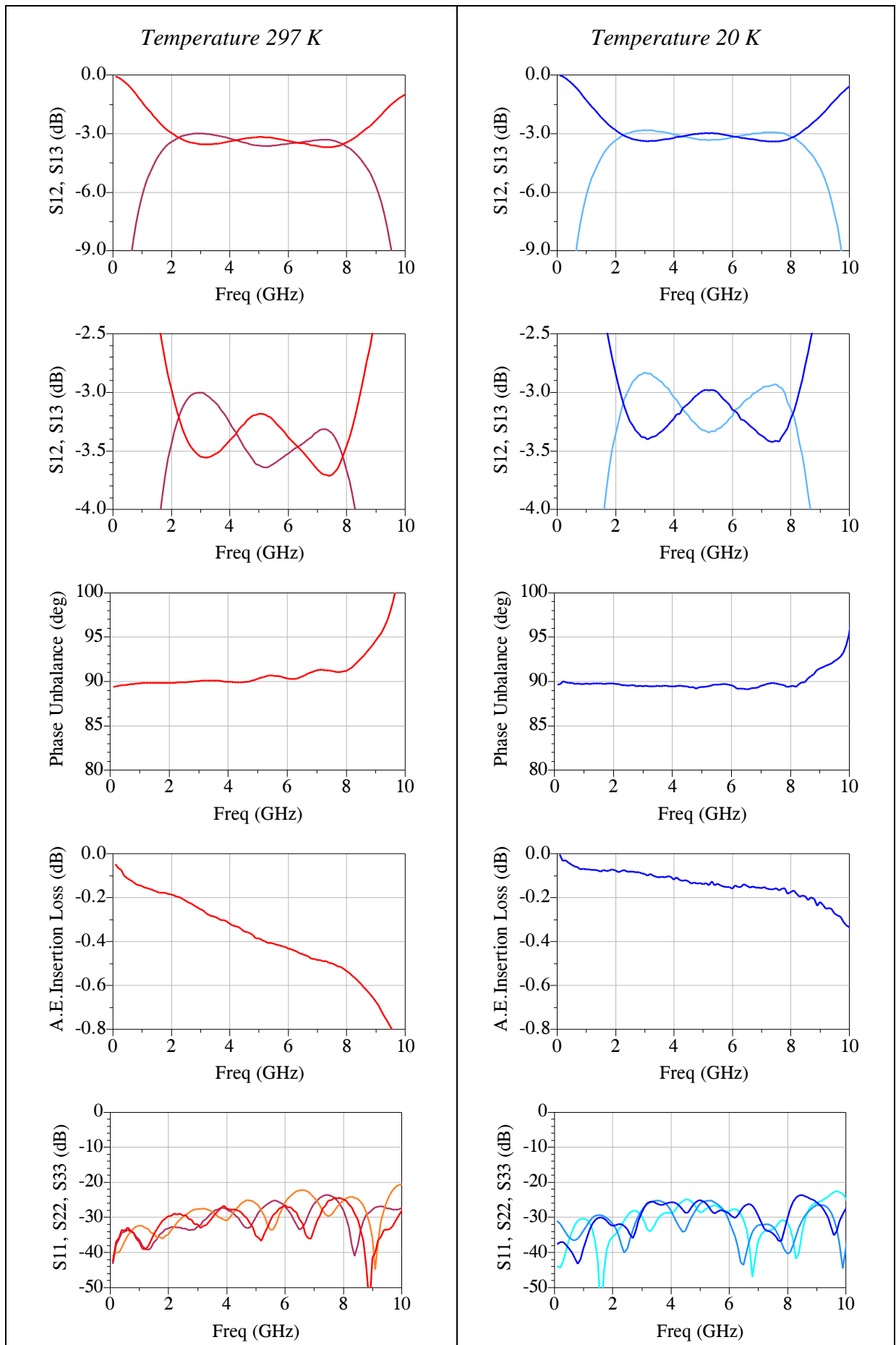
Dimensions in mm.



ELECTRICAL SCHEMATIC



MEASUREMENTS



MEASURED PERFORMANCE

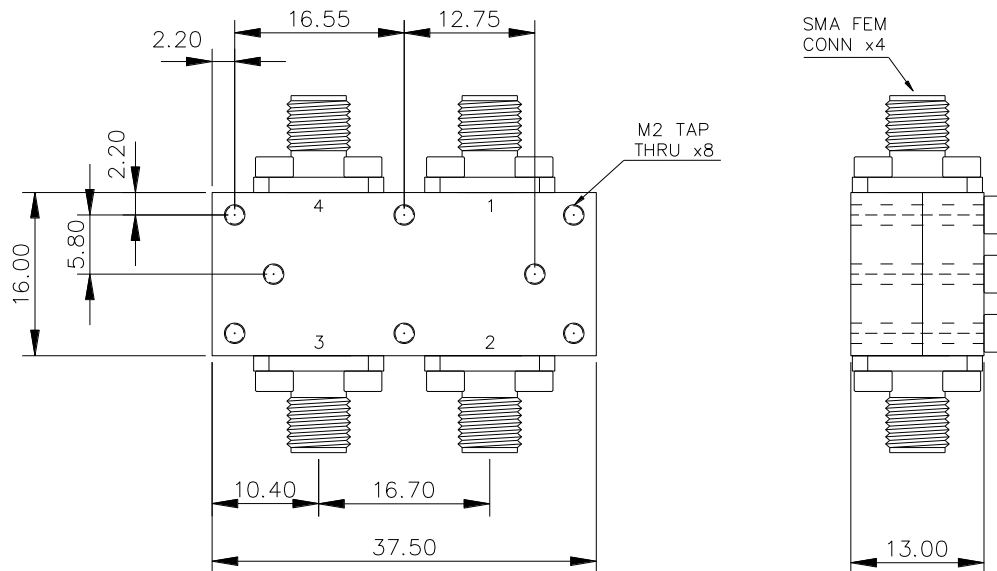
Serial Number	YH90X 1007	
Description	3dB 90° cryogenic hybrid	
Frequency Band	4 - 12 GHz	
Nominal Coupling	3 dB	
Connector	SMA female, sliding pin	
Weight (typ.)	36 g (1.27 oz)	
<i>Temperature</i>	297 K	20 K
A. E. Insertion Loss dB (max.) ^{*1}	0.5 dB	0.23 dB
Return Loss (max. any port)	-21 dB	-21 dB
Amplitude Unbalance (max.)	± 0.31 dB	± 0.4 dB
Phase Unbalance (max.)	± 3°	± 2.5°

*1: Average Equivalent Insertion Loss (dB), $L_{eq} = 10 \log_{10} (|s_{11}|^2 + |s_{12}|^2 + |s_{13}|^2 + |s_{14}|^2)$

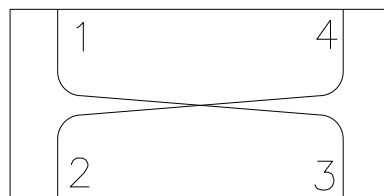
Frequency Subband	7.5 – 9 GHz	
Nominal Coupling	3 dB	
<i>Temperature</i>	297 K	20 K
A. E. Insertion Loss dB (max.) ^{*1}	0.44 dB	0.17 dB
Return Loss (max. any port)	-22.7 dB	-22.7 dB
Amplitude Unbalance (max.)	± 0.18 dB	± 0.16 dB
Phase Unbalance (max.)	± 2.7°	± 2.5°

OUTLINE DRAWING

Dimensions in mm.



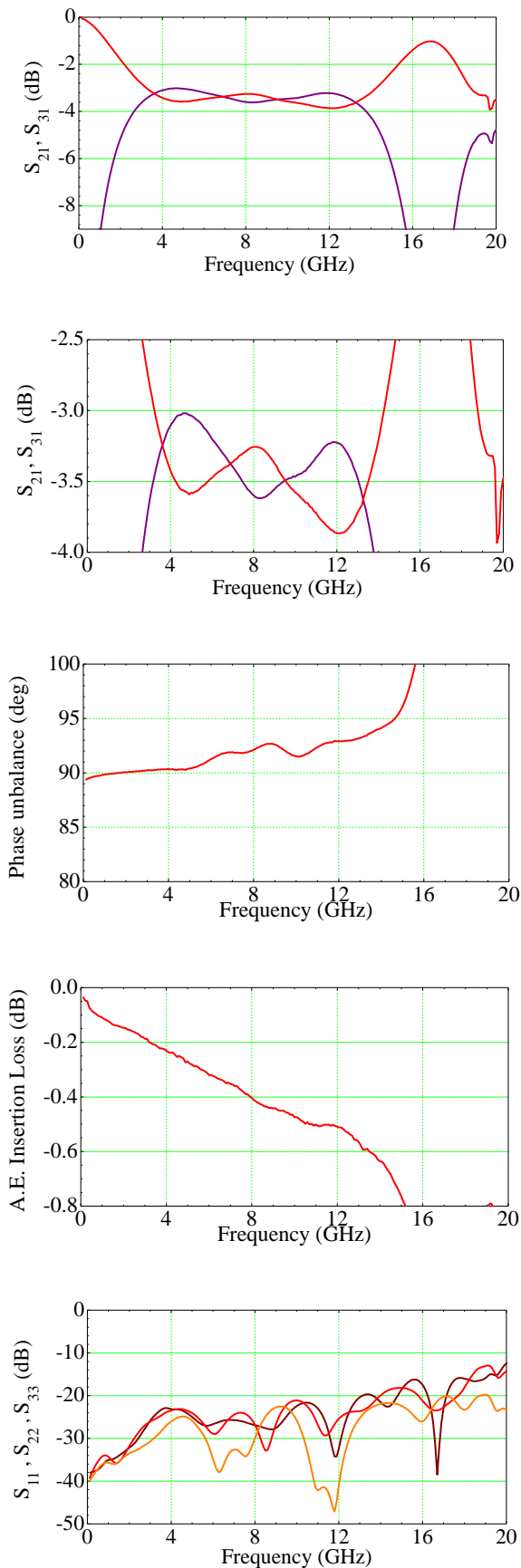
ELECTRICAL SCHEMATIC



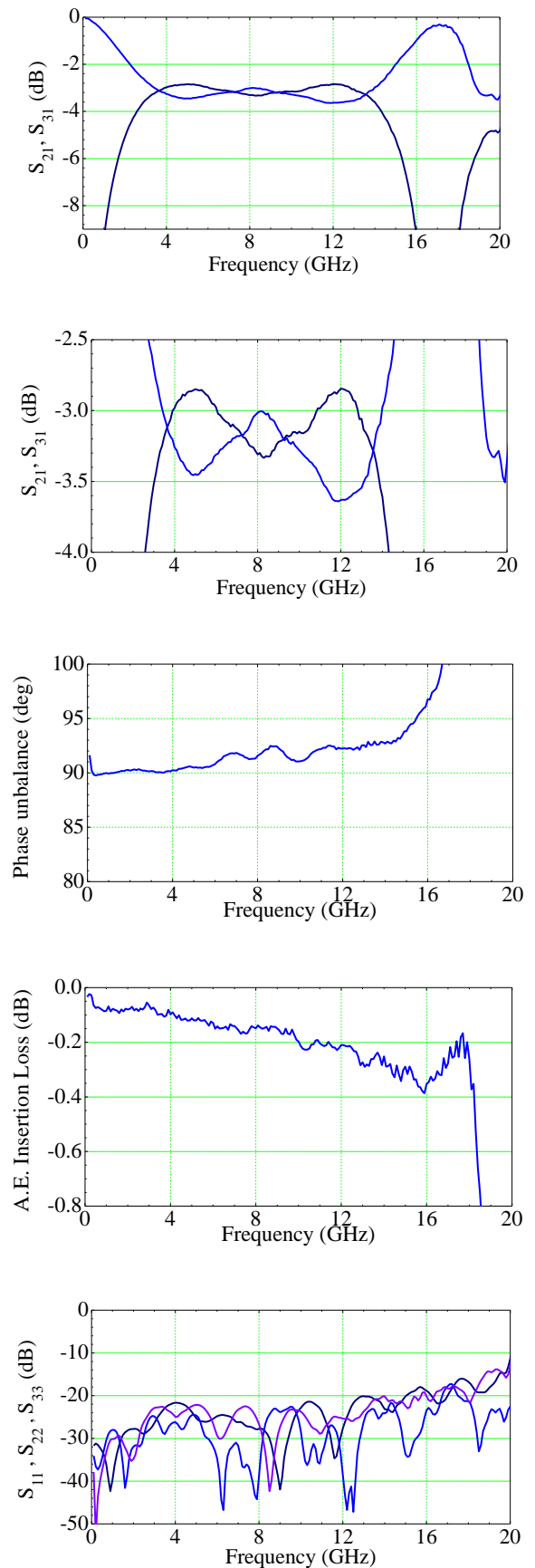


MEASUREMENTS

Temperature 297 K



Temperature 20 K



MEASURED PERFORMANCE

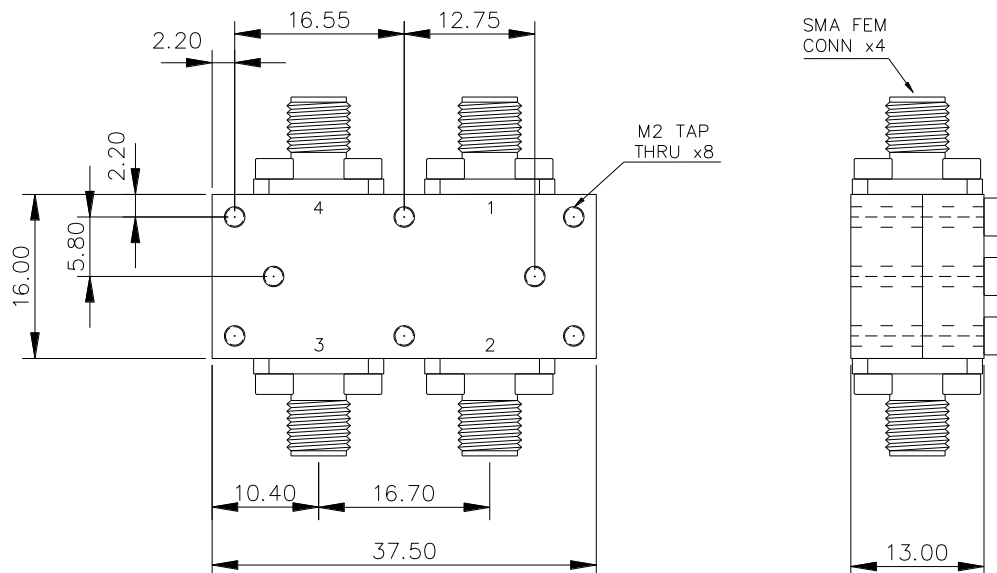
Serial Number	YH90X 1018	
Description	3dB 90° cryogenic hybrid	
Frequency Band	4 - 12 GHz	
Nominal Coupling	3 dB	
Connector	SMA female, sliding pin	
Weight (typ.)	36 g (1.27 oz)	
<i>Temperature</i>	297 K	20 K
A. E. Insertion Loss dB (max.) ^{*1}	0.5 dB	0.23 dB
Return Loss (max. any port)	-22 dB	-21 dB
Amplitude Unbalance (max.)	± 0.25 dB	± 0.27 dB
Phase Unbalance (max.)	± 1.1°	± 1°

*1: Average Equivalent Insertion Loss (dB), $L_{eq} = 10 \log_{10} (|s_{11}|^2 + |s_{12}|^2 + |s_{13}|^2 + |s_{14}|^2)$

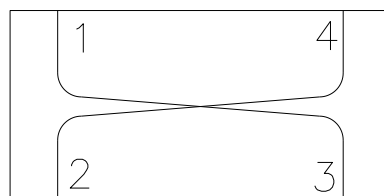
Frequency Subband	7.5 – 9 GHz	
Nominal Coupling	3 dB	
<i>Temperature</i>	297 K	20 K
A. E. Insertion Loss dB (max.) ^{*1}	0.42 dB	0.17 dB
Return Loss (max. any port)	-25.4 dB	-27 dB
Amplitude Unbalance (max.)	± 0.23 dB	± 0.2 dB
Phase Unbalance (max.)	± 1°	± 0.8°

OUTLINE DRAWING

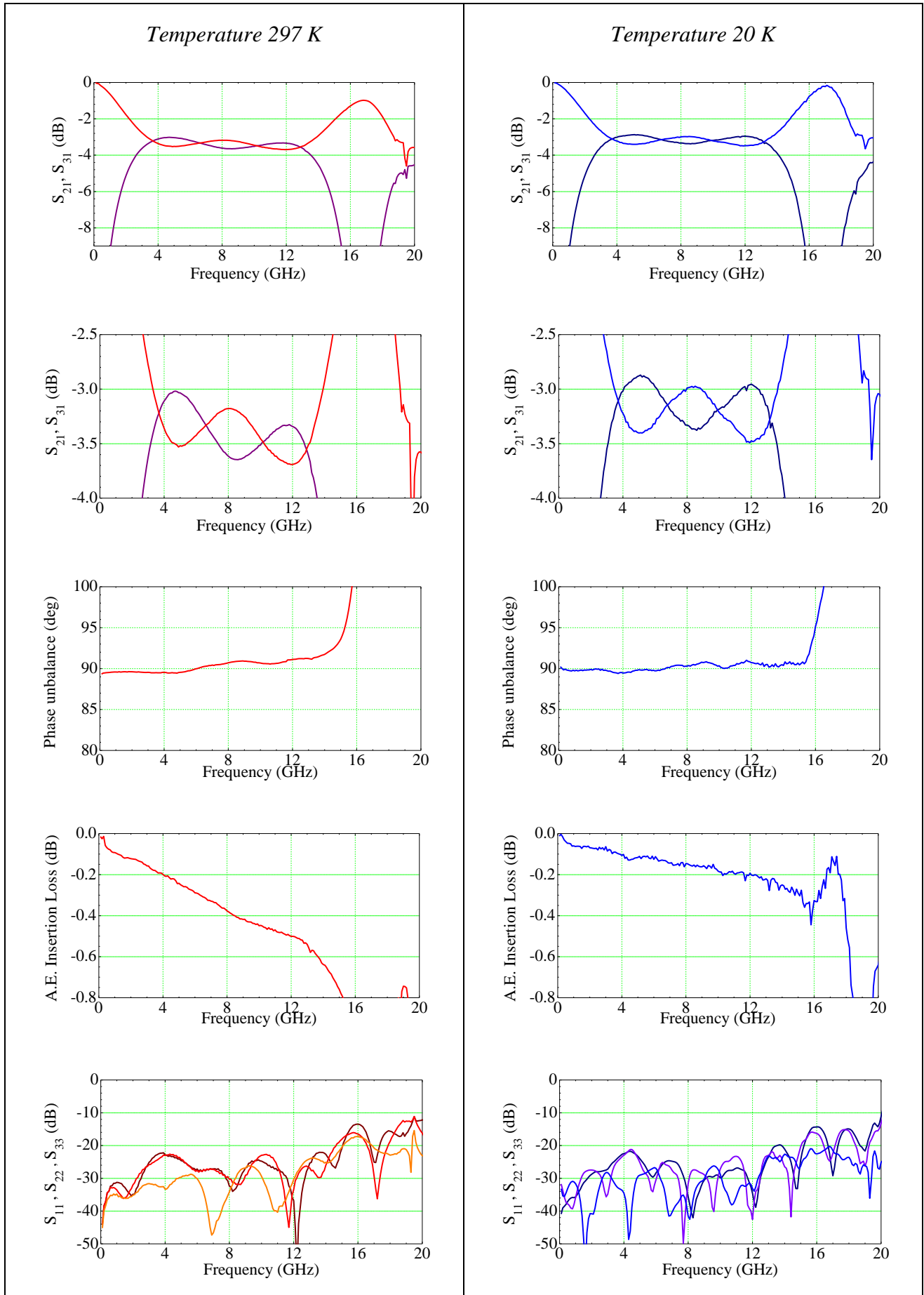
Dimensions in mm.



ELECTRICAL SCHEMATIC



MEASUREMENTS



MEASURED PERFORMANCE

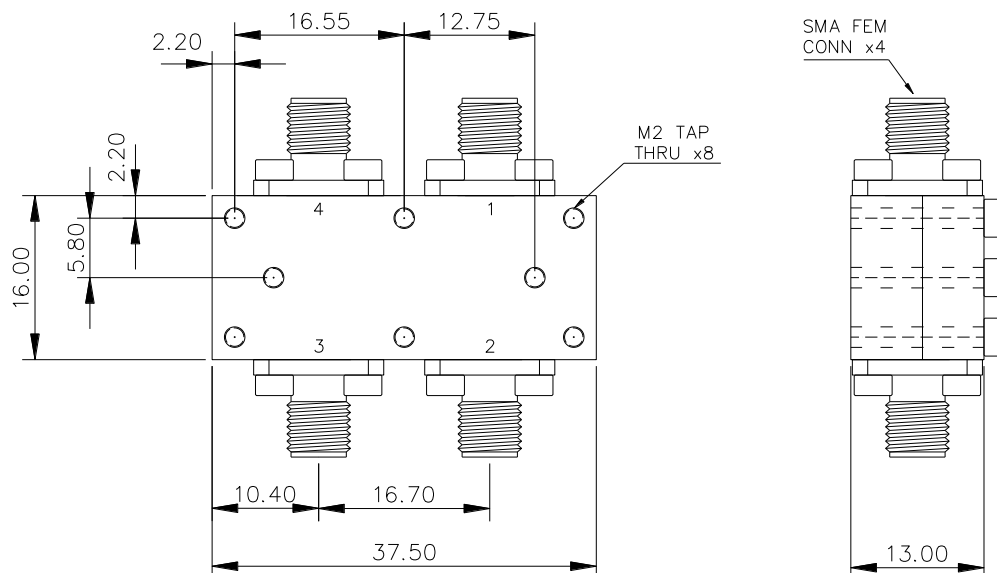
Serial Number	YH90X 1019	
Description	3dB 90° cryogenic hybrid	
Frequency Band	4 - 12 GHz	
Nominal Coupling	3 dB	
Connector	SMA female, sliding pin	
Weight (typ.)	36 g (1.27 oz)	
<i>Temperature</i>	297 K	20 K
A. E. Insertion Loss dB (max.) ^{*1}	0.55 dB	0.21 dB
Return Loss (max. any port)	-19 dB	-17.9 dB
Amplitude Unbalance (max.)	± 0.27 dB	± 0.3 dB
Phase Unbalance (max.)	± 2°	± 2.3°

*1: Average Equivalent Insertion Loss (dB), $L_{eq} = 10 \log_{10} (|s_{11}|^2 + |s_{12}|^2 + |s_{13}|^2 + |s_{14}|^2)$

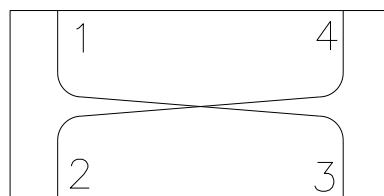
Frequency Subband	7.5 – 9 GHz	
Nominal Coupling	3 dB	
<i>Temperature</i>	297 K	20 K
A. E. Insertion Loss dB (max.) ^{*1}	0.45 dB	0.15 dB
Return Loss (max. any port)	-19.3 dB	-20.9 dB
Amplitude Unbalance (max.)	± 0.27 dB	± 0.3 dB
Phase Unbalance (max.)	± 1.5°	± 2°

OUTLINE DRAWING

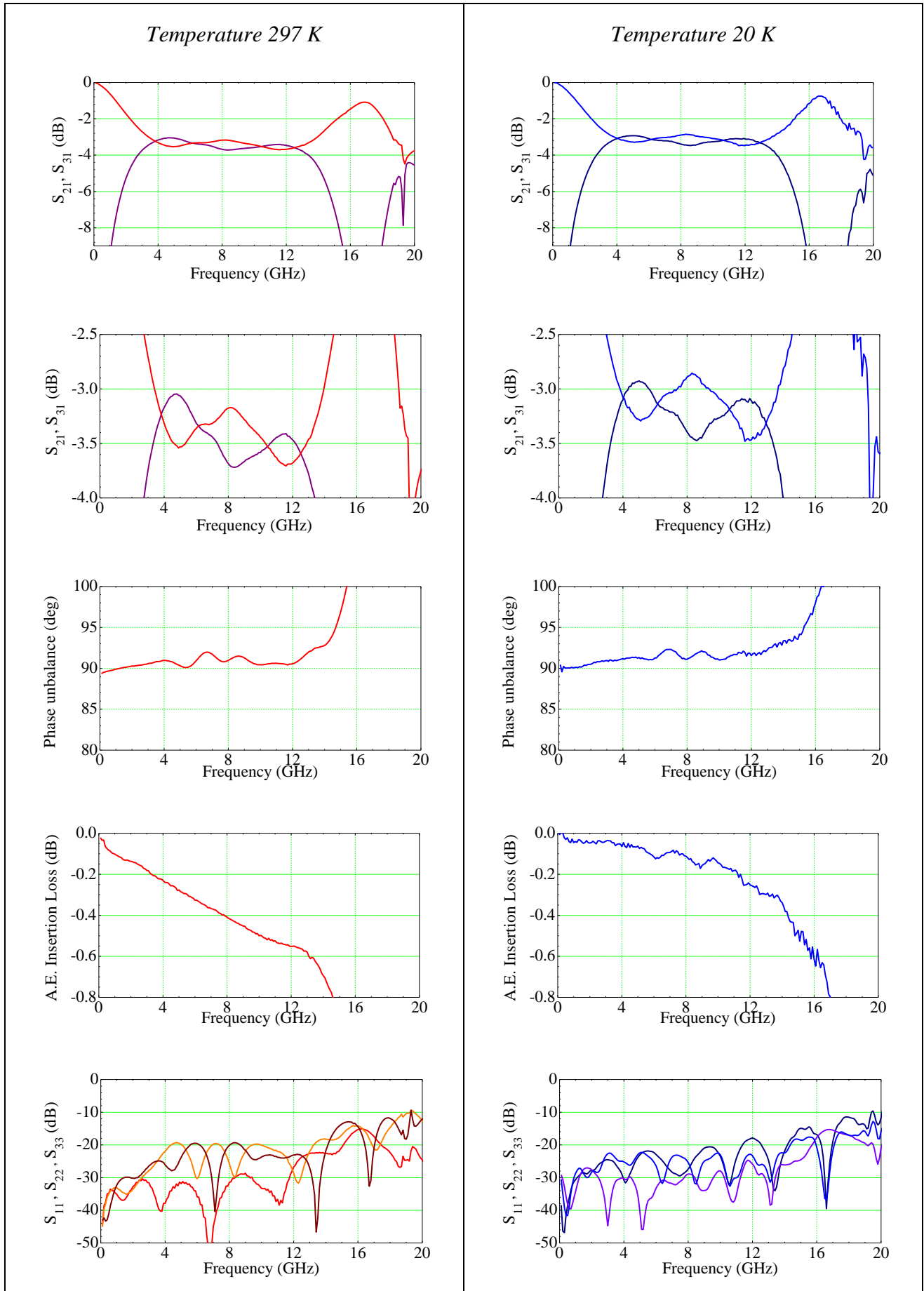
Dimensions in mm.



ELECTRICAL SCHEMATIC



MEASUREMENTS





3 Conclusions

We have designed and manufactured several multioctave stripline 3dB 90° coaxial hybrids couplers for the bands 1-4.4 GHz, 2-8 GHz and 4-12-GHz, specially conceived to operate when cooled to 20 K. Its coupling and reflection characteristics show very little temperature dependence. The units are a very compact, low-loss, reliable, repetitive and low thermal mass devices, capable to withstand extreme thermal cycling.

The worst case performance obtained in each band is presented in Table 2.

Yebes Hybrid model	Amplitude unbalance (± dB)	Phase unbalance (± deg)	Return loss (dB)	A. E. Insertion Loss (dB)	T (K)
YH90S (1-4.4 GHz)	0.32	4	-20	0.53	297
	0.36	4.8	-18.4	0.26	20
YH90SC (2-8 GHz)	0.3	2.4	-20	0.55	297
	0.35	3.4	-20	0.18	20
YH90X (4-12 GHz)	0.31	3	-19	0.55	297
	0.4	2.5	-18	0.23	20

Table 2. Worst case performance obtained in the units tested.