FETS RFQ Coupler

Initial Design Info

by Peter Savage

1st July 2010

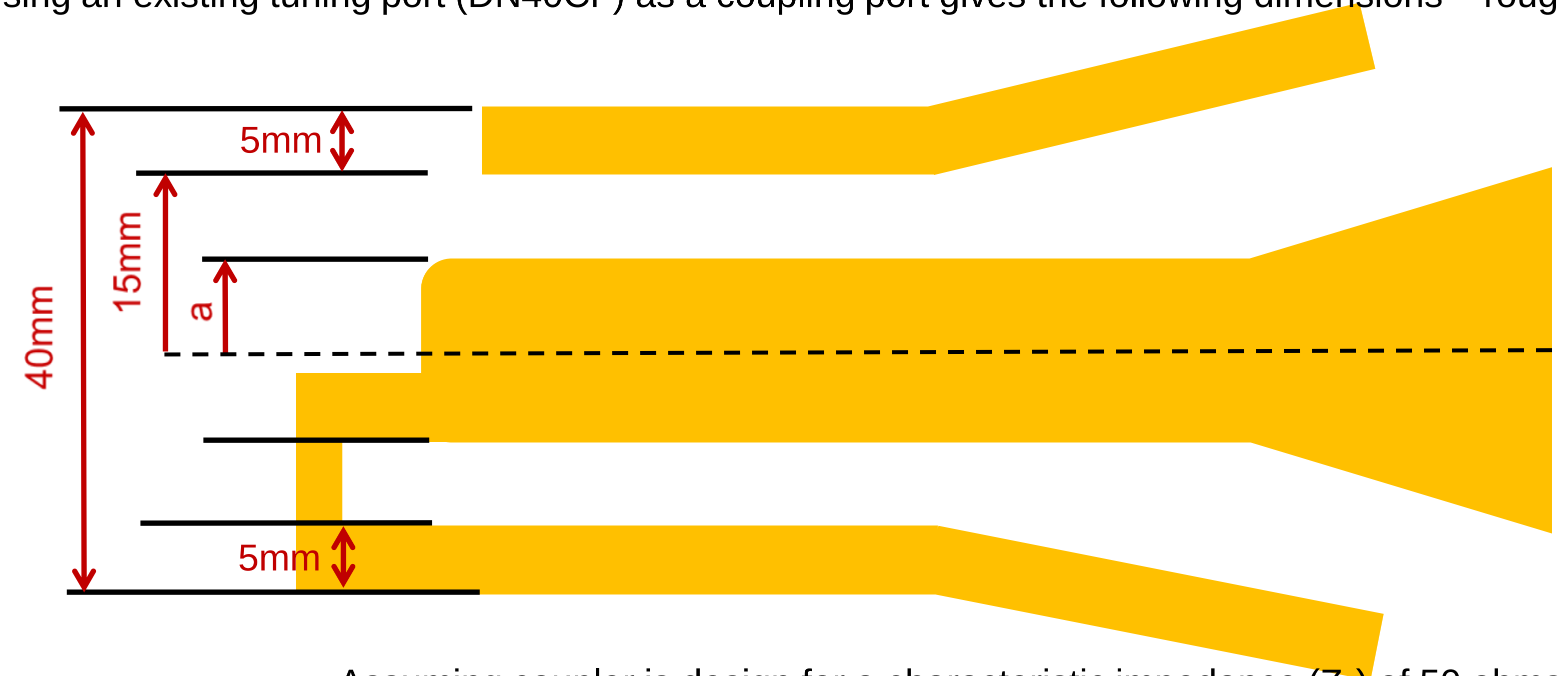
GOAL:

To gather enough facts to be able to start designing a 324MHz FETS RFQ coupler.

The design will be a first best guess that will enable us to do some modelling (COMSOL) so that we start to understand the problems.

QN: What size is the coupler at the loop end?

Using an existing tuning port (DN40CF) as a coupling port gives the following dimensions – roughly.



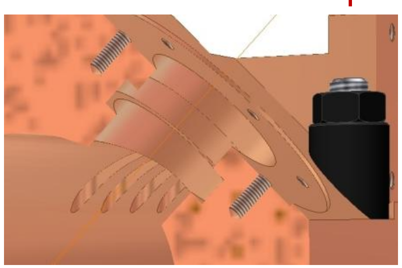
Assuming coupler is design for a characteristic impedance (Z_c) of 50 ohms.

Characteristic Impedance (Z_c) = 60 ln (b/a)

where b is the outer radius = 15mm
therefore, b/a = 2.3

a = 6.5mm = 0.0065m

DN40CF port



In other words, a DN40CF port suggests an inner core diameter of approx 13mm.

Toshiba Klystron E3740A Specification	
Frequency (MHz)	324
Output Power (MW)	3.0
Efficiency (%)	55
Gain (dB)	50
R.F. Pulse Length (μs)	620
Beam Pulse Length (μs)	700
Pulse Rate (pps)	50
Beam Voltage (kV)	110
Anode Voltage (kV)	94
Beam Current (A)	50
Beam Perveance ($I/V^{1.5}$)	1.37×10^{-6}
No. Of Cavities	5
Window	Coaxial
Output Flange	WR-2300
Weight (kg)	730
Tube Length (m)	4.55

How much power?

Klystron can deliver 3 MW, we need approx 1 MW

Beam power = energy rise x current
$= 3 \times 10^6$ (eV) x 65×10^{-3} (A)
= 195 kW

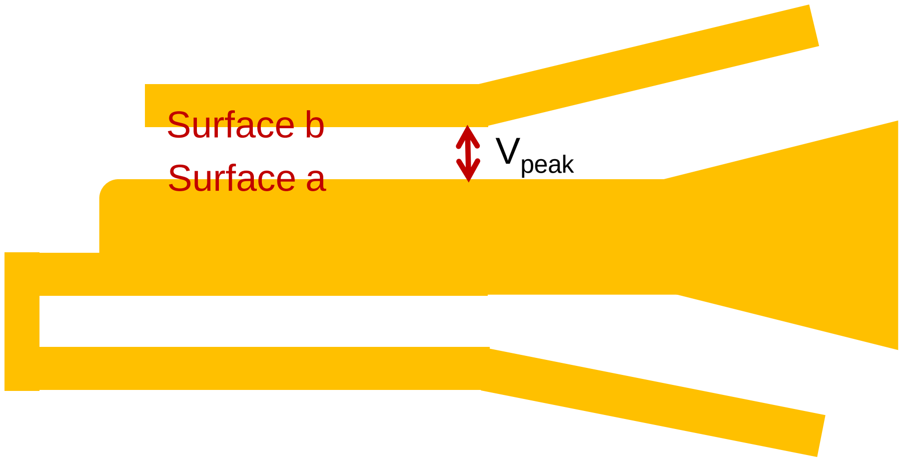
Leaving approx 800kW going into bulk copper

QN: What is the peak voltage?

The 324MHz Klystron can deliver 1MW peak power and hence 100kW average power at 10% duty cycle.

As a starting point let's assume we have 4 couplers delivering an average power of 25kW each.

NOTE: (for each coupler)
Average power P_A = 25kW
Peak power P_P= 250kW



For a power P (in Watts) flowing along the coax line the peak voltage between the inner and outer conductor is given by:

$V_{peak} = \sqrt{2.P_P.Z_c}$ where: P_P = 250kW
Z_c = 50 ohms
therefore V_{peak} = 5000V

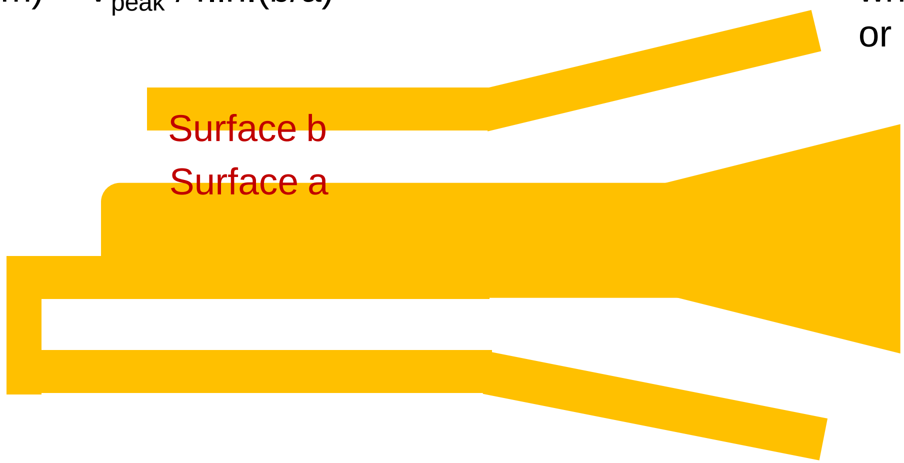
But! If the power should get reflected we could get double that so let's assume:

V_{peak} = 10kV ....for reference, vane voltage = 85kV

QN: What are the electric fields at surfaces a and b?

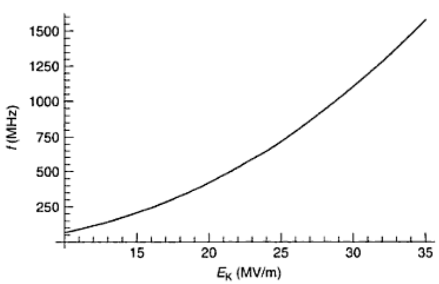
Electric field E (V/m) = V_{peak} / r.ln.(b/a)

where r = a = 0.0065m
or r = b = 0.015m



Electric field at a = E_a = 10000 / 0.0065 ln (2.3)
Electric field at b = E_b = 10000 / 0.015 ln (2.3)

E_a = 1.85 MV/m
E_b = 0.8 MV/m



$$f(MHz) = 1.64 E_K^2 e^{-8.5/E_K}$$

Kilpatrick limit at 324MHz in a vacuum = 17.8 MV/m

Our highest electric field (at surface a) is 1/10th the limit.

Conclusion: A DN40CF port could be used for a 250kW coupler.

QN: What size cable do we need?

TRANSMISSION LINE PRODUCTS 1

RFS

HELIFLEX® Cable

HCA318-50 Series
3-1/8" Air Coax

APPLICATIONS

TV, Broadcast

GENERAL INFORMATION	
Cable Type	Air-Dielectric, Corrugated
Size	3-1/8"
STRUCTURE	
Inner Conductor Material	Corrugated Copper Tube
Diameter Inner Conductor, mm (in)	34.8 (1.37)
Diameter Dielectric, mm (in)	75.3 (2.96)
Outer Conductor Material	Corrugated Copper
Diameter Copper Outer Conductor, mm (in)	85.5 (3.36)
Diameter over Jacket Nominal, mm (in)	90.5 (3.56)
MECHANICAL SPECIFICATIONS	
Cable Weight, kg/m (lb/ft)	3.3 (2.25)
Minimum Bending Radius, Single Bend, mm (in)	380 (15)
Minimum Bending Radius, Repeated Bends, mm (in)	1100 (43)
Tensile Strength, N (lb)	2600 (585)
Recommended / Maximum Clamp Spacing, m (ft)	0.8 / 1.2 (2.75 / 4.0)
ELECTRICAL SPECIFICATIONS	
Impedance, Ohm	50 +/- 0.5
Velocity, percent	96
Capacitance, pF/m (pF/ft)	70.0 (21.3)
Inductance, µH/m (µH/ft)	0.175 (0.053)
Maximum Frequency, GHz	1.5
Peak Power Rating, kW	940
RF Peak Voltage, Volts	9700
Jacket Spark, Volt RMS	8000
Inner Conductor dc Resistance, ohm/1000 m (ohm/1000 ft)	0.43 (0.13)
Outer Conductor dc Resistance, ohm/1000 m (Ohm/1000 ft)	0.13 (0.04)

See Installation, Operation and Storage Temperatures on page 28.

HCA318-50J/JB ATTENUATION AND AVERAGE POWER

Frequency MHz	Attenuation dB/100 m	Attenuation dB/100 ft	Average Power kW
0.5	0.0245	0.0075	793
1.0	0.0346	0.0106	560
1.5	0.0425	0.0129	457
2.0	0.0491	0.0150	395
10	0.111	0.0337	175
20	0.158	0.0480	123
30	0.194	0.0591	100
50	0.252	0.0769	77.3
88	0.338	0.103	57.9
100	0.362	0.110	54.2
108	0.377	0.115	52.1
150	0.448	0.136	44.0
174	0.484	0.148	40.8
200	0.521	0.159	38.0
300	0.648	0.198	30.9
400	0.757	0.231	26.7
450	0.808	0.246	25.1
500	0.856	0.261	23.8
512	0.867	0.264	23.6
600	0.946	0.288	21.8
700	1.03	0.314	20.2
800	1.11	0.339	18.9
824	1.13	0.344	18.6
894	1.18	0.360	17.9
900	1.19	0.362	17.9
925	1.21	0.367	17.6
960	1.23	0.375	17.3
1000	1.26	0.384	17.0
1250	1.43	0.436	15.3
1500	1.59	0.485	14.1

Standard Conditions:
For attenuation: VSWR 1.0, cable temperature 20° C (68° F).
For average power: VSWR 1.0, ambient temperature 40° C (104°F), inner conductor temperature 115° C (239° F). No solar loading.

CONNECTORS AND ACCESSORIES	
Connectors	See pages 79-81
Jumpers	See pages 82-87
Accessories	See pages 103-105
Coaxial Devices	See pages 106-108
Technical Appendix	See pages 639-648

"For an air line the limit is given by the breakdown strength of air.

Looking at commercial lines of ~1"-9" diameter they seem to be rated for a limit of 1.1-1.3 MV/m which is I guess consistent with the DC breakdown limit in dry air of ~3 MV/m.

A commercial 1-5/8" diameter air coax I found for example has a max (peak) power rating of 270 kW. However the average power is limited to 11 kW at 300 MHz so losses would seem to be more of a limit than sparking for our high duty factor.

If we wanted to have 1 MW divided 4 ways at 10% duty factor then we need 25 kW average per coax and it looks like that would need 3-1/8" coax even though it is well over-rated in terms of voltage." – Alan Letchford

ANSWER: 3-1/8" if we use 4 x 250kW couplers.

CONCLUSION:

Knowing the impedance leads us to the geometry - and knowing the power and frequency we can calculate the peak voltage, and then the electric fields – to see whether breakdown is a problem.

I have enough info to create a CAD model using the geometry shown here for the loop end and assuming a 3-1/8” coax at the air end.

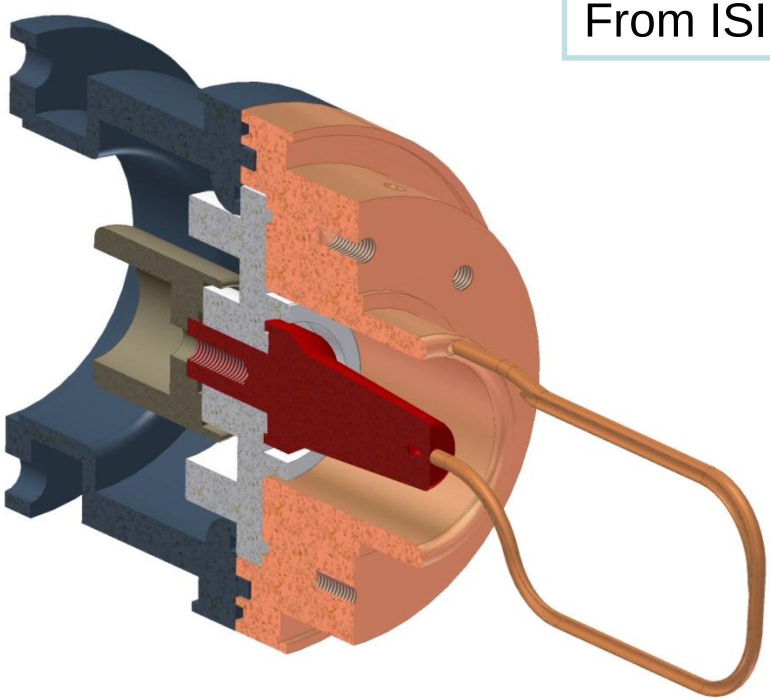
Between the vacuum and air side I will use an ISIS based window design.

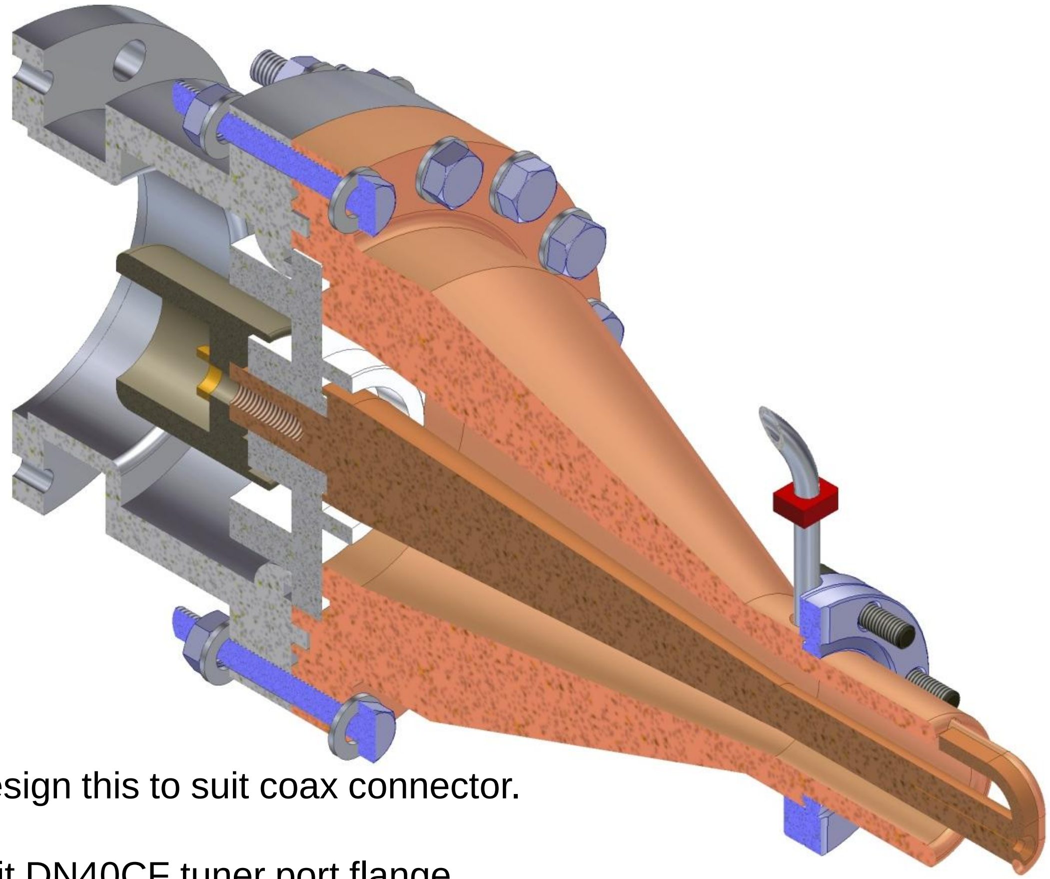
MORE:

"Just one caveat though about using the 40mm port: If we have an RF vacuum window at the port then it is likely to be the window that is the limiting factor not the peak surface field in the coax line. Because the window material will have a higher dielectric constant than air or vacuum the field will be concentrated around the area of the window. Also the coax inner diameter has to be adjusted at the position of the window because the formula you've used is for a dielectric constant of 1 ie air/vacuum*. There's no simple way of determining the field enhancement at the window so we'll only get this from some further modelling which will tell us if there's likely to be a problem of breakdown at the window". – Alan L.

Waveguide frequency bands and interior dimensions			
Frequency Band	Waveguide Standard	Frequency Limits (GHz)	Inside Dimensions (inches)
	WR-2300	0.32 - 0.49	23.000 x 11.500
	WR-2100	0.35 - 0.53	21.000 x 10.500
	WR-1800	0.43 - 0.62	18.000 x 9.000
	WR-1500	0.49 - 0.74	15.000 x 7.500
	WR-1150	0.64 - 0.96	11.500 x 5.750
	WR-1000	0.75 - 1.1	9.975 x 4.875
	WR-770	0.96 - 1.5	7.700 x 3.385
	WR-650	1.12 to 1.70	6.500 x 3.250
R band	WR-430	1.70 to 2.60	4.300 x 2.150
D band	WR-340	2.20 to 3.30	3.400 x 1.700
S band	WR-284	2.60 to 3.95	2.840 x 1.340
E band	WR-229	3.30 to 4.90	2.290 x 1.150
G band	WR-187	3.95 to 5.85	1.872 x 0.872

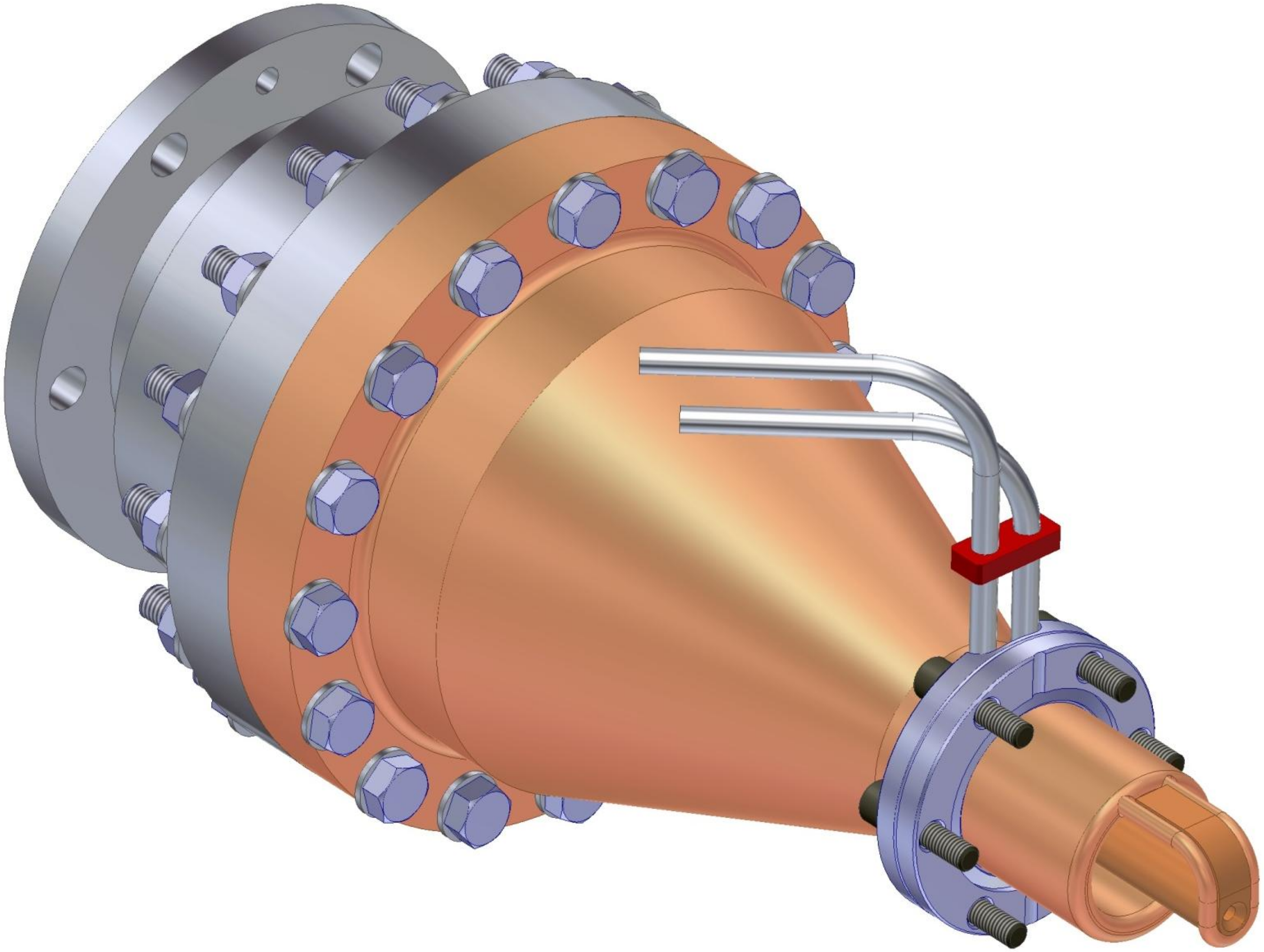
From ISIS coupler to FETS coupler





1. Reuses ISIS coupler back end – need to design this to suit coax connector.
2. Reuses ISIS design ceramic window.
3. Extended and reduced diameter nose to suit DN40CF tuner port flange.
4. Diameters of inner and outer coax conductors follow ratio of 2.3 maintaining impedance of 50 ohms.
5. Coupling loop is water cooled.
6. Outer copper conductor is a vacuum brazed assembly.

More images....



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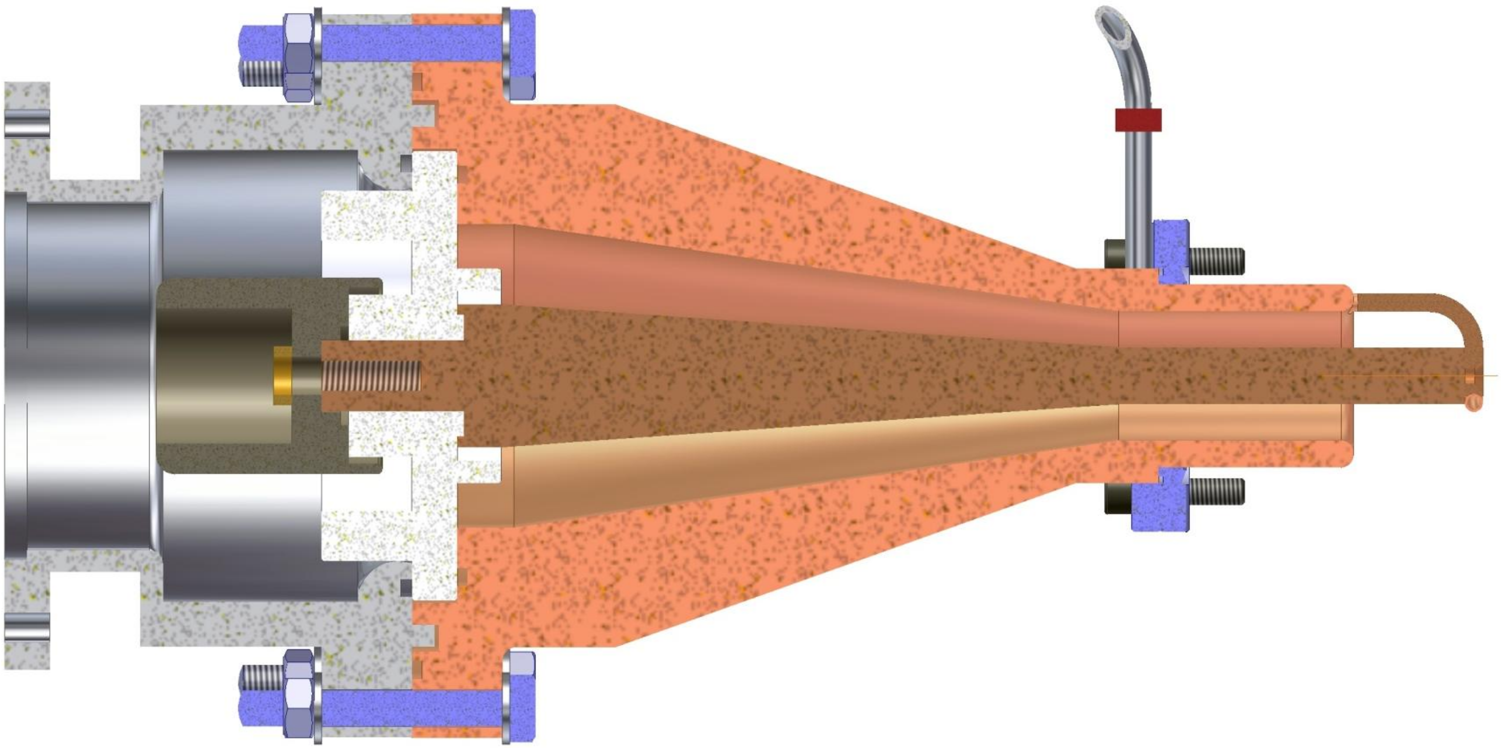

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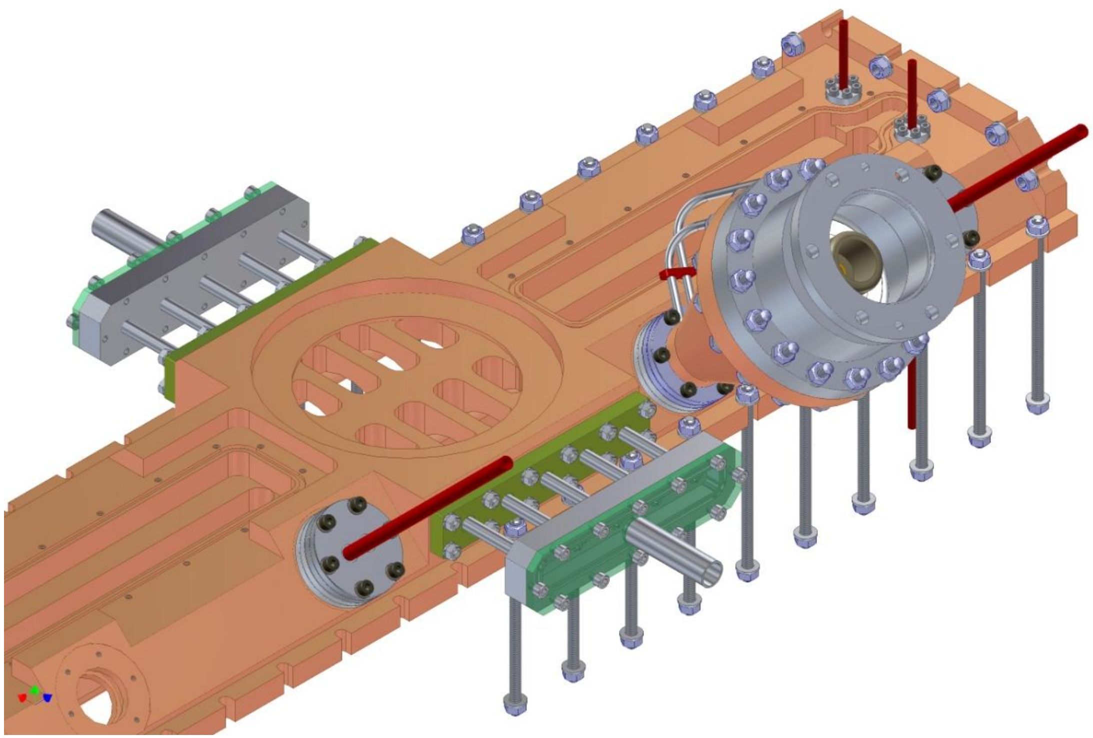
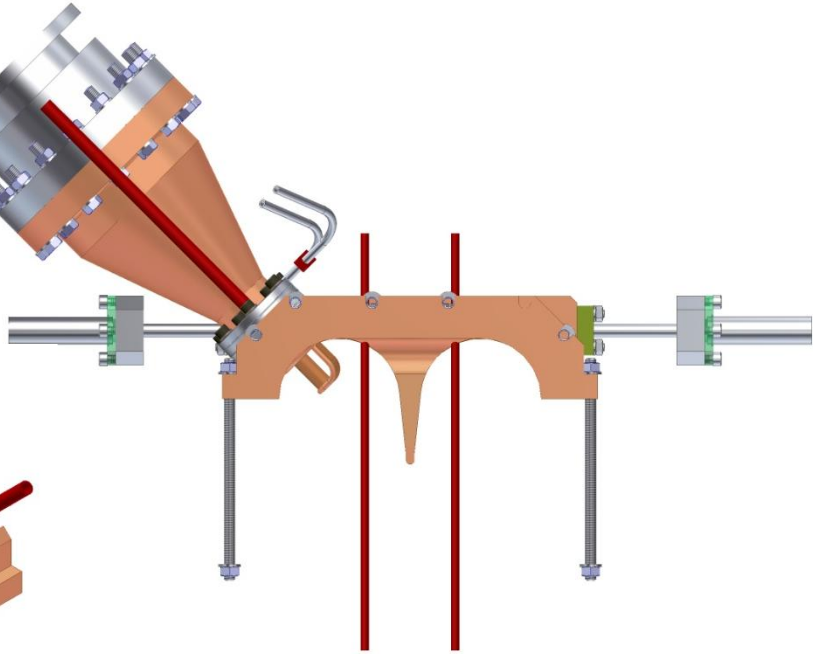
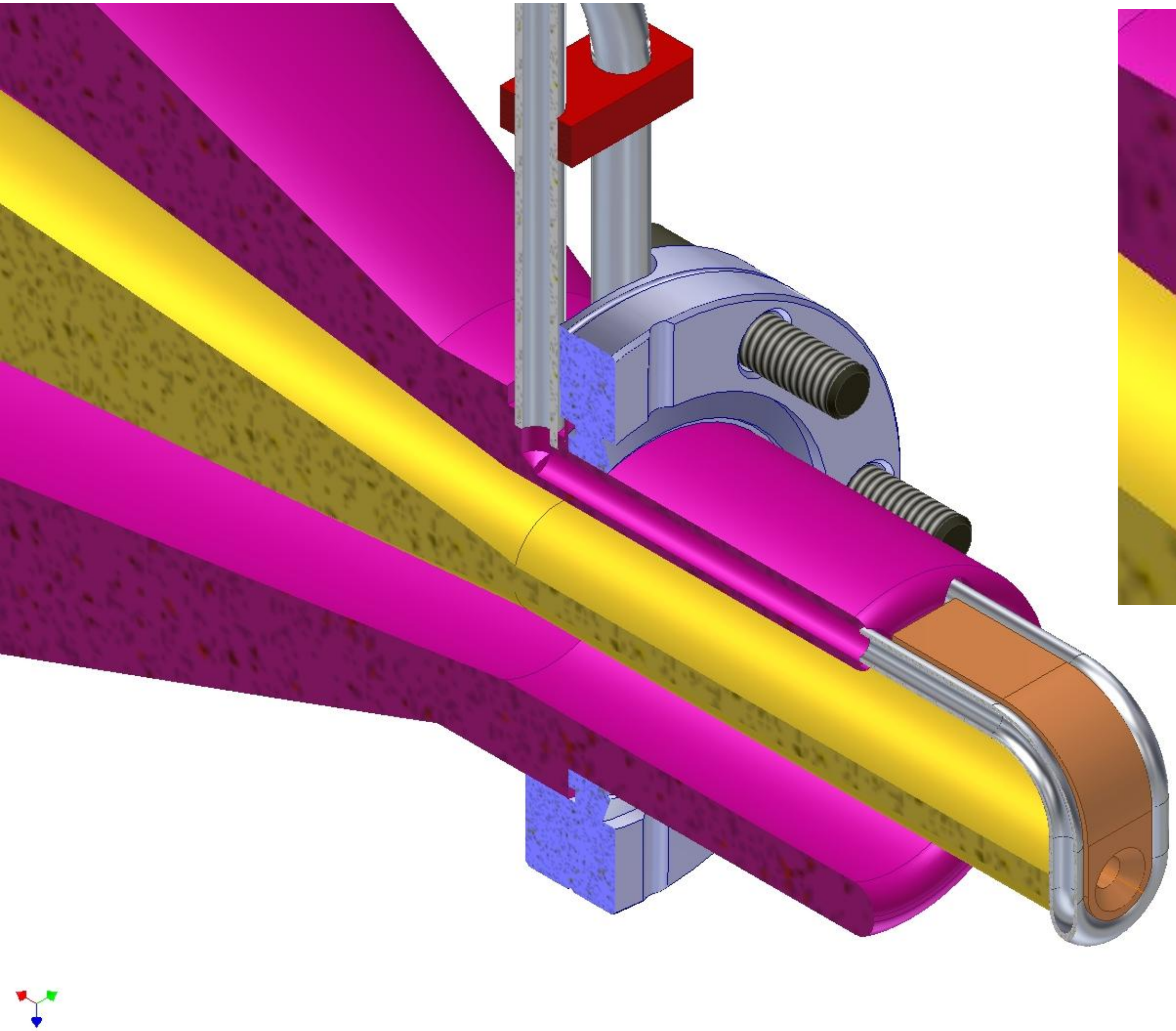
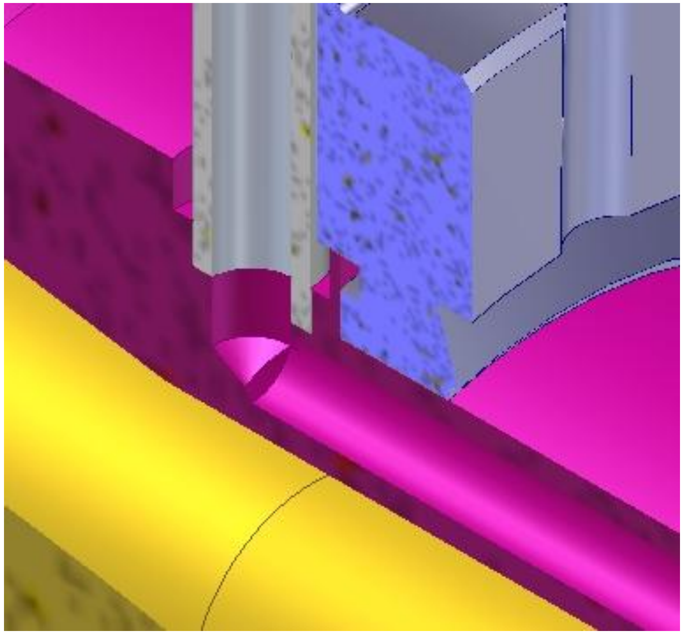


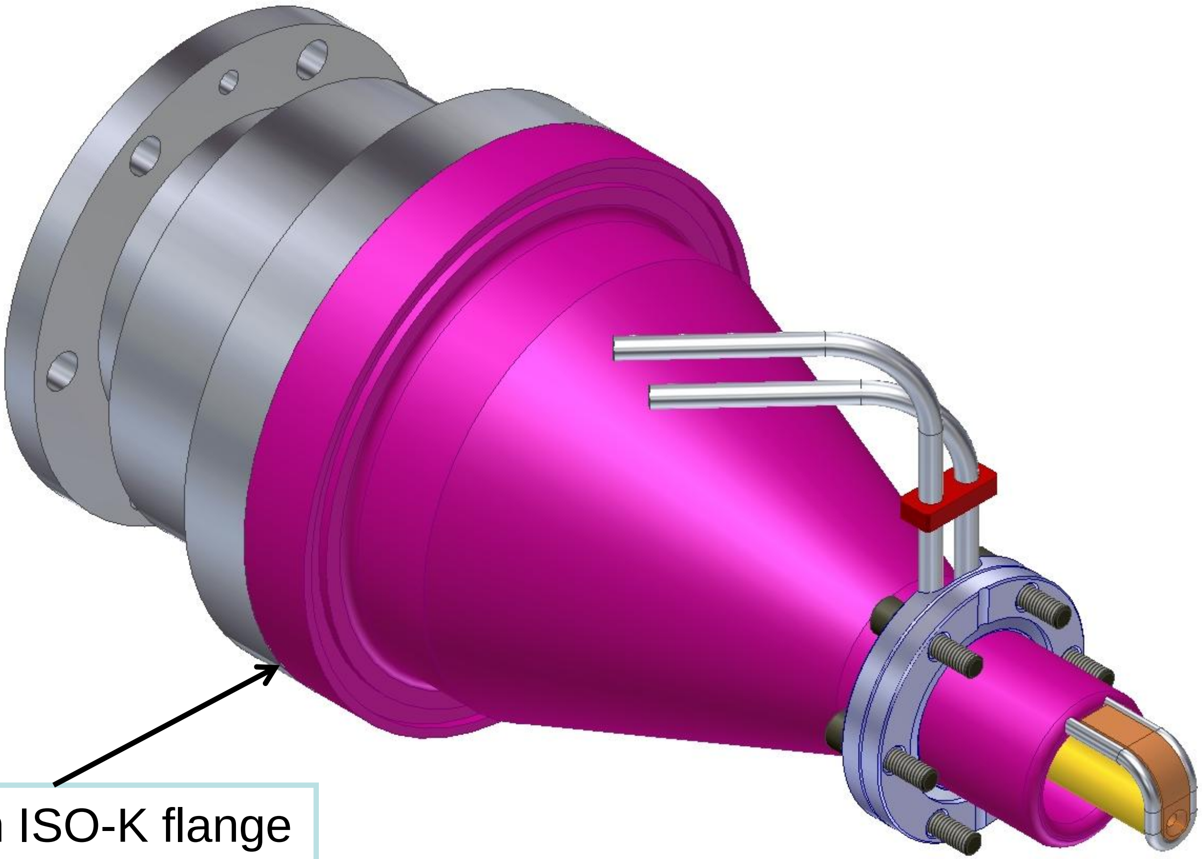


More images....





More images....



Using an ISO-K flange to allow rotation of the end loop.

CONCLUSION:

1. Please let me know if you spot anything obviously wrong with this design.

2. Once we are all happy I can create a de-featured model to be used for FEA simulation.

Product Data Sheet **HCA618-50J**

RFS

6 1/8" HELIFLEX® Air-Dielectric Coaxial Cable

Product Description

HELIFLEX® 6-1/8" low loss air dielectric cable

Application: TV, Broadcast

6 1/8" HELIFLEX® Air Dielectric Coaxial Cable

Features/Benefits

- **Low Attenuation**
  The low attenuation of HELIFLEX® coaxial cable results in highly efficient signal transfer in your RF system.
- **Complete Shielding**
  The solid outer conductor of HELIFLEX® coaxial cable creates a continuous RFI/EMI shield that minimizes system interference.
- **Low VSWR**
  Special low VSWR versions of HELIFLEX® coaxial cables contribute to low system noise.
- **Outstanding Intermodulation Performance**
  HELIFLEX® coaxial cable's solid inner and outer conductors virtually eliminate intermods. Intermodulation performance is also confirmed with state-of-the-art equipment at the RFS factory.
- **High Power Rating**
  Due to their low attenuation, outstanding heat transfer properties and temperature stabilized dielectric materials, HELIFLEX® cable provides safe long term operating life at high transmit power levels.
- **Wide Range of Application**
  Typical areas of application are: feedlines for broadcast and terrestrial microwave antennas, wireless cellular, PCS and ESMR base stations, cabling of antenna arrays, and radio equipment interconnects.

Frequency [MHz]	Attenuation [dB/100m]	Attenuation [dB/100ft]	Power [kW]
0.5	0.0128	0.0039	2500
1.0	0.0181	0.0055	1770
1.5	0.0222	0.0068	1440
2.0	0.0256	0.0078	1250
10	0.0578	0.0176	554
20	0.0822	0.0251	390
30	0.101	0.0308	318
50	0.132	0.0401	243
88	0.176	0.0538	183
100	0.189	0.0575	171
108	0.196	0.0599	165
150	0.233	0.0711	139
174	0.252	0.0770	129
200	0.272	[illegible]	[illegible]
300	0.338	0.103	97.0
400	0.395	0.120	83.6
450	0.421	0.128	78.8
500	0.446	0.136	74.7
512	0.452	0.138	73.7
600	0.493	0.150	68.1
700	0.537	0.164	63.0
800	0.579	0.176	58.9
824	0.588	0.179	58.1
860	0.602	0.184	56.9

Attenuation at 20°C (68°F) cable temperature
Mean power rating at 40°C (104°F) ambient temperature

Technical Features

Structure

Inner conductor:	Corrugated Copper Tube	[mm (in)]	67.0 (2.63)
Dielectric:	Helical Polyethylene Spacer	[mm (in)]	147.0 (5.78)
Outer conductor:	Corrugated Copper	[mm (in)]	162.0 (6.37)
Jacket:	Polyethylene, PE	[mm (in)]	169.0 (6.65)

Mechanical Properties

Mean power rating at [illegible] ambient temperature

Mechanical Properties

Weight, approximately	[kg/m (lb/ft)]	10.0 (6.7)
Minimum bending radius, single bending	[mm (in)]	1000 (39)
Minimum bending radius, repeated bending	[mm (in)]	1500 (59)
Bending moment	[Nm (lb-ft)]	1000 (738)
Max. tensile force	[N (lb)]	6000 (1349)
Recommended / maximum clamp spacing	[m (ft)]	1.0 / 2.0 (3.3 / 6.6)

Electrical Properties

Characteristic impedance	[Ω]	50 +/- 0.5
Relative propagation velocity	[%]	97
Capacitance	[pF/m (pF/ft)]	69.0 (21.0)
Inductance	[μH/m (μH/ft)]	0.173 (0.053)
Max. operating frequency	[GHz]	0.86
Jacket spark test RMS	[V]	8000
Peak power rating	[kW]	2890
RF Peak voltage rating	[V]	17000
DC-resistance inner conductor	[Ω/km (Ω/1000ft)]	0.17 (0.052)
DC-resistance outer conductor	[Ω/km (Ω/1000ft)]	0.044 (0.013)

Recommended Temperature Range

Storage temperature	[°C (°F)]	-70 to +85 (-94 to +185)
Installation temperature	[°C (°F)]	-40 to +60 (-40 to +140)
Operation temperature	[°C (°F)]	-50 to +85 (-58 to +185)

Other Characteristics

Fire Performance:	Halogene Free		
VSWR Performance:	Standard	[dB (VSWR)]	Typical 20.8dB (1.2:1 VSWR) or better within the operation bands of most global frequency ranges. Premium also available. Contact factory for options in your specific frequency band.
Other Options:	Phase stabilized and phase matched cables and assemblies are available upon request.		

All information contained in the present datasheet is subject to confirmation at time of ordering

Product Data Sheet **HCA495-50J**

RFS

5" HELIFLEX® Air-Dielectric Coaxial Cable

Product Description

HELIFLEX® 5" low loss air dielectric cable

Application: TV, Broadcast

5" HELIFLEX® Air Dielectric Coaxial Cable

Features/Benefits

- **Low Attenuation**
  The low attenuation of HELIFLEX® coaxial cable results in highly efficient signal transfer in your RF system.
- **Complete Shielding**
  The solid outer conductor of HELIFLEX® coaxial cable creates a continuous RFI/EMI shield that minimizes system interference.
- **Low VSWR**
  Special low VSWR versions of HELIFLEX® coaxial cables contribute to low system noise.
- **Outstanding Intermodulation Performance**
  HELIFLEX® coaxial cable's solid inner and outer conductors virtually eliminate intermods. Intermodulation performance is also confirmed with state-of-the-art equipment at the RFS factory.
- **High Power Rating**
  Due to their low attenuation, outstanding heat transfer properties and temperature stabilized dielectric materials, HELIFLEX® cable provides safe long term operating life at high transmit power levels.
- **Wide Range of Application**
  Typical areas of application are: feedlines for broadcast and terrestrial microwave antennas, wireless cellular, PCS and ESMR base stations, cabling of antenna arrays, and radio equipment interconnects.

Frequency [MHz]	Attenuation [dB/100m]	Attenuation [dB/100ft]	Power [kW]
0.5	0.0195	0.0059	1200
1.0	0.0276	0.0084	848
1.5	0.0338	0.0103	692
2.0	0.0391	0.0119	599
10	0.0879	0.0268	266
20	0.125	0.0380	187
30	0.153	0.0467	153
50	0.199	0.0606	118
88	0.266	0.0810	88.3
100	0.284	0.0865	82.7
108	0.295	0.0900	79.7
150	0.350	0.107	67.3
174	0.378	0.115	62.4
200	[illegible]	[illegible]	[illegible]
300	0.503	0.153	47.1
400	[illegible]	[illegible]	[illegible]
450	0.623	0.190	38.3
500	0.659	0.201	36.3
512	0.667	0.203	35.9
600	0.726	0.221	33.1
700	0.789	0.240	30.5
800	0.848	0.258	28.5
824	0.861	0.263	28.1
894	0.900	0.274	27.0
900	0.904	0.275	26.9
925	0.917	0.280	26.5
960	0.936	0.285	26.0
1000	0.957	0.292	25.5

Attenuation at 20°C (68°F) cable temperature
Mean power rating at 40°C (104°F) ambient temperature

Technical Features

Structure

Inner conductor:	Corrugated Copper Tube	[mm (in)]	45.0 (1.77)
Dielectric:	Helical Polyethylene Spacer	[mm (in)]	98.1 (3.86)
Outer conductor:	Corrugated Copper	[mm (in)]	109.3 (4.30)
Jacket:	Polyethylene, PE	[mm (in)]	115.1 (4.53)

Mechanical Properties

Weight, approximately	[kg/m (lb/ft)]	4.5 (3.0)
Minimum bending radius, single bending	[mm (in)]	500 (20)
Minimum bending radius, repeated bending	[mm (in)]	1200 (47)
[illegible]	[illegible]	[illegible]

Technical Features

Structure

Inner conductor:	Corrugated Copper Tube	[mm (in)]	45.0 (1.77)
Dielectric:	Helical Polyethylene Spacer	[mm (in)]	98.1 (3.86)
Outer conductor:	Corrugated Copper	[mm (in)]	109.3 (4.30)
Jacket:	Polyethylene, PE	[mm (in)]	115.1 (4.53)

Mechanical Properties

Weight, approximately	[kg/m (lb/ft)]	4.5 (3.0)
Minimum bending radius, single bending	[mm (in)]	500 (20)
Minimum bending radius, repeated bending	[mm (in)]	1200 (47)
Bending moment	[Nm (lb-ft)]	335 (247)
Max. tensile force	[N (lb)]	3000 (674)
Recommended / maximum clamp spacing	[m (ft)]	1.0 / 2.0 (3.3 / 6.6)

Electrical Properties

Characteristic impedance	[Ω]	50 +/- 0.5
Relative propagation velocity	[%]	97
Capacitance	[pF/m (pF/ft)]	68.0 (20.7)
Inductance	[µH/m (µH/ft)]	0.170 (0.052)
Max. operating frequency	[GHz]	1
Jacket spark test RMS	[V]	8000
Peak power rating	[kW]	1560
RF Peak voltage rating	[V]	12500
DC-resistance inner conductor	[Ω/km (Ω/1000ft)]	0.31 (0.095)
DC-resistance outer conductor	[Ω/km (Ω/1000ft)]	0.094 (0.029)

Recommended Temperature Range

Storage temperature	[°C (°F)]	-70 to +85 (-94 to +185)
Installation temperature	[°C (°F)]	-40 to +60 (-40 to +140)
Operation temperature	[°C (°F)]	-50 to +85 (-58 to +185)

Other Characteristics

Fire Performance:	Halogene Free		
VSWR Performance:	Standard	[dB (VSWR)]	Typical 20.8dB (1.2:1 VSWR) or better within the operation bands of most global frequency ranges. Premium also available. Contact factory for options in your specific frequency band.
Other Options:	Phase stabilized and phase matched cables and assemblies are available upon request.		

500	0.659	0.201	36.3
512	0.667	0.203	35.9
600	0.726	0.221	33.1
700	0.789	0.240	30.5
800	0.848	0.258	28.5
824	0.861	0.263	28.1
894	0.900	0.274	27.0
900	0.904	0.275	26.9
925	0.917	0.280	26.5
960	0.936	0.285	26.0
1000	0.957	0.292	25.5

Attenuation at 20°C (68°F) cable temperature
Mean power rating at 40°C (104°F) ambient temperature

All information contained in the present datasheet is subject to confirmation at time of ordering