Novel planar transmission line coupling elements for use in deployable antenna systems

Alan Thompson, Martin S. Thompson
Eureco Technologies Ltd

Beam-Forming Network (BFN) Technologies for Deployable Low-Frequency Direct Radiating Array (DRA) Antennas

- Current Technology
- Coaxial Cable
  - Small Diameter Selected
    - High Loss
    - Low Mass
    - Flexible
    - Mutually Exclusive Properties!
    - Low Loss — Low loss BFN not realisable
  - Low Antenna Efficiency — Mission/System Performance Limited
  - Higher Transmitter Power Requirement — Multipaction Issues
  - Higher Energy Demand — Larger Solar Panels; Higher Mass; Larger Battery Capacity; Larger Power Conditioning Subsystem
  - Amplitude & Phase Instabilities — Degraded Antenna Radiation Pattern — Mission/System Performance Limited
  - Possible Passive Intermodulation (PIM) Issues — Mission/System Performance Limited
  - Large Diameter Selected
    - High Mass
    - High Flexural Stiffness — Cumbersome — Routing Issues; Test Issues; Accommodation Issues
    - High Resistive Torque
    - Deployment Issues — Larger Deployment Mechanisms — Accommodation Issues; Higher Mass; Higher Energy Demand

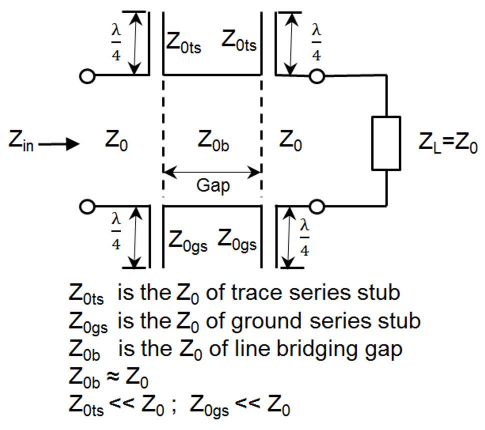
Summary

The use of coaxial cable in a BFN can cause many issues:

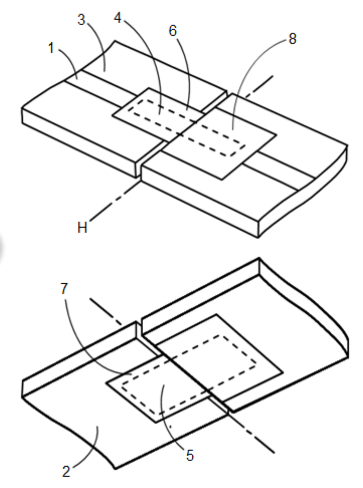
- High attenuation
- Low antenna efficiency
- Higher energy demand
- Poor amplitude and phase stability
- Distortion of radiation pattern
- Passive intermodulation (PIM)
- High resistive torque
- Bulky RF harness
- Higher total satellite system mass
- Limited Mission/System performance

Novel Planar Transmission Line Coupling Elements

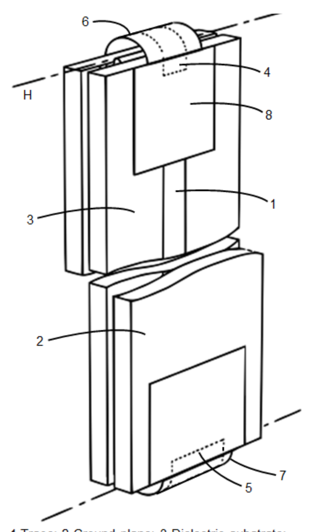
- Simplified Equivalent Circuit
- Computed S-parameter Plots: UHF-band, P-band, L-band, S-band
- Deployed State
- Stowed State



Z_{0ts} is the Z_0 of trace series stub
Z_{0gs} is the Z_0 of ground series stub
Z_{0b} is the Z_0 of line bridging gap
$Z_{0b} \approx Z_0$
$Z_{0ts} << Z_0$; $Z_{0gs} << Z_0$



1 Trace; 2 Ground plane; 3 Dielectric substrate; 4 Flexible trace; 5 Flexible ground plane; 6 Flexible trace dielectric; 7 Flexible ground dielectric; 8 Dielectric guide cover; H Hinge axis



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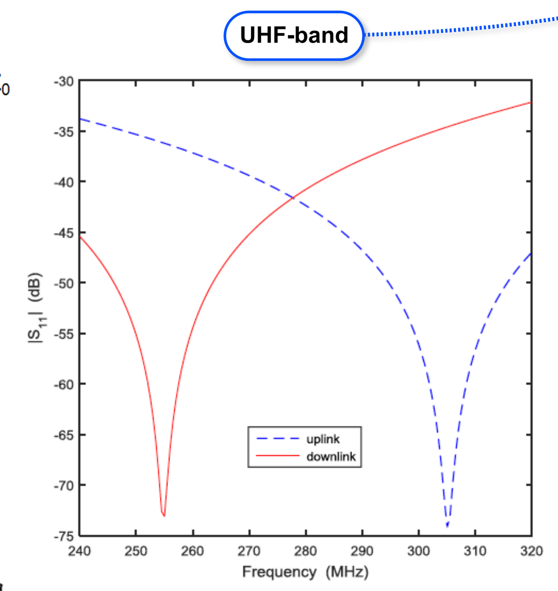
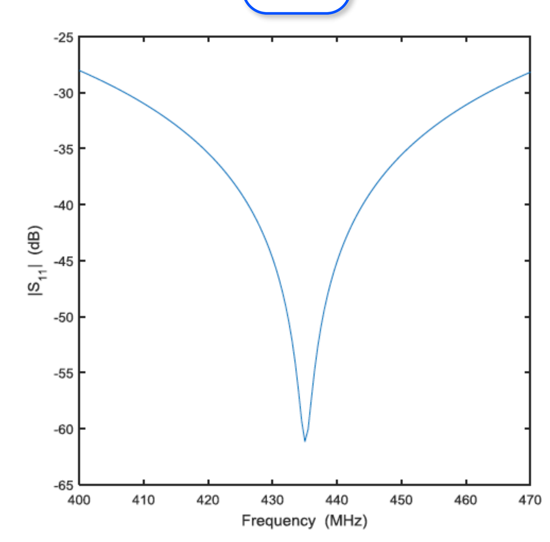
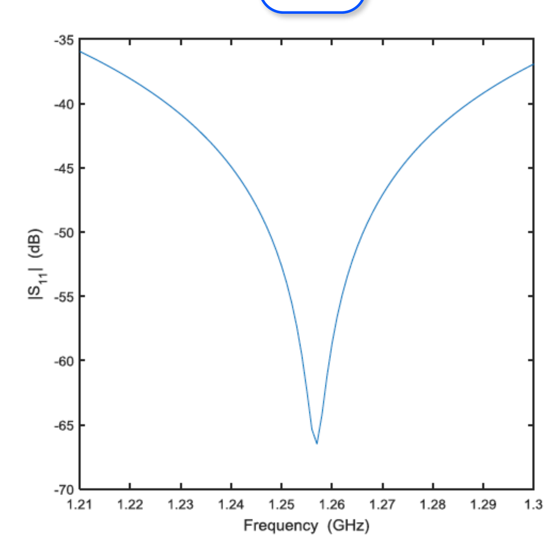
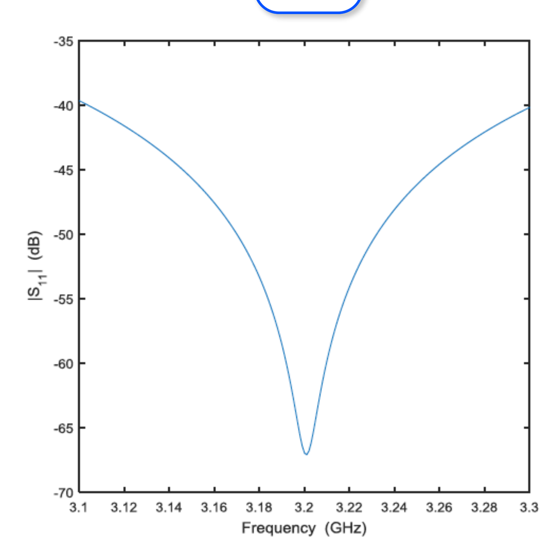
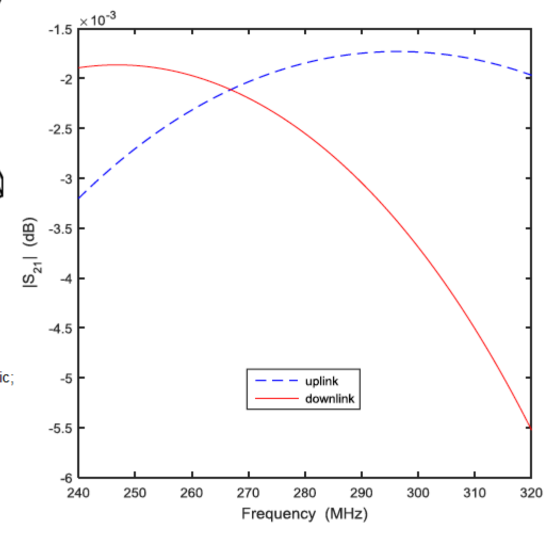
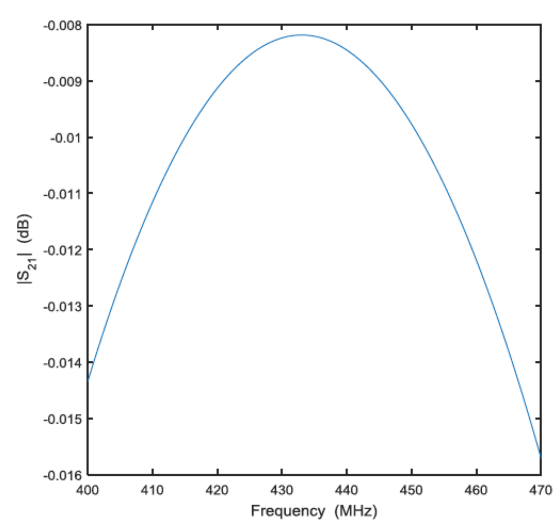


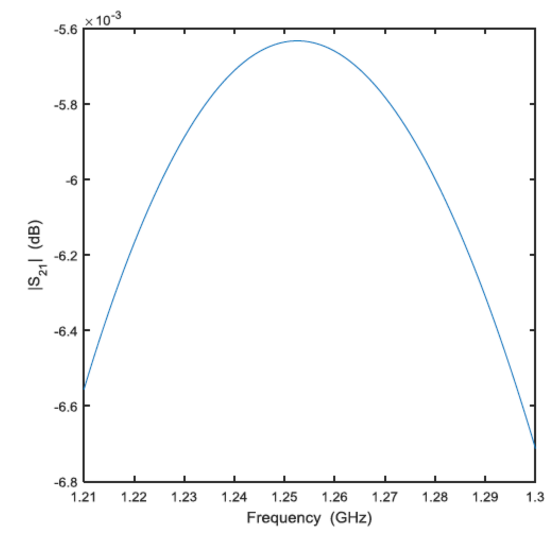


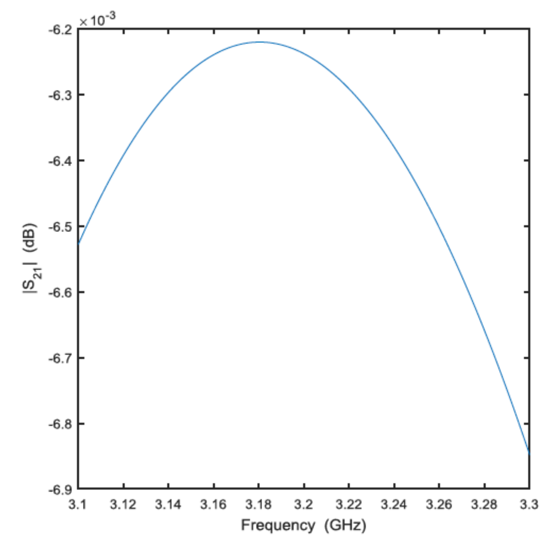




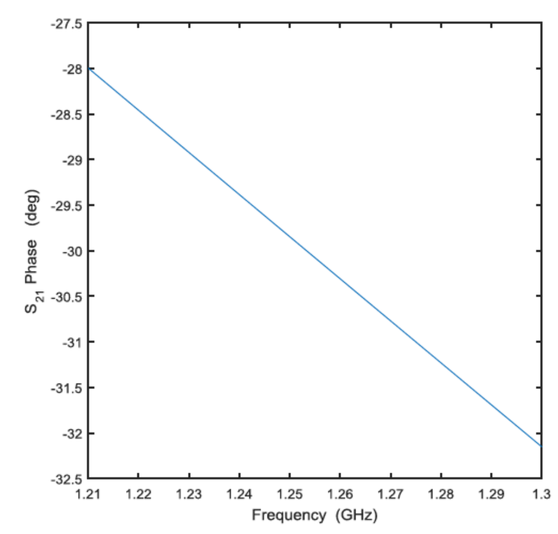








Band	Coupling element loss dB	Microstrip attenuation dB/m	Stripline attenuation dB/m	Coaxial Cable Type SHF2.4M attenuation dB/m
UHF	0.002	0.008	0.009	0.345
P	0.008	0.025	0.024	0.388
L	0.007	0.051	0.051	0.707
S	0.007	0.163	0.147	1.137



Summary

Planar transmission line coupling elements were invented to provide a means of bridging the gaps at the inter-panel junctions of DRA panels without recourse to RF coaxial cable harnesses, normally used in a BFN, with the aim of avoiding the related issues.

In the stowed (folded) state, flexible dielectric bridges, containing either a flexible trace or a flexible ground plane, are in a folded arched form at the inter-panel junction.

During the deployment phase, the flexible dielectric bridges unfold and slide over their respective traces and ground planes until the deployed state is reached.

There is no metal-to-metal contact in the coupling elements. PIM issues are thus eliminated or minimised if PIM prevention rules are followed for other parts of the antenna.

A simplified equivalent circuit of the coupling elements, bridging a gap in a two-section microstrip transmission line, has been derived and analysed for the deployed state.

MATLAB/RF Toolbox was used to compute the S-parameters for the simplified equivalent circuit.

Results of the computations indicate:

- adequate return loss
- low insertion loss
- linear phase against frequency, i.e. a constant true time delay (TTD)

In the frequency bands of interest, the computed return loss and insertion loss for the coupling elements are superior to the values measured for the state-of-the-art Power Sub-Miniature (PSM) connector, an SMA-like connector developed for space applications.

An Enabling Technology for Enhanced System Performance and Mission Benefits

- Low Loss at Inter-panel Junctions
  - Low Resistive Torque — Easier Deployment of DRA Panels
  - NO Metal-to-Metal Contact — Very Low Passive Intermodulation (PIM) — Enhanced System Performance — Mission Benefits
- Enables use of Planar Transmission Line in the BFN
  - Planar Transmission Line Contributes to Antenna Stiffness — Higher Eigenfrequencies — Easier Task for Attitude & Orbit Control System (AOCS) — Improved Pointing of Antenna Beam — Enhanced System Performance — Mission Benefits
  - Very Low Loss in the BFN — Higher Antenna Efficiency
    - Lower Energy Requirement — Lower Mass
    - Improved Noise Equivalent Sigma Nought (NESN) in a SAR System — Mission Benefits
    - Lower Bit Error Rate (BER) in a Communication System — Mission Benefits
  - Centralisation of Transmit/Receive Modules (TRM) and Digital Beam-Forming (DBF) Electronics — Enhanced System Performance — Mission Benefits
  - Highly Stable Amplitude and Phase — Stable Antenna Radiation Pattern — Enhanced System Performance — Mission Benefits

Summary

The novel planar transmission line coupling elements are an enabling technology providing the means to increase the performance of a DRA antenna. Benefits include:

- Very low loss in the BFN
- High antenna efficiency
- Stable radiation pattern
- Improved beam pointing accuracy
- Very low PIM
- Centralisation of TRMs and DBF electronics, made possible by the low-loss BFN, lowers the mass of the deployable panels and reduces cost.
- Easier deployment due to reduced resistive torque
- Enhanced system performance
- Mission benefits

Funding and Partners Required

- Design & Development
  - Thermal Model Simulation
  - Mechanical Model Simulation
  - Breadboard Models Evaluation
  - Electrical Model Simulation
  - Technology Readiness Levels (TRL) Progression
  - Viability Assessment for Future Missions
- Spin-off Applications
  - Deployable Array-Fed Reflector (DAFR)
  - Deployable RF Boom
  - Antenna Deployment Using the Energy Stored in the Stowed Coupling Elements — CubeSat

Applications by Frequency Band

- VHF-band Automatic Identification System (AIS)
- UHF SATCOM
- P-band SAR
- L-band SAR
- L-band Global Navigation Satellite System - Reflected GNSS-R
- L-band Radiometer
- S-band Telemetry, Tracking & Command (TT&C)
- S-band SAR

Summary

Funding and interested parties are required to support the design, development and test activities for progressing the TRL of the novel coupling element technology.

The coupling elements, used in conjunction with low-loss planar transmission line (microstrip or stripline), offer an alternative to coaxial cable BFN technology.

The new BFN technology should be suitable in the deployment of DRA antennas from large through to small satellites, including CubeSats, for applications in VHF through to, and possibly beyond S-band.

Potential benefits include:

- Simplified and lower cost implementation of DBF
- Enhanced communications from higher signal-to-noise ratio (S/N) and reduced PIM
- Better retrieval of low biomass values in SAR missions
- Higher quality interferometric SAR measurements
- Improved performance of passive receive-only dual-pol SAR
- Reduced overall system cost