Broadband Slotted Coaxial Antenna Technology

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NAB Breakfast

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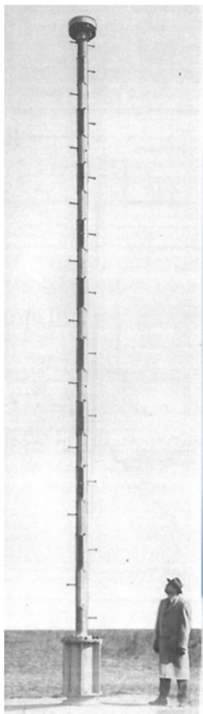
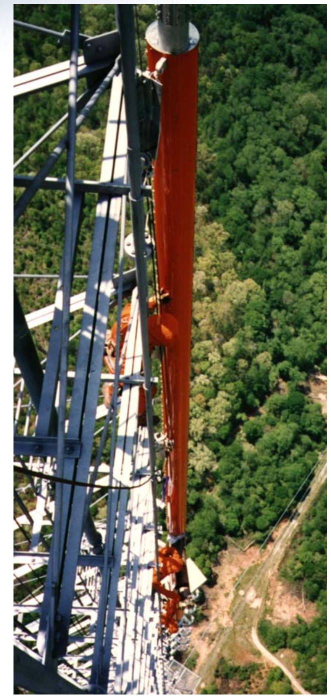
Slotted Coaxial Antennas

RCA shipped first pylon antenna in 1952. Over 500 prior to 1982.





1952 | 1982 | 1994 | 2014

500 in 30 years

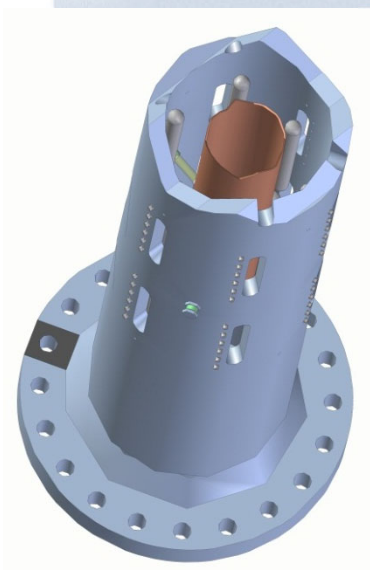
How many slotted coaxial antennas has Dielectric shipped since 1994?

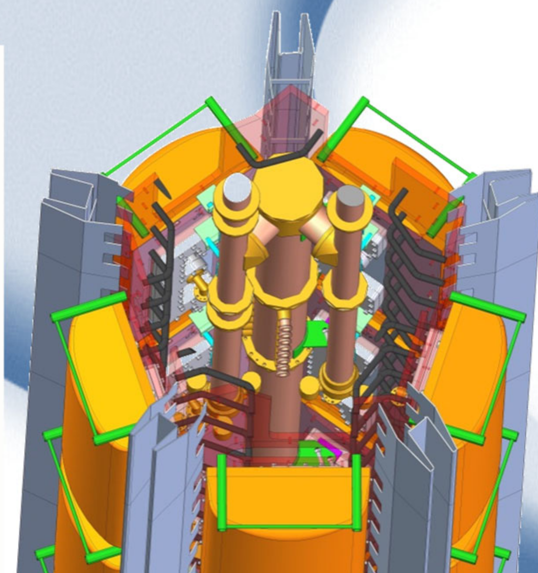
Slotted Coaxial Antenna Advantages

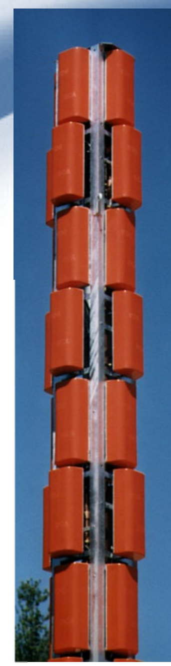
Dielectric

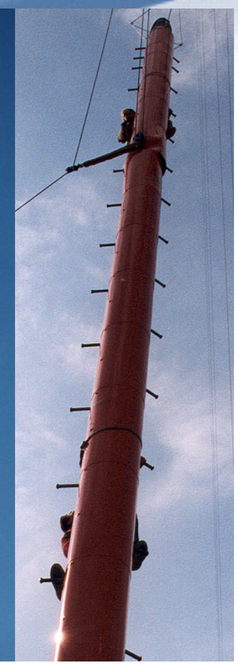
Advantages over broadband panel antennas

- Much smaller size
  - Less windload
- Higher reliability
  - Less connections
  - Less parts







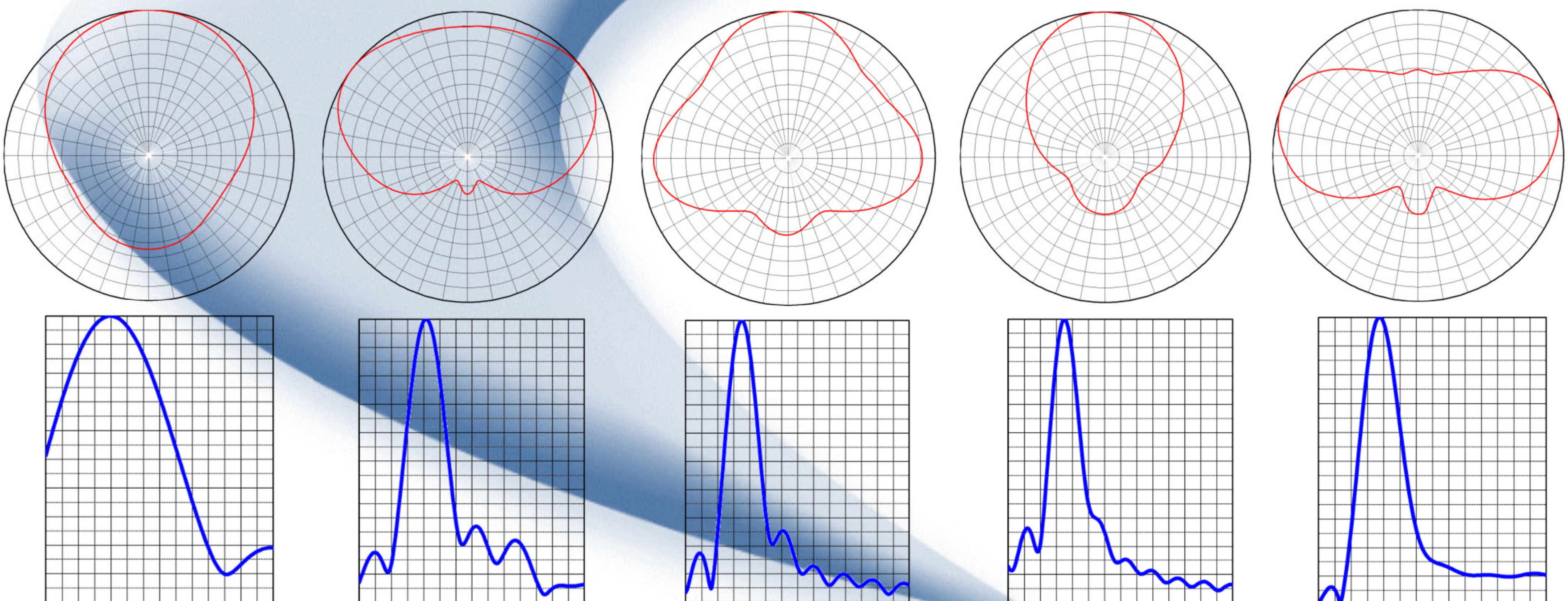


1966 RCA ad

Slotted Coaxial Antenna Advantages

Versatility - Azimuth and elevation patterns can be tailored to meet any coverage requirement without adding a lot of complexity

- Azimuth
  - Pipe size
  - # of slots around
  - Fins - directors
- Elevation
  - Number of layers
  - Illumination



Dielectric

One disadvantage – Inherently narrow bandwidth

Most applications – usage is only considered for single channel operation

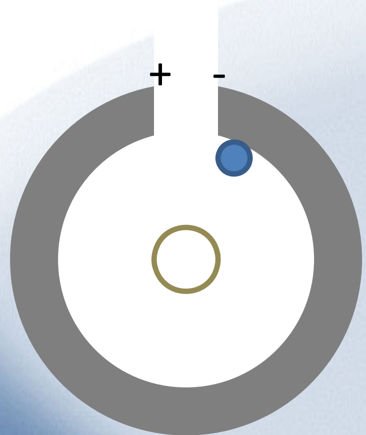
The natural bandwidth – typically 1% at UHF

$$\%bw = \frac{f_h - f_l}{f_0} x100$$

Today's presentation

- Various methods to increase the bandwidth of a slotted coaxial antenna
- Cumulative effect can boost the bandwidth to near 10%
- 10 channels for UHF

Slotted Coaxial Antennas



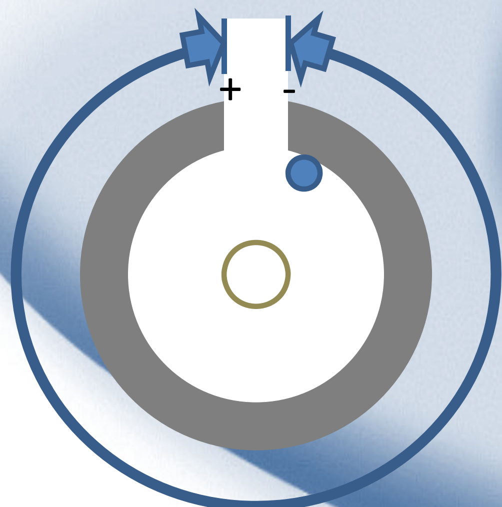
Narrow-band slot radiator

Broad-band slot radiator

Why are slotted coaxial antennas narrow-band?

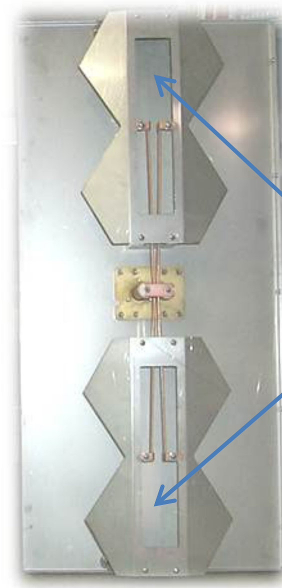
Slotted Coaxial Antennas

Fundamental BW limitation imposed by cylinder



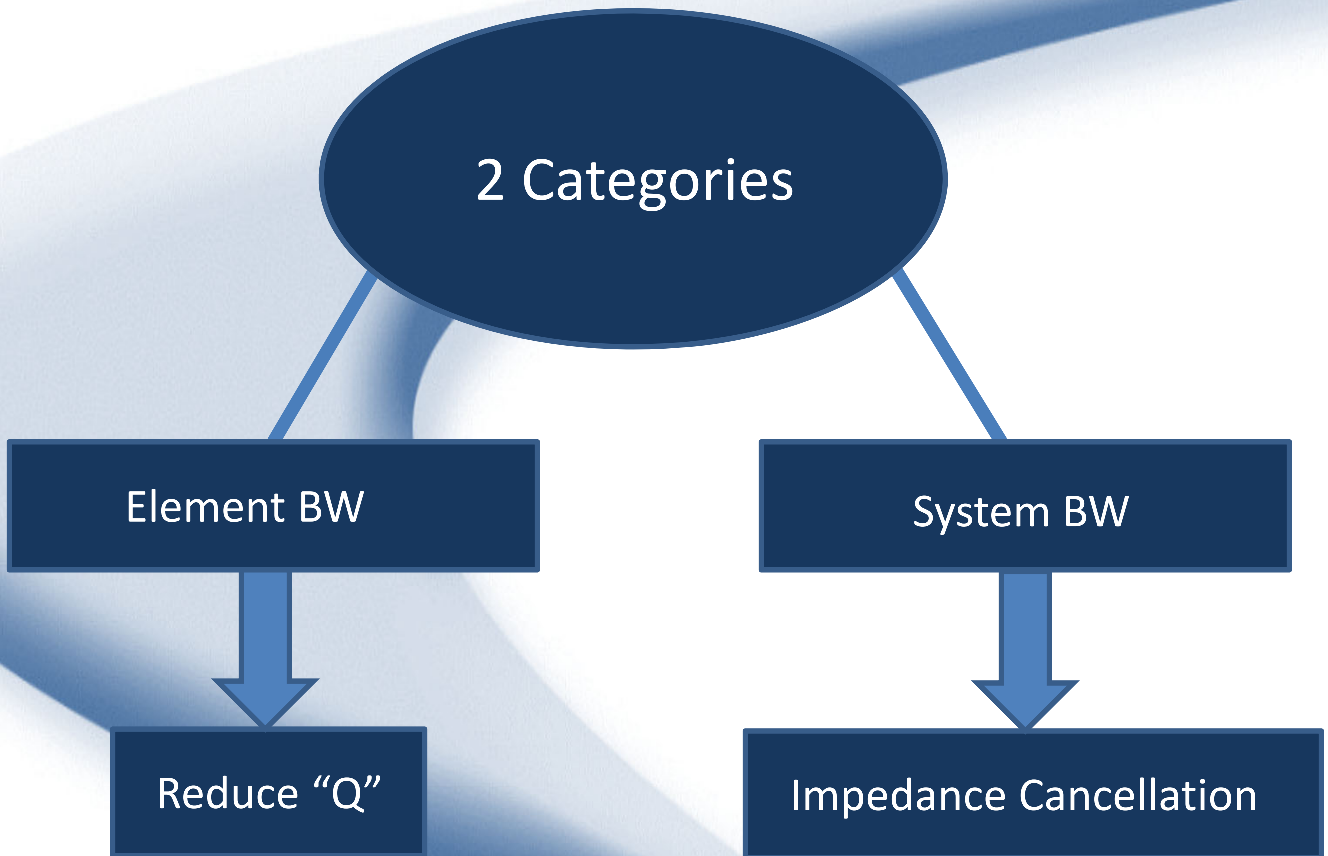
Frequency dependent length

Remove length dependence



Broadband slot radiators

Techniques to Improve Bandwidth

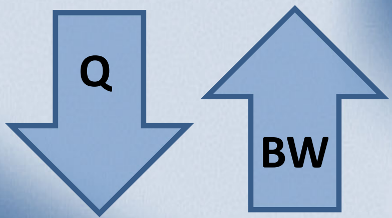


Quality Factor "Q"

Fundamental form: $$Q = w \frac{energy\ stored}{average\ power\ disipated}$$

R.M. Fano derived the fundamental bounds for narrowband antennas to be:

$$bw = \frac{\pi}{Q ln \left\{ \frac{VSWR + 1}{VSWR - 1} \right\}}$$



VSWR is the maximum allowable within the passband

1950

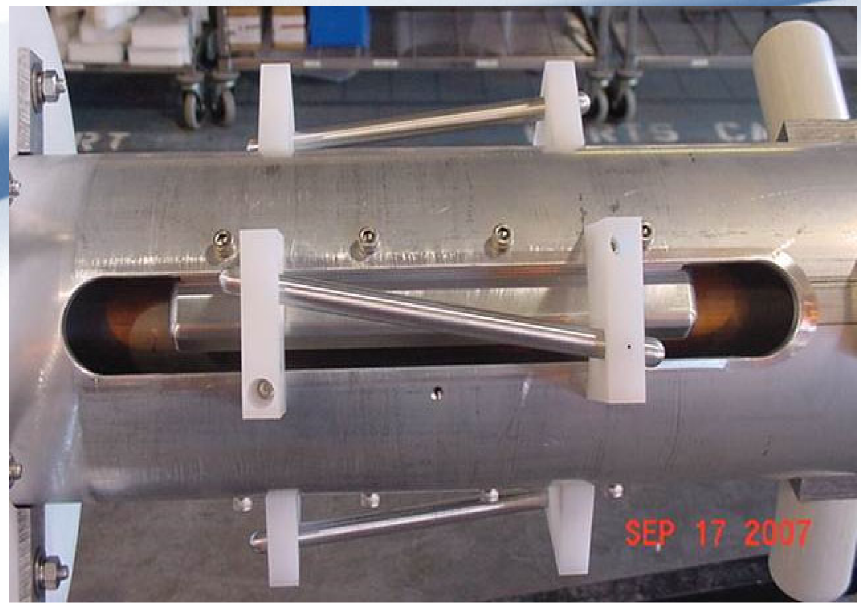
Expected improvement in bandwidth for given Q reduction:

$$\%bw = \frac{\pi}{ln \left\{ \frac{VSWR + 1}{VSWR - 1} \right\}} \left[\frac{1}{Q_2} - \frac{1}{Q_1} \right]$$

Techniques to Reduce Q of a Slotted Coaxial Antenna

Parasitic dipole over a slot radiator

- Provides elliptical or circular polarization
- Lowers the Q of the circuit
  - Increases the operating bandwidth

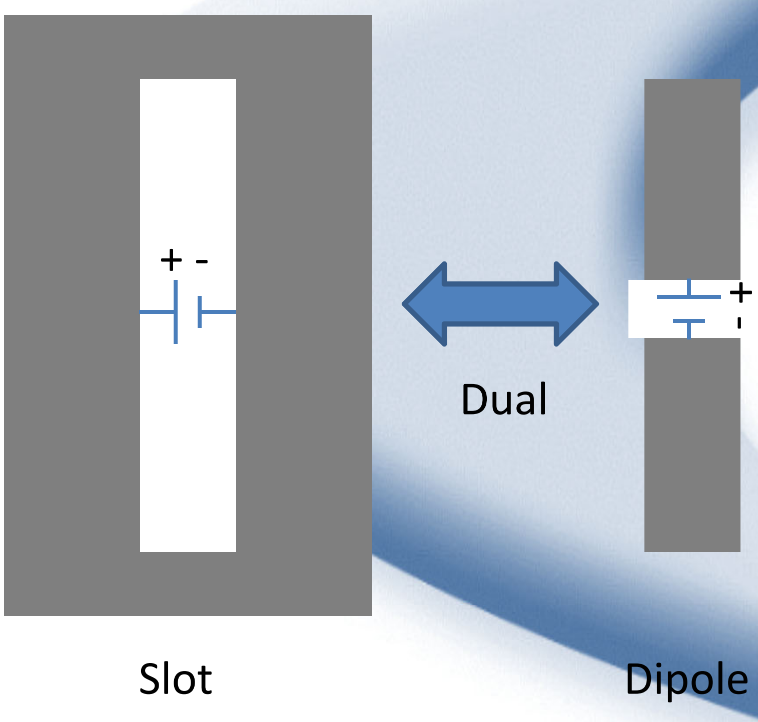


In 1827 his principle states that the diffraction pattern from an opaque body is identical to that from a hole of the same size and shape.

Who is this famous French physicist?

Babinet's Principle

In 1946 H.G. Booker put Babinet's Principle into antenna terms relating aperture duals



Impedance relationship

$$Z_S = \frac{\eta^2}{4Z_D}$$

$$Z_S Z_D = \frac{1}{4}\eta^2 \ represents\ a\ real\ number,$$

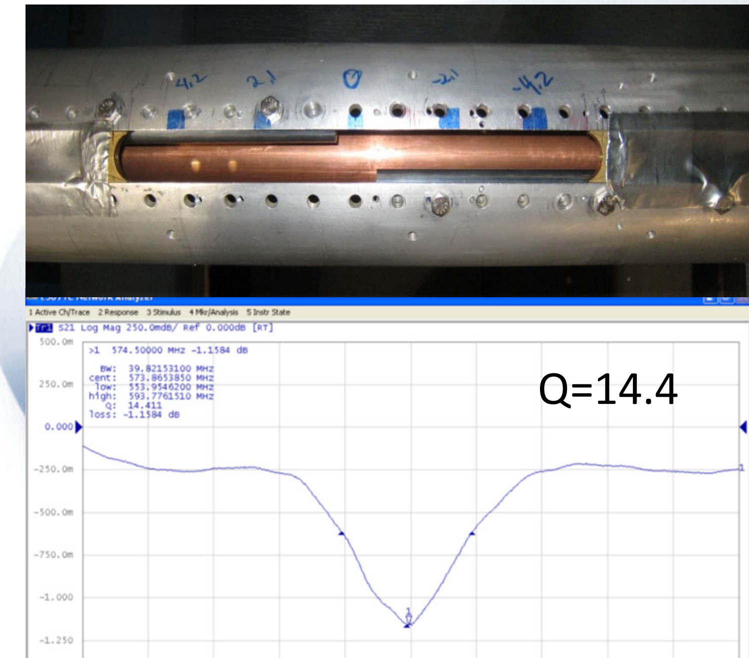
$$(R_D + jX_D)(R_S + jX_S)\ is\ real$$

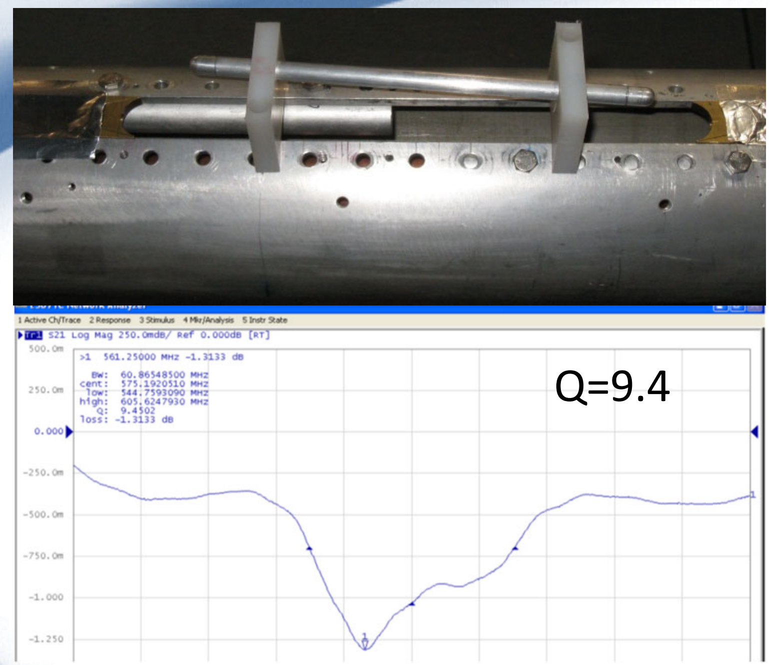
$$\Rightarrow R_S X_D = -R_D X_S$$

Implies inverse relationship between the slot and dipole Z and therefore will provide a level of cancellation when added together in the same circuit

Babinet's Principle

Quantify level of bandwidth improvement



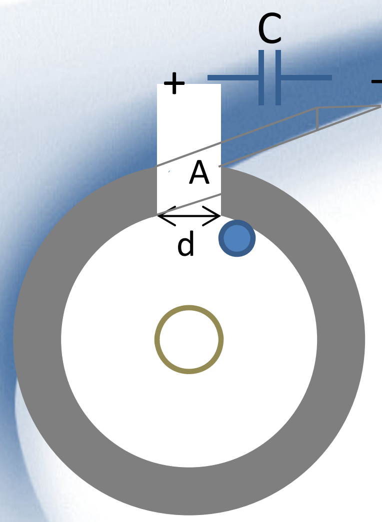


$$\%bw = \frac{\pi}{ln\left\{\frac{VSWR+1}{VSWR-1}\right\}}\left[\frac{1}{Q_2}-\frac{1}{Q_1}\right]$$

For a maximum allowable VSWR of 1.1:1, the expected improvement in BW is **3.8%**

Relationship Between Coaxial Pipe Thickness and Q

Dielectric



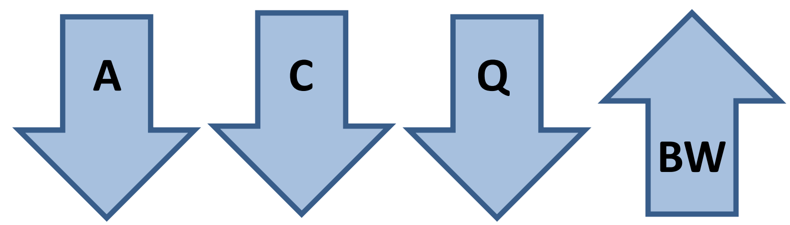
Can be viewed as parallel plates with a capacitance between slot walls

When a resonate circuit is loaded the loaded Q is :

$$Q_L = \frac{\omega_0 C}{G_{Total}}$$

For a parallel plate capacitor, C is directly proportional to A

$$C = \frac{\epsilon A}{d}$$

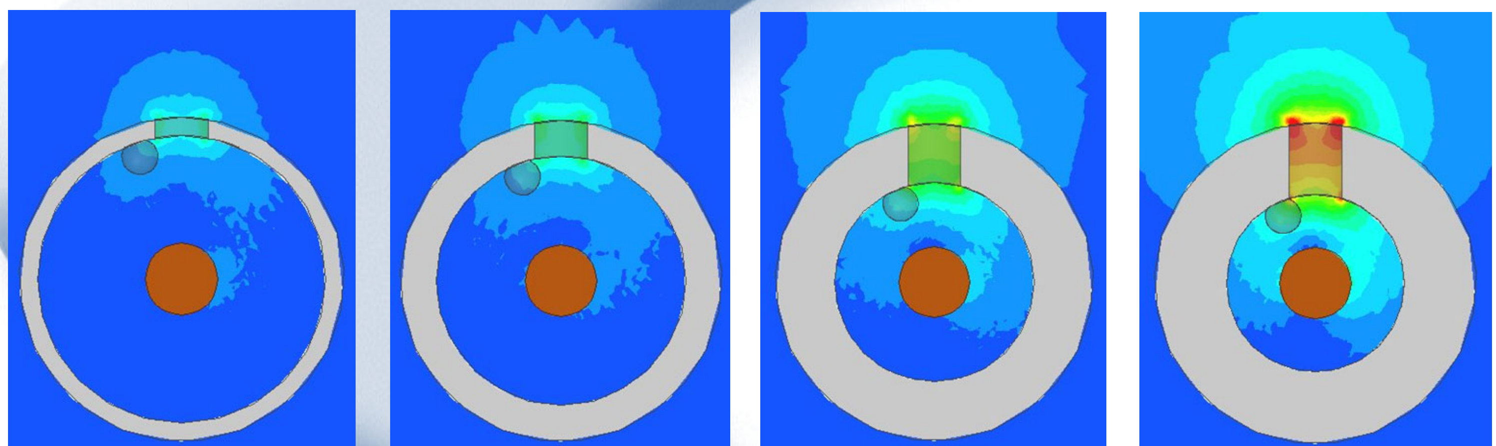


Relationship Between Coaxial Pipe Thickness and Q

Dielectric

In practice, C is not directly proportional to A of the slot walls

HFSS simulation – field intensity vs. pipe thickness of a slotted coaxial antenna

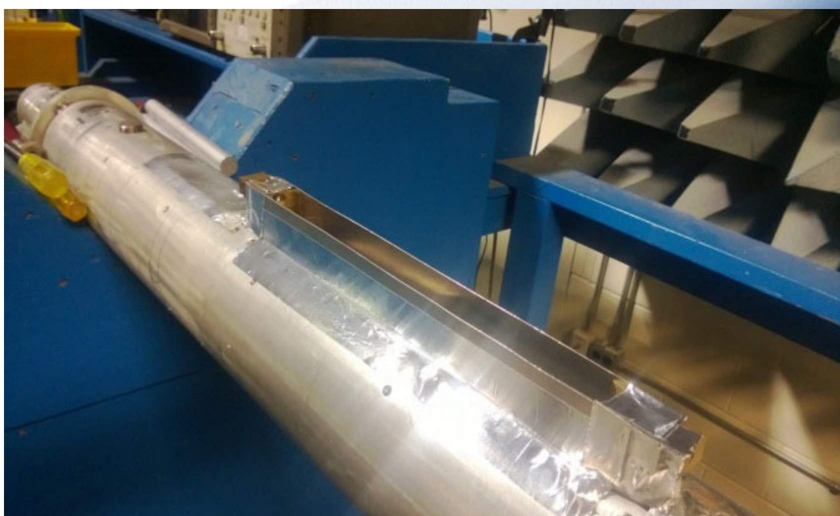


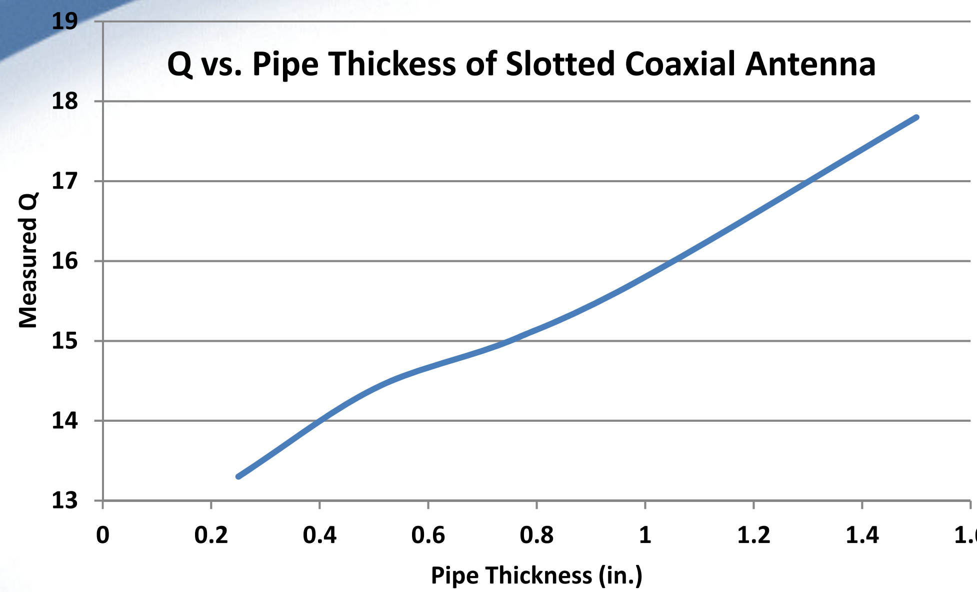
½” wall | 1 wall | 1½” wall | 2” wall

Fields inside the slot are not evenly distributed

Relationship Between Coaxial Pipe Thickness and Q

The true relationship between coaxial pipe thickness and Q is found through experimentation



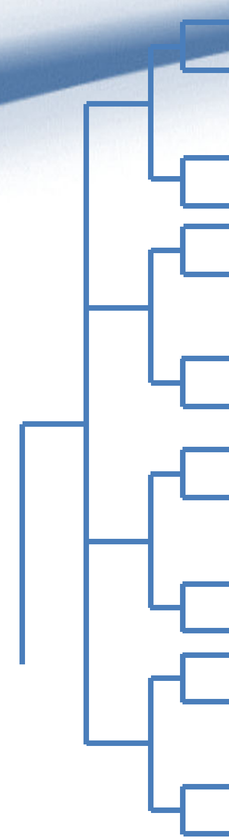


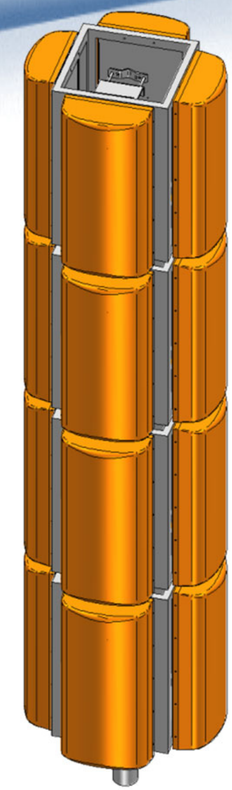
$$\%bw = \frac{\pi}{ln\left\{\frac{VSWR+1}{VSWR-1}\right\}}\left[\frac{1}{Q_2} - \frac{1}{Q_1}\right]$$

For a maximum allowable VSWR of 1.1:1, reducing the wall thickness from 1” to .25” results in an expected improvement in BW of **1.5%**

Multi-Sectional Phase Cancellation

- Feeding broadband panel antennas with a corporate feed system is common practice
    - Stable frequency response provides stable elevation pattern response
    - Provides a level of impedance cancellation
        - Multiple out of phase reflections from similar loads





- Slotted coaxial antennas can be sectionalized in order to take advantage of phase cancellation

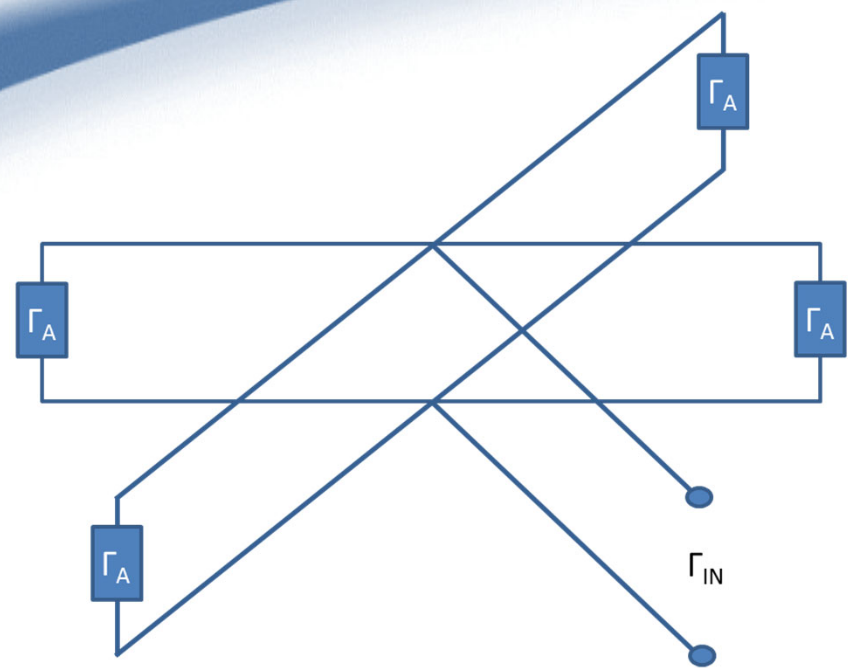
Multi-Sectional Phase Cancellation

Calculate the optimum phase relationship between sections for maximum cancellation

Analysis:

Γ_A= RC of individual radiators or antenna section

$$\Gamma_{IN} = \sum_{p=1}^{n} \Gamma_A \, e^{-j\beta(p-1)\phi_l} \qquad \beta = \frac{2\pi}{\lambda}$$



ϕ_l = Phase offset into each feedline

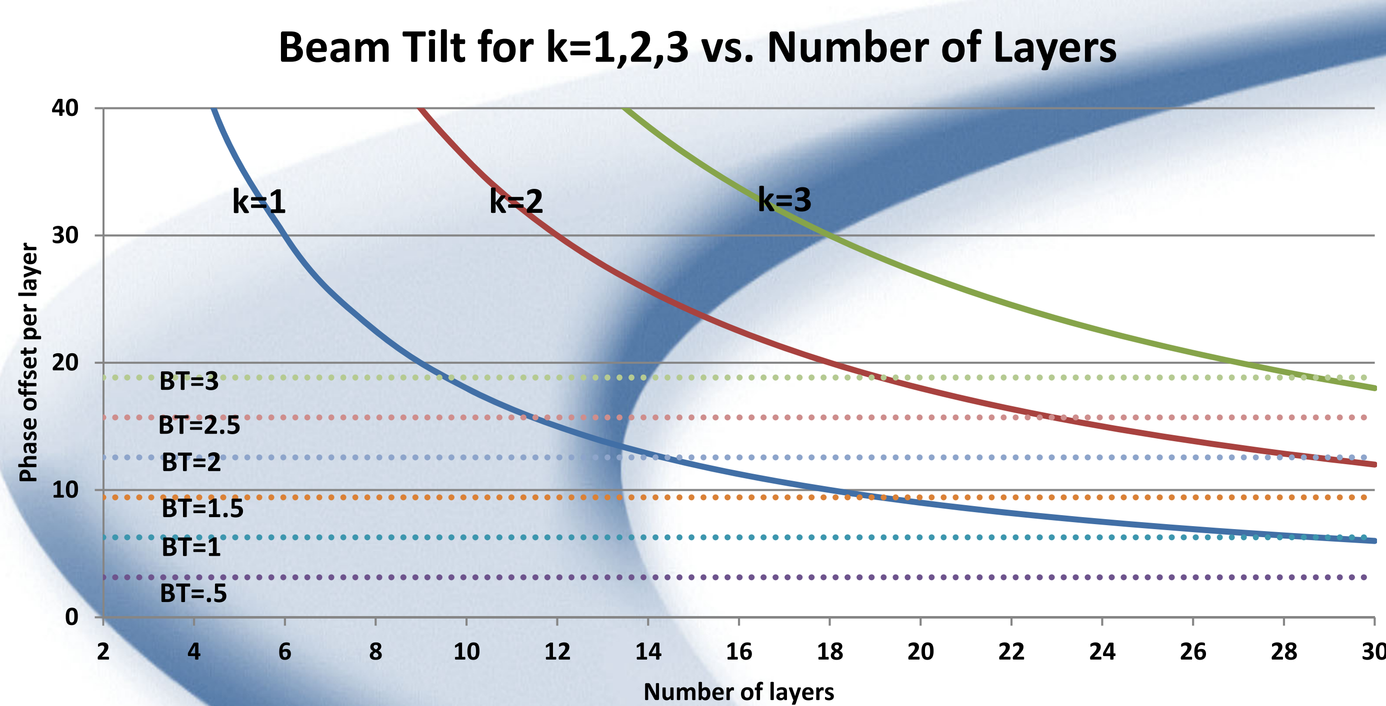
n= number of radiators or antenna sections

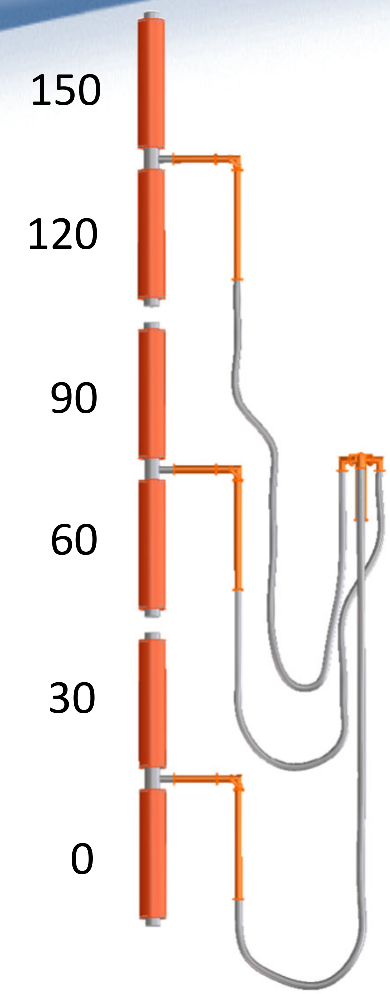
For full cancellation $\Gamma_{IN} = 0$

$$\phi_l = \frac{k\lambda}{2n} \quad for\ k = 1,2,3 \ldots\ldots$$

Corresponding beam tilt produced by the phase offset $BT = sin^{-1}\left(\frac{\phi_l}{360}\right)$

Multi-Sectional Phase Cancellation





Example : 24 layer antenna split into 6 sections. For optimal impedance cancellation and for k=1

- BT=1.1 deg.
- Phase offset of 7.5 deg. per layer
- Phase offset of 30 deg. per section

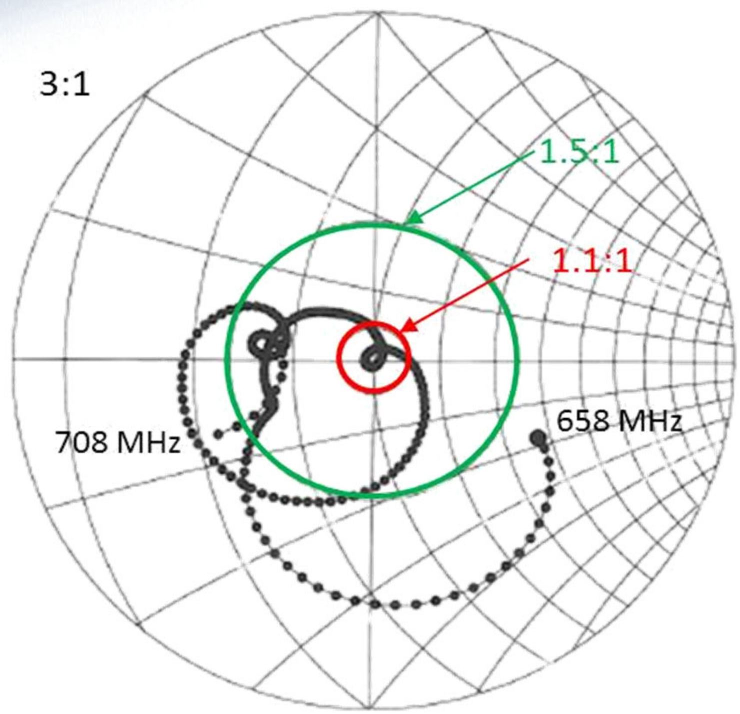
Multi-Sectional Phase Cancellation

How much bandwidth improvement to expect when using optimum phase cancellation on a real multi-sectional antenna?

Measurement of a typical single section slotted coaxial antenna section

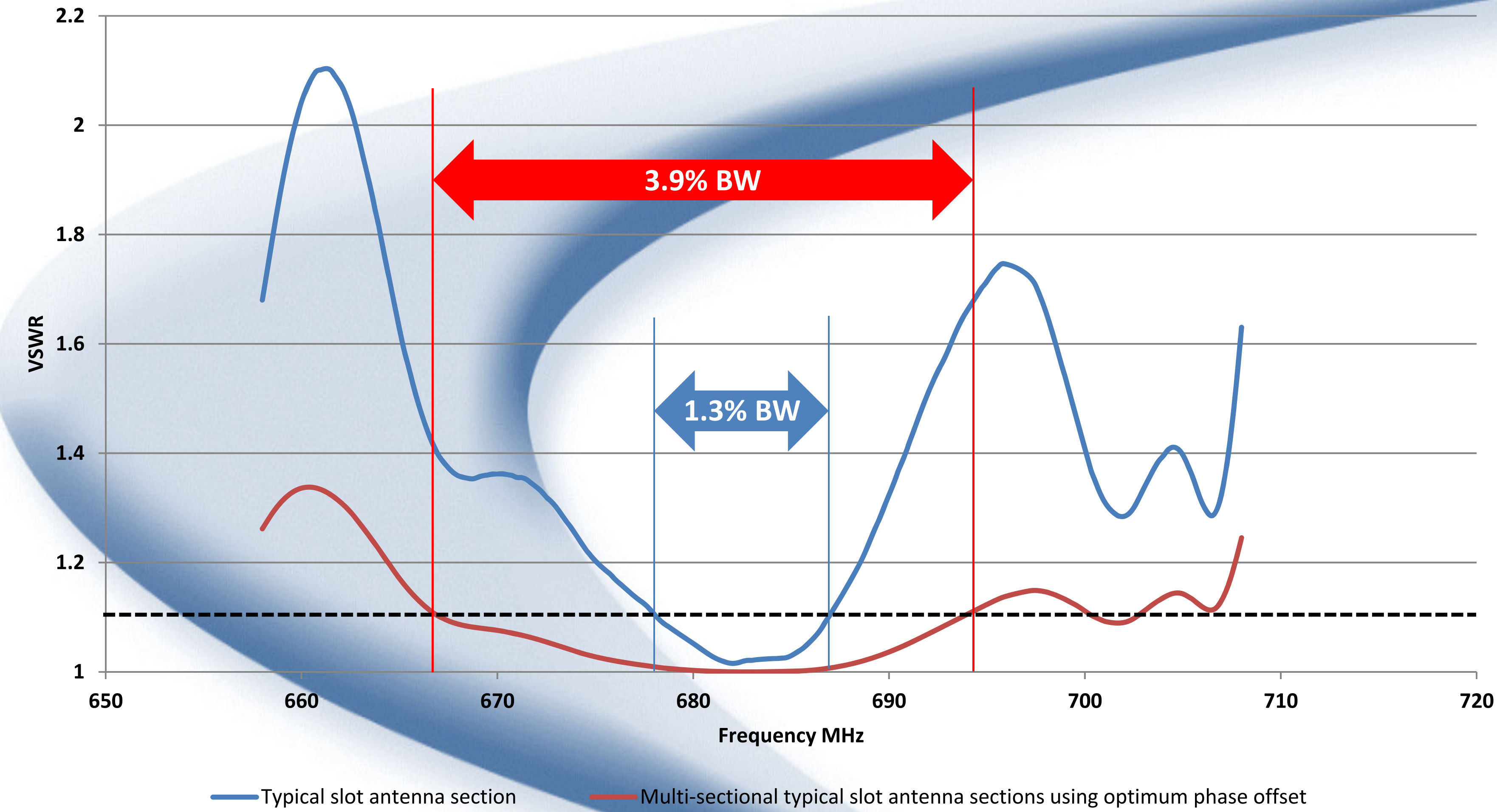
- Includes real slot antenna response
- Includes phase run out in feed lines

$$\Gamma_{IN} = \sum_{p=1}^{n} \Gamma_A \, e^{-j\beta(p-1)\emptyset_l} \qquad \beta = \frac{2\pi}{\lambda}$$



Multi-Sectional Phase Cancellation

Dielectric



For a maximum allowable VSWR of 1.1:1, the expected enlargement in BW is **2.6%**

Cumulative effect

Cumulative effect of the techniques can boost the bandwidth of a slotted coaxial antenna to near 10%.

Method	Improvement in Bandwidth
Natural Bandwidth	1.0%
Babinet's Principle	3.8%
Thin Wall Pipe	1.5%
Phase Cancellation	2.6%
Total	**8.9%**

Case Study

Example of a broadband slotted coaxial antenna design

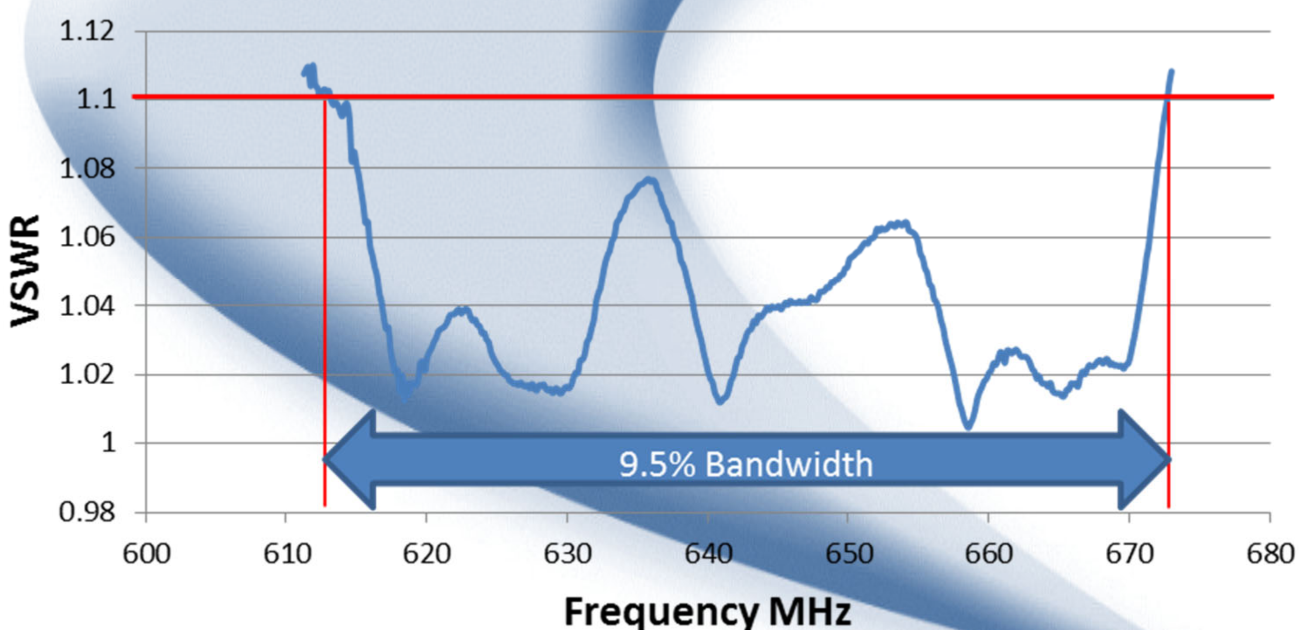
WNYT Glens Falls, NY   TLP-12W/VP-R (SP)   channels 39 & 45

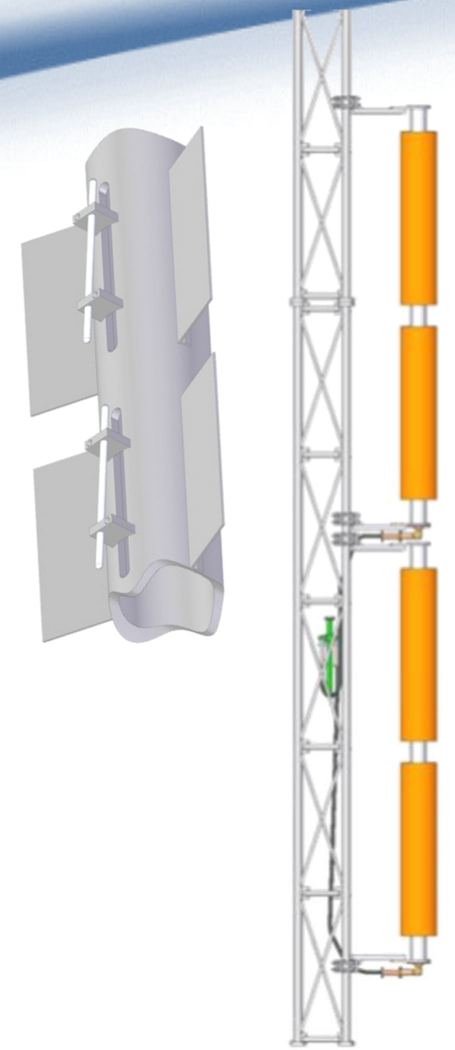
- 12 layer antenna with 4 way split
- Manufactured in ½" wall aluminum
- Elliptically polarized

Multi-sectional phase cancellation

Lower Q from thin wall

Leveraging Babinet's principle





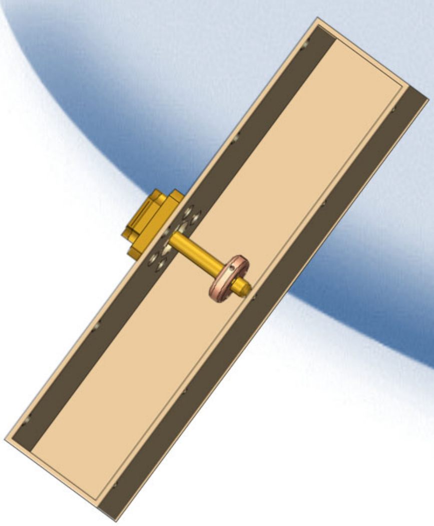
Channels 38 to 47 under 1.1:1

Broadband options other than panels

Slot cavity designs can have over 35% bandwidth

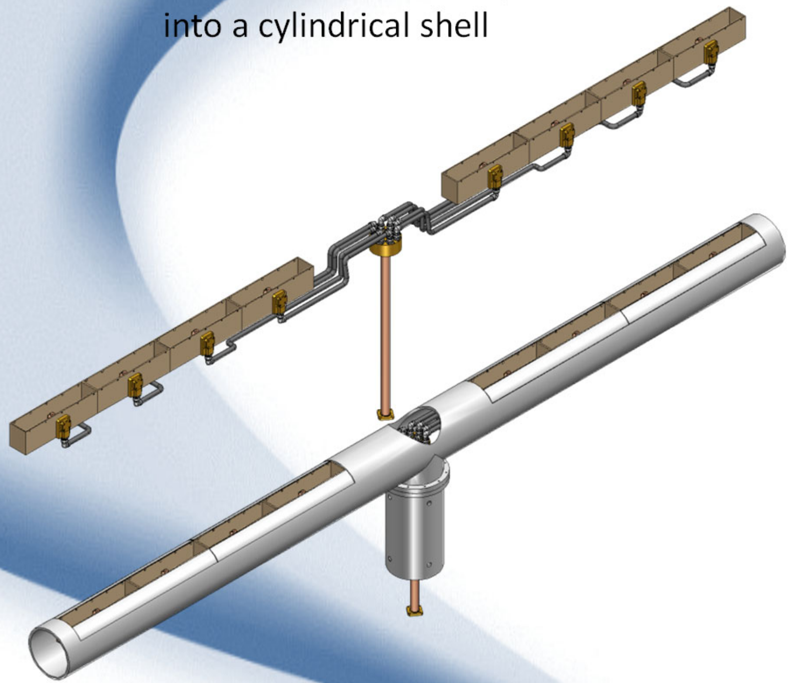
Basic building block

- •Slot cavity radiator
- •Broadband waveguide to coax transition
- •Inherently simple and rugged



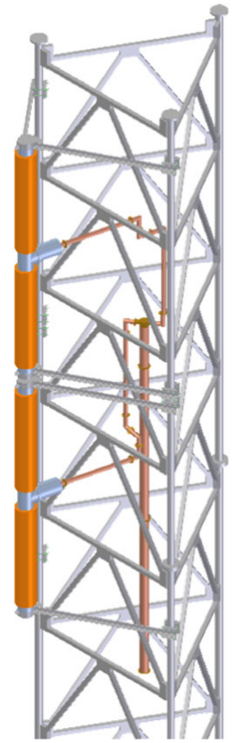
Antenna section

- •Radiator units fed by an 8 way power divider
- •Slot cavities are clamped into a cylindrical shell



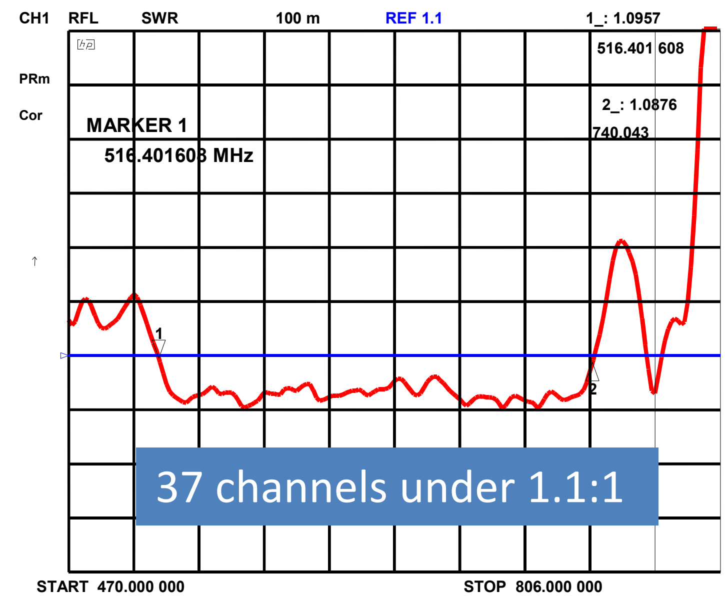
Array

- •8 bay sections can be stacked into a larger array of 16, 24 or 32 sections



TFU-WB

TFU-WB "Wideband Cavity Slot Antenna"



Tradeoffs compared to coaxial slot:

- Larger diameter
- Azimuth pattern flexibility
  - Single slot
- Horizontally polarized

Conclusion

Dielectric

1. The cumulative effect of using a conjugate dipole on a thin walled pipe and sectionalizing for phase cancellation can boost the operating bandwidth of a slotted coaxial antenna to near 10%.

2. Slot cavity designs can reach full band operation but lack some of the flexibility offered by slotted coaxial antennas.

Dielectric

Questions?

TRUSTED FOR DECADES, READY FOR TOMORROW.