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A Critique and New Concept on Gain Bandwidth Limitation of Omnidirectional Antennas

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Fractional Bandwidth Is Inadequate for Broadband Problems

• Electrical engineering (EE) *in the past*
  – deals with *narrowband* problems
  – uses fractional bandwidth (in %)

• Audio engineering
  – deals with *ultrawideband* problems
  – measures bandwidth in octaves
  – does not and cannot use fractional bandwidth

• EE is increasingly ultrawideband
  – fractional bandwidth not adequate
  – needs new measure for bandwidth
Various Definitions for Bandwidth

- **Fractional Bandwidth** $B_f$
  
  $$B_f \equiv \frac{\Delta F}{F_o} \equiv \frac{(F_H - F_L)}{F_o} \quad \text{(in \%)}$$
  
  $$= 2 \frac{(F_H - F_L)}{(F_H + F_L)} < 200\%$$

- **Octaval Bandwidth** $B_o$ (a new definition for EE)
  
  $$B_o \equiv \frac{F_H}{F_L} \quad \text{(In unit like the SWR)}$$

- **Relation between** $B_f$ **and** $B_o$
  
  $$B_f = 2 \frac{(B_o - 1)}{(B_o + 1)}$$
Octaval Bandwidth $B_o$, Fractional Bandwidth $B_f$, and Approximate Quality Factor $Q_a$
What Is the Bandwidth of an Antenna?

• Dependent on the performance criteria
  – gain (minimum peak gain, minimum gain in spatial coverage, etc.)
  – Pattern or directivity
  – maximum sidelobes
  – SWR, efficiency
  – system performance (diversity gain, etc.)
• Dependent on definition of bandwidth
  – Fractional bandwidth
  – Octaval bandwidth (NEW!)
Fractional or Octaval Bandwidth?

• Fractional bandwidth
  – Suitable for resonant antennas
  – NOT suitable for non-resonant antennas such as
    • Frequency-independent antennas
    • Broadband traveling-wave antennas

• Octaval bandwidth
  – Suitable for both resonant and non-resonant antennas
The Chu Theory on Gain Bandwidth of Antennas Is Too Narrow

- Zero dissipative loss assumption
- Single-port impedance
  - not characteristic of non-resonant antennas
  - Based on Q and fractional bandwidth
- Not suitable for non-resonant antennas
- $B_f \sim 1/(2 \, Q_a)$ is valid only for $Q_a > 4$
- Antenna performance criteria too narrow
A 1-10 GHz Mode-0 SMM Antenna

WEO Model SMM-1G10G-0-
An Omnidirectional Conformable TW (Traveling Wave) Antenna

- Planar TW surface $S$
- Matching structure
- TW
- Feed cable
- Ground plane
- $z$ (Zenith)
- $\theta$
Measured Gain of an Omnidirectional TW (Traveling Wave) Antenna

WEO Model SMM-1G10G-0-

Gain, dBi

Frequency, GHz

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Octaval Bandwidth of a Wang Omnidirectional Antenna

Bandwidth vs Minimum Gain Threshold for WEO Antenna SMM-1G10G-0-

Octaval Bandwidth ($F_H/F_L$) vs Minimum Antenna Gain, dBi
Bandwidth of This Antenna Exceeds the Limitation Imposed by Classical Theory?! 

For the 1-10 GHz WEO model

- Theoretical limitation
  - \( ka = 2\pi \times 3/11.3 = 1.597 \) at 1 GHz
  - \( Q_{\text{exact}} = 0.869 \)
  - \( B_f = 1 / Q_{\text{exact}} = 115\% \)
  - \( B_O = (2 + B_f)/(2 - B_f) \)
    \[ = 3.711 \quad \text{(computed based on } Q_{\text{exact}}) \]

- Measured bandwidth (1 dBi minimum gain)
  - \( B_f = 164\% \)
  - \( B_O = 10 \)
Fractional Bandwidth Limitation versus Antenna Size $ka$

Bandwidth $B_f$ and $Q$ vs $ka$

- $k = 2\pi/\lambda$
- $a$ = radius of sphere enclosing antenna

$B_f \sim 1/Q$

Wang antenna (1-10 GHz SMM mode-0)

$Q$ (McCLean, 1996)

$Q_a$ (Chu, 1948)

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Bandwidth of Wang Antenna Is Beyond the Classical Theoretical Physical Limitation!

Octoval Bandwidth $B_o$ and $Q$ vs $ka$

$k = 2\pi/\lambda$
$a =$ radius of sphere enclosing antenna

$B_o = (2 + B_f)/(2 - B_f)$

$B_f \sim 1/Q$

Wang antenna (1-10 GHz SMM mode-0)

$Q$ (McClean, 1996)

$Q_a$ (Chu, 1948)

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Concluding Remarks

- Classical Chu theory on antenna bandwidth limitation is not applicable to broadband antennas.
- Limitation of antenna bandwidth
  - depending on the performance criteria
- The fractional bandwidth, and quality factor Q
  - inadequate for broadband antennas
- For broadband antennas
  - “Octaval Bandwidth” is a more appropriate and even necessary concept/terminology.