Considerations for -10 dBc IBOC Combined Station Side Mount Master FM Antenna Design

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IEEE

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Increasing to -10 dBc IBOC provides a challenge

Situation becomes more complex when combining stations into one transmitting system

Today's Presentation

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- How voltage peaks for combined stations should be determined
- How voltage and power handling limits are derived
- Look at practical safety and correction factors
- Develop analytical expressions to analyze the safety factors when combining multiple stations

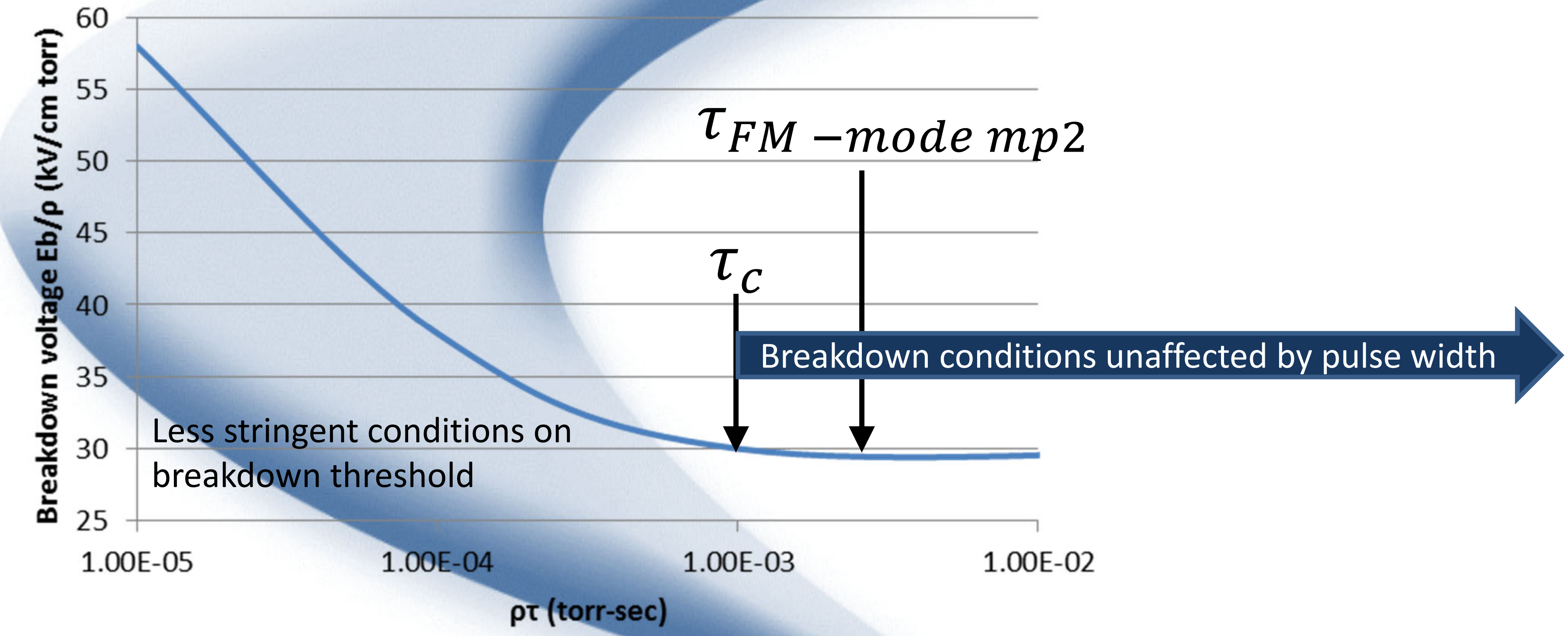
Today's focus

- How to design the antenna to handle the high voltage additions associated with -10 dBc IBOC
  - Breakdown prevention methods
  - Techniques to boost the voltage safety factor

Review

Shorter pulse durations require higher amounts of voltage to induce breakdown

Defined the critical pulse width



$\tau_{FM\,-mode\;mp2}$

τ_c

Breakdown conditions unaffected by pulse width

Less stringent conditions on breakdown threshold

No de-rating factor can be used for short pulse duration in FM IBOC

Review

Defined the voltage breakdown condition as the point where the co-phased voltages coincide to a level exceeding the PAPR's used in the power and voltage handling calculations

Calculate the number of probable breakdown events in a
100 year period in IBOC extended mode MP2

$$N_e = 6.09x10^{14}n \cdot (e^{-PAPR_{linear}})^n$$

Where n is the number of combined stations

If 1 event in 100 years is the acceptable limit then

$$PAPR_{dB} = 10log\left[-ln\left(\sqrt[n]{\frac{1}{6.09x10^{14}}}\right)\right]$$

But what if the number of probable events is less then 1 in a 100 year period?

Review

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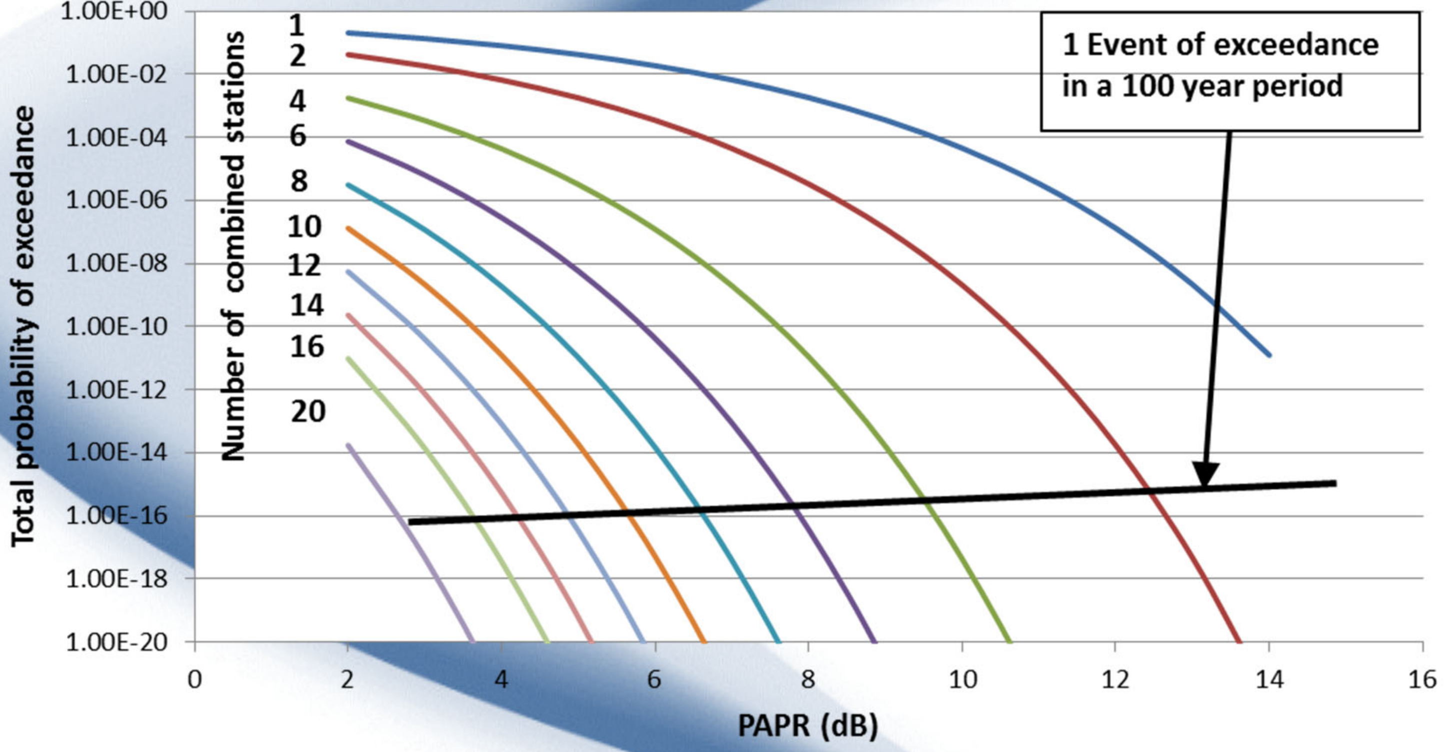
Handling voltage additions when the probability of exceedance is less then 1 in 100 years

Guideline:

When combining multiple stations and the total probability of exceedance drops below the 1 in 100 year occurrence, the PAPR's used in voltage handling calculations should be reduced such that the voltages reflect those that will produce the defined 1 in 100 year criteria.

Review

Recommended PAPR's to be used for total voltage handling calculations verses number of stations for a 1 in 100 years probability of exceedance



FM-IBOC Combining

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3 Methods of producing the IBOC hybrid FM signal

- Low level combining
- High level combining
- Space combining

Require separate transmitters

Benefits of low level combining

- Reduces number of components
- Reduces floor space

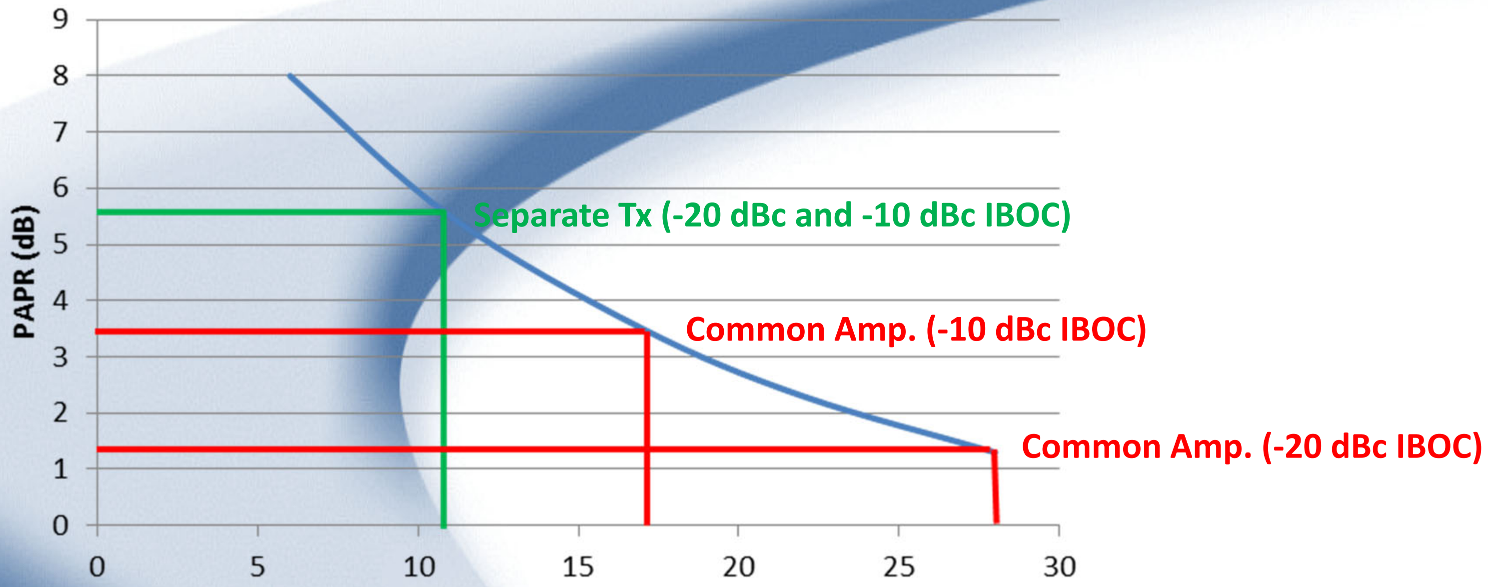
Minimizes impact to broadcaster

- Advances in crest factor reduction allows the peaks of the HD carriers to be moved to the FM analog space

	PAPR for given IBOC level		
	-20 dBc	-14 dBc	-10 dBc
Separate Tx	5.5 dB	5.5 dB	5.5 dB
Common Tx	1.3 dB	2.3 dB	3.5 dB

So what does this mean to our voltage addition guideline?

Separate Tx. Vs. Common Amp.



Number of combined stations that must be taken into account with full PAPR in voltage handling calculations for a 1 in 100 year breakdown event probability before using the PAPR reduction guideline

When using common amplification, the PAPR reduction guideline for voltage handling calculations does not come into play

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The voltage and power handling calculations for combined FM IBOC stations **CANNOT** take advantage of

- PAPR reduction factors
- Short pulse reduction factors

Antenna design must rely on:

- Breakdown prevention methods
- Techniques to boost the voltage safety factor

Antenna Bandwidth

Co-located multi-station combining with -10 dBc IBOC implies

- High power
- High voltage
- Broad bandwidth

Broad bandwidth is necessary to ensure low Q

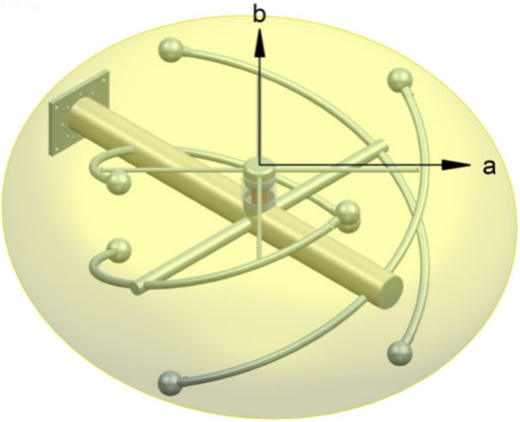
$$Q = w\frac{energy\ stored}{average\ power\ disipated}$$

Low Q is required to handle the extra power and high voltages associated with -10 dBc IBOC with high safety margin

Antenna Bandwidth

It can be shown that the maximum achievable bandwidth of a circularly polarized antenna radiator fitting within an oblong bounded region and using simple practical matching techniques for a desired VSWR level is given by:

$$bw = 3.9 \cdot \left[\frac{VSWR - 1}{\frac{a}{2b}\left(\frac{1}{k^3 a^3} + \frac{2}{ka}\right)\sqrt{VSWR}} \right]$$



Where : a and b are the major and minor ellipse radii

VSWR is the maximum allowed within the passband

Observations

- Maximum realizable bandwidth of the antenna is purely a function of size.
- Define the minimum size requirements.
  - For full band FM operation (20% bandwidth) with a 1.15:1 VSWR specification
    - a= 19” (38” diameter)
    - b= 11” (22” height)

Antenna Bandwidth

The antenna radiator should be as large as possible

- To handle the extra power
- Voltage stack-up associated with combined stations with -10 dBc IBOC

Increasing the size beyond the minimum requirement unnecessarily increases

- Wind load
- Cost

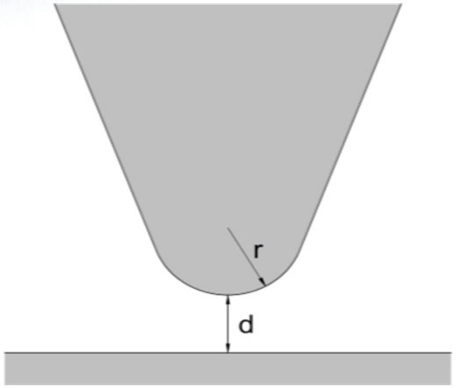
Methods to increase power handling and decrease the probability of voltage breakdown

- Geometrical considerations
- Pressurization

Geometrical Considerations – Sharp Edge Factor

The electric field intensity near a conductor is inversely proportional to the radius of curvature (r)

$$E_m \approx \frac{2V}{r\,ln\left(1+\frac{4d}{r}\right)}$$



Sharp edges have a greater potential for breakdown and sparking

$$SF = \frac{V_{peak\ RF}}{\left(\sum_1^n \sqrt{2Z_0 P_{avg-analog}} + \sum_1^n \sqrt{2Z_0 P_{avg-IBOC} PAPR}\right) C_{VSWR}}$$

Assuming all stations are using IBOC at the same level and same PAPR

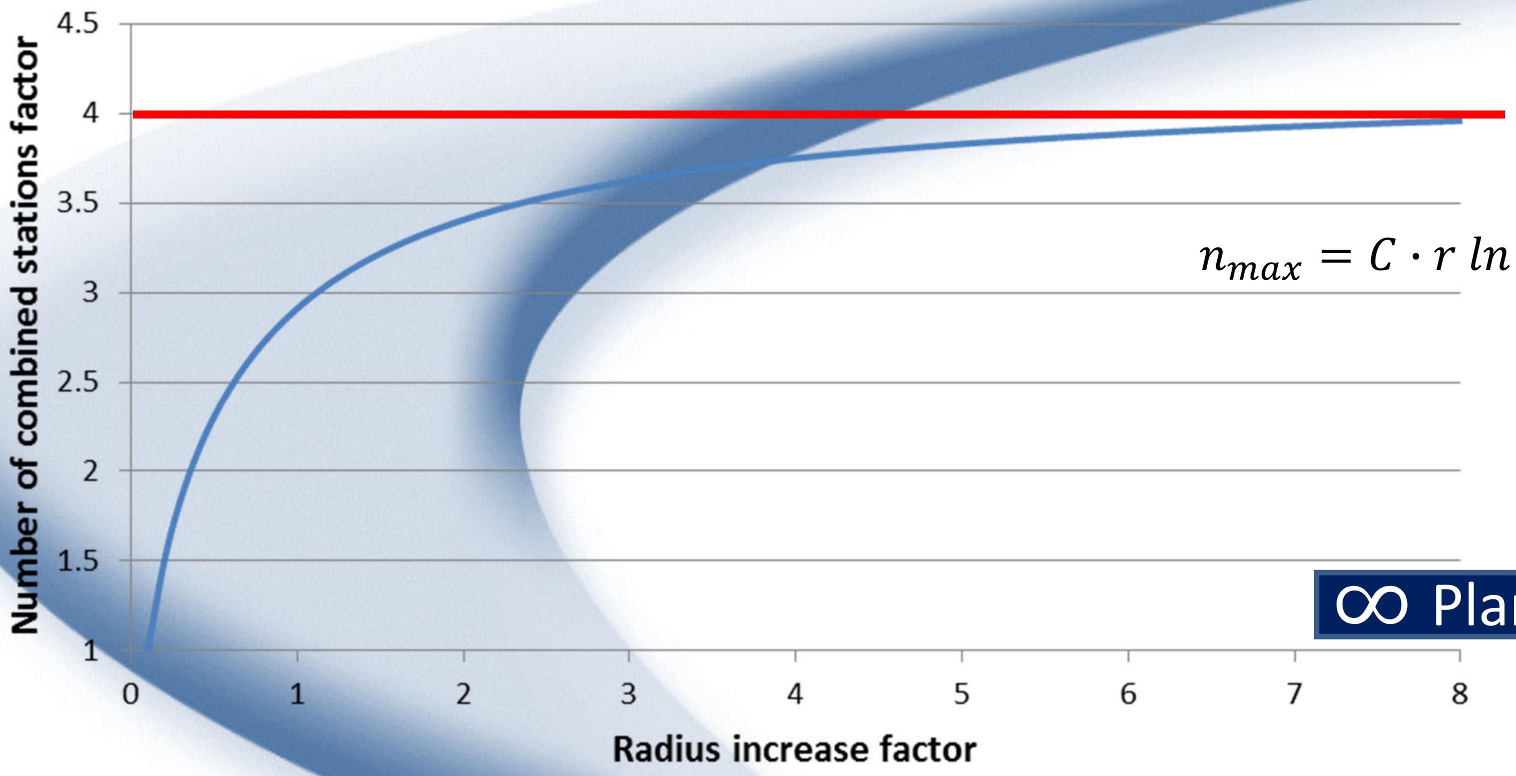
$$n_{max} = \frac{V_{peak\ RF}}{SF\left(V_{p-analog} + V_{p-IBOC}\right) C_{VSWR}}$$

Therefore:

$$n_{max} \propto r\,ln\left(1+\frac{1}{r}\right)$$

The maximum number of stations that can safely be combined is proportional to the radius of curvature through a natural log function

Geometrical Considerations – Sharp Edge Factor



$$n_{max} = C \cdot r\, ln\left(1 + \frac{1}{r}\right)$$

∞ Plane

The number of stations that can be safely combined can be increased by a factor of 4 by removing any sharp edges and using large radiuses

Pressurization Factor

Peak power and voltage ratings can be increased with pressurization using dry air or nitrogen

Paschen's law (1889)

- Verified experimentally for dc breakdown
- Does not include frequency and pulse width

$$V_B = \frac{apd}{\ln(pd) + b}$$

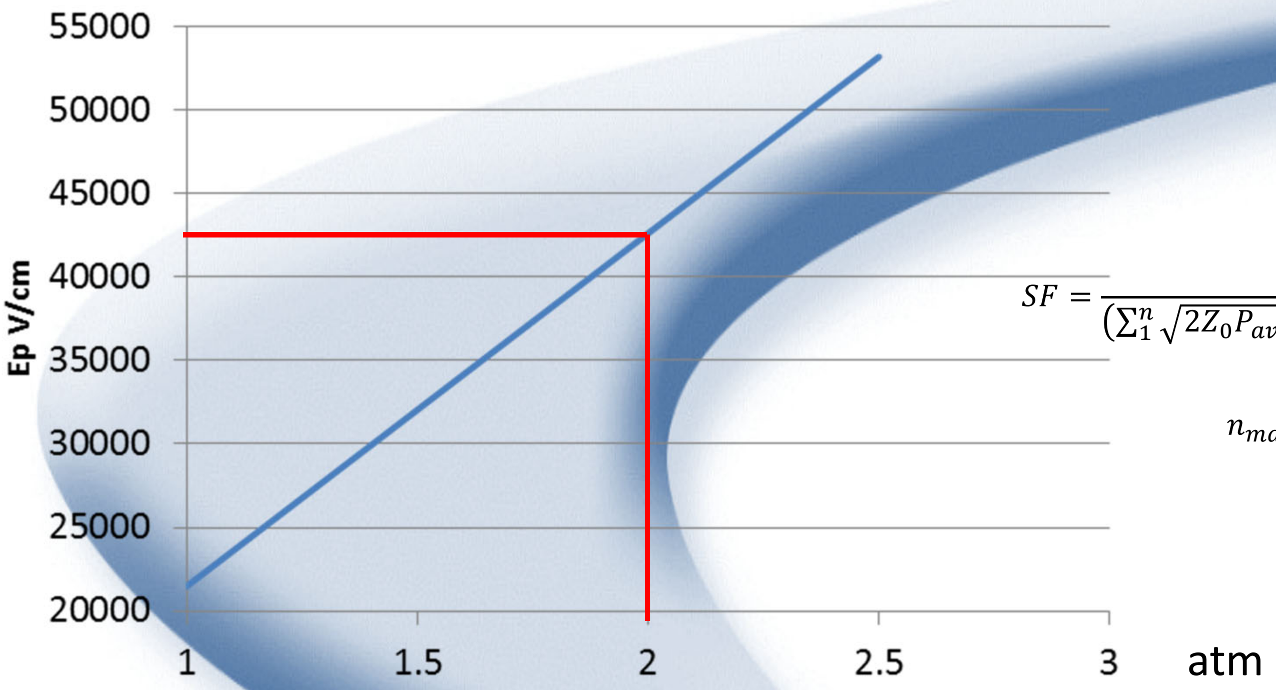
More accurate approach

- Semi-analytical method

$$E_p = 3.75p\left(1 + \frac{\omega^2}{25x10^{18}p^2}\right)^{1/2} x \left(\frac{10^6}{p^2 {L_{eff}}^2} + 6.4x10^4 + \frac{20}{p\tau_p}\right)^{3/16} \qquad p = p_0 \frac{273}{273 + T_0}$$

Air ionization threshold can be calculated in terms of the frequency, pulse width and pressure

Pressurization Factor



760	1520	2280	Torr
0	15	30	psi increase

$$T_0 = 20°C$$

$$\tau_p = 5.2\ usec$$

$$f = 98\ MHz$$

$$SF = \frac{V_{peak\ RF}}{\left(\sum_1^n \sqrt{2Z_0 P_{avg-analog}} + \sum_1^n \sqrt{2Z_0 P_{avg-IBOC} PAPR}\right) C_{VSWR}}$$

$$n_{max} = \frac{V_{peak\ RF}}{SF\left(V_{p-analog} + V_{p-IBOC}\right) C_{VSWR}}$$

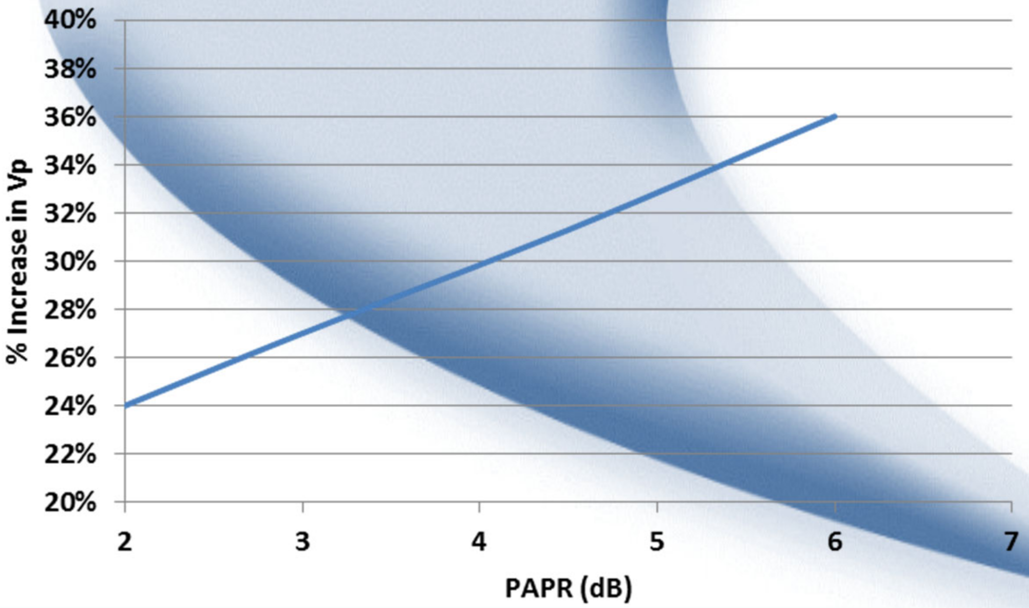
$$n_{max} \propto V_{peak}$$

The number of stations that can be safely combined can be increased by a factor of 2 by adding 15 psi of pressure

IBOC Level Increase vs. Voltage Breakdown

$$IBOC\ level\ (dB) = \frac{P_I}{P_A} = 10\ log \left\{ \frac{\left[\left(\dfrac{V_{peak}}{n \cdot \dfrac{2 \cdot VSWR}{VSWR + 1} \cdot SF} - \left(\sqrt{2Z_0 P_A} \right) \right) \right]^2}{2Z_0 P_A \cdot PAPR} \right\}$$

% Increase needed in V_{peak} to go from -20 dBc to -10 dBc IBOC



If the goal is not to add more stations but to increase from -20 dBc to -10 dBc IBOC then approximately 30% increase in breakdown voltage is needed

Geometry and Pressure Factors

Summary

- Eliminating sharp edges and using large radiuses has a theoretical limit of voltage breakdown increase of 4X
- Adding 15 psi of pressure increases the voltage breakdown by 2X

Employing both techniques can theoretically increase the total number of stations that can be safely combined into an antenna system by 8X

- If the goal is not to add more stations but to increase from -20 dBc to -10 dBc IBOC then approximately 30% increase in breakdown voltage is needed

Practical Application of Theory

Theoretical analysis helps with initial design criteria but higher accuracy is required for specific situations

Determining peak voltage and power handling

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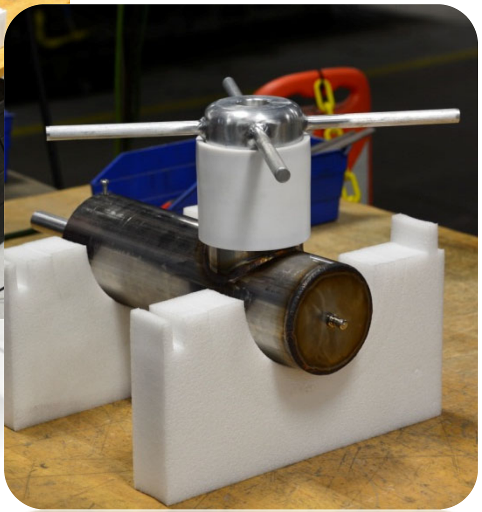
Accepted method:

- Perform DC Hi-Pot
- Determine DC breakdown level
- Relate DC breakdown to RF breakdown

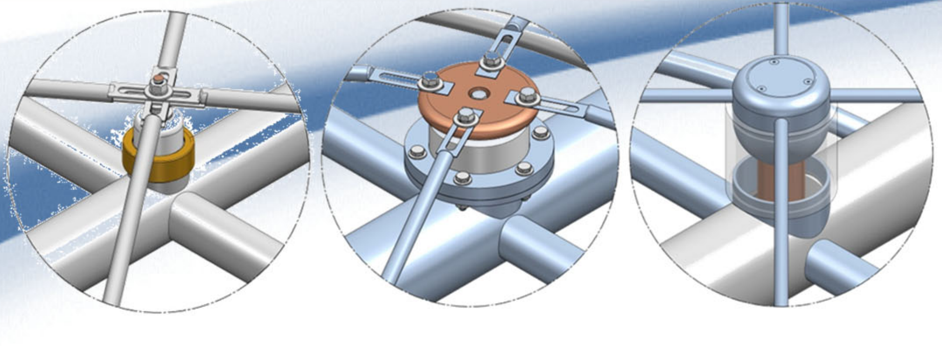


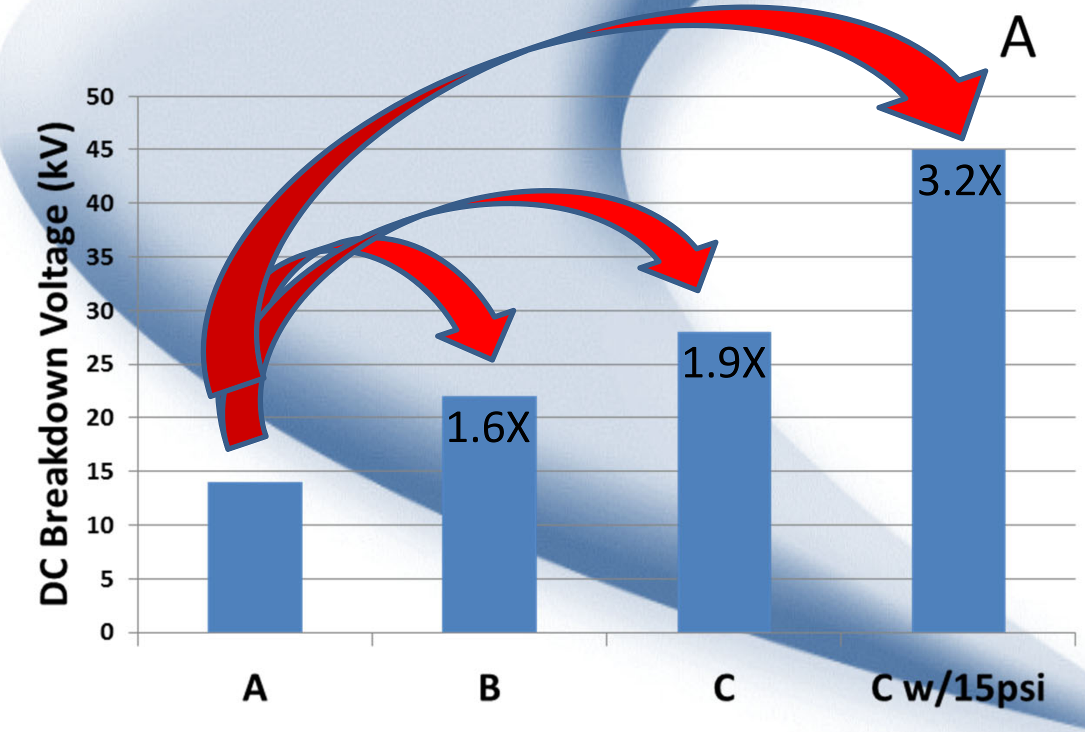
$$V_{Peak\ RF} = .7 * V_{DC}$$

DC to RF factor is based on the fact that RF breakdown voltage has been experimentally measured at 22.8 kV/cm instead of the accepted value of 29 kV/cm

Practical Applications

DC Hi-Pot experiments conducted on three types of FM antenna tap points



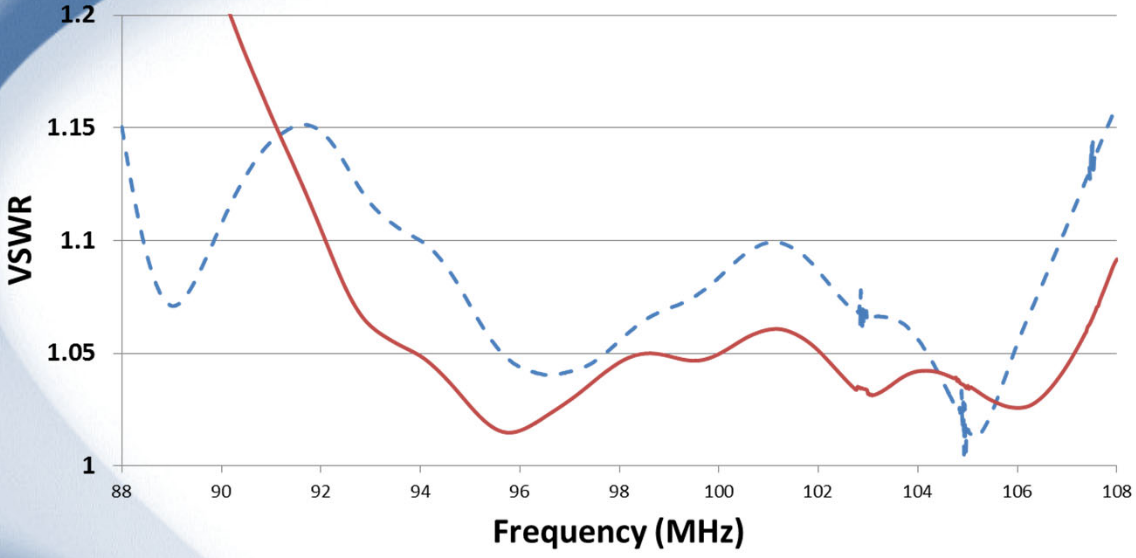


Results from this example indicate the combined channel capacity of this style antenna can be increased by a factor of 3.2 through carful design and pressurization of the tap point

Validating Theory

- For full band FM operation (20% bandwidth) with a 1.15:1 VSWR specification
  - a= 19” (38” diameter)
  - b= 11” (22” height)

Capable of handling (8) 20kw stations all with -10 dB IBOC



━ Optimized for the channels of interest (94 MHz to 107 MHz under 1.06:1 VSWR

┅ Optimized for the full FM band (88 MHz to 108 MHz under 1.15:1 VSWR

Broadband – Multi channel DCR-U FM antenna for Miami

Conclusion

- Voltage breakdown is one of the major limitations in high power multi-channel FM-IBOC transmission system design
- Due to the long pulse duration of FM-IBOC, no de-rating factors can be used in determining the probability of voltage breakdown
- Lower PAPR's associated with common amplification eliminate the possibility of using a PAPR reduction factor in the voltage and power handling calculations for combined stations
- Antenna voltage breakdown prevention methods can be summarized
  - Use large bandwidth radiators to reduce stored energy
  - Reduce the field strength in gaps by avoiding sharp edges and using rounded corners
  - Employ pressurization

Following these rules and applying the combination of analysis, test and experience allows FM antennas to be adequately designed to handle the extra power, bandwidth and voltage additions associated with an increase to -10 dBc IBOC

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Questions?

TRUSTED FOR DECADES,
READY FOR TOMORROW.