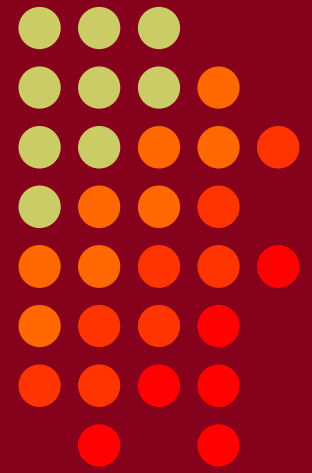
# CTU Presents

## *Coax Connectors, a Deep Look at What Can Go Wrong*

*by*

*Greg Ordy, W8WWV*



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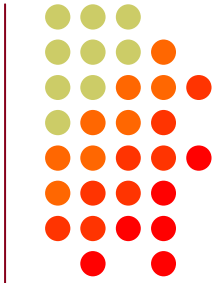
# Topics to Cover



1. Let's Step Outside (of the station) for a Moment.
2. What is **PIM?** (**P**assive **I**nter**m**odulation)
3. Examples From the Field.
4. Techniques to Find the Problem.
5. Techniques to Avoid/Fix the Problem.
6. Acknowledgements.
7. References, Further Information.

- **This presentation has been updated since published in the CTU printed material.**

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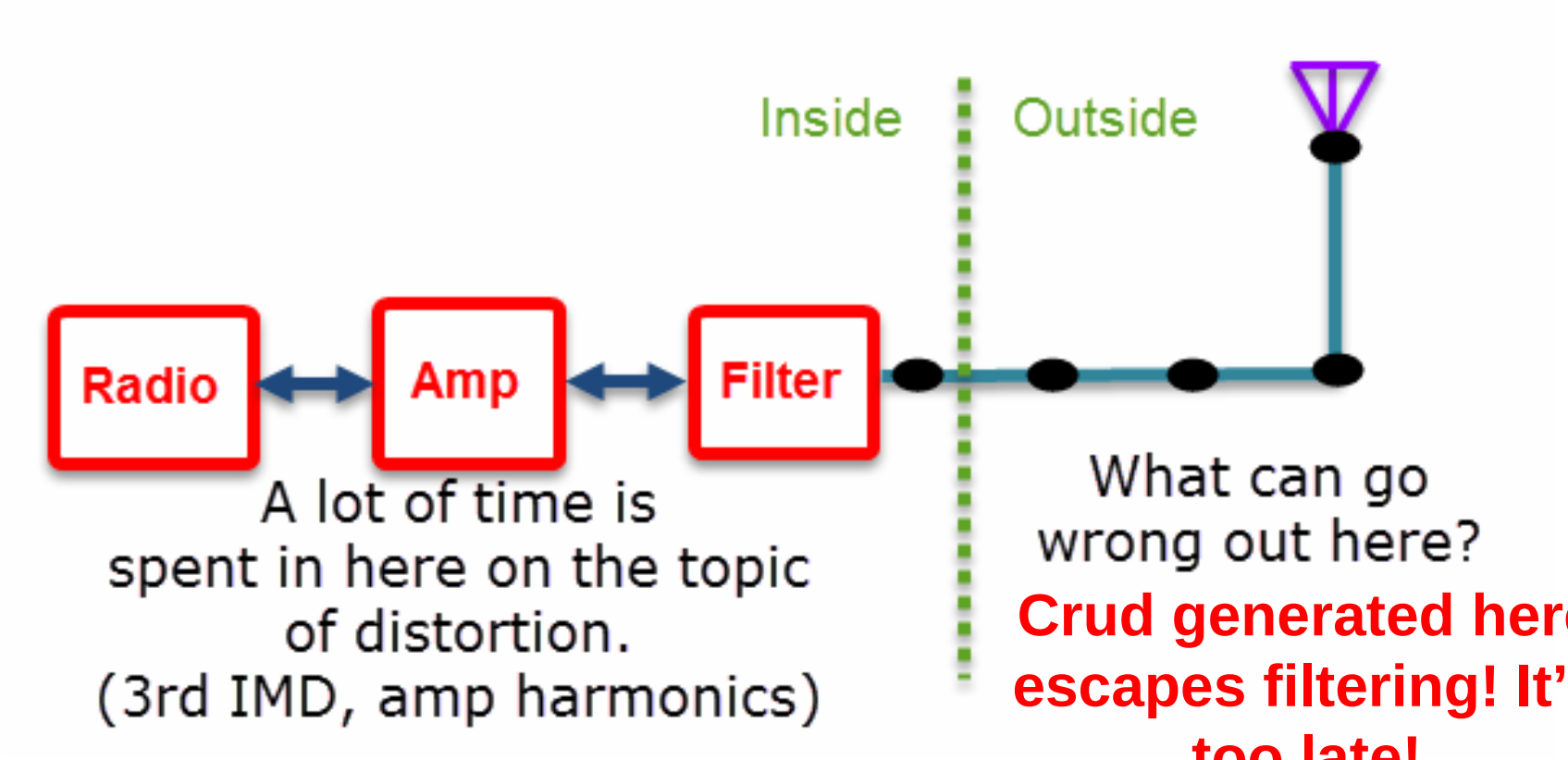
# Let's Step Outside for a Moment

- It seems like the opportunities for something to go wrong around the old ham station are endless…
- In this session the focus will be on problems with normally passive and linear devices, usually located outside, and usually taken for granted.
- The session title names the *coax connector*, but the problems and solutions can be generalized to most any metal to metal connection.
  - Coax connectors are naturally in contact with lots of RF.
- Another title might be: *How to Avoid Accidental Diodes*, or, *How to Keep Your Quackenbush Clean.*
- RF + Diodes = Crud (and we want to avoid crud)

# Let's Step Outside for a Moment (2)

- Simple station block diagram:

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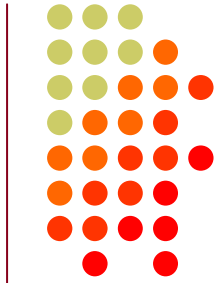
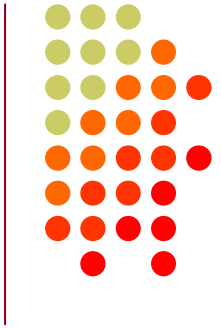
# Let's Step Outside for a Moment (3)



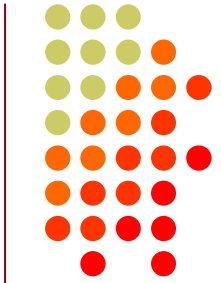
- Of course a lot can go wrong outside!
  - Towers can collapse, antennas can fall, etc.
- Beyond those obvious problems, **distortion**, the creation of spurious signals that interfere with desired signals, can be generated by innocent looking passive devices, like coax connectors.
- One category of the distortion is called **PIM** – *passive intermodulation distortion*.

# What is PIM?



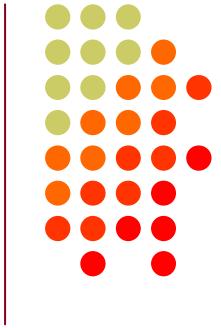
- "**PIM** is a form of intermodulation distortion that occurs in components normally thought of as linear, such as cables, connectors, antennas, and towers. When subject to high RF power, these devices can generate spurious signals. PIM shows up as a set of unwanted signals created by the mixing of two or more strong RF signals in a non-linear device, such as in a loose or corroded connector, or in nearby rust. Other names for PIM include the *diode effect* and the *rusty bolt effect*." (*Nicholas Cannon, Anritsu*)

# What is PIM? (2)



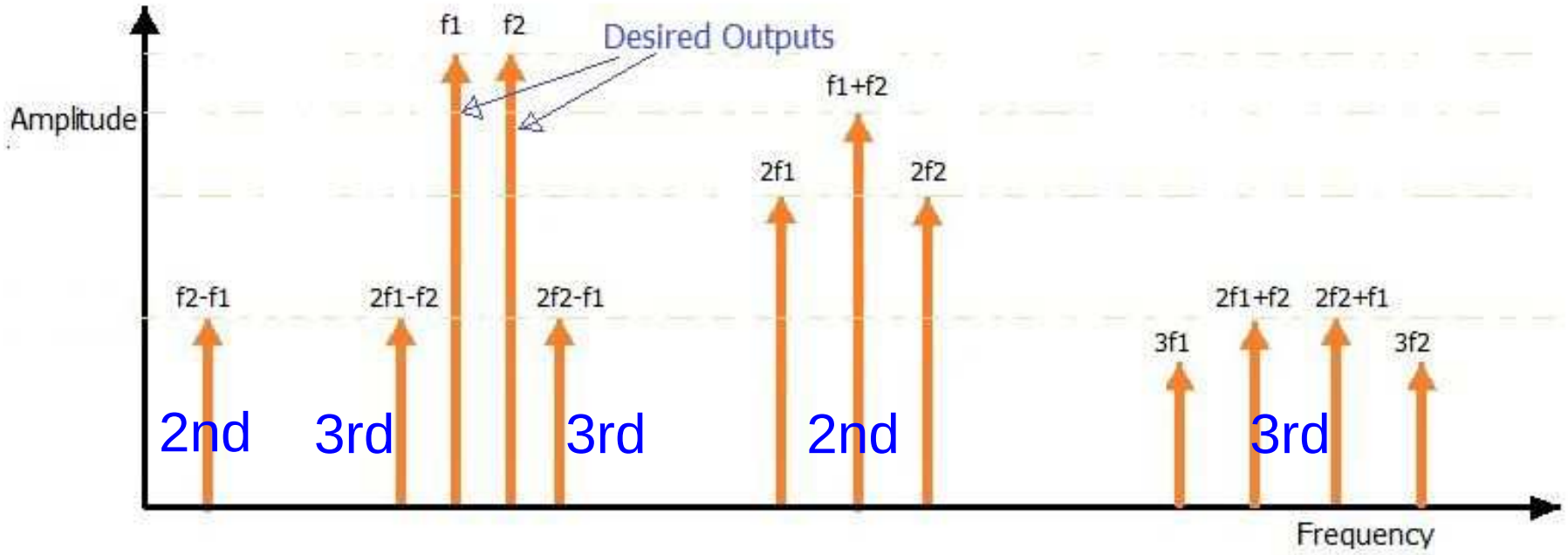
- PIM is a hot topic in the cellular/mobile services.
- They have multiple transmitters/receivers/antennas jammed onto a single tower, and, the many added challenges inherent in GHz operation (usually due to short wavelengths (resonant metal is relatively short)).
- The problem can occur at HF too.
- The contest station with multiple transmitters/receivers/antennas and nearby commercial broadcast stations has a similar *RF rich* environment and lots of connectors and connections.
  - Towers, guy lines, fences, power lines, cables, etc.
- The causes, culprits, and solutions are largely the same. (meaning we can learn from those services!)

# What is PIM? (3)



- PIM gets more discussion than simple harmonic generation because in the two signal 3rd order cases you can generate spurious signals in the operating band – so they are right up in your grill.
  - You are forced to deal with your own pollution.
- But, there are many amateur bands with harmonic relationships and the opportunities to be negatively impacted by spurious signals goes far beyond PIM if PIM implies two signals.
- It's all the same underlying problem – diodes where you don't want diodes. Passive becomes active. Linear becomes non-linear.

# What is PIM? (4)

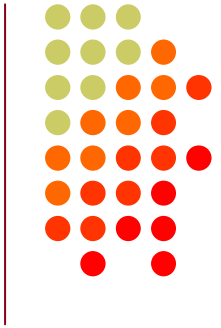



- Fundamental, second order, third order products.
- Does not require 2 signals.
- It is possible to generate broadband *crud* (noise) as well as energy at specific frequencies related to the fundamentals.

# What is PIM? (5)

- **Common causes of PIM (thanks to Ian Poole):**
  - (how to make a diode without really trying….)
- Dirty, oxidized, rusty, loose, corroded connections.
- Irregular contact areas (cat's whisker).
- Use of ferromagnetic metals: e.g. iron, nickel, steel.
- Deterioration due to moisture entry (salt spray).
- Deterioration due to spark discharges creating craters/voids that then accumulate dirt/oxidation.
- Metal flakes/shavings/whiskers crossing over RF conductors.

# What is PIM? (6)



- Joints where dissimilar metals meet.
- Coaxial connectors: joints with dissimilar metal in contact and exposure to the atmosphere and weather.
- Coaxial cable (the outer braid is nothing but an endless number of overlapping mechanical connections). A foil layer can help. Less of an issue at HF as opposed to GHz.
- The proverbial rusty fence, metal roof, loose and dirty gutter, or broken insulator (and on and on).
- Obviously Mother Nature invented diodes long before we noticed or needed them!
- Point Contact Diode discovery: Ferdinand Braun, 1874. He is better known for his invention of the CRT oscilloscope, 1897. He shared the 1909 Nobel Prize with Marconi for his "*Contributions to Wireless Telegraphy*".

# What is PIM? (7)

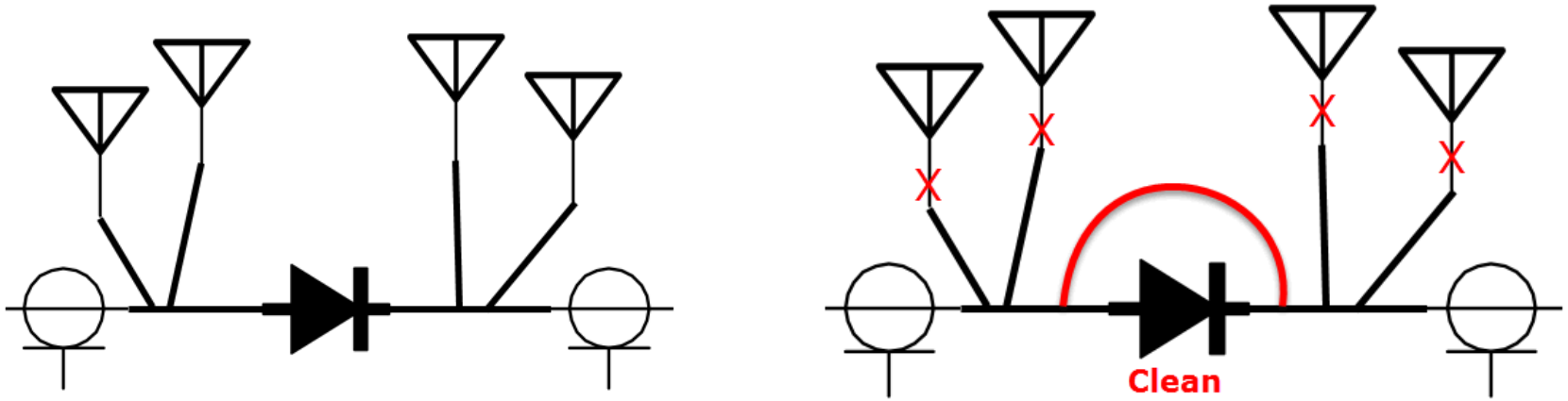
- Does a non-linear diode-like junction cause trouble if it falls over by itself in the woods?
- Not really – we also need to deliver RF energy into it (the signals), and conduct the undesired IMD products away from it and eventually to a receiver.
- Connectors and transmission lines are perfect for this since they carry RF as part of their job.
- Anything else that can act like an antenna can also contribute to energy flowing in or out.
  - And if a resonant conductor, then even more so.
  - With a direct or parasitic connection.

# What is PIM? (8)

- In the cellular/mobile industries, PIM is not a matter of **PIM/no PIM**, but rather it is **expected**, and the question is if it is at a high enough level to interfere with desired signals.
- With the popular 2X20 Watt test, a (just) passing PIM level is -97 dBm/140 dBc. (unavoidable)
- **BTW** – the UHF connector was invented by E. **Clarke Quackenbush** (~1930s: American Phenolic -> Amphenol).
  - **How many Quackenbushes are in your station?**
  - **His initials are CQ…. (coincidence???)**

# What is PIM? (9)

- Problems can occur when unwanted diodes spring up, and have opportunities for current to flow through them.
- Solutions include cleaning, bypassing (e.g. tower section, ring rotator), and choking.
- You can remove/negate the diode and/or deny it *easy* incoming or outgoing RF.
- No good way to bypass connectors, can only keep then clean.

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**ARRL RFI Book is very good**

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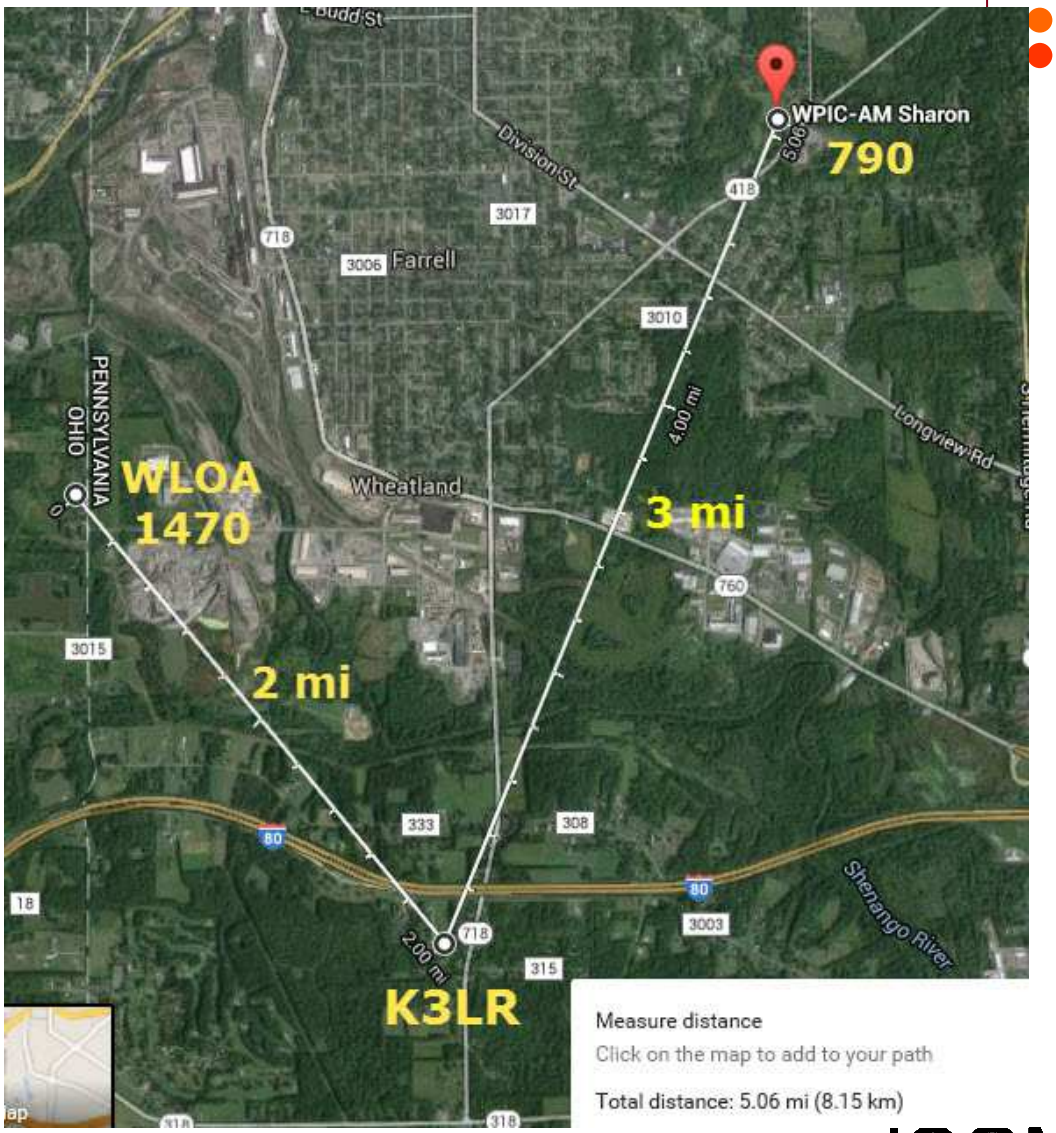
# Examples From the Field

- **K3LR** "*Mixers*":
- 2 X 1470 + 790 = 3730 KHz.
- 2 X 1470 + 570 (WKBN) = 3510.
- S9 levels during the day (you can listen to the stations).
- Low power directional at night.
- **Where is the PIM generator(s)???**
- 1 X 1470 + 408 (HBD) = 1878
- HBD = Hubbard Airport  Non Directional Beacon

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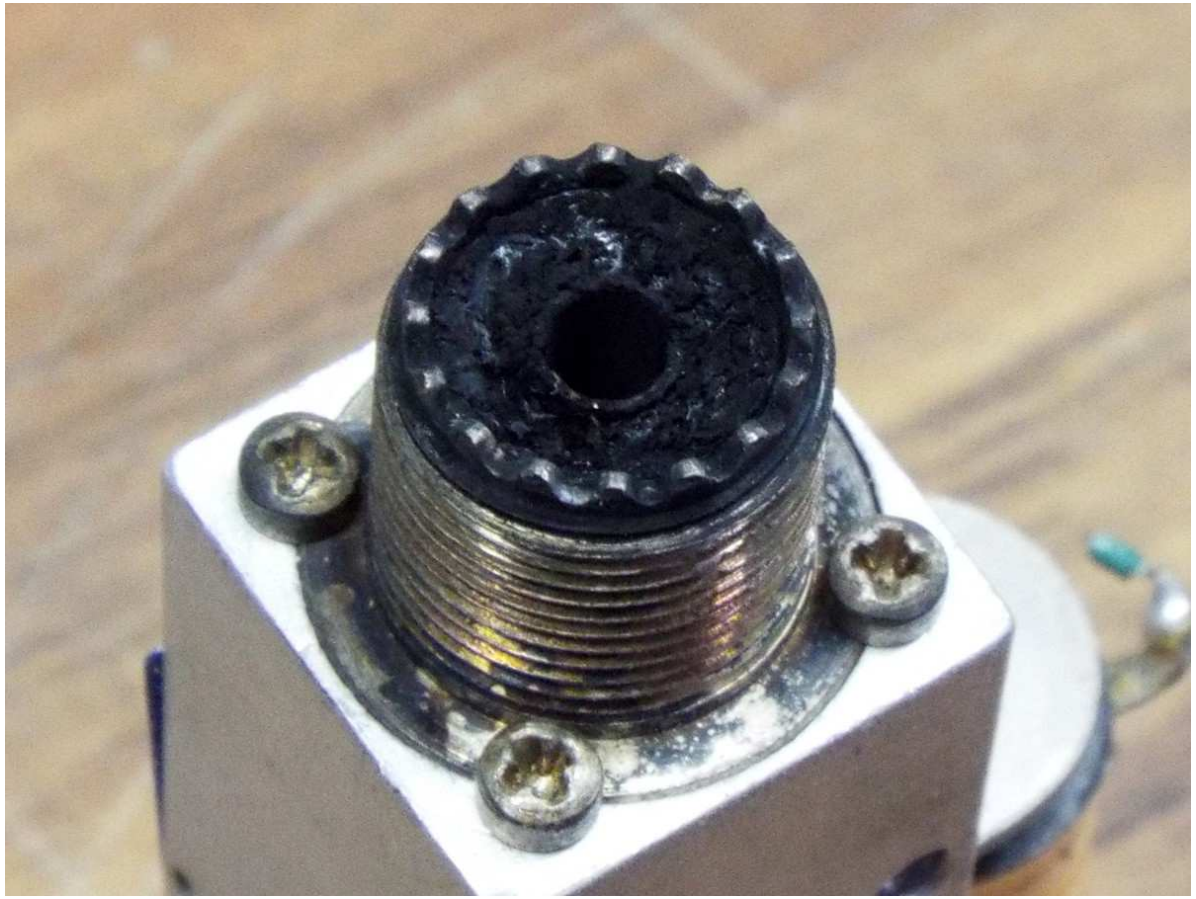
# Examples from the Field (2)

- The classic *burned* UHF connector.
- Contamination can lead to arcing but also a diode.
- This is a Dow-Key switch, used inside.



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# Examples from the Field (3)

- Two sides of a jumper with a burned barrel.
- Contamination leading to flashover?
- Center pin “vaporized”
- Center insulator failure?
- Yes, that is snow in the background, replaced on a warm March day.
- These are extreme failures – diodes need not look obviously bad.

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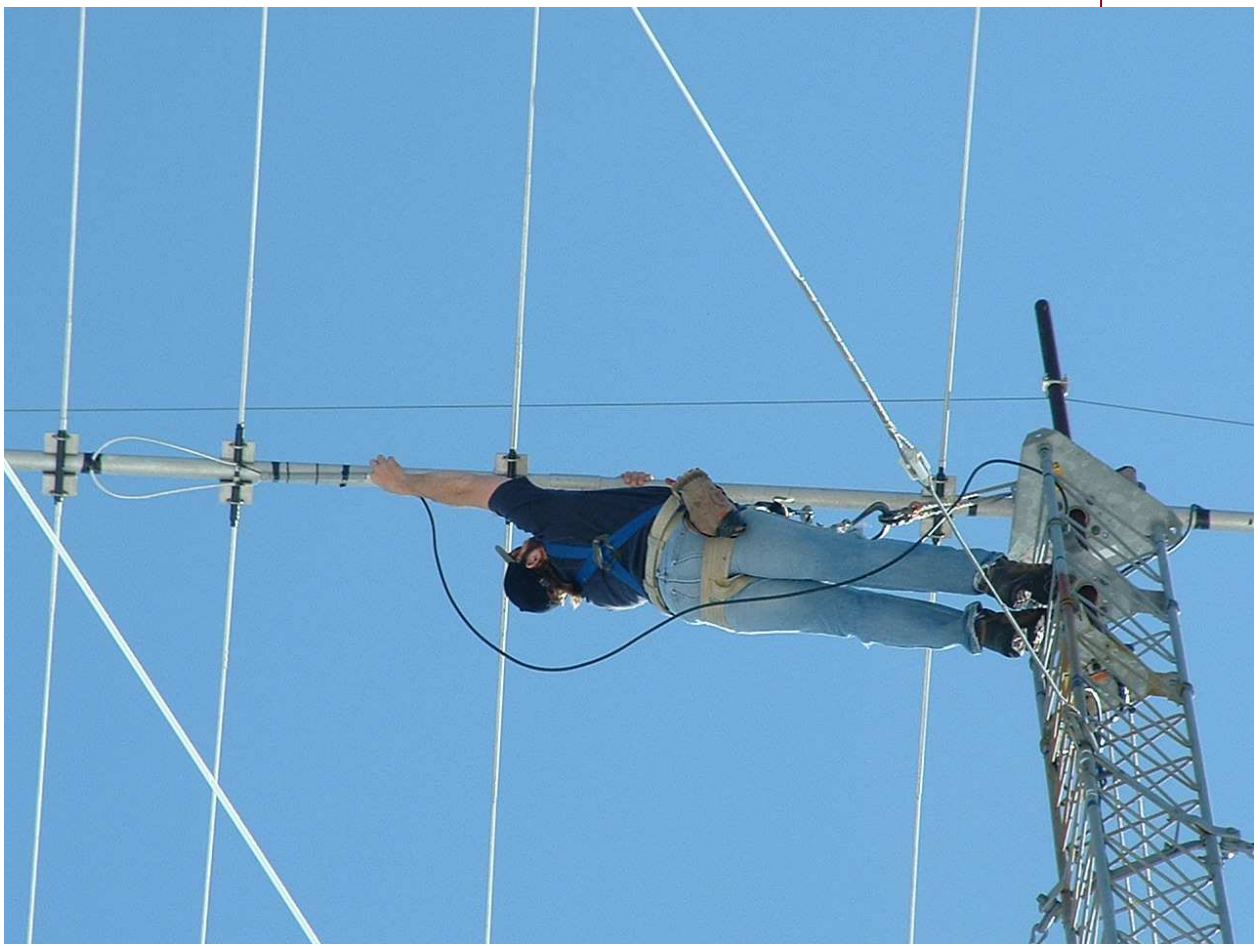
# Examples from the Field (4)

- It can be tough to get to the damaged connector!
- The tower end of the rotator loop was burned.
- Val, W8KIC (SK) 10m



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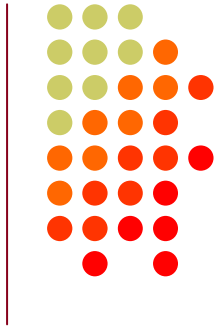
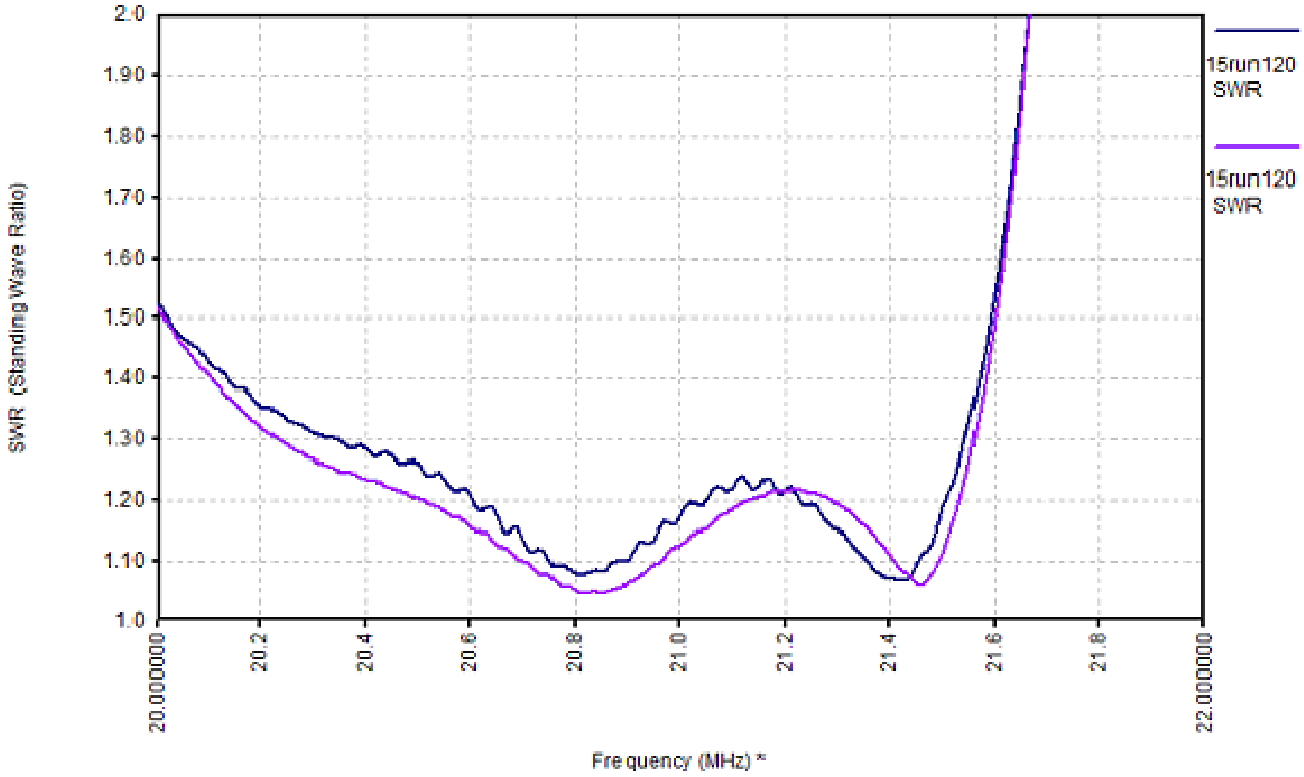
# Techniques to Find the Problem



- It can be very hard to find PIM problems.
- It is probably easier, therefore, to work a little harder to prevent them rather than have one show up and then try to find it.
- In other words, be *proactive* and not *reactive.*
- An ounce of prevention is worth a pound of cure.
- Everything deteriorates with time.

# Techniques to Find the Problem (2)

- Save periodic SWR sweeps and compare for unexpected changes.
- Can detect all sorts of problems.
- Many antenna analyzers/VNAs support saving sweeps on the PC.

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# Techniques to Find the Problem (3)

- **TDR – Time Domain Reflectometry**
- Conceptually similar to *radar* – send signals down a transmission line, see what comes reflecting back at what time. Relate time to distance through velocity factor.
  - With enough resolution, can detect the connectors in a line, even bends in the line. Any impedance bump will show.
- Although traditionally a stand-alone instrument, you can arrive at the same results by applying an inverse Fourier Transform to an reflection (impedance) sweep, converting magnitude/phase at frequency to time then to distance.
- If the VNA/antenna analyzer can sweep up to several hundred MHz, you can get good results (resolution on the line).
- This can be accomplished with additional software added to a VNA/antenna analyzer. We get TDR without an additional device!
- The AIM, VNWA, and most of the Rigexpert VNAs have this feature, maybe more than I am unaware of.

# Techniques to Find the Problem (4)

- TDR graphs are somewhat like reading a body scan – skill is needed to interpret the signs.
- The Rigexpert AA-230 Zoom TDR. Measure: 16’ RG-213 -barrel- 32’ RG-213 -barrel- 64’ RG-213 – open.

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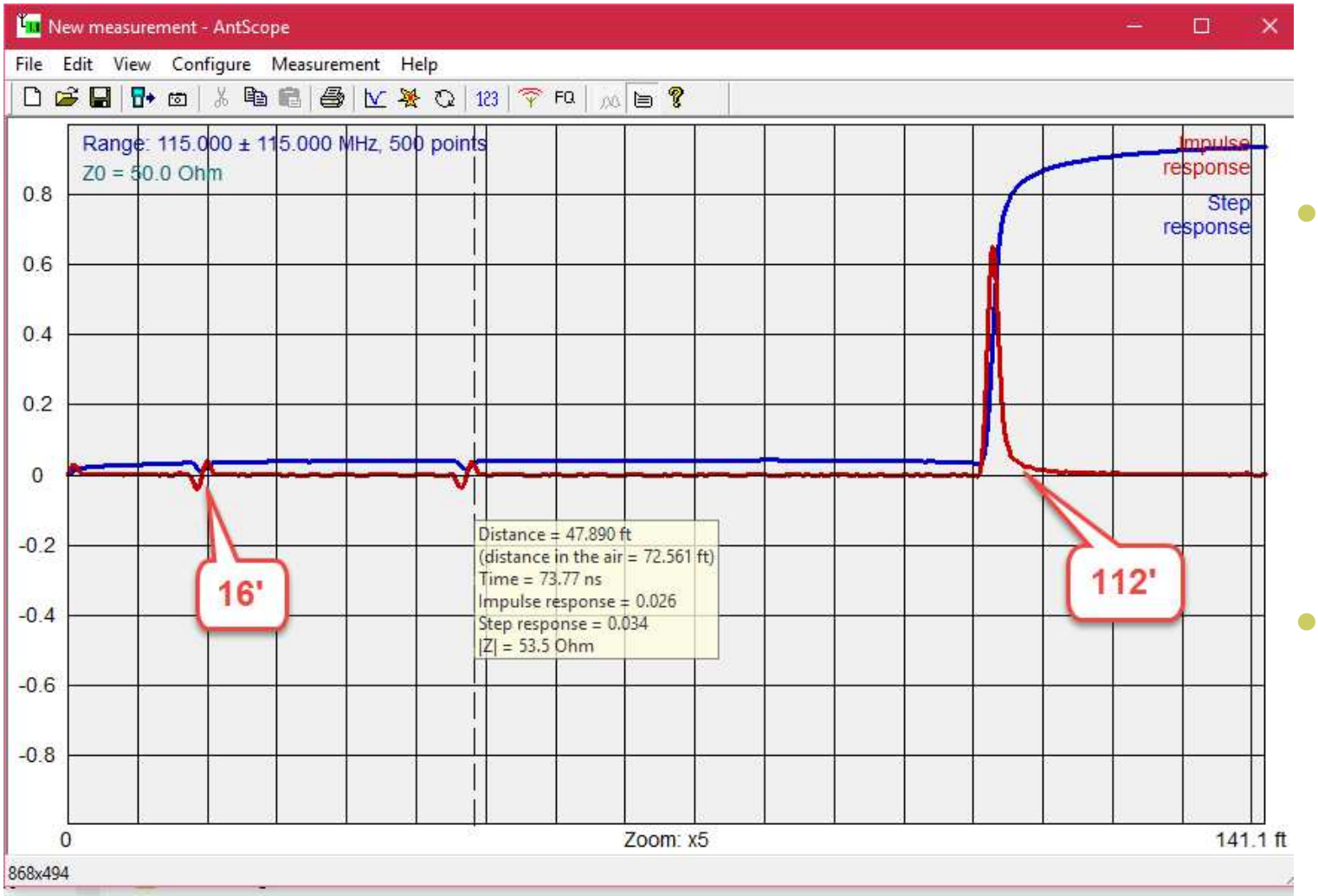
# Techniques to Find the Problem (5)




- Currently need to move the mouse over the graph to create a data popup tooltip.
- I can ***see*** the UHF barrels!

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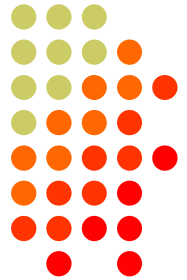
# Techniques to Find the Problem (6)

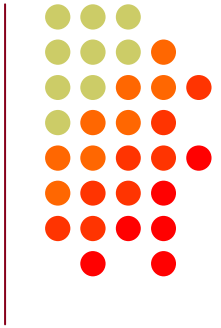
- Spectrum analyzers can be good for finding spurious signals across a wide frequency range.
  - Watch as you key the transmitter, perhaps with a filter.
- Portable receivers (e.g. ICOM IC-R20) with appropriate antennas are good *sniffers*.
- Consider polarization – the K3LR *Mixer* probably has a substantial vertical component to allow enough RF energy to reach the *mixing diode(s)*, since the AM broadcast antennas are verticals.
- Chokes (like mix 31 *Snap-Its*) can be added to lines to see if they break up resonances and change the mixing products.
  - This assumes that the line is acting as an antenna and not a transmission line.
- Does the weather impact the mixer? Hot/Cold/Rain/Dry?

# Techniques to Avoid/Fix the Problem



- From the Electro Rent Europe (they rent commercial PIM test equipment (cellular/mobile)) web site:
- **Q**: What are the most common causes of PIM?
- **A**: From testing over 2000 feeder lines, 75% of problems are found in **poor quality, poorly assembled, dirty connectors**. Other contributors are poor component plating, ferromagnetic materials, low contact pressure (connectors not torqued correctly). [this is at UHF]
- Poor weatherproofing is an invitation for problems.

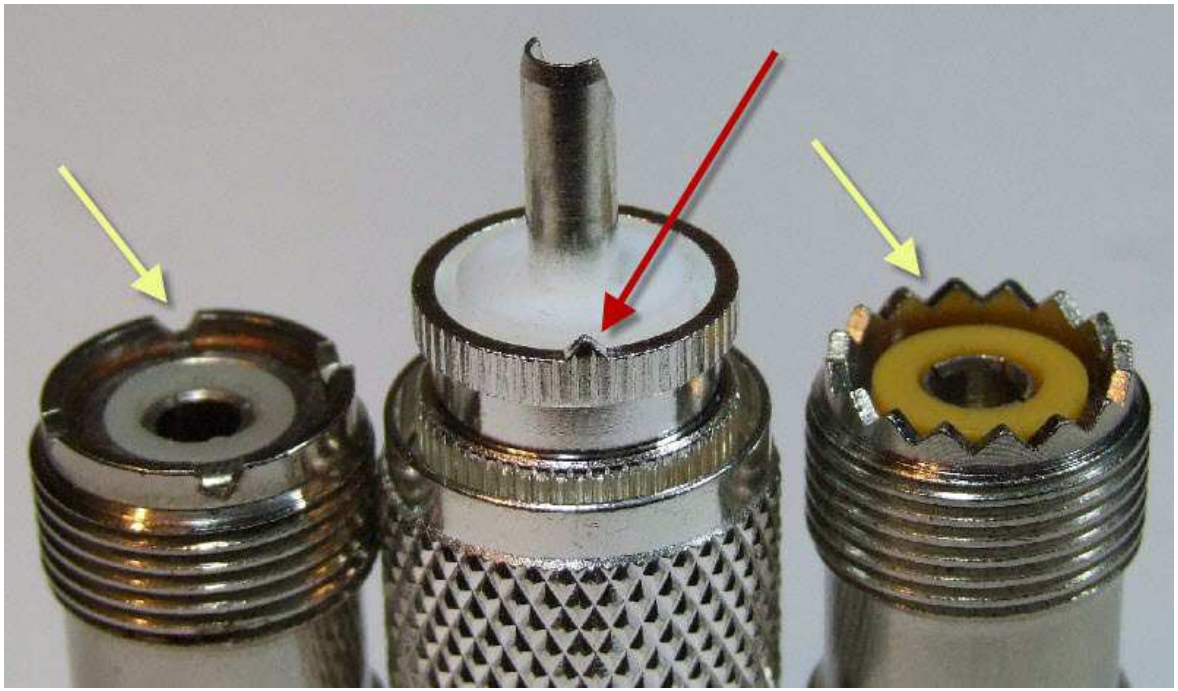
# Techniques to Avoid/Fix the Problem (2)



- This session is **not** going to get into the topic of installing PL-259's (Quackenbushes).
  - That is a worthy topic for an entire session!
  - Several different approaches are out there.
  - Practice makes perfect.
- We can, however, spend a minute talking about *Properly Seating UHF Plugs*.
  - NCJ (National Contest Journal, Jan./Feb. 2016)

# Techniques to Avoid/Fix the Problem (3)

- Male PL-259 plugs have V-shaped pins, female jacks have some number of V-shaped grooves to accept the pins.
- **What can possibly go wrong?**



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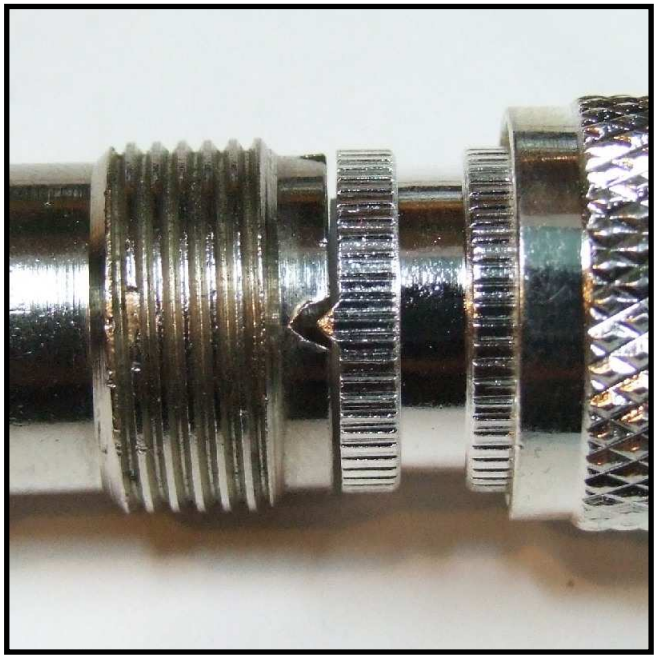
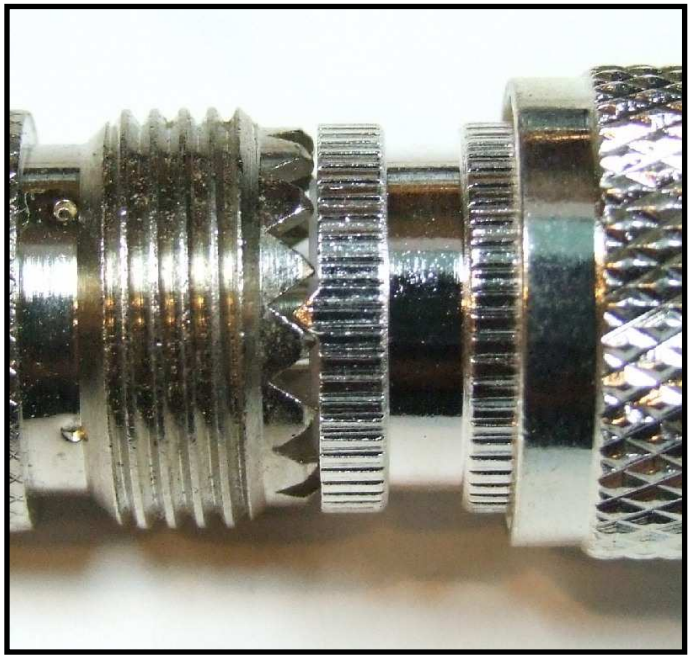
# Techniques to Avoid/Fix the Problem (4)

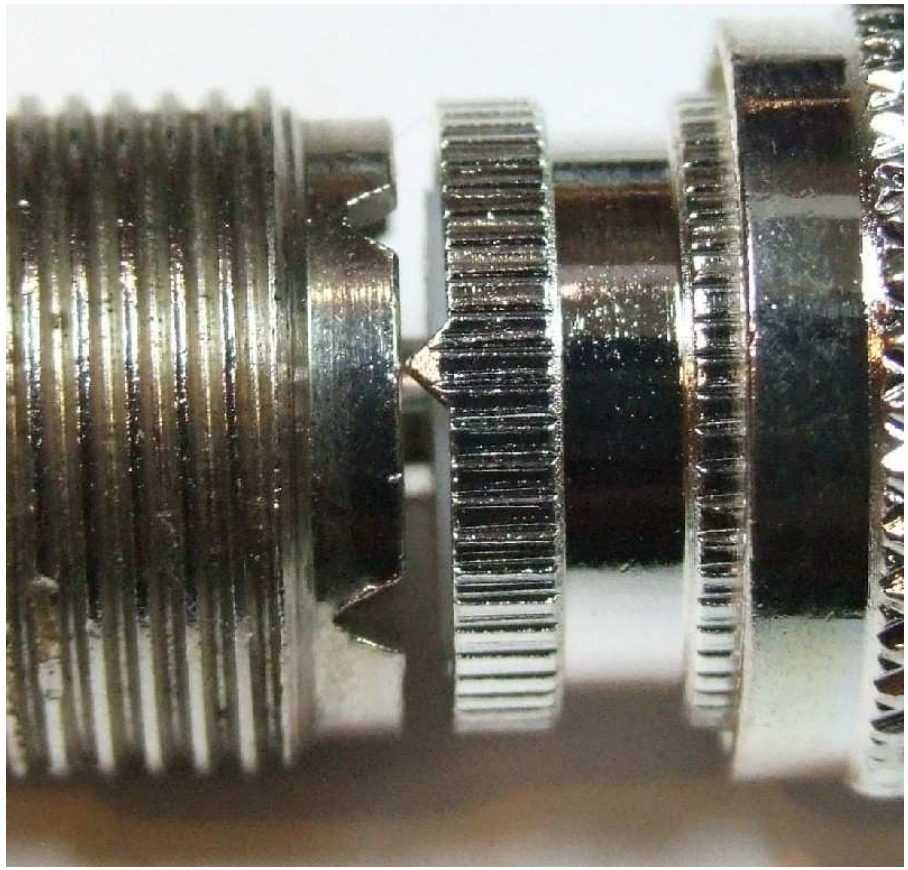




- The goal is to get the pins **fully** in the grooves, with the faces of the plug and jack in firm contact (ground).
- Don’t rely upon the plug shell to be ground.
- The shell just pulls the two faces together.

# Techniques to Avoid/Fix the Problem (5)

- The problem is that the V pins can ***hang up*** outside of the groove, or *even on the groove wall*.
- The connection may seem tight, but, over time, with vibration and thermal cycles, the pin will find the groove bottom, and now the compression on the union is released.
- A connection you thought was tight is now loose!



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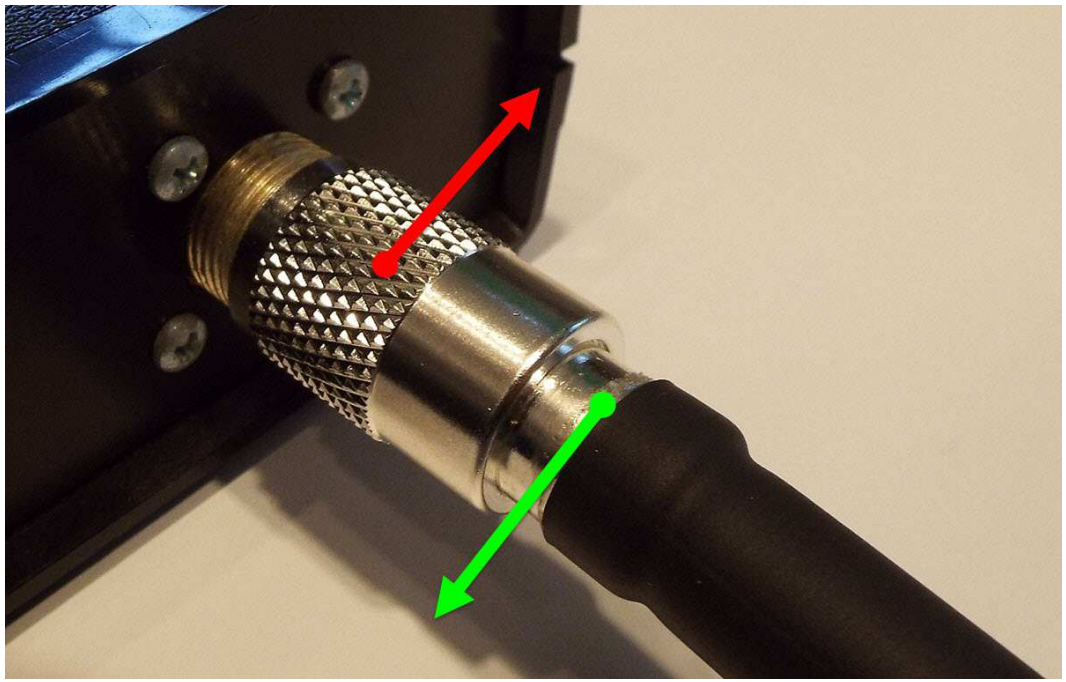
# Techniques to Avoid/Fix the Problem (6)

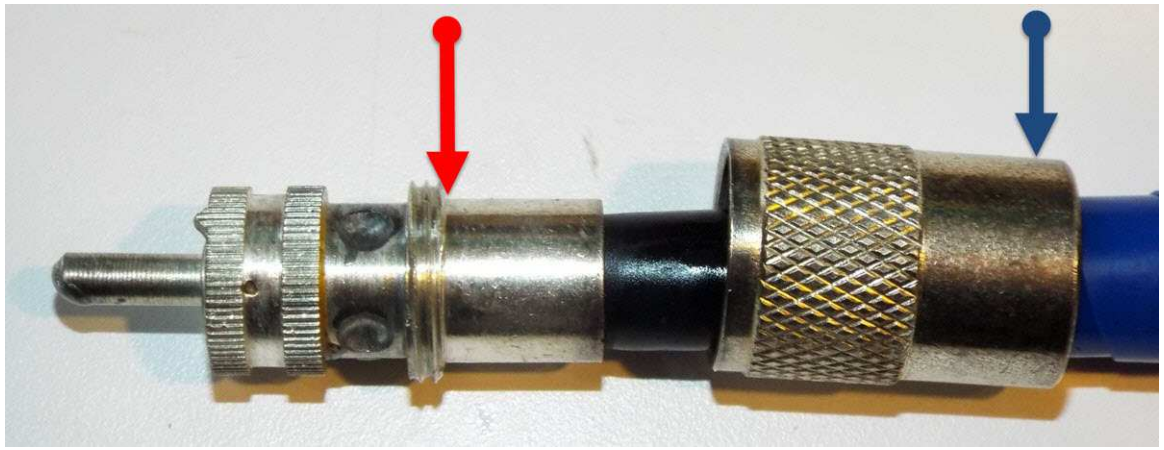


This is probably due to the informal standard of the connector, and the relatively low quality control of an inexpensive connector.

- The solution, as you approach a **snug shell**, is to grab the plug behind the shell and **turn it counter clockwise**. This ***releases*** a hung up pin, and allows for additional tightening.
- Repeat until truly tight – often several releases are possible.

# Techniques to Avoid/Fix the Problem (7)

- Anything that inhibits the smooth turning of the shell interferes with the seating process.
- The shell ultimately *pushes* the plug into the female by riding up against the lip at the end of the shell (blue->red)
- Check that the shell does turn smoothly when pushing. We want to push in the plug, not turn it, perhaps out of the groove.
- Clean if necessary, I have even (*slightly*) lubed that surface.



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# Techniques to Avoid/Fix the Problem (8)

- The old center pin…. What is the specified/required degree of friction or grip between the center pin and the female? (got me!)
- Seems like at the very least, you should be able to hang a connector by the pin. (too loose can lead to PIM)
- Sometimes, they just fall out!
- When the either one or both connectors can't be replaced, I've been known to either add solder to the outside of the pin, or, bring in the diameter of the female.

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# Techniques to Avoid/Fix the Problem (9)

- Some additional thoughts on the connectors and connections:
- Use something like Channellocks/slip-joint/water pump pliers to tighten up the shell. (try not to deform the shell with too much pressure)
  - How tight? Tight enough that it cannot be removed by hand.
  - Some places – like on towers, are almost constantly vibrating.
- Use quality connectors and adapters. Some folks swear by **Amphenol** (e.g. 83-1SP, 83-1J), although expensive. I like the Max Gain Systems PL-259.
- 4 groove jacks can be tough to work with when the cable is short and stiff. (you need enough cable rotation to get the pin in the groove)
- If you can grab the PL-259 ***behind the shell*** and detect any movement, then there is a potential problem.
- There seems to be an increase in the number of amateur products from Russia and China. In some cases (of those products) I have seen panel mount SO-239's that *just aren't right*.
  - It's as if the thread pitch is wrong, or there is too much plating – you can't seat the PL-259. No matter how tight, the PL-259 *rocks* and won't seat.
- There are many products to clean/polish metal. Try Lysol Toilet Bowl cleaner!

# Techniques to Avoid/Fix the Problem (10)

- It has become popular to add about 1.5” of *adhesive lined heat shrink* to the end of the PL-259 body – to protect the plug/coax joint.

  PL-259 > UG-175/176 > RG-142

  PL-259 > RG-213

- Be sure that you trust the assembler, since you can’t back off the shell to check the body solder holes.

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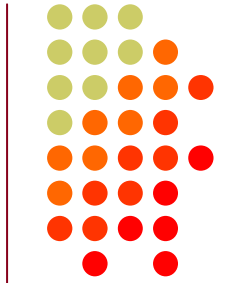
# Techniques to Avoid/Fix the Problem (11)

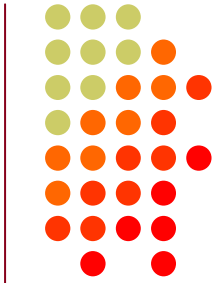
- **Weatherproofing.**
- This is a big topic with quasi-religious overtones.
- I do not wish to start any fights, and if you feel so inclined, please take it outside ☺.
- I have gathered these ideas from talking to a number of large station owners and top contesters.
  - What matters is the test of time, and these ideas have been time tested.
- I'm sure some good ideas have been skipped.
- Please feel free to email me your comments and ideas and I will update this information.

# Techniques to Avoid/Fix the Problem (12)



- Some terminology:
- **Wrap**: an overlapping winding of tape that extends from before the junction to after the junction.
  - An overlap of ½ of the tape width is common.
- **Layer**: One or more wraps of the same tape.
  - When you move to a different material you change layers.
  - A layer has one or more wraps.
- Instead of stacking Yagi's we are stacking tape layers!

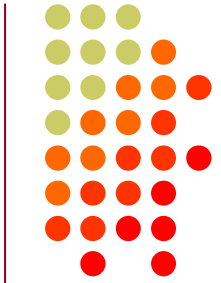
# Techniques to Avoid/Fix the Problem (13)



- The different approaches have a similar shared *stacking* philosophy.

1. The **first** or base layer is made from self-fusing / self-bonding / self-amalgamating tape that literally fuses with itself and makes an impenetrable and seamless coating over the junction. Keeps out water and even air.
2. The **second** or top layer is about protecting the first layer from weather and the UV rays from the sun.

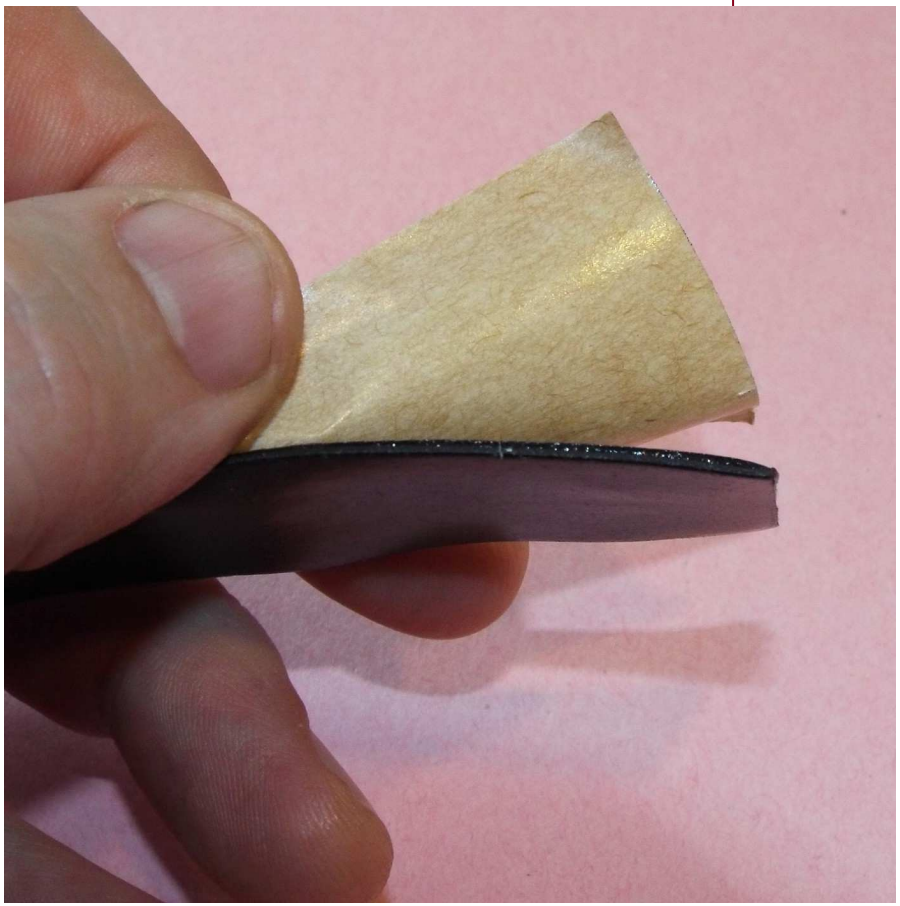
# Techniques to Avoid/Fix the Problem (14)



- There are many self-fusing tapes with a wide variety of common and product names.
  - *Self-fusing*, *self-bonding*, *self-amalgamating*, *self-vulcanizing*, *F4*, *Rescue*, *Tommy*, *Centerline,* and *Fix-It*. Can be called *splicing tape* too.
- A version of butyl tape similar to *Coax-Seal*™, and used in the cellular industry is commonly called: *Monkey-Sh*t*.
- There is also *CoaxWrap (non-adhesive silicon tape).*
- These tapes comes in two versions – **linerless** and **lined**.
  - Because the tape will become one with itself, the liner, usually paper or plastic, serves to keep the tape from becoming a hockey puck while on the roll.

# Techniques to Avoid/Fix the Problem (15)

- Although *linerless* self-fusing tape exists, what that really means is that a liner-like coating is added to one side of the tape (so it doesn't fuse with itself on the roll). Scotch 130C is an example.
- This is the paper liner on Scotch 2228.



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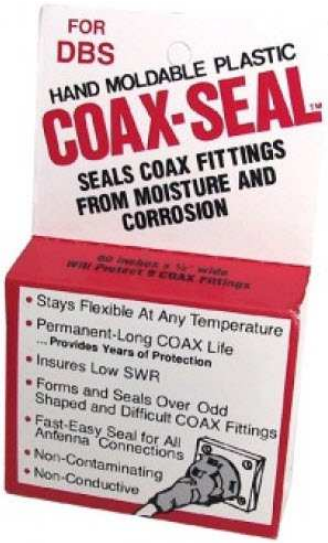
# Techniques to Avoid/Fix the Problem (16)

- There are too many self-fusing tapes to list. Some popular ham choices are Scotch 130C and Coax-Seal.



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# Techniques to Avoid/Fix the Problem (17)

- Top layer tape needs to survive the weather and sun. Thickness and temperature rating become important characteristics.
- Scotch 88 is considered king, with 33 a close 2nd.


88 is 8.5 mils, 33 is 7 mils, Ace is 8.5 mils

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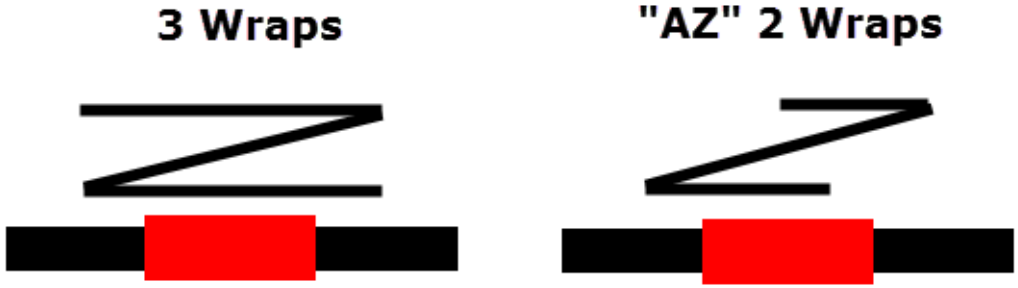
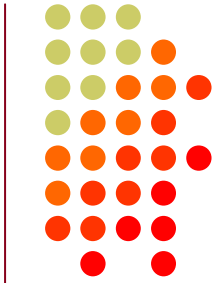
# Techniques to Avoid/Fix the Problem (18)

- These are the two layers – what about the wraps?
- The usual suggestion is 2 or 3 wraps per layer.




- The “AZ” design is two wraps that leaves the tape end in the middle of the junction to make finding it easier in the future (source: Ohio Bell).

# Techniques to Avoid/Fix the Problem (19)



- Although 2 wraps of 130C followed by 2 wraps of 88 is popular, there are many other variations.
  - Let's call that: 2X130C / 2X88.
- Because that first layer can be very sticky/gummy (especially if Coax-Seal), the concept of a *Courtesy Wrap* evolved. This is a first single wrap layer of 88 intended to make it easier to remove the self-fusing layer.
  - We could call that: 1X88 / 2X130C / 2X88.

# Techniques to Avoid/Fix the Problem (20)

- I know of at least one ham who has used *Saran Wrap* as the *Courtesy Wrap*.
- The *Courtesy Wrap* has fallen out of favor since it is a barrier between the junction and the self-fusing layer.
- In order to get some help in eventually removing the tape, one clever idea is to *reverse* the application of 130C, with the *sticky side out*.
  - We could call this: 2X130C**R** / 2X88.
  - Some folks think this is a bad idea, even if it helps. It's a form of *Courtesy Wrap* (with less grip on the metal).
- A *very heavy duty* scheme is:
  - 2X130C / 2X88 / Scotchkote / 2X88 (if water is the issue)

# Techniques to Avoid/Fix the Problem (21)

- The rear of the Scotch 2228 tape box.
- Stretching of self-fusing tape is often suggested.
- They also suggest a top layer of 88/33!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# Techniques to Avoid/Fix the Problem (22)

- Carefully cut open weatherproofing after 12+ years.
- Each to see the imprint of the features on the connectors.
- The connectors were bright and shiny, and looked like new.

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# Techniques to Avoid/Fix the Problem (23)

- Many tapes come in a range of widths.
- Cut the tape, don't pull on it until it stretches and tears. (that compromises the end of the tape)
- On vertical runs, tape from bottom to top, like shingles on a roof, to improve water runoff without penetration into the windings.
- Many folks prefer UHF connectors over N for HF use.
- Chokes and grounds can be used to break up resonances in cables. (this is yet another session!)
- Be careful when using steel wool to shine up metal: it can leave steel whiskers which make good diodes.

# Techniques to Avoid/Fix the Problem (24)

- Be careful when cutting hardline with a hacksaw – remove all metal flakes and paint flakes from the cable.
  - An unpainted high tooth count blade with minimal kerf width is recommended.
- Remove all flux/residue from connectors.
  - I like using a brass brush: cleans and shines without digging into the metal. Any metal bits must be removed!

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# Techniques to Avoid/Fix Problem (25)

- What about this “STUF”?
- Displaces water and air around center pin.
- Lots of folks have it on the shelf (like me), but don’t really trust it or use it.
- Has been reported to eventually dry out and become crystalline, which seems like a bad idea.


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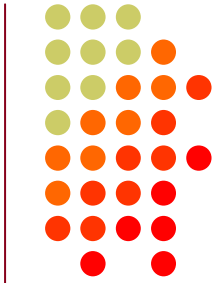
# Techniques to Avoid/Fix the Problem (26)

- Scotchkote
- Not the same as liquid electrical tape.
  - That has a spray form too
- Considered to be especially good for keeping out water – as in buried applications.

# Weatherproofing Summary



- A taxonomy for describing weatherproofing:
- Wraps versus Layers (A layer is some number of wraps of the same tape).
- 130C = your selected self-fusing tape.
- 88 = your selected top layer tape.
- Some examples:
  - 2X130C / 2X88 (standard)
  - 3X130C / 3X88 (more protection)
  - 2X130C / 2X88 / Scotchkote / 2X88 (water concern)
  - 1X88 / 2X130C / 2X88 (Courtesy Wrap)
  - 2X130C**R** / 2X88 (Courtesy Wrap lite)

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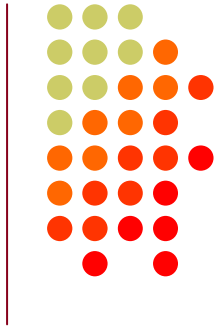
# Final Thoughts



- If you keep your Quackenbushes clean, tight, and wrapped in Monkey Sh*t you won't have any problems…

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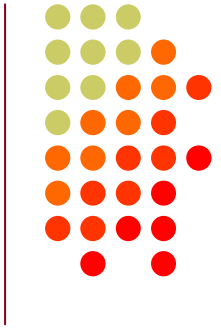
# Many Thanks go to…..



- This presentation could not have been prepared without the help and input of many, including:
- Tom, K8AZ; Tim, W3YQ; Tim, K3LR; Jeff, AC0C; “Parky”; Gary, K9RX

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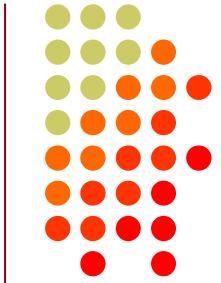
# References and Further Information



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- The ARRL RFI Book
- http://www.radio-electronics.com/info/rf-technology-design/passive-intermodulation-pim/basics-tutorial.php
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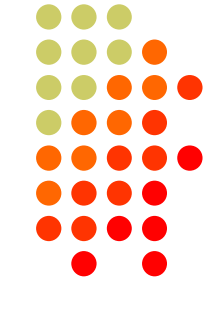

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