

To: W4DEX es The Microwave Group.
 From: Dick, K2RIW 7/7/02.
 Re: Calculating and Correcting Radome Reflections.

Dexter, W4DEX asked an interesting question about the reflections he measured from a piece of Radome material. His question caused me to write the following report. His question is duplicated here:

"The low density foam material I used to plug my homebrew 5.7 GHz horn has deteriorated after exposure to the weather for many years. After hurricane Hugo passed through I picked up several sheets of what appears to be fiberglass that were blown off a Western Electric microwave horn. This horn was placed in service about 35 years ago. Service and air pressure had been removed from this antenna, the reason the cover didn't survive the winds."

"Thinking this material may be a good cover for the homebrew horn I did a crude loss test on it. On a 6 GHz horn with a mouth of 8.5 by 11.5 inches I could see no loss when the material was placed directly over the horn. But when I moved the material away from the horn I could see loss ripples apparently at distances proportional to the wavelength. If this material is a good microwave dielectric why do I see these ripples?"

CALCULATING and CORRECTING RADOME REFLECTIONS by Dick Knadle, K2RIW.

INTRODUCTION -- There are almost no Radome materials that will provide complete transparency. But with care, that non-transparency can be made very small. There are at least three general approaches to choosing a Radome material.

(1) If the Radome material has a thickness that is a very small fraction of a wavelength, and it is a reasonably low loss dielectric material, then the reflection will be very small -- you will soon see why in the example. This is called the "thin skin Radome" approach. At say, 2 GHz and below, this first approach works very well. But, as we move up in frequency, and use much smaller wavelengths, we are forced into another approach because that same "skin" is no longer "thin" enough.

(2) As the thickness of the Radome material becomes a larger fraction of a wavelength, the reflection and impedance disturbance it causes at the mouth of a horn can no longer be ignored. In some cases the Radome's dielectric disturbance can be designed into the horn's impedance match, as the horn's probe design is being engineered into the throat area.

(3) If we choose a low-loss dielectric material that is a multiple of one half wavelength thick, then the reflection can be made to almost vanish. However, without using multiple layers of carefully chosen materials (approach 3A), this approach may be too narrow band in frequency response, or in angular response, for some broadband applications.

I'm going to provide a procedure by which you can estimate the amount of reflection, and how to correct it. But first a little basic theory.

IMPEDANCE -- Free space is a transmission medium which shares many of the same characteristics as wave guide and coaxial cable. That medium has an intrinsic impedance of 377 ohms. Although that number may sound a little crazy, you will have to accept the fact that Mother Nature just "designed" it that way. Whenever you place ordinary dielectric materials into that free space, you are lowering that 377 ohm impedance, and you are lowering the velocity factor of a wave traveling through that part of space. The amount of change of that impedance, the new velocity factor, and the reflections it

causes are very similar to what happens when you put the same dielectric material into a piece of wave guide, or into a piece of air-line coaxial cable. The example will demonstrate this.

THREE DIMENSIONS OR ONE? -- Many people are confused by the fact that Free Space is three dimensional (it has length, width, and height), even though a piece of coaxial cable seems to be mostly one dimensional (it has length). In many cases you can consider Free Space as having only one dimension (it's length) and with some care, you will derive a good estimated answer.

MISMATCHED CABLES -- Many amateurs and engineers have learned to calculate what happens when you put mismatched cables together -- such as putting a piece of 70 ohm cable in series with a piece of 50 ohm cable. Many of them use a Smith Chart to plot the result, and some have learned how to use a calculator to derive an even more accurate answer. But, the calculator approach has less "visibility" and some gross errors can occur. A prudent amateur/engineer will use the calculator, and then back up the result on a Smith Chart.

DON'T OVERLOOK 70 OHMS -- Cable TV companies use 70 ohm cable because it has lower loss. Excess loss to them means money spent on more amplifiers per mile needed to overcome that loss through the many miles of their system. Therefore, large volumes of 70 ohm cable are produced cheaply, and lots of it becomes available to lucky amateurs at VERY ATTRACTIVE prices (often FREE). Due to a misunderstanding of the rules of mixing cable impedances, many amateurs refuse to take advantage of this bargain material. They seem to believe that their system will explode if they don't maintain 50 ohms (plus, or minus 1 ohm) everywhere in their system.

LEARN HOW TO MIX THEM -- A more informed amateur will learn how to mix 70 ohm cable into their 50 ohm system, and as you are about to discover, the proper procedures are not very different from adding a Radome to their microwave system.

CABLE and RADOME COMPARISONS

COAX and RADOME SIMILARITIES -- I'm first going to place a piece of plastic inside of a 50 ohm air-line coaxial cable that is part of a UHF antenna system. We will calculate the reflections that results from this mismatched cable. Then we are going to use a piece of the identical type of plastic, as a Radome, in front of a Microwave antenna system. We will calculate the effect of this addition, and compare the results.

DON'T BE AFRAID OF RADOMES -- Many amateurs are able to calculate the reflections in mismatched coaxial cables. Soon you will see how similar this to adding a Radome to a Microwave antenna. After this you may no longer be afraid to calculate the impact of various Radome materials, and you will feel comfortable in choosing the best Radome material, of those that are available to you. It is even possible that some of your wife's kitchen materials can serve as Radome material, but you'd better first get her permission -- Hi.

ADDED PLASTIC IN A COAXIAL CABLE (IS IT A MISMATCH?) -- Here is a sample calculation. Assume I have a mythical kind of air-line (hard line) 50 ohm coaxial cable that is feeding my 50 ohm 432 MHz antenna. For the moment assume that the center conductor stays in the center of the cable without requiring any supporting material. Therefore this mythical hard line will have air as the dielectric, and the velocity factor will be 1.0 (the speed of light). I've decided to perform an experiment, so I purchased a piece of Teflon rod that has the same outside diameter as the inside diameter of the hard line's outer conductor. I'll cut off a 1 inch (2.54 cm) length of this rod and I will drill a hole in it that matches the outside diameter of the hard line's center conductor. Now I'll remove the hard line connector at the antenna end of the cable, and force the 1 inch length of machined Teflon into the cable, and replace the connector.

THE FORMULAS -- Teflon has a dielectric constant of 2.1 The impedances (Z_0) of a coaxial cable, and its velocity factor (vf) are equal to:

$$Z_0 = [1/(\text{Square Root } \epsilon_r)] * 138 * \text{LOG}(D/d)$$

$$v_f = [1/(\text{Square Root } \epsilon_r)]$$

Where:

ϵ_r = Relative Dielectric Constant of Teflon (2.1)
 Square Root of ϵ_r = 1.45, 1 over this = 0.69
 $138 * \text{LOG}(D/d)$ = Undisturbed Air Line Cable impedance, which was 50 ohms.

Therefore, the cable has an impedance of 34.5 ohms, and a velocity factor of 69% in the vicinity of the machined Teflon piece. The free space wavelength of a 432 MHz signal is 27.32 inches (69.40 cm). The 432 MHz wave will travel more slowly through the Teflon piece by the velocity factor, so the piece will seem to have a length of $1"/0.69$ or 1.45 inches in air. Therefore, this piece of the cable will be 0.053 wavelength long.

DID WE KILL THE SIGNAL? -- Effectively we have connected a 1.45 inch length piece of 34.5 ohm air line cable at the end of a 50 ohm transmission line that is feeding a 50 ohm antenna. To the average amateur, this sounds like a terrible thing to do. Imagine how you would feel if your tower rigger told you that a 1.45" long UHF Connector, that had an impedance of 34.5 ohms, had been placed on the top of your beautiful 50 ohm hard line. Many amateurs would fire him! Well, before we get too excited, let's see what's really happening.

WHAT DOES MR. SMITH SAY? -- A Smith Chart (or calculator) will tell you that the input impedance (Z_{in}) of the 34.5 ohm cable section that is 0.053 lambda long (19.1 degrees) and terminated with a 50 ohm antenna will be an impedance of (44.73, -j10.5) ohms, which is a little low in resistance, and slightly capacitive. The voltage reflection coefficient (ρ) will be $|(Z_{in}-Z_0)/(Z_{in}+Z_0)| = 0.123 = -18.18$ dB. The rest of the 50 ohm hard line will feed this section, and it will experience a reflection of -18.18 dB, which is a VSWR of 1.28:1. That mismatched section will cause a possible power loss of 0.07 dB, which is rather negligible in my book. So, let's not fire that tower rigger, until we find out how good a job he did when weatherproofing that so-called "terrible" connector.

THE TEFLON RADOME -- Now let me take a sheet of that Teflon that is 0.042 inches (1.06 mm) thick and place it across the mouth of my 10.368 GHz feed horn as a Radome. The free space wavelength at that frequency is 1.138 inches (2.89 cm). I chose Teflon sheet with a thickness 0.042 inches because it also will calculate to be 0.053 lambda thick (19.1 degrees), when I include the velocity factor of the Teflon (69%). That 0.042 inch of Teflon will have the delay equivalent of 0.060 inches of air. The mouth of the horn usually feeds the free space impedance of 377 ohms. But now I have placed a sheet of plastic across it that has lowered that local impedance by the same factor $[1/(\text{Square Root } \epsilon_r)] = 0.69$, therefore, the impedance inside the Teflon is 260.2 ohms.

HOW GOOD IS THIS RADOME? -- To sum it up, we have an equivalent system that is a sheet of plastic material that has an internal impedance of 260.2 ohms that has a delay similar to 0.060 inches of free space, or 0.053 lambda (19.1 degrees) at 10.368 GHz. If I normalize my Smith Chart to a 260.2 ohm transmission line that is 19.1 degrees long and terminated with 377 ohms (the free space "load" in front of [outside of] the Radome), I'll discover that the input impedance to the Teflon (on the horn side) is (337.3, -j79.1) ohms. That impedance is being fed by the 377 ohm output impedance of the horn. The horn will experience a reflection from the Teflon of about -18.2 dB, and the horn's VSWR will be about 1.28:1, assuming that the horn was perfectly matched to free space before I added the Teflon Radome. Notice how similar these reflection numbers are to the previous coax cable system.

COAX TO RADOME SIMILARITY -- By now I think you see the similarity between the coaxial cable (at 432 MHz) with the added 1" piece of Teflon, and the 0.042" sheet of Teflon that I put in front of the 10.368 GHz horn. In each case I boiled the transmission system down to a one dimensional model and analyzed it as if it was a mismatched piece of transmission line added to a previously matched transmission system. Once we have converted it into the simplified model, the Smith Chart type of plotting (or

calculating) can give us a very good approximation of what the impact will be. From that analysis we can decide that the impact of the proposed Radome is acceptable, or it needs further modification.

THICKER RADOMES -- If you need a Radome with a lot of strength (thickness), or if you are working at a super high frequency where you can't keep the Radome as thin as you would like (in wavelengths), then you are forced into using Radome approach (2) or (3). The guys who have mixed pieces of 70 ohm cable within a 50 ohm system have discovered that a cable of any impedance (like the 70 ohm one) will present the desired 50 ohm impedance if that 70 ohm piece is an exact multiple of $1/2$ wavelength long (including its velocity factor). Well, when constructing a Radome out of a "thick" piece of dielectric material, the same principle holds -- it will repeat the 377 ohm free space impedance, if its thickness is a multiple of $1/2$ wavelength (when including the velocity factor) at the operating frequency.

A COAX SANDWICH -- If you want to really get fancy (and maybe open up your own Radome factory), consider what the smart guys have done when mixing multiple pieces of mismatched cable into their transmission line system -- they analyze it by using the Smith Chart technique multiple times, once for each transition in cable impedance. They discovered that if the cable impedances change at a slower rate, or with a Binomial Distribution, than the bandwidth of the impedance matching becomes much broader. For instance: (1) you could build a $1/4$ wave impedance matching transformer that matches two parallel antennas (25 ohms total) to your 50 system by using a $1/4$ wave 35.4 ohm piece of cable (the geometric mean) -- that's a one step matcher that is somewhat narrow band; (2) or you could do the matching in two or three intermediate steps, and have a much more broadband matching system. You could call this a "sandwich" of coax impedances.

A RADOME SANDWICH -- By the same process, your Radome doesn't have to be made from one thickness of one material. By using multiple layers of properly chosen materials, it is possible to construct a Radome "sandwich" that is much more broadband in both frequency response as well as angular response. The process of analyzing these can be done as if it is multiple pieces of transmission line. The multiple layers of optical coatings that are placed on high quality optical lenses, also is a "sandwich" that uses this principle to increase the broad bandwidth of "impedance matching" into and out of the glass that lowers the surface reflectivity of the glass and increases the light thruput (brightness).

A SPATIAL CIRCUIT -- As you can see, a Radome is really a "spatial tuned circuit" that is capable of doing many kinds of impedance matching. Obviously there is a lot more to this story, and some smart people have spent much of a professional career studying Radome sandwiches of many layers -- sometimes they even including intermediate "layers" of air.

LOSS TANGENT -- I didn't get into the "Loss Tangent" discussion of the chosen Radome materials. This is because you are going to use such a small number of wavelengths of the stuff that the loss from that factor is usually quite small, unless you make the Radome out of carbon granules -- Hi! Try asking a guy who designs anechoic absorber materials how much reflection loss he can give you when using a material that is only 0.053 wavelength thick. Unless he is using the real exotic stuff, you'll be amazed how little loss he can create under those conditions.

RIPPLE IMPACT OF RADOME MOVEMENT

LET'S MOVE THE TEFLON -- As a method to study the impact of Radome motion, let's first try the experiment in the coax system. We're going to find out what will happen inside the 50 ohm cable if the 1 inch long Teflon slug was pushed further down into the 50 ohm cable. Let's say that I used a dowel to push the slug down into the cable by 6.8 inches (17.3 cm), which is $1/4$ wavelength at 432 MHz in our air dielectric cable.

THE NEW VSWR: IS IT THE SAME? -- The output end of the Teflon slug is still looking into 50 ohms. Before the move, it looked directly into the 50 ohm 432 MHz antenna. After the move, it looks into $1/4$ wave of 50 ohm cable, that in turn feeds the 50 ohm antenna. Therefore, the Teflon is still causing a reflection of -18.18 dB, and a 1.28:1 system VSWR. It would be easy to say that nothing has changed,

electrically. But, a very subtle change has taken place. The phase of that -18.18 dB reflected signal has just been rotated by 180 degrees, and we have just moved to the opposite side of the Smith Chart. Simplistically, you could say that the Reflection starts at the input end of the piece of Teflon. And, that Teflon has just been moved 1/4 wave closer to the transmitter. Now the Teflon "sees" the transmitter's signal 1/4 wave sooner, it reflects a small portion back down to the transmitter, and the line length from the Teflon to the transmitter is 1/4 wave shorter. Therefore, the transmitter "sees" that reflected signal 1/2 wave sooner (a total phase shift of 180 degrees).

WHAT IS THE TRANSMITTER's RESPONSE? -- Almost all tube and solid state transmitters are NOT a 50 ohm source. They are closer to a constant current generator (a much higher impedance). They are engineered to provide the rated performance when loaded with 50 ohms. You could say they are "power matched" or "performance matched" to 50 ohms, but they are not "impedance matched" to 50 ohms. This makes the transmitter very sensitive to the phase angle of a reflected signal.

THE BIRD TEST -- If I placed a perfect Bird Power Meter at the transmitter and monitored the Forward power, I would see a complete cycle of "power ripple" every time I moved the Teflon slug 1/2 wavelength. This is what is happening:

- Because the transmitter is such a high impedance (that is far from 50 ohms resistive) it can not absorb much of that -18.18 dB reflected signal.
- Therefore, most of the reflected signal that "hits" the transmitter is re-reflected forward and goes back up the line.
- As we change the phase angle of the reflected signal (by moving the Teflon slug), we are determining whether the re-reflected signal is in-phase, or out-of-phase with the signal that the transmitter is producing at this time.
- This is most likely the cause of the "power ripples" that W4DEX experienced.

I think you can see the relation between the movement of a slug of Teflon in a coax cable, and the movement of a Radome in front of a transmitting horn. A "thin skinned" Radome is always producing a small amount of reflected signal. And most transmitters are quite sensitive to the phase angle of the reflected signal. That's why they are frequently subjected to a 360 degree VSWR "load pulling" test, when they are intended for a critical application.

Dexter saw the motion of his Radome material producing "loss ripples." I feel pretty sure that the real cause of the ripples was that the transmitted power was "rippling." If Dexter places a well-balanced directional power meter at the transmitter, and repeats the moving Radome material test, I believe he can confirm this hypothesis.

Alternately, Dexter can place a 10 dB pad after the transmitter, and repeat the test. The pad should make the transmitter appear more like a "50 ohm" source (or the wave guide equivalent), and the rippling should mostly disappear.

RIPPLE MAGNITUDE EVALUATION

INTRODUCTION – We now have all the information needed to calculate the amount of ripple in transmitter power that could occur as we either: (1) move the Teflon slug inside the 50 ohm coax cable; or (2) move the piece of Radome material in front of a microwave horn.

TO REVIEW -- In the previous paragraphs of this saga, I had speculated that the apparent "ripples in insertion loss" that Dexter, W4DEX had experienced when he moved the distance of the Radome material in front of his microwave horn were really ripples in the power output from his transmitter. Presented here is a simplified way to estimate the dB's of peak-to-peak ripple.

WHAT CAUSED THE REFLECTION? -- Previously we calculated that you create a -18.18 dB (or dBc) reflected signal when you either:

- (1) place a 1 inch slug of Teflon into a 50 ohm air line at 432 MHz, or

(2) place a 0.042 inch sheet of Teflon in front of a 10.368 GHz feed horn.

I speculated that much of the -18.18 dB reflection signal was being re-reflected by the transmitter back up the line, and the re-reflection either falls in-phase or out-of-phase with the power that the transmitter is now producing, thus causing the ripple.

THE ASSUMPTIONS -- Here are the assumptions:

- I'll first assume that the transmitter is a perfect constant current generator (some VHF ones are pretty close to this), that's the worse condition.
- I'll assume that only a small amount of the power reaching the Radome material is being reflected (-18.18 dB is pretty small, 98.5% of the power goes through).
- I'll assume that the transmission line insertion loss is low.

SIMPLIFIED ANALYSIS -- These assumptions allow me to do some rather simple voltage additions and subtractions that are much easier to understand, and should be fairly accurate. However, the following simplified analysis technique will break down if the Radome's reflection coefficient becomes large (like -10 dB or greater). In that case the reflecting voltages will bounce back and forth many times between the transmitter and Radome, with an exponential decay, and the more accurate analysis would require a converging infinite-series type of equation.

SHE THINKS IN VOLTS -- An amazing number of technologists have not been told (or convinced) that Mother Nature almost always considers RF energy from a VOLTAGE viewpoint. Many amateurs will try to calculate multiple signals (that are on the same frequency) as if they are being combined in a POWER manner; but that method of analysis will usually lead to large errors.

HOW BIG IS THE RIPPLE? -- In our 0.042 inch thick 10.368 GHz Teflon Radome situation, we have created a -18.18 dB reflection signal, due to our Radome material creating a minor disturbance in the impedance of free space. That reflection signal has a voltage ratio of $\text{ANTILOG}(-18.18/20) = 0.123$ (relative volts). When we move the Radome material to the place where the transmitter re-reflected signal is co-phase with the transmitter primary signal, we get a VOLTAGE SUM of $1 + 0.123 = 1.123$ volts. At the Radome location where the two signals are anti-phase, the combined VOLTAGE is $1.0 - 0.123 = 0.877$. To calculate the possible Peak-to-Peak ripple we convert these VOLTAGE ratios back to power. The Peak-to-Peak ripple is $20 \cdot \text{LOG}(1.123/0.877) = 2.15$ dB.

THE SURPRISE -- Most amateurs and engineers consider a -18.18 dB reflection (a 1.24:1 VSWR system) as a very good. They say, "hell, it's sending 98.5% of the power, in the right direction -- out through the Radome." They are usually amazed when they find that such a great system is capable of ripples as large as 2.15 dB; and most of that ripple is because of that little bit of power (the 1.5%) that was reflected (plus the transmitter's characteristics).

THE PAD FIX -- Bear in mind that ripple as big as 2.15 dB is only possible if the transmitter is a pure current generator, and is thus, completely reflective. Many transmitters are not quite that bad, but some are pretty close. If we placed a good variable attenuator at the transmitter, we would see the ripple decreases to almost 0.0 dB, as the attenuation becomes large.

A 10 dB PAD DOES WONDERS -- Let's see what happens if we set the attenuator at 10 dB. The -18.18 dB reflected signal has to go through the 10 dB pad twice before it re-joins the signal (VOLTAGES) that are flowing up the cable. That 20 dB of extra loss makes the reflection signal decrease to: $-18.18 - 20 = -38.18$ dBc. By the same process as before, the ripple in this situation calculates to be 0.214 dB Peak-to-Peak.

GOOD VSWR MEASUREMENTS REQUIRE CARE -- This example makes it clear why a good technologist insists on padding a transmitter (or signal generator) when he is making serious VSWR measurements of an unknown device. Ripples in the signal source power can create a considerable measurement error; the cause is quite subtle, and usually not anticipated. There are sweeping signal

generators (such as a Gigatronics) that have an output leveling circuit. This can help, but only if the leveling loop signal sampler is located after the ripple-causing circuitry (the constant current source) within the generator. If the ripple is being caused by a defective cable that's attached to the signal generator, the internal leveling loop will not help.

CONCLUSION ABOUT VSWR-RIPPLE INTERACTIONS -- Back on 7/7/02 it may have seemed like Dexter, W4DEX was asking a somewhat simple question, "why does the moving Radome show insertion loss ripples?" As we have seen, the causative agents are probably VSWR, and transmitter power-ripple related. The subtle effects that VSWR can cause are usually much more complicated than first realized. Tune across any ham band and you will soon hear someone stating his VSWR theories that are logical sounding, but often very wrong. HP's series of Vector Network Analyzers contain massive computer programs that represent many servo loops that are busily performing a "12 point correction" algorithm to remove the myriad of errors that inter-component reflections can cause. As some philosopher once said, "If you think the problem is simple, then you probably don't understand the problem."

SIGNAL SOURCE LEVELING SOLUTIONS

SIGNAL SOURCE LEVELING SOLUTIONS -- Jerry, K0CQ has suggested using wave guide tuning screws to correct the signal source reflection problem. I agree with the concept, but tuning screws can have scratchy thread contacting problems. I would rather use an HP-X880A Wave Guide E-H tuner (if I was using WR-90 guide). And yes, these methods are a heroic way that I could demonstrate the concept of "signal source reflection phase sensitivity" to a classroom full of VSWR-skeptical students. Others might call these "source impedance correction" methods, or "source normalization" methods. Too bad the commercial suppliers do not make a micro wave version of an Automatic Antenna Tuner.

"EXTERNAL" LEVELING -- A more elegant solution would be to sample the total Forward Power that is being applied to the horn by using a Directional Coupler, and send that sample back to the "External Leveling" port of the Sweep Signal Generator (such as a Gigatronics). Then use the "External Leveling" mode. With this method the servomechanism will do all the work for you, with the power leveling taking place at a millisecond rate as you move the Radome material. It is always nicer to see an effect displayed in "real time." I fear that modern students might become impatient with the more manual methods. The benefit of this method can be demonstrated by turning the "External Leveling" on and off.

THE NEXT LEVEL OF RIPPLE -- Now, here is the real kicker. Even with near-perfect signal source leveling, there will still be a small amount of ripple present as the Radome material is being moved. This could be called the horn's "reactive near field loading" problem. One way to look at this is realize that the horn does not have 100% aperture efficiency during signal reception. RADAR mavens will say the horn has a boresight "scattering area," or RCS (Radar Cross Section). In other words, a small amount of the signal that is reflected from the Radome material will not be accepted by the horn. This signal will also be re-reflected forward to the Radome material, and it will fall in-phase or out-of-phase with the primary signal, as the Radome is moved.

ACCEPT SOME SCATTERING -- The bottom line is, almost any material (like Radome material) that you place into free space will disturb Mother Nature's sacred 377 ohm "pristine" environment, and you are going to get some signal scattering. If you are skilled at Radome "spatially tuned circuit" engineering, you can make that scattering very small. But, the effects can not be made to completely disappear.

FSS: ACTIVE AND PASSIVE -- Not all of the materials that you can use for making a Radome are dielectric types, and capacitive. There is a science field called Frequency Selective Surfaces (FSS). By using exotically-shaped metallic objects and metallic sheets that have repetitive patterns cut into them (in conjunction with dielectric materials), you can make a Radome that has the properties of a band pass filter, band stop filter, phase retarder, phase advancer, polarization rotator, circular polarization generator, lens, beam former, beam steerer, dispersion corrector, etc. By adding passive and active diodes and transistors into the Radome you can generate harmonic frequencies, electronically steer the beam, and even generate a

Radome that has gain or frequency translation (distributed amplification and mixing). Almost all of the circuit engineering concepts you have learned for Printed Circuit applications can be applied to a Radome design.

APPENDIX -- For those who want to use a calculator for doing "Smith Chart" like calculations, here are my favorite equations. You'll have to use a calculator that can tolerate complex numbers (or write a sub-routine that does this). The complex input impedance (Z_{in}) of a mismatched piece of transmission line (or Radome) is equal to:

$$Z_{in} = Z_o * (Z_r + j * Z_o * \text{TAN}(L)) / (Z_o + j * Z_r * \text{TAN}(L))$$

$\text{Rho} = \text{Absolute Value } [(Z_{in} - Z_o) / (Z_{in} + Z_o)]$; Z_{in} is usually complex, Z_o is often 50 ohms.

Reflection (dB) = $20 * \text{LOG}(\text{Rho})$

VSWR = $(1 + \text{Rho}) / (1 - \text{Rho})$

Power Transmitted (Per cent) = $100 * (1 - \text{Rho}^2)$; (Worst case).

Power Lost (Per cent) = $100 * \text{Rho}^2$ (Worst Case).

Where:

Z_o = Line Impedance being analyzed (34.5, 50, 70, 260.2 ohms, etc.)

Z_r = The Load Impedance that terminates that line (50, 377 or it could be complex)

j = The complex operator (Square Root of -1)

TAN = Trigonometric TANGENT Function

L = Line Length (in degrees), if that's the way your machine uses TAN.

Rho = Voltage Reflection Coefficient due to an impedance mismatch.

I hope this makes you feel a little more comfortable about Radomes, they are really not that magic. Please feel free to correct the mistakes.

73 es Good VHF/UHF/SHF/EHF Optical DX

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web: <http://consult-li.com/listings/RKKnadle.htm>