MAXIMUM DISH EFFICIENCY AND THE BEST ANTENNA SIDELOBE LEVELS

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INTRODUCTION -- What follows is long winded, but it is intended as a mini-tutorial that I hope will give some microwavers a better understanding about the highly misunderstood area of Maximizing Gain, Aperture Efficiency, Properly Feeding Parabolas, and the Proper Sidelobe Levels that Must be present in a properly operating high efficiency aperture-type antenna.

THE FORMULA -- The most important factor that determines the achievable Gain of a microwave antenna is it's area. The formula that is the bedrock of the antenna measuring/designing industry and science is:

Gain = (4*Pi*Ae) / (Lambda^2)

Where:
Ae = Effective Area, often 55% of the Physical Area
Pi = 3.1416
Lambda = Wavelength in the same units as Ae

GAIN EQUALS AREA -- When you study that formula you can come to an interesting conclusion; at a fixed frequency everything is a constant except the Ae. Therefore Gain equals a Constant x Area. If you want to double the Gain of your antenna (that's a +3.01 dB Gain increase) you have to double it's effective area.

ILLUMINATION -- All of the above assumes that you are properly illuminating that new area you added. In most Parabolic Dish situations (offset and center fed) that Gain is maximized when you choose a feed horn that has the -10 dB pattern fall at the edge of the illuminated surface (including the extra path length to the edge). That will usually give you a Dish with a Aperture Efficiency of about 55 to 60%.

100% EFFICIENCY? -- You can almost achieve a 100% Aperture Efficiency. All you have to do is design a feed horn that illuminates every square inch of the dish with the same power, and have that power abruptly fall off to zero at the edge of the dish (no spill over). To have that much control of the feeds Primary Pattern will require a properly-fed, Cluster Feed, Phased Array of about 1,000 elements, and that feed assembly will be about 30 wavelengths in diameter. If you are working with a Dish that is 120 wavelengths in diameter, this is almost doable.

A REAL DISH -- Since many of our antennas are only 20 wavelengths in diameter, that approach is not practical. You would end up with more gain in the feed horn assembly, than in the whole Dish antenna system. You would be better off just aiming the feed at the target and eliminating the Dish reflector.

APERTURE EFFICIENCY -- The subject of Dish aperture efficiency is highly misunderstood. Most amateurs (and engineers) believe that the lack of 100% Aperture Efficiency, or 100% Main Lobe Efficiency, represents a true Power Loss (it does not), and that the "lost power" is in the sidelobes (it is not).

THERE IS NO LOSS -- In a reasonably-constructed 55% aperture efficiency Parabolic Dish antenna system, if you apply 100 watts to that antenna, 99.9 watts will be radiated into space. Aperture Efficiency (surface efficiency) is a measure of the True Gain of your antenna versus the theoretically achievable Gain of an antenna of equal area. The desirable 100% aperture efficiency will only be achieved when:

1. The complete surface is illuminated with the exact same number of watts per square inch.
2. There is no phase error on any of those square inches -- this means no bumps in the reflector and no feed horn phase errors in the Primary Pattern.
3. And there is no spill-over energy being wasted.

WHAT'S PRACTICAL -- You can either loose a lot of sleep fretting over how you are going to make your aperture efficiency go from 55% up to 65%, or you can simply add another foot to the diameter to the Parabolic Reflector (and properly illuminate it) -- both may yield the same gain increase. The second approach is much faster, cheaper, and practical.

MANY ANTENNAS HAVE 100% ? -- The world is filled up with Parabolic Antennas that have an aperture efficiency of about 98% -- they are called "Diffraction Limited" Telescopes. My 8 inch diameter telescope has about that aperture efficiency. It achieves this because the Parabolic Reflector is 370,000 wavelengths in diameter, and the Feed Horn (the Eye Piece) does create the desirable Primary Pattern; it is 9,000 wavelengths in diameter, that allows it to do that.

SIDELOBES vs EFFICIENCY -- Here is the real kicker concerning sidelobes and sidelobe "wasted" energy. A Diffraction Limited telescope could be described as one where the Parabolic Reflector has about 1/20 wavelength accuracy, and the rest of the optical system is working properly. That telescope could easily have an Aperture Efficiency of 98%. That's the highest Gain you are ever going to get out of that available area. But now, lets see what it is really doing.

THE AIRY DISC -- As all astronomers know, every Diffraction Limited telescope creates a "picture" (the antenna pattern) that contains an Airy Disc. That means that around every star in the image you will see some dim rings (the sidelobes). The Airy Disk is present in all diffraction limited optics systems (and in all antenna patterns). A proper Airy Disk does not represent a system error. However, if a system error is present, the Airy Disk will change in a characteristic way that's beautifully pictured in Suiter's book, "Star Testing Astronomical Telescopes: A Manual for Optical Evaluation and Adjustment" by Harold Richard Suiter, $29.95 at Amazon.com.

HOW MUCH POWER IN THOSE SIDELOBES? -- From my Melles Griot "Optics Guide 5" catalog, in the section entitled Fundamental Optics, they say that the Diffraction Limited Airy disc will have a Central Maximum region relative intensity of 1.0 (that's the antenna's main lobe at boresight), and 83.8% of the energy is located there. The first ring (I call this the 1st sidelobe), will have a relative intensity of 0.0175 (I call this -17.57 dB), and will contain 7.2% of the energy. The second ring relative intensity will be 0.0042 (I call this -23.77 dB), and will contain 2.8% of the energy. The 3rd ring intensity is 0.0016 (I call this -27.96 dB), containing 1.5% energy. The 4th ring is 0.0008 (I call this -30.97 dB), containing 1.0% energy, and a bunch more dimmer rings with less and less energy (the remaining 3.7%).

100% APERTURE EFFICIENCY CHARACTERISTICS -- Now let's review those last statements. A Diffraction Limited 100% aperture efficient telescope has 83.8

% of the received energy located in the main lobe, 7.2% of the received energy located in the first sidelobe, 2.8% of the received energy is located in the second sidelobe, and 1.5% of the received energy is located in the 3rd sidelobe, etc. These are the best numbers you are ever going to get from a perfect, round aperture, that is not an infinite number of wavelengths in diameter.

REMOVE THE SIDELOBES, NO WAY! -- There is an amazing number of amateurs and engineers out there who are dreaming about getting rid of ALL of those side lobes and their "wasted" energy. This is a VERY FUTILE EFFORT. When a circular aperture HAS 100% aperture efficiency, it WILL HAVE sidelobes that are exactly that strong (-17.57 dB [1st sidelobe], -23.77 dB [2nd sidelobe], -27.96 dB [3rd sidelobe], etc.) and the amount of energy in each of those sidelobes WILL BE exactly the numbers indicated (7.2%, 2.8%, 1.5%, etc.).

REAL DESIGNS -- You can definitely design an antenna with weaker sidelobes; but it WILL HAVE less Gain. You can design an antenna with stronger sidelobes; and it also WILL HAVE less Gain. You can then design a low loss (no pads) circular aperture antenna with exactly those magic sidelobe levels; and it will have the MAXIMUM GAIN for that size aperture.

IS THIS REASONABLE? -- Of coarse this doesn't seem to make sense, but that's the way "Mother Nature" and Diffraction Limiter 100% aperture efficiency antennas (and telescopes) behave. Those sidelobes are the result of the abrupt change in the illumination taper at the edge of the aperture – Mother Nature reacts to them by creating sidelobes. You could slowly taper the energy as you approach the edge of the aperture; that will decrease the abruptness of the illumination taper and it will lower the sidelobes, but the available Gain will decrease when you do this. You can't have it both ways (maximum Gain and no sidelobes).

SO LET'S STOP THE INSANITY -- It's time we microwavers, amateurs, engineers, and interested scientists stop seeking Maximum Gain antennas that have minuscule sidelobes; it isn't going to happen. At least I can say, it's not going to happen in THIS universe, that operates with THIS SET of the Laws of Physics that determine our antenna patterns by using what the mathematicians call Window Functions -- that's the way you feed an aperture.

THE YAGI CONNECTION -- A well tuned long Yagi antenna has a nearly circular aperture with a nearly uniform aperture distribution. It is interesting to note that such a Yagi usually has a set of sidelobes that are very nearly -17.5, -23.8, -27.9, and -30.9 dB. I think we have been looking at the Yagi antenna's "Airy disc" for a long time, we just didn't give it that name.

DISH COMPARISON -- A well tuned Parabolic Dish antenna has weaker sidelobes than these, simply because the best available feed horns need to use an Amplitude Taper of -10 dB at the Dish perimeter.

GOOD OPTICS BOOKS -- For those microwavers who wish to dig deeper and try to understand this material I recommend reading some of the better optics books. I soon recognized that the guys who have gotten the subject of High Aperture Efficiency down to a science are the optics people. They can easily do this because their "parabolic antennas" frequently are more than 100,000 wavelengths in diameter. Their "feed horn" is called the eyepiece. Their books can give us a lot of insight into what is really achievable with our microwave antennas.

THE REFERENCE -- Here is what I believe is one of the best books on optics. It's modern, well illustrated with computer-generated graphics and photos, and it's in it's 3rd edition: Eugene Hecht, "Optics", Addison-Wesley, 3rd edition, 1998. It's much nicer than the classic, Born and Wolfe, "Principles of Optics", Cambridge University Press, seventh edition, 1999.

AIRY DISC DEFINITION -- Chapter 5, page 228 of Hecht says: "Because an instrument can only collect a portion of the incident wavefront to be reformed into an image, there will always be diffraction: the light will deviate from straight-line propagation and spread out somewhat in the image plane. When an optical system with a circular aperture receives plane waves, rather than there being an image "point", the light actually spreads out into a tiny circular spot (called the Airy disc, containing about 84% of the energy), surrounded by very faint rings. The radius of the Airy disc determines the overlapping of neighboring images and therefore the resolution. That's why an imaging system that is as perfect as possible is referred to as Diffraction Limited. For a perfect instrument, the ideal theoretical angular resolution is given by the radius of the Airy disc, which is [1.22 x Lambda / D] radians (this is the Rayleigh criteria). Another way to present the angular resolution is [2.52 x 10^5 x Lambda / D] arc-seconds." I added the parenthesis.

73 es Good VHF/UHF/SHF/EHF/EME DX,
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