SATELLITE SPACING - THE NO PARKING SIGN
A Report On The Problems and Some Solutions

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Abstract

The text describes a novel optical design, featuring innovative reflex plates for small aperture (3m) antennas along with new technology in feed horn design and application.

When used as a microwave antenna system, the design forces the antenna to assume the performance and radiation pattern characteristics of a much larger aperture, opening the door for small aperture use at 2° orbital spacing.

The design also incorporates a new combination of materials and manufacturing processes which have greatly expanded the operating frequency range, service life, and field maintenance of the system.

Space communications is the newest frontier; to suggest, at this early stage, that our industry is incapable of solving a corridor crowding potential may be irresponsible. Satellites are now allotted 4° parking slots across the Geostationary parkway; the FCC is suggesting that the allocated separation be reduced to provide for more growth. We can, and must, anticipate that 3° spacing is both inevitable and temporary - followed by 2° spacing.

Accordingly, this report will address itself to these problems and to some solutions for satellite communications.

Reduction of satellite spacing means different problems to different sections of our industry, but the common thread which binds us all is "interference". To reduce the effect of the anticipated interference on earth stations, the FCC has proposed a change to Part 25.209 to read $29-25\,\mathrm{Log}_{10}\theta$ for 1° - 7°. This proposal effectively reduces the field of view of the antenna so that it sees less angular space at 22,300Nm. Good, large aperture antennas (5m+) now enjoy this view restriction per the inverse relationship between aperture size and beam width.

Small aperture antennas, however, have not been noted for narrow field of view, especially the rapidly expanding 3m sector of our market. The conventional 3 meter antenna has the widest field of view of the classic parabolic configurations so should suffer the most at 2° orbital spacing. To make a small aperture antenna work, and work superbly at 2° spacing, will involve an unconventional approach to design and manufacture, though the objectives are simple:

1) Develop a 3m reflector configuration which narrows the 3_{db} beam width and the peak beam.
2) Develop a feed system which significantly increases gain and suppresses side lobes.

We will first examine the reflector. Let's establish a photographic analogy to better understand antenna optics. Let's define our antenna as a camera and a distant satellite as the subject to be photographed - not forgetting that it is an invisible target. We know its general location in space and that it is generating an infinitesmal amount of light. Logically, we select the largest aperture lens at our disposal for maximum light gathering potential, understanding that there is an inverse relationship between "big" and "good". We aim our camera into the designated area in space, use our light meter to better pin-point our aim, take a few test shots and suddenly we have an exposure of the invisible subject. But we never know where the subject is relative to our field of view; we receive the same exposure when the subject is in the corner of our viewing field, as is the case when it is centered within our lens. To make matters worse, our field of view is 1,860 miles, and our target only 10 feet in diameter - our margin for sighting error is more than modest.

Now, let's switch to a super telephoto lens and halve our field of view (now 930 miles) though we all know that this lens change will reduce our speed which lessens our exposure, so we have lost more than we've gained. True, we could construct a telephoto lens of sufficient aperture and speed to restore the loss, but that would cost dearly - yet we are still confronted with a potential sighting error of 930 miles.

Why is it so important to have good composition (a centered subject) and a restricted field of view? The answer should now be obvious for without the ability to discriminate and sight a specific subject, the addition of other closely spaced subjects could make your camera useless: But don't throw your camera away yet!

In that we are not photographing a discrete subject, only recording all its available light, we can optically restrict what your camera sees without effecting its speed or distorting the energy creating the exposure. Let's add a long black tube over your lens that extends out into space 12 inches, 12 feet or 12 miles. Suddenly, this blinder forces you to pin-point your target or the lens will not see the subject. Because your subject is a speck in space, and all of its energy is traveling parallel to your tube, no light is lost once the tube is pointed at the subject - so you have the necessary exposure and your aiming accuracy (field of view) is directly proportional to the length of the tube extended over the lens. And, most importantly, this tube prevents your lens from seeing <u>other subjects</u> that are moving closer to your <u>primary subject</u>, so unwanted light is rejected.

A satellite antenna, fortunately, is optically very different from a lens; a lens is refractive (transparent) and an antenna is reflective (opaque). As a reflector, our antenna responds to the law of reflection (all energy will reflect from its surface at its angle of entrance). By using this ancient and immutable law of physics, we can now easily construct an equivalent version of the blinder tubes by the use of optical reflex plates within the concavity of our antenna.

If these optical reflex plates are positioned or aimed perpendicular to the satellite, the emitted energy from the satellite is unobscured by these plates and a full signal is recorded. However, any error in the aim of the antenna will cause a corresponding change in the reflex plate's reflection angle; if the satellite is off-axis to the optical center of the antenna, its reflection angle will be off-axis to the reflex plates of the antenna, and the incoming signal is now obscured or shadowed from the detector.

Technically, we have constructed a metal maze in which there is a restricted and narrow entrance. As with the tubes, we now have the ability to pin-point our target and to reject the light being emitted from neighboring satellites. As with the blinder tube, the degree of rejection and the field of view is a function of the size and termination point of the optical reflex plates and the focal length of our antenna. Using conventional optical equations, a 2° field of view is an easy task; it is now theoretically possible to mass produce small aperture ($\lesssim$3m) antenna systems with a viewing angle of under 2°.

To understand the problem of 2° spacing with respect to 3m or smaller apertures will call for a quick primer in optics and the determination of the field of view for a specific aperture size. In optics, a parabola is classified as a "Diffraction Limited Optical System" and as such, exhibits a Fraunhoffer ① diffraction distribution for a circular aperture. To determine the field of view of the aperture we must know the central angular radius of the peak beam at the base. This radius is given by the following formula:

$$\text{Radius } \varnothing = 1.22 \times \frac{\text{Wave Length in Meters}}{\text{Diameter in Meters}} \quad ②$$

To translate this to field of view we simply multiply this angle by the distance between the earth station and the satellite. In our case, for geostationary use, it's 22.3Knm. Knowing this we can now predict the base angular radius of any aperture at any frequency and determine its field of view in miles. Remembering that 2° spacing is roughly 930 miles point to point between satellites, this sets our maximum field of view at 1860 miles as the go/no go field of view limit for 2° reception. Determining the field of view for a 3 meter aperture at a wave length of 8.11 cm ($3.7GH_z$) we have;

$$\varnothing = 1.22 \times \frac{\text{Wave Length in Meters}}{\text{Diameter in Meters}}$$

$$\varnothing = \frac{1.22 \times 8.11 \times .01}{10' \times 12'' \times .0254}$$

$$\varnothing = \frac{1.22 \times .0811}{3.048} = \frac{.099}{3.05} = .0324 \text{ Radians}$$

Converting that resultant to degrees we have: $.0324 \times 57.3 = 1.86^{\circ}$

This is the angular field of view in degrees either side of zero for the peak beam. To determine the full field of view for the aperture at that frequency double the angle, convert it to radians and multiply by 22,300nm.

$1.86^{\circ} \times 2 \times .0174 \times 22{,}300 = 1443.7$ miles According to this equation a 3m aperture at the designated frequency should have a field of view of less than 1860 miles which should satisfy part of the requirement for 2° reception. So what's the problem?

In reality a 3m antenna, or any antenna, is, optically speaking, quite poor. We must remember that these mathematical equations are assuming 100% accuracy throughout all aspects of reflector design, manufacture, and assembly. Figure A is an example of a conventional 3m antenna at a frequency of $3.7GH_z$ vertical pole. Its base angle is 6.5°. Converting the base angle to field of view we have $6.5^{\circ} \times .0174 \times 22{,}300 = 2{,}522.1$ miles. <u>Now</u>, the real problem is in better focus--the peak beam is 662 miles wider than our limit of 1860 miles. Fig. B is a typical vertical pole pattern for our own SAR 10.3 at $3.7GH_z$, using a commercially available scalar feed. Here we have a base angular dimension of 4.19°. Converting this to field of view we have: $4.19^{\circ} \times .0174 \times 22{,}300 = 1625.7$ miles. Now our peak beam field of view is almost 235 miles under our limit which more than satisfied the 2° requirement. The 3db beam width on this pattern is 1.65°.

Fig. A Scale: 1° Per Division

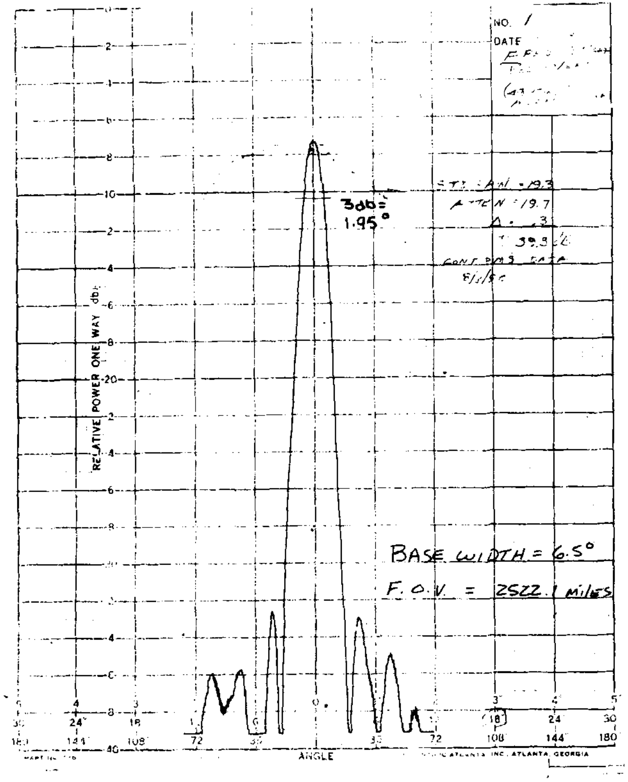
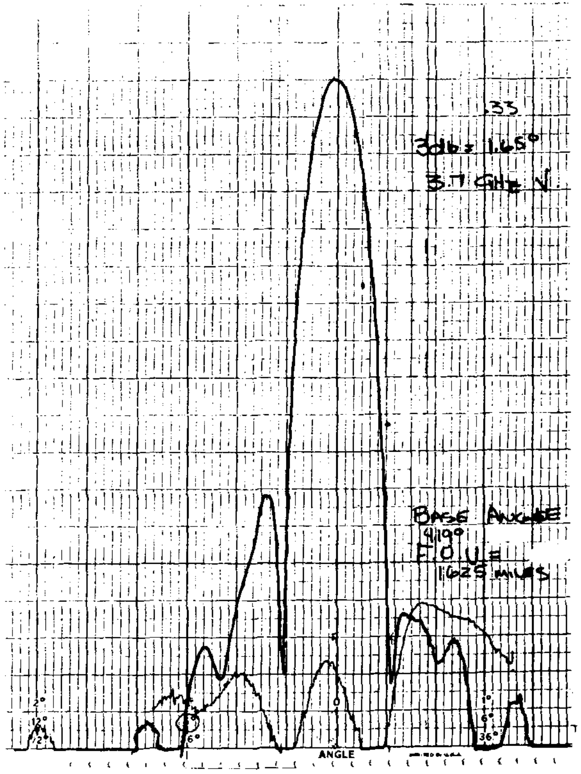


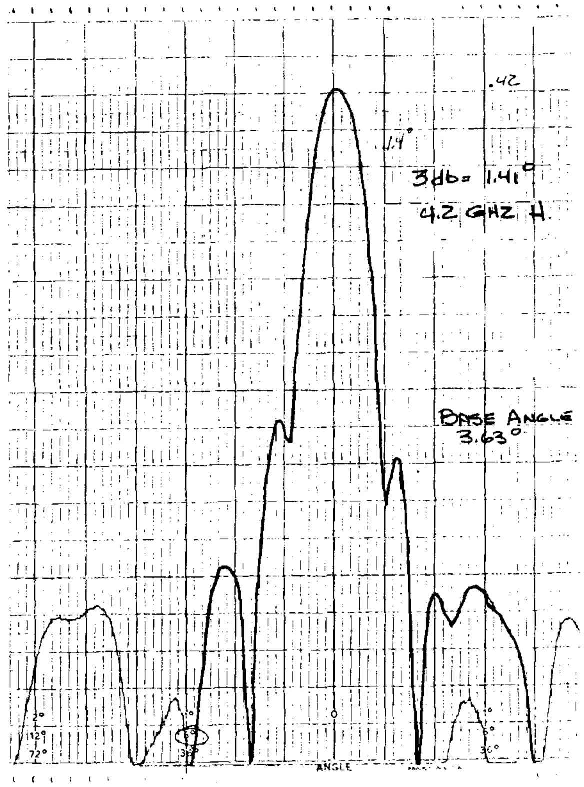
Fig. B Scale: .33° Per Division



We at SAVAC achieve this restricted field of view partially through the use of our optical reflex plates within the concavity of the antenna. The plates cause the distribution of energy per degree of angle to roll off the peak much faster than would normally occur in a conventional unobstructed parabolic reflector. By increasing the height of the plates, further reductions of beam width can be achieved.

Fig. C is a pattern of the SAR 10.4 at 4.2 GH_z H. pole. (again using a commercial scalar feed). The 10.4 system had a 3 db beam width of 1.4° and a base angle of 3.63° (1408 f.o.v.). While there are many other functions of our reflex plates, their main optical function is to achieve the reduced base angle and 3db beam width of the aperture so that it sees one and only one satellite at 2° spacing. Now that we have developed a reflector with a field of view that meets 2° spacing, the remaining challenge is side lobe control to minimize interference.

Fig. C Scale: .33° Per Division



Side lobes can be manipulated by either one or both of the following techniques:

a) Side lobe position
b) Side lobe magnitude

SAVAC has chosen to influence both parameters to insure more trouble free reception at 2° spacing. Side lobe position is largely controlled by the F/D of the dish. For example, Fig. D is a breakdown of the 1st side lobe position at 3 frequencies for the SAR 10.3 and 10.4 using a ratio equivelent reflex plate height. The side lobes on the .42 are on the average 1° nearer the peak beam than the .33. While both will work at 2° spacing the .42 provides a more comfortable margin.

Side lobe magnitude is altered by developing a new concept in feed horn design which significantly increases net gain, allowing for extremely low edge illumination tapers, while maintaining a 41+dbi gain figure--and secondarily, the suppression of near in lobes. SAVAC has filed patents on just such a feed. It incorporates a precision scalar configuration which exhibits superior beam width equalization and phase center control but most importantly, incorporates a new concept in transition from circular to 229 guide.

Fig. D

10.3	39"Focus	10.4	51"Focus
F/D = .33		F/D = .42	
Freq.	Position	Freq.	Position
3.7	3.74°	3.7	2.4°
4.0	2.47°	4.0	2.28°
4.2	2.23°	4.2	2.80°

As this new feed was incorporated into our reflector, the overall antenna efficiency increased 15%, yielding an antenna gain unparalleled by any other 3m antenna.

This designed increase in gain permitted us more freedom in the use of the new feed system, to further refine our performance:

1) To significantly under illuminate the antenna for the suppression of far out lobes.
2) To selectively illuminate the balance of the antenna for near in lobe suppression.

It is well known that different degrees of edge illumination tapers can be achieved by controlling the primary radiation patterns of a horn. One can achieve as wide as 180° or as little as 15° by altering the number, size, spacing, and flare angle of the convolutions in the horn. SAVAC selectively illuminated areas of the antenna for the control of near in lobes.

The face of a feed horn can be "mapped" to pin-point those areas of the reflector most influenced by a given sector of the feed. Once the secondary radiation patterns are cut, one can determine the angular position of the lobes by inspection, and relate it to a physical region of the antenna.

The remaining job is to identify that sector of the feed which illuminates that region of the antenna and modify it so that it under illuminates that region. The net result is suppressed near in lobes.

Since the side lobes are fixed as a function of the aperture size and F/D, all horns are factory set and are interchangeable to any SAVAC antenna of common F/D.

The SAR 10 antenna is the industry's first entirely vacuum formed, optically graded reflector. Typical reflector RMS is approximately .003". The reflector consists of two parts.

1) Vacuum formed optical substrates formed from high impact ABS.
2) A 100% R. F. reflective film which is secured to the reflective side.

By virtue of our cold lamination process, the surface RMS provided by the parent tooling is preserved throughout all phases of manufacturing which allows us to offer an RMS which could only previously be obtained via a costly spun aluminum process.

When the manufacturing process is complete, the ABS substrate is sandwiched between UV and IR stablized films. This combination of polymers protects the substrate from the most harsh outdoor environments for a period which should exceed 10 years.

Vacuum forming is by no means a new art but it has many advantages when used as a manufacturing tool for satellite antennas. For example, the tooling required is cost effective; molds can be quickly modified or repaired with a minimum of time and money.

Process parameters such as shrinkage can be controlled to within .020" from lot to lot throughout the year. This uniformity guarantees the end user two major benefits:

1) Repeatable and predictable performance from all units.
2) Stocked and off the shelf replacement reflector segments for the antenna.

Factory replacement parts are not limited to the reflector segments only. In fact, all components of the antenna are field serviceable and replaceable.

SAVAC is currently developing a retro fit kit for conventional small aperture antennas which will include 3 items.

1) RF reflective film
2) Optical reflex plates
3) SAVAC feed, less the provision for near in lobe control.

When an antenna is retrofitted using the above mentioned kit, it will improve efficiency 8-15% and will exhibit a related increase in gain on the order of 1 to 2 dbi.

The near optical grade reflector surface on the SAR 10 boasts the widest available frequency range of all small aperture antennas on the market today (well in excess of 30GH$_z$).

Due to the optical reflex plate configuration the antenna has consistently demonstrated lower wind loading and noise temperature specifications.

Perhaps the most important advantage is with respect to shipping logistics.

The SAR 10 antennas require less volume to ship as a result of the "nesting" of the parts. Because of weight to volume ratio of the package, the antenna is inherently cheaper to ship on a commercial carrier than other 4 piece or 1 piece fiberglass counterparts, which represents a considerable cost savings to all buyers.

It has often been said that necessity is the mother of invention and the SAR 10 is a good case in point. The antenna for the future will have to contend with a number of new problems not prevalent in the past, including:

A) Decreased orbital spacing
B) Increasingly noisier ambients, and
C) Reception from hybrid dual frequency satellites -- to name a few.

The SAR 10 antennas in our opinion are the only small aperture antennas which were designed in anticipation of the known spacing problems, as well as other.

The 80's hold a virtual renaissance in technological advances for satellite communications. The SAR 10 antennas and feeds represent only a small part of the wonders to come. Almost unbelievable advances in LNA's, receivers, and transmission line are just around the corner.

We at SAVAC are proud to be a part of this communications revolution, and hope to share with you still more improvements when we meet again.

ACKNOWLEDGEMENTS

The author wishes to thank the following people for their contributions and help in preparing this paper:

1) Marvin P. Hodges: Director, SAVAC Int., Inc
2) Dr. Richard Buchroeder: President, Optical Center, Tucson, AR.
3) Tony Sciarrino: President, Space Machine & Design, Consultant - SAVAC Int., Inc.
4) Carl Schmitt: Manager Spectrum Engineering, Comsat General

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