Short Papers

Computer-Aided Design of Reflector Antennas: The Green Bank Radio Telescope

Marco A. B. Terada and Warren L. Stutzman

***Abstract*— This paper presents an evaluation of the electrical performance of the Green Bank Telescope (GBT) reflector antenna [1], [2], operating as single- and dual-offset configurations, as well as a general overview of the GBT system. The GBT dual-offset Gregorian configuration is designed for low cross polarization (XPOL) using the dual-offset reflector antenna (DORA) synthesis package code developed by the authors [3]. The procedure implemented in DORA to upgrade an existing main reflector to a low cross-polarized dual-offset Gregorian reflector antenna is also described in this paper. All computed patterns were obtained with the parabolic reflector analysis code (PRAC) program, also developed by the authors [3], and with the commercial code GRASP7.[1] The Green Bank Telescope (GBT) radiation patterns and performance values, which include original data not available anywhere else as far as the authors know, indicate that low XPOL performance can be achieved with a dual-offset configuration, provided that a low XPOL feed is used. The GBT configuration is employed as a case example for the aforementioned procedure. However, an effort is made to present the main conclusions as generically as possible.**

***Index Terms*— Green Bank Radio Telescope, low cross-polarization design algorithms, single- and dual-offset reflector configurations.**

I. Introduction

The Green Bank Radio Telescope (GBT) will be the largest fully steerable radio telescope in the world. It is currently under construction and is expected to be completed by 1999. Its offset design provides a clear 100-m-diameter projected aperture. The GBT structure can be pointed to view the entire sky down to a 5° elevation angle using a wheel and track mechanical design. The reflecting surface consists of 2000 solid panels that can be positioned using actuators behind the panels. A laser-ranging system will be used to determine the positions of the panels, adjusting surface accuracy with closed loop control.

The GBT is connected to radiometers that can receive signals in several frequency bands. From 290 to 1230 MHz, the GBT operates as a single-offset reflector using a feed assembly aimed directly at the main reflector. From 1 to 45 GHz, it operates as a Gregorian dual-offset reflector using the feeds in the receiver room that are aimed at the ellipsoidal subreflector. The Gregorian configuration has the focal point in front of the subreflector, allowing it to remain fixed even when the telescope operates in the single-offset reflector mode. This is not possible with a Cassegrain configuration [1].

In this paper, we evaluate the electrical performance of the GBT single and dual configurations using the programs parabolic reflector analysis code (PRAC) and general reflector antenna synthesis package (GRASP7).[1] The GBT dual-offset Gregorian configuration is designed for low cross polarization (XPOL) using the code dual-offset reflector antenna (DORA) code synthesis package, developed by the authors [3]. The geometrical parameters determined with DORA are in very good agreement with the ones published in [1]. New dual configurations employing the GBT offset main reflector can be obtained with DORA if input parameters, such as the subreflector size obtained from [1], are changed.

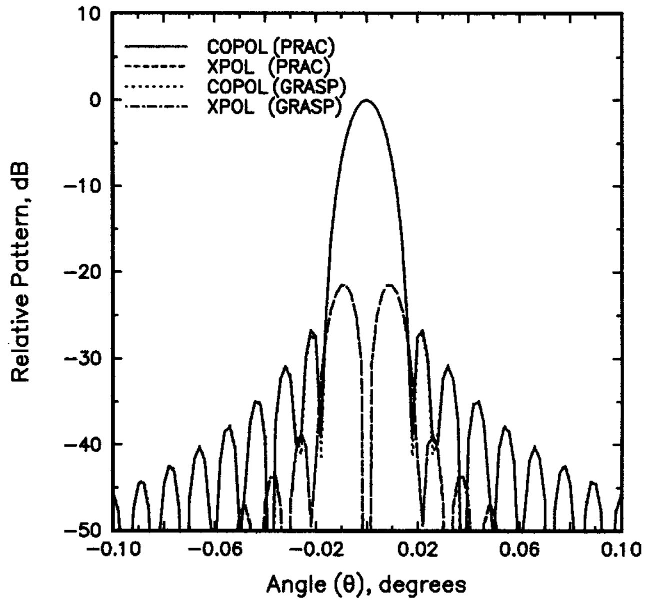

Fig. 1. Radiation patterns of the GBT single-offset reflector configuration of Table I ($f = 15$ GHz).

II. The GBT Single-Offset Configuration

We start by examining the GBT single-offset configuration with the characteristics listed in Table I. Fig. 1 shows the computed co- and cross-polarized patterns for the offset parabolic reflector of Table I in the plane normal to the plane of symmetry. XPOL is expected to be maximum in this plane [4]. The patterns were computed using both the commercial code GRASP7[1] and the program PRAC.

PRAC is a user-friendly code developed by the authors to analyze axisymmetric and offset parabolic reflectors. PRAC evaluates the radiation integral (physical-optics surface-current integration) with the Jacobi–Bessel method [5], [6], and yields the co- and cross-polarized radiated fields with high accuracy and efficiency. PRAC is currently being used by many universities and major industries worldwide, and an academic version of the code will be distributed with the second edition of [7].

We note from Fig. 1 that both PRAC and GRASP7 yield almost identical results for this reflector configuration. Table I also lists the computed performance values, which were obtained at 15 GHz to be compared with the results listed in Section III for the GBT dual-offset configuration. We note from Table I that gain is 82.87 dBi and XPOL is −21.54 dB (61.33 dBi), as computed by PRAC. This example is typical of single-offset reflectors and shows that single-

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M. A. B. Terada is with the Antenna Group, Department of Electrical Engineering, University of Brasilia, CEP 70.919-970 Brazil (e-mail: terada@unb.br).

W. L. Stutzman is with the Antenna Laboratory, Department of Electrical Engineering, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061 USA (e-mail: stutzman@vt.edu).

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[1] TICRA Eng., *GRASP7—Single and Dual Reflector Antenna Program Package,* Copenhagen, Denmark.

TABLE I
GEOMETRICAL PARAMETERS AND PERFORMANCE VALUES FOR THE GBT SINGLE-OFFSET REFLECTOR CONFIGURATION

Main Reflector Configuration:		
Shape: Offset paraboloid		
Projected diameter (*D*), m	100.0	
Parent ref. diameter (*Dp*), m	208.0	
Focal length (*F*), m	60.0	
Offset of reflector center (*H*), m	54.0	
Feed Configuration:	**PRAC**	**GRASP**
Polarization	Linear (*xf*)	Linear (*xf*)
Pattern shape	$\cos^{4.58}$	Gaussian
Gain (*Gf*), dBi	13.08	13.14
10-dB beamwidth, degrees	77.92	77.92
Feed angle (ψf), degrees	42.77	42.77
Feed taper (Lower,Upper), dB	(-10.0,-10.0)	(-10.0,-10.0)
System Performance:	**PRAC**	**GRASP**
Gain (*G*), dBi	82.87	82.79
Cross Polarization level (XPOL), dB	-21.54	-21.56
Side lobe level (SLL), dB	-26.72	-27.21
Aperture efficiency (ε_{ap}), %	78.48	77.05

offset paraboloids illuminated by conventional feeds are limited by XPOL performance. An XPOL level of approximately -22 dB is often unacceptable high [3], [8]. In the following section, we add an ellipsoidal subreflector to the GBT offset paraboloid in order to form a low XPOL dual-offset Gregorian configuration.

III. THE GBT DUAL-OFFSET GREGORIAN CONFIGURATION

Dual-offset reflector configurations can be designed for low geometrical optics XPOL when illuminated by a pure linearly polarized (LP) feed [9], [10]. Our goal is to study how the GBT single-offset reflector of Table I can be upgraded to a low cross-polarized dual-offset Gregorian reflector antenna. This can be accomplished by adding a concave ellipsoidal subreflector to the original single reflector system. The general geometry of a dual-offset Gregorian antenna and all associated symbols is presented in Fig. 2. The Gregorian configuration allows the main reflector to be used in either mode without the need of removing the subreflector. This is not possible with a Cassegrain configuration [1].

The procedure developed in [3], which has its initial part similar to [9] and [10], and was implemented in the DORA code, is especially useful in upgrading existing single reflector configurations with any degree of offset and is applied to the GBT offset paraboloid of Table I to determine the corresponding low cross-polarized dual configuration. Design parameters, such as the desired subreflector size, were obtained from [1]. The resulting configuration is listed in Table II and agrees well with the one published in [1]. It is worth noting that DORA uses the main reflector as a fixed input parameter, a feature that makes DORA especially recommended for the GBT case example, given that the GBT offset main reflector once built cannot be easily changed. Although not performed in this work, new dual

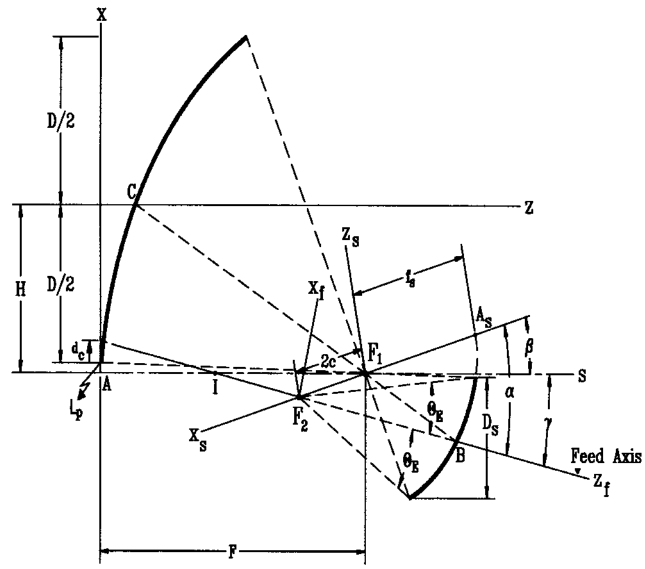

Fig. 2. Geometry for the dual-offset Gregorian reflector antenna.

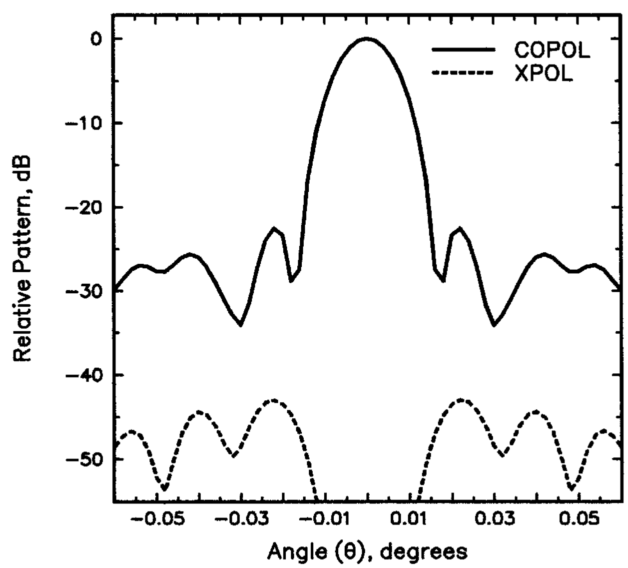

Fig. 3. Radiation patterns of the GBT dual-offset reflector configuration of Table II ($f = 15$ GHz).

configurations employing the GBT offset main reflector of Table I can be obtained with DORA for different design parameters, such as a new subreflector size or feed configuration.

Fig. 3 shows the co- and cross-polarized patterns computed at 15 GHz by GRASP in the plane normal to the plane of symmetry (i.e., the yz-plane in Fig. 2). Table II also presents the performance values at 15 GHz computed with GRASP in this same plane. We note that XPOL is now -43.01 dB, more than 20 dB lower than the XPOL of the single configuration in Table I. However, a feed antenna with high XPOL will likely degrade the total system XPOL performance.

IV. XPOL REDUCTION WITH PRACTICAL MANUFACTURING CONSTRAINTS

Cost-effective designs require that an existing single-offset reflector mold be used to construct the main reflector of a dual configuration. However, many such molds are for just fully offset geometries (i.e., the bottom of the reflector just touches its axis of symmetry). This,

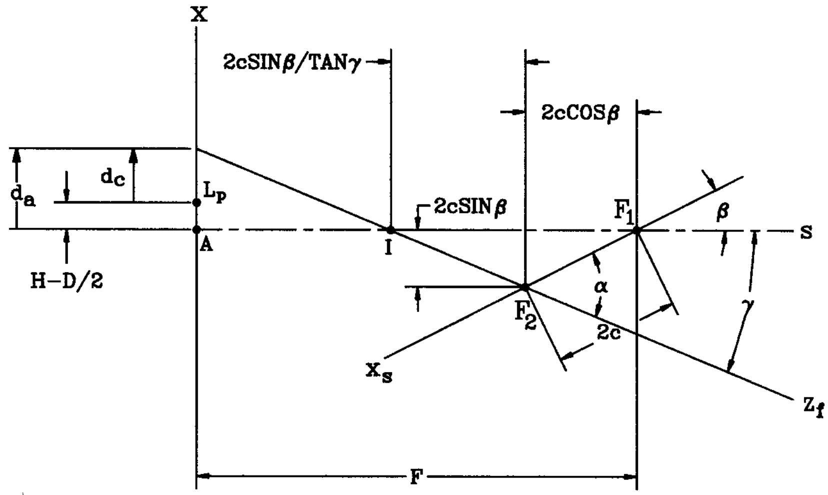

Fig. 4. Geometrical determination of the distance d_c.

TABLE II
GEOMETRICAL AND PERFORMANCE VALUES FOR THE GBT DUAL-OFFSET REFLECTOR CONFIGURATION

Main Reflector Configuration:	
Shape: Offset paraboloid	
Projected diameter (*D*), m	100.0
Parent ref. diameter (*Dp*), m	208.0
Focal length (*F*), m	60.0
Offset of reflector center (*H*), m	54.0
Subreflector Configuration:	
Shape: Offset ellipsoid	
Projected height (D_S), m	7.55
Parameter *c* of ellipse, m	5.9855
Parameter f_S of ellipse, m	5.3542
Eccentricity *e*	0.5278
Angle (β), degrees	5.58
Feed Configuration:	**GRASP**
Polarization	Linear (*xf*)
Pattern shape	Gaussian
Gain (*Gf*), dBi	21.31
10-dB beamwidth, degrees	30.00
Angle (α), degrees	17.91
Angle (γ), degrees	12.33
Clearance distance (d_c), m	5.3468
System Performance:	**GRASP**
Gain (*G*), dBi	82.83
Cross Polarization level (XPOL), dB	-43.01
Side lobe level (SLL), dB	-22.56
Spillover loss, dB	0.94
Aperture efficiency (ε_{ap}), %	77.76

in turn, leads to a dual-reflector configuration that is Gregorian with the feed axis z_f intersecting the main reflector. The same problem may also occur in certain Gregorian configurations even when the main reflector is not just fully offset. It is desirable that the final design provide suitable clearance between the main reflector and the feed axis in order to access the feed antenna with a straight section of waveguide, thus reducing the complexity and cost of the mechanical structure. This feature is especially valuable when a dual-offset reflector configuration is to be produced in large scale, and does not necessarily apply to the GBT dual-offset configuration studied in this paper.

In general, the distance d_c between the projection of the bottom of the main reflector (point L_p in Fig. 2) and the feed axis displacement from the reflector axis s, as shown in Fig. 4, is given by

$$d_c = F\tan\gamma - 2c(\sin\beta + \cos\beta\tan\gamma) - (H - D/2). \quad (1)$$

All symbols are defined in Fig. 3. The angle γ is related to α and β as

$$\gamma = \alpha - \beta \quad (2)$$

which follows from the triangle formed by the points I, F_1, and F_2 in Fig. 4.

We note from Figs. 2 and 4 that for $d_c = 0$, the feed axis strikes the projection of the bottom edge of the main reflector (point L_p). For $d_c < 0$, there is a clearance between the bottom of the main reflector and the feed axis. From Table II, we note that the clearance distance d_c for the GBT dual-offset configuration, computed according to (1), is 5.3468 m. This shows that the feed axis intersects the main reflector of the dual configuration. However, due to the large dimensions of the reflectors, it is not necessary to impose the clearance constraint mentioned in this section. Nevertheless, this case example shows that the feed axis can intersect main reflectors that are not necessarily just fully offset. In general, the problem depends on the degree of offset H and on the physical dimensions of the reflectors, as showed by the GBT case example.

When required, which is not the case of the GBT dual-offset configuration, feed region clearance can be achieved by rotating the parent ellipsoid (i.e., the conical surface from where the offset subreflector is generated) until a desired clearance is obtained. The rotation, as implemented in the code DORA, is performed in a way such that the feed remains pointed toward the intersection of the new subreflector and the ray coming from the center of the main reflector. The procedure avoids the introduction of spillover and phase errors, thus maintaining a satisfactory aperture efficiency and broad operational bandwidth.

The nonconventional design obtained after the rotation of the parent ellipsoid may present an XPOL degradation due to the fact that the minimum XPOL conditions—Mizugutch and Rusch conditions [9], [10]—are no longer satisfied. Our solution to this problem is to alter the value of the subreflector eccentricity, while keeping all orientation angles constant. In general, eccentricity values greater than the one employed before the rotation will reduce system XPOL. The synthesis algorithm implemented in DORA produces a low cross-polarized (-35-dB or better) dual-offset Gregorian antenna which has adequate clearance between the feed axis and the bottom of the main reflector. In addition, the resulting configuration has the ability to operate with either an LP or a circularly polarized (CP) feed over a wide bandwidth without the need of being repositioned (no substantial beam squint). The GBT radio telescope is to be illuminated by CP feeds and, therefore, beam squint must be carefully taken into account for proper operation. Detailed information on CP feeds and beam squint can be found in [8].

V. Conclusions

The electrical performance of the GBT reflector antenna was evaluated with the commercial code GRASP7 and the code PRAC. The code DORA, developed by the authors, was employed to upgrade the GBT single-offset configuration to a low cross-polarized dual-offset Gregorian reflector configuration. The results from DORA are in very good agreement with published ones [1]. The procedure implemented in DORA, as discussed in this paper, uses the main reflector as a fixed input parameter, a feature that makes DORA especially recommended for the GBT case example, given that the GBT offset main reflector once built cannot be easily changed. New designs for the GBT suboptics assembly can be obtained with DORA if the subreflector size, or other parameter such as the feed configuration, is changed.

The computer simulations confirmed a low XPOL level when the GBT dual configuration is illuminated by a purely polarized feed antenna. A single feed antenna or array with high XPOL will likely degrade the total system XPOL performance. Finally, a procedure was described to reduce XPOL in dual-offset Gregorian reflector antennas while attending practical manufacturing constraints, such as an adequate feed region clearance. An effort was made to present the main conclusions as generically as possible.

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Recirculating Loop for Experimental Evaluation of EDFA Saturated Regime Effects on Optical Communication Systems

Claudio Mazzali and Hugo L. Fragnito

***Abstract*—We demonstrate an optical-fiber recirculating loop for experimental simulation of long-haul optical communication systems using cascaded erbium-doped fiber amplifiers (EDFA's) operating in the gain saturation regime. The loop contains sections of dispersion shifted fibers (DSF's), standard fiber, and a set of in-line devices, such as tuning filters, optical amplifiers, polarization controllers, and a variable attenuator. The main results presented here are related to the observation of the effects due to the slow dynamics of the EDFA. We also discuss the validity of using an optical attenuator to simulate an extra length of fiber.**

***Index Terms*—Optical amplifiers, optical communications, recirculating loops.**

I. Introduction

Optical recirculating loops are useful tools for experimental simulations of long-distance communications ($>$100 km) where the performance of system components can be evaluated at a greatly reduced cost as compared to straight transmission experiments or field tests. Fiber loops with erbium-doped fiber amplifiers (EDFA's) can be used to experimentally investigate new transmission concepts such as dispersion management, solitons, and wavelength division multiplexing (WDM), and study, for example, the fundamental limits of ultra-long-distance linear and nonlinear (soliton) communications [1]–[4]. In these studies, the EDFA's operate in the linear gain regime and, thus, simulate a link with EDFA's spaced at 25–50 km. There is considerable recent interest in links with booster amplifiers separated by distances $>$100 km so as to minimize the number of amplifiers and reduce the system cost.

In this paper, we analyze the behavior of fiber loops when the EDFA's operate in the saturated gain regime. Fig. 1 shows a schematic of our experimental setup. The optical devices and their positions within the loop are changed for different experiments, thus we present in Fig. 1 a standard setup just for the purpose of discussing the main features of fiber loops

The signal source is a mode-locked erbium-doped fiber laser that generates 10-ps pulses at a repetition rate of 2.5 GHz [5]. The output from this laser is amplified by a booster EDFA and switched on and off by a lithium–niobate electro-optic switch that modulates the train

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The authors are with the Instituto de Física Gleb Wataghin-DEQ, UNICAMP, Campinas, CEP 13.083–970, São Paulo, Brazil.

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