Appendix A
Telescope Description and Nomenclature

1.0 Introduction

This appendix discusses the terminology used throughout this report to identify each part of the telescope, and in particular the cables and cable sockets that are the primary focus of the forensic investigation. This appendix also outlines some of the key dimensions and properties of the telescope structure.

2.0 Telescope

The telescope was the largest instrument at the Arecibo Observatory and the largest single-aperture radio telescope in the world until 2016. The main components of the telescope are shown in Figure 1 and Figure 2, and its dimensions are shown in Figure 3.

The **primary reflector** is a 1,000-foot-diameter spherical cap built in a natural sinkhole and supported by a cable net system. The surface of the primary reflector is comprised of approximately 40,000 perforated aluminum panels.

Located along the perimeter of the primary reflector is a **ground screen** – a 50-foot-tall wire mesh barrier that mitigates radio interference between the telescope and the surrounding terrain.

The radio feeds of the telescope are mounted on a **suspended structure** located approximately 500 feet above the center of the primary reflector. This structure is further described in section 3.0 of this appendix.

Supporting the suspended structure are three concrete **towers** on three hills surrounding the primary reflector. The towers are numbered 4, 8 and 12, as if located at 4 o'clock, 8 o'clock and 12 o'clock on a clock dial where 12 o'clock is north. This 4-8-12 system is also used for the cable and anchors connected to each tower.

The main cables, also simply referred to as the **mains**, support the suspended structure from the top of the towers. The mains include the original mains and auxiliary mains, which were installed during construction and the second upgrade of the telescope, respectively. The mains are further described in section 4.0 of this appendix, and their socket connections in section 5.0.

The top of the towers are tied back to the ground with backstay cables, also simply referred to as **backstays**. Like the mains, the backstays include the original backstays and auxiliary backstays, and are further described in sections 4.0 and 5.0 of this appendix.

At ground level, the backstays are connected to concrete **anchorages** located in the hills further back from the primary reflector.

The **waveguide** is a pedestrian bridge providing access to the suspended structure from the base of tower 12, and also carrying power and radio waves to the instruments on the suspended structure (hence the term waveguide). The waveguide is supported from the top of the three towers with its own system of cables, and is structurally independent from the suspended structure.

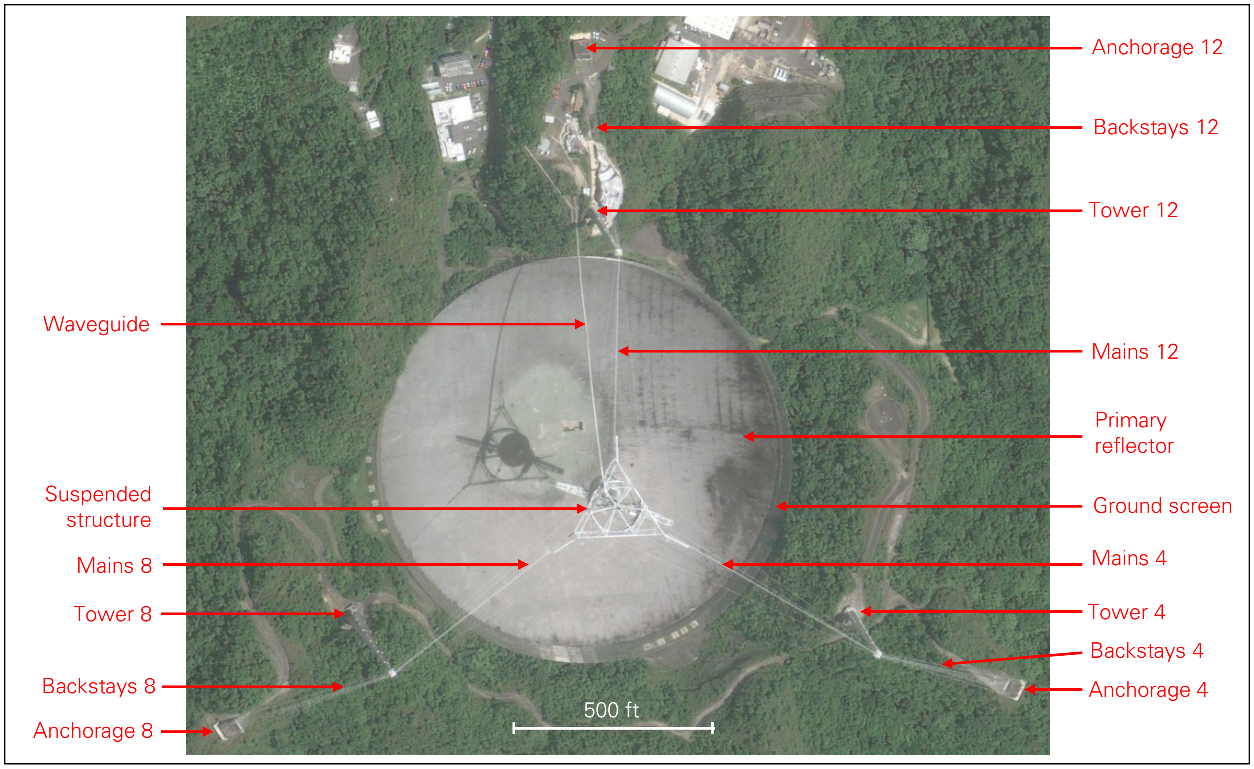

Figure 1: Main components of upgraded telescope *(photo: NSF)*.

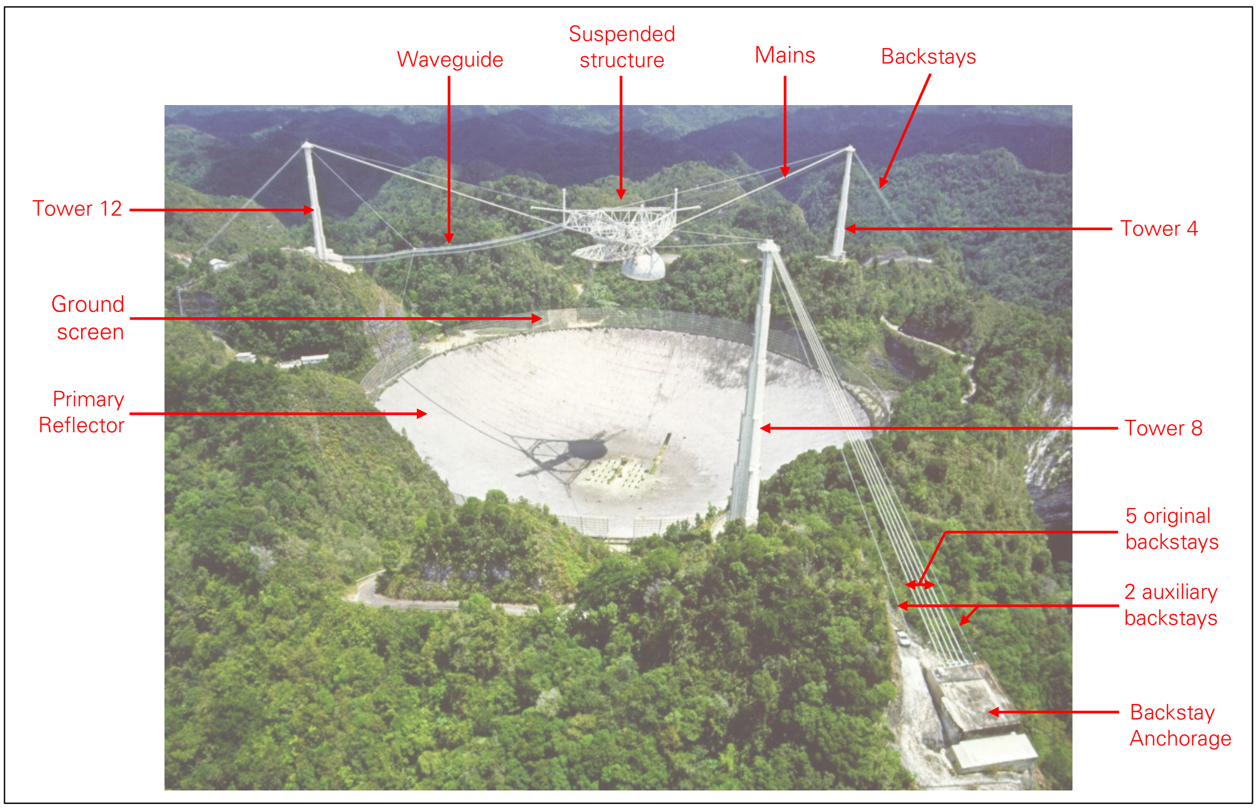

Figure 2: Main components of upgraded telescope *(photo: NSF)*.

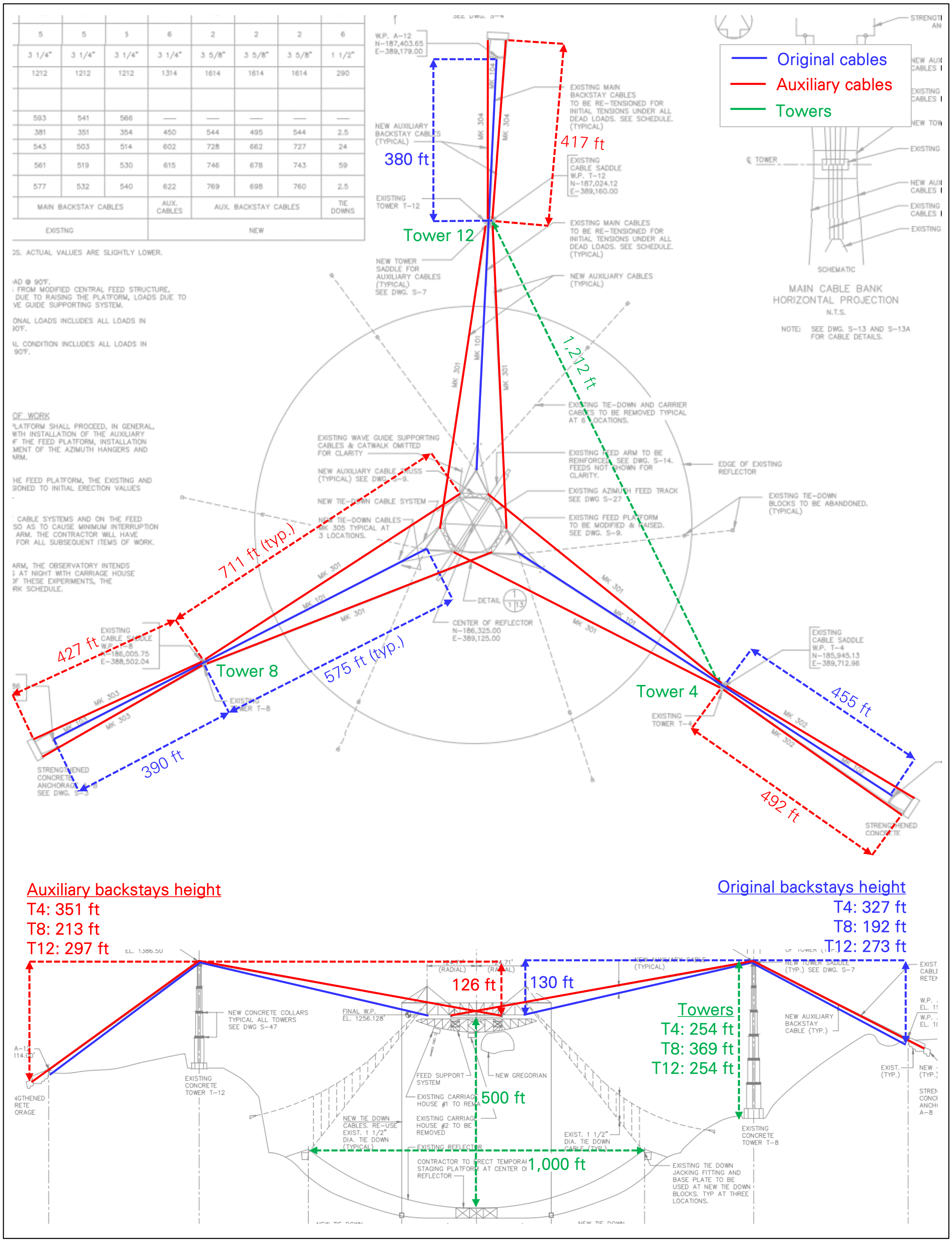

Figure 3: Dimensions of upgraded telescope
(background images: structural drawings, courtesy of NAIC Arecibo Observatory, a facility of the NSF).

3.0 Suspended Structure

The suspended structure supports the radio feeds of the telescope approximately 500 feet above the primary reflector, with moving parts that can change the position of the feeds and steer the telescope, while the primary reflector remains fixed on the ground. This section describes the main components of the suspended structure. Further information on the history, weight and typical movement of these components is provided in Appendix C and H.

The suspended structure and supported equipment were modified over the years. Before the second upgrade completed in 1997, the general configuration was as shown in Figure 4 and is described below.

As the upper part of the suspended structure, the platform consists of several steel trusses (Figure 6) and is a triangular structure supported by four cables (original mains) at each corner. The platform is fixed in space, except for the slight movement induced by environmental loads such as temperature and wind. The bottom of the platform supports the **ring girder**, which is a circular track allowing the rotation of the azimuth arm below.

As a bow-shaped truss structure suspended from the platform, the **azimuth arm** can rotate about a vertical axis passing through the center of the platform, and is supported by trolleys whose wheels sit on the ring girder. The pivot point at the center of the platform prevents the azimuth arm from moving laterally from the center, but does not carry any of the azimuth arm's weight.

The bottom of the azimuth arm supports two parallel **azimuth tracks**. In the original structure, two **carriage houses** were suspended from the azimuth arm, each supported by trolleys whose wheels sat on the azimuth tracks, allowing movement along the bottom of the azimuth arm. The carriage houses supported the radio feeds of the telescope, and one of these was removed as part of the second upgrade.

Each corner of the platform was connected to the ground with two **inclined tiedowns,** which were also removed as part of the second upgrade.

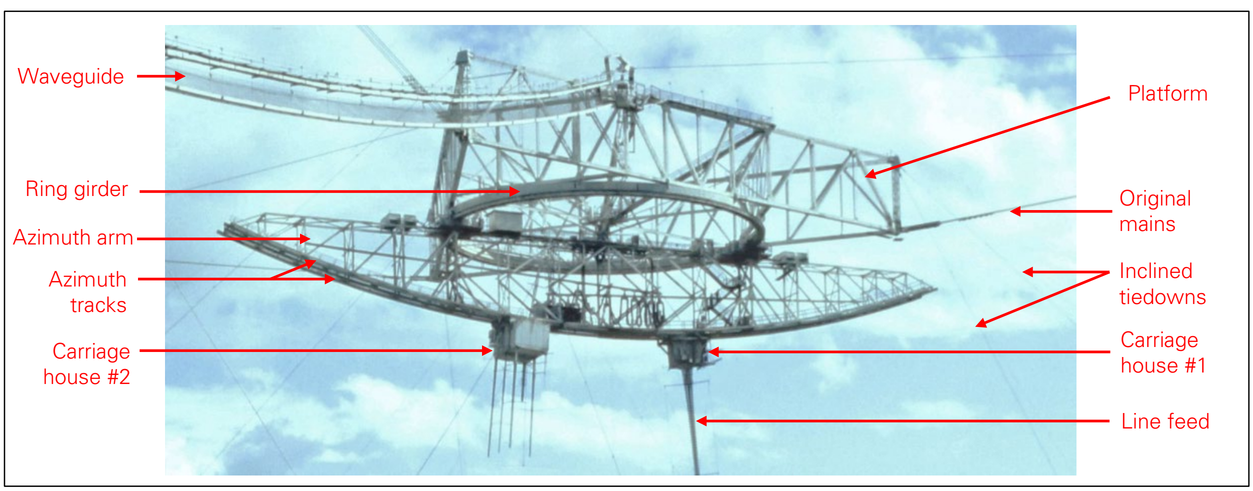

Figure 4: Original suspended structure in 1982 *(photo: Manfred Niermann, Wikipedia - CC BY-SA 4.0).*

Major modifications to the suspended structure were made during the second upgrade of the telescope, which was completed in 1997. The upgraded suspended structure is shown in Figure 5, and the principal changes made to the original structure are described below.

One of the carriage houses was removed from the azimuth arm and replaced with the **Gregorian**, a dome-shaped enclosure that contains telescope feeds and secondary and tertiary reflectors. Like the removed carriage house, the Gregorian is supported by trolleys whose wheels sit on the azimuth tracks, allowing movement along the bottom of the azimuth arm. Because the Gregorian is heavier than the remaining carriage house, which supports the **line feed**, a **counterweight** was installed on the azimuth arm. The counterweight is a fixed tray loaded with lead bricks and pellets.

The six inclined tiedowns were removed and replaced with three **vertical tiedowns**, each of which consists of two cables. An **outrigger** was added at each corner of the platform in order to keep the tiedowns clear of the azimuth arm. Two additional cables (auxiliary mains) were installed between each tower and the platform, and between each tower and its anchor on the ground.

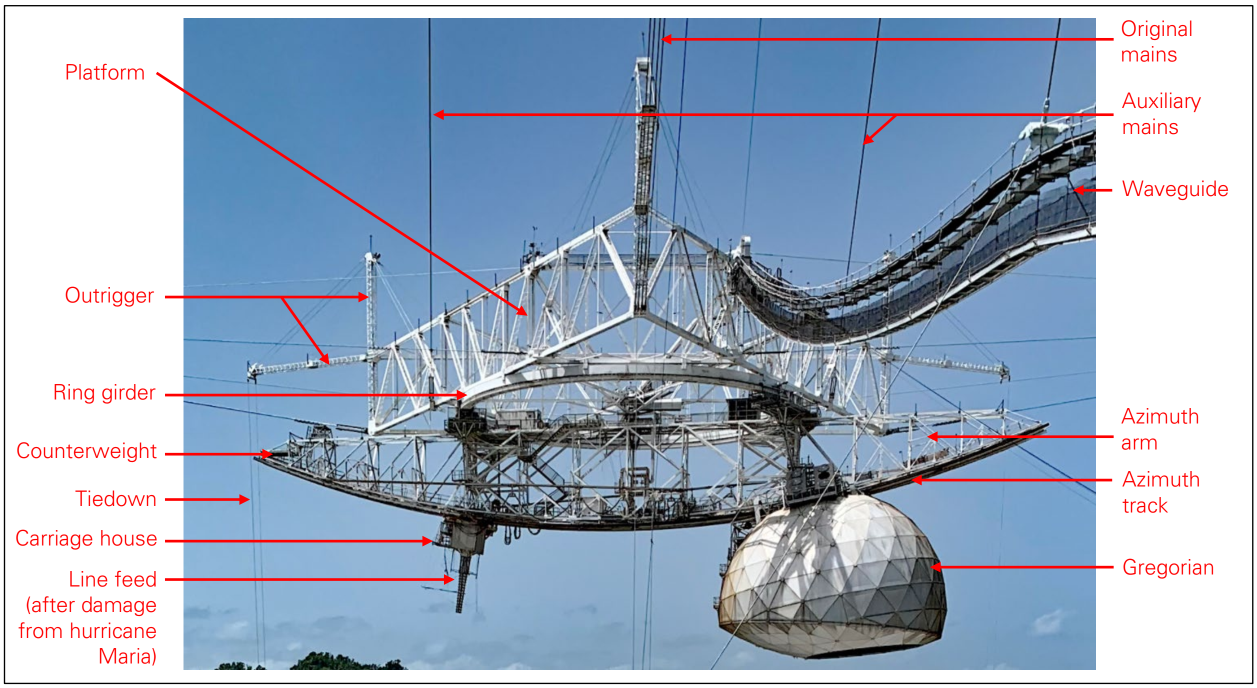

Figure 5: Upgraded suspended structure in 2019 *(photo: Mario Roberto Durán Ortiz, Wikipedia - CC BY-SA 4.0).*

The general dimensions and truss nomenclature for the suspended structure are shown in Figure 6.

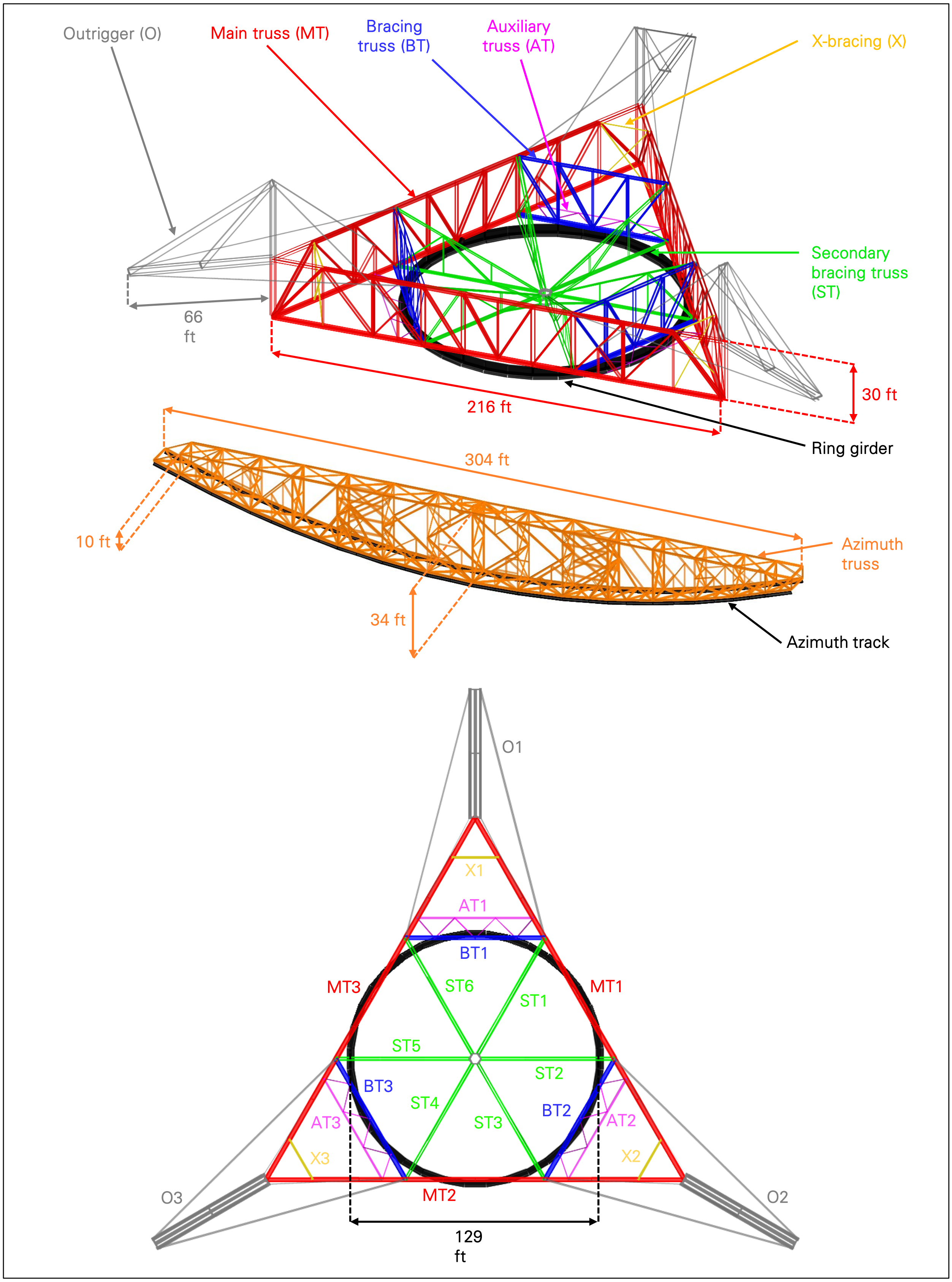

Figure 6: Truss nomenclature and dimensions of upgraded suspended structure.

4.0 Cables

The telescope structure includes three types of cables: the mains between towers and platform, the backstays between towers and ground, and the tiedowns between platform and ground. A cable is considered **original** if it was installed during construction of the telescope (with the exception of B12-3, replaced in 1981 but still considered original), and **auxiliary** if it was installed during the second upgrade, completed in 1997. Each cable is assigned a unique ID, as shown in Figure 7.

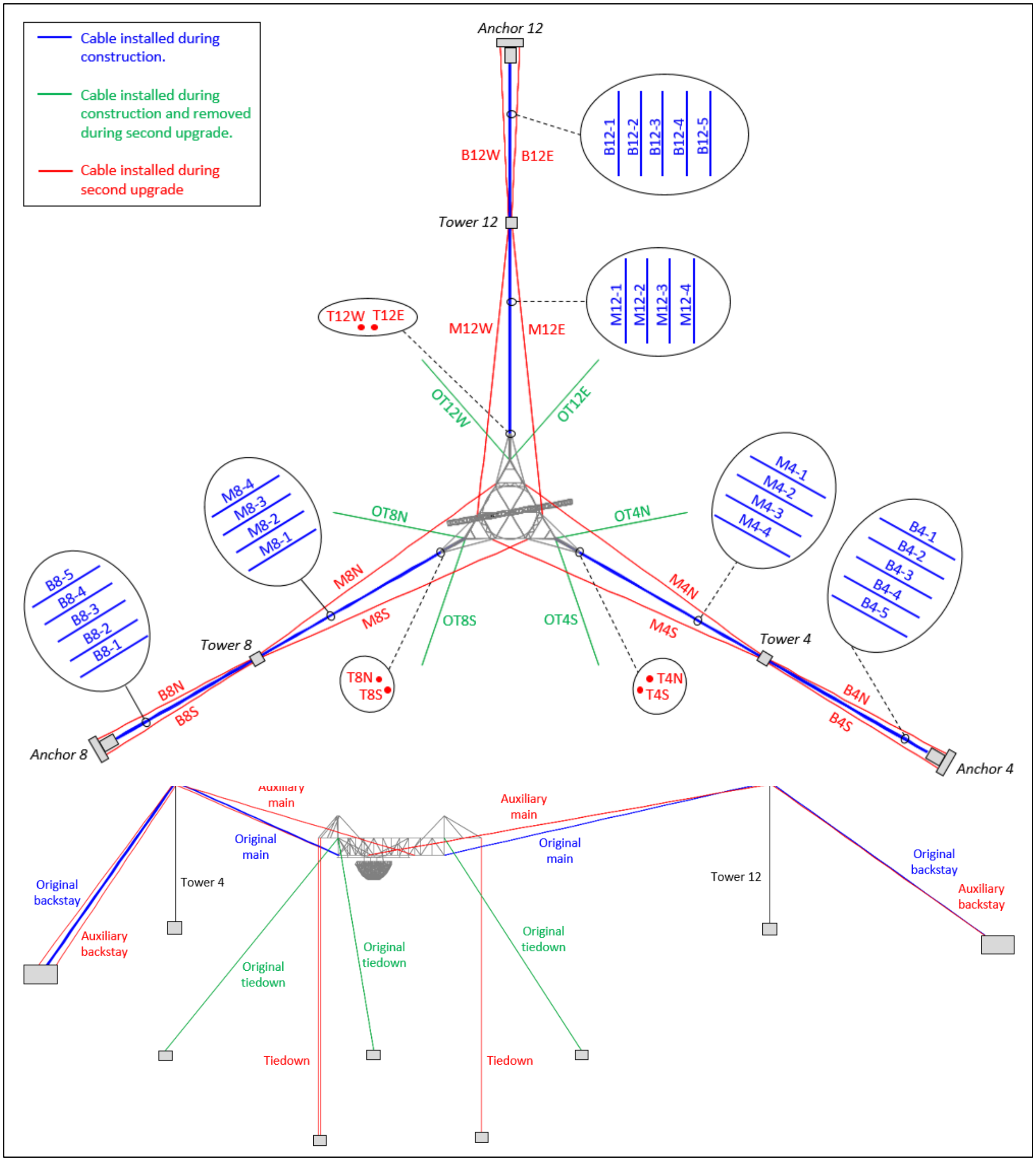

Figure 7: Cable nomenclature and IDs.

Each telescope **cable** is a single **strand** of galvanized steel **wires**. While we primarily use the term cable, the term strand is used in some of the documents that we reviewed, and the two terms are considered synonymous in this report.

As shown in Figure 8, the steel wires of a cable are arranged in concentric **layers**. The innermost layer is referred to as the **core** and may be comprised of a single wire or several smaller wires. The wires are woven helicoidally, in alternating helix direction between adjacent layers.

There are five different cable sections among the mains and backstays of the telescope. Photographs and key properties of each section are shown in Figure 9.

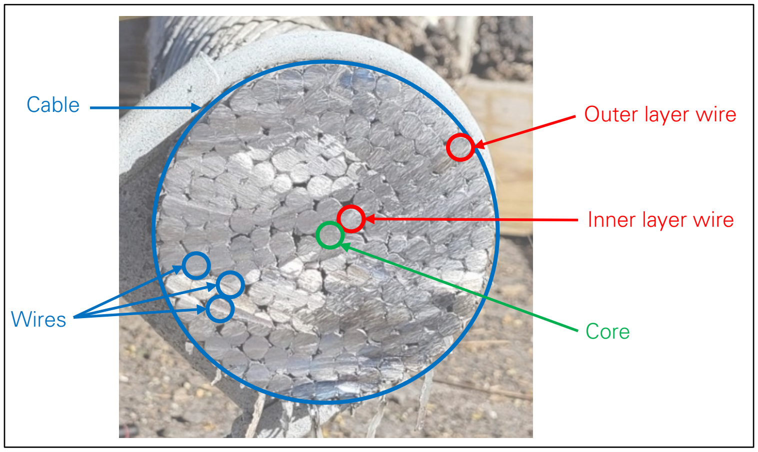

Figure 8: Cable and wire nomenclature, shown on an auxiliary backstay section.

<u>Original main</u>
Cable diameter = 3 in
Wire diameter = 13/64 in
Number of wires = 168
Linear weight[1] = 19 lbf/ft
Min. breaking strength[2] = 1,044 kip

<u>Auxiliary main</u>
Cable diameter = 3 1/4 in
Wire diameter = 1/4 in
Number of wires = 126
Linear weight[1] = 22 lbf/ft
Min. breaking strength[2] = 1,314 kip

<u>Original backstay</u>
Cable diameter = 3 1/4 in
Wire diameter = 13/64 in
Number of wires = 216
Linear weight[1] = 22 lbf/ft
Min. breaking strength[2] = 1,212 kip

<u>Auxiliary backstay</u>
Cable diameter = 3 5/8 in
142 wires of 1/4 in diameter
23 wires of 3/16 in diameter
Linear weight[1] = 28 lbf/ft
Min. breaking strength[2] = 1,614 kip

<u>Replacement B12-3</u>
Cable diameter = 3 1/4 in
Wire diameter = 1/4 in
Number of wires = 126
Linear weight[1] = 22 lbf/ft
Min. breaking strength[3] = 1,314 kip

[1] Typical linear weight per ASTM A586.
[2] Per 1992 structural drawings for second upgrade.
[3] Assumed identical to auxiliary mains.

Figure 9: Cable properties.

5.0 Cable Sockets

The mains and backstays are connected to the platform, towers, and anchors with spelter sockets. As shown in Figure 10, each socket is uniquely identified with the letter P (platform), T (tower) or G (ground) appended to the corresponding cable ID.

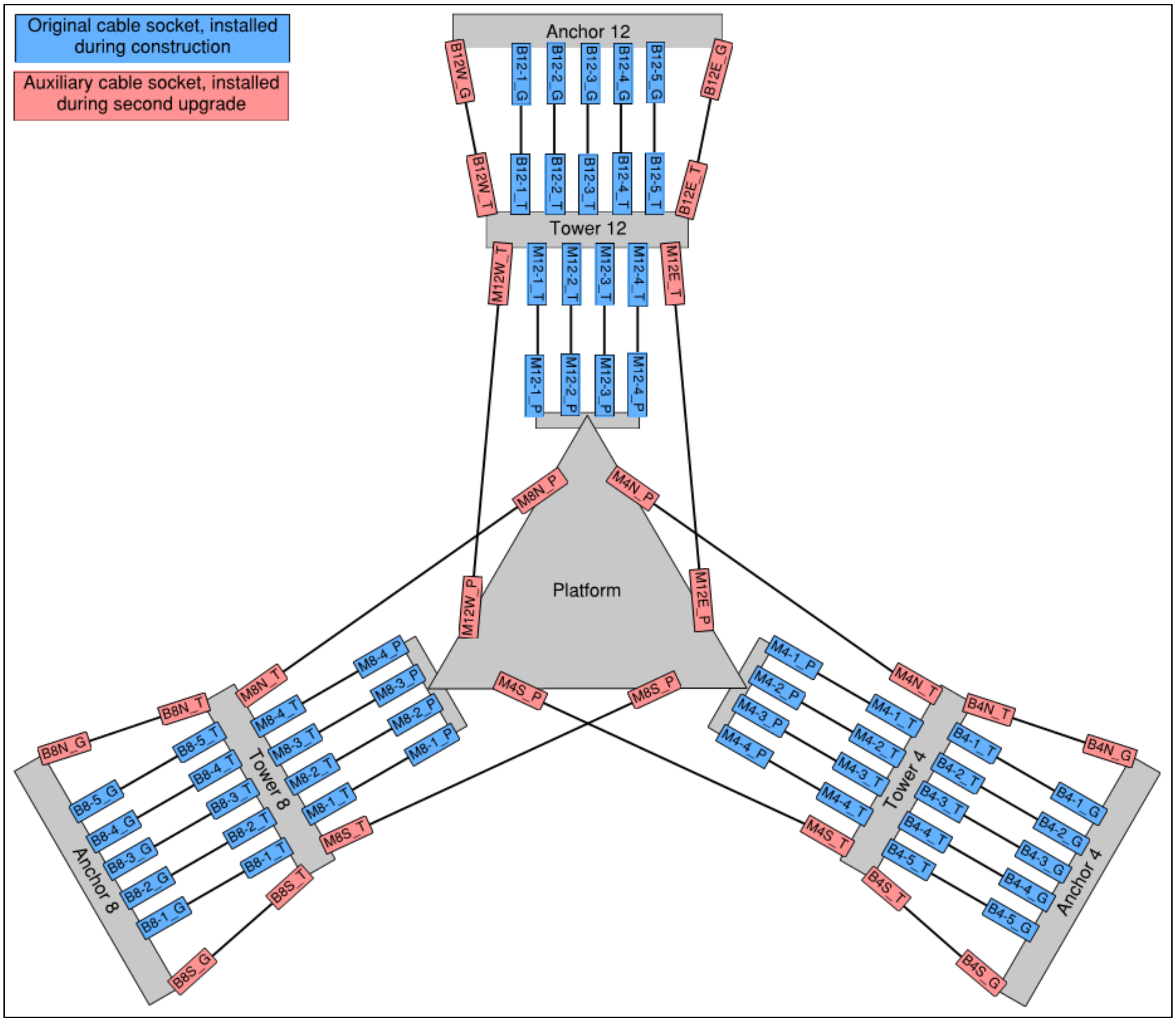

Figure 10: Socket IDs.

The terminology used to describe spelter sockets in this report is illustrated in Figure 11. Each socket is a steel block with a cone-shaped **cavity**, and the cables enter the socket through its **front** end. The other end of the socket is referred to as the **back** and is connected to the supporting structure, which may be the platform, a tower, or an anchor.

In the cone-shaped cavity of the steel block, a **zinc casting** fills the gaps between the broomed-out wires of the cable. The some of the telescope’s sockets feature a **shoulder** at the front, which is a step in the diameter of the socket's cavity.

For this investigation, we define the **cable slip** as the distance between the front end of the steel block and the front edge of the zinc casting around the cable. This is the distance by which the cable has displaced with respect to the socket since the casting was poured.

Figure 11: Spelter socket nomenclature, shown on socket B4N_G cut open at Socotec's laboratory *(photo: Socotec).*

6.0 Organizations

The organizations referred to in this report are listed in Table 1.

Table 1: List of relevant organizations.

Name	Acronym used in this report	Involvement with the Arecibo Telescope
Ammann & Whitney	AW	Ammann & Whitney (AW) was a structural engineering consulting firm based in New York, NY. AW was the Structural Engineer of Record for the first and second upgrades of the Arecibo Telescope, as well as smaller structural modifications. AW also performed several structural inspections of the Telescope. AW merged with Louis Berger in 2016.
Bethlehem Steel		Bethlehem Steel was a steelmaking company based in Bethlehem, PA. Bethlehem Steel fabricated the steel members of the suspended structure and all of cable sockets of the Arecibo Telescope.
Comsat RSI	RSI	Comsat RSI was a satellite antenna manufacturer and was the prime contractor for the second upgrade of the Arecibo Telescope.
Cornell University	CU	Cornell University managed and operated the Arecibo Observatory from 1963 to 2011.
Elgood-Mayo Corp.		Elgood-Mayo was a subcontractor of Comsat RSI for second upgrade of the Arecibo Telescope. Elgood-Mayo was responsible for tensioning the structure's cables.
Louis Berger		Louis Berger is an engineering consulting firm based in Morristown, NJ. In 2016 Louis Berger merged with AW, which was regularly used as Engineering of Record for structural work on the Arecibo Telescope. In 2018, Louis Berger was acquired by WSP.
National Astronomy and Ionosphere Center	NAIC	Other name of the Arecibo Observatory.
Praeger-Kavanagh		Praeger-Kavanagh was an engineering consulting firm based in New York, NY. Praeger-Kavanagh was the engineer for the original structural of the Arecibo Telescope.
SRI International		SRI International in a nonprofit scientific research institute based in Menlo Park, CA. SRI International managed and operated the Arecibo Observatory from 2011 to 2018.
Temcor		Temcor was the engineer and manufacturer of the Gregorian dome for the second upgrade of the Arecibo Telescope. Temcor is now part of CST.
University of Central Florida	UCF	The University of Central Florida leads a consortium (with Universidad Metropolitana in San Juan and Yang Enterprises) that has been managing and operating the Arecibo Observatory since 2018.
Von Seb		Von Seb was the architect of the original Arecibo Telescope.
Williamsport Wirerope Works	WWW	Former name of Wirerope Works
Wirerope Works		Wirerope Works is a fabricator of steel cables (wire ropes and single strands) based in Williamsport, PA. Wirerope Works fabricated and socketed the auxiliary cables of the Arecibo Telescope. Wirerope Works also socketed the free end of the cable recovered from the collapsed telescope for load testing.
WSP	WSP	WSP is an engineering consulting firm based in Canada. In 2018, WSP acquired Louis Berger, who had previously merged with the Arecibo Telescope's Engineer of Record Amman & Whitney.