Annexure A

AGREED AMENDMENTS TO THE PROPOSED TAURANGA CITY PLAN

3 Definitions

amateur radio configuration
The antennas, aerials (including rods, wires and tubes) and associated supporting structures which are owned and used by licensed amateur radio operators.

network utility (network utilities)
Any activity relating to;
a)...

m) The operation and maintenance of *network utility* service
But excludes;
n) *amateur radio configurations.*

4H Purpose of the Permitted Intrusion Rules

Generally building bulk and scale is determined by the height, setback and overshadowing provisions of the relevant underlying zone. There will, however be instances where it is appropriate for design features or building components that are integral to the function of that building (e.g., chimneys, balustrades, plant rooms, etc.) to breach these provisions where their dimensions are not considered to create adverse effects on the amenity of adjoining properties.

In addition there is also a need for the Plan to recognise the Port of Tauranga and Tauranga City Airport and ensure that the day-to-day operation of both these activities can continue as safely and efficiently as possible.

Where an intruding building component cannot comply with the dimensions specified in these provisions then its potential adverse effects will need to be assessed against the relevant provision of the underlying zone.

Amateur radio configurations do not come within the definition of Network Utilities and are not subject to the same rules. For clarity the provisions relating to *amateur radio configurations* in the Residential and Rural Residential Zones are set out as part of the permitted intrusions provisions of this Chapter.

4H.1 Objectives and Policies for Permitted Intrusions

4H.1.1 Objective – Permitted Intrusions
Design features and building components are able to breach height and setback requirements where their dimensions are not considered to have an adverse effect on amenity values.

4H.1.1.1 Policy – Permitted Intrusions
By enabling design features and building components to intrude into height, setback and overshadowing requirements to an extent where they are not considered to generate adverse effects on the amenity of adjoining properties or the surrounding neighbourhood.

4H.1.2 Objective – Amateur Radio Configurations

Amateur radio configurations are provided for where they do not have an adverse effect on existing and anticipated residential or rural residential amenity and character.

4H.1.2.1 Policy – Amateur Radio Configurations

By enabling *amateur radio configurations* to intrude into the zone based permitted activity standards for height, overshadowing, streetscape and setback requirements for the Residential or Rural Residential Zone in which they are located to the extent they are not considered to generate adverse effects on the existing and anticipated residential or rural residential character and amenity of adjoining properties or the surrounding neighbourhood.

4H.2 Permitted Activity Rules

Note: For radio and telecommunication masts, aerials, antenna dishes, antenna panels and electric lines meeting the definition of a "Network Utility (Network Utilities)" refer to Chapter 10 – Network Utilities and Designations.

Note: For amateur radio configurations refer to Rule 4H.2.4 Permitted Activities – Permitted Intrusions for Amateur Radio Configurations in the Residential and Rural Residential Zones.

Note: Where an activity does not comply with a Permitted Activity Rule for Permitted Intrusions, it shall be assessed under the Activity Status of the relevant Chapter Rule with the exception of Amateur Radio Configurations which shall be assessed under the activity status contained within Chapter 4H.

Note: Permitted Intrusions in the Transmission Plan Area shall comply with the New Zealand Electrical Code of Practice 2001:34.

Note: The height of crop protection structures shall comply with Rule 16A.8.2 – Building Height.

4H.2.3 Permitted Height and Viewshaft Protection Area Intrusions

...

b) In all other zones:

- i) A *design feature* or *building component*, which does not exceed the maximum permitted *height* by more than 2 metres and/or an external dimension of 2 metres in any other direction (excluding diagonal measurements);
- ii) Satellite and microwave dishes, radio and telecommunication *aerials* and *antenna* which comply with the provisions of *Chapter 10 – Network Utilities and Designations*; or
- iii) Private (for residential and recreational purposes) radio and telecommunication *antennas* (being no greater than $2m^2$ in area) and *aerials* (being no greater than 80mm in diameter) excluding *amateur radio configurations;*

  ...

4H.2.4 Permitted Activities – Permitted Intrusions for Amateur Radio Configurations in the Residential and Rural Residential Zones

Note: Where an activity does not comply with the Permitted Activity Intrusion Rule it shall be considered a Restricted Discretionary Activity, unless stated otherwise.

The following *amateur radio configurations* are permitted activities under this Rule, unless:

a) the provisions of 4I (Specified Airport Slopes and Surfaces) applies; and/or
b) they are proposed to be located within or on one or more of the following Plan Areas: Special Ecological Plan Area; Outstanding Natural Features and Landscapes Plan Area, Important Amenity Plan Area; Coastal Hazard Erosion Plan Area, Coastal Protection Plan Area, Flood Hazard Plan Area; High Voltage Transmission Plan Area; and/or
b) they are proposed to be located within or on the site of an Item listed in Appendix 7A: Register of Built Heritage or Appendix 7B: Register of Significant Maori Items, or an archaeological site identified on Council's GIS database.

in which case the provisions of 4I, the relevant Plan Area(s) and/or heritage provisions shall prevail:

Antennas

a) Where attached to a building or other structure (including a mast) radio and telecommunications antenna up to and including 2m in diameter for an antenna dish and not exceeding $2m^2$ in area or 2m in any dimension for a panel antenna; provided the antenna does not overhang a site boundary; and

b) One pedestal mounted antenna per site provided that:
   i) The antenna is pivoted less than 4m above the ground with a maximum diameter of 5m; and
   ii) The pedestal and/or the antenna are located in accordance with the streetscape, setback and overshadowing standards applying to buildings in the zone in which they are located.

Supporting Structures

d) No more than six support poles for wire aerials of less than 115mm in outside diameter per site provided:

   i) The maximum height of the support poles is the maximum building height applying in the zone in which they are located;

   ii) The streetscape, setback and overshadowing standards shall not apply to these support poles;

   iii) Where guy wires are used these must not exceed 12mm in diameter; and

   iv) At no point must any guy wire overhang the boundary.

One pole support structure (excluding support poles for wire aerials) or lattice support structure per site provided that:

i) The maximum height of the pole support structure is 9m and the maximum dimension of the pole is 115mm; or

ii) The maximum height of the lattice support structure is 9m and the maximum width of the lattice support structure is 900mm to 8m in height and 660mm to 9m in height; and

iii) The pole or lattice structure is located in accordance with the streetscape and setback standards applying to buildings in the zone in which they are located. For the purpose of this rule the overshadowing standards shall not apply to the pole or lattice support structure; and

iv) Where guy wires are used these must not exceed 12mm in diameter; and

v) At no point must any guy wire overhang the boundary.

Note: The provisions of 4I relating to Specified Airport Slopes and Surfaces also apply and if not met shall prevail over this rule.

4H.2.5 Restricted Discretionary Activity Rules – Amateur Radio Configurations in the Residential and Rural Residential Zones.

The following is a Restricted Discretionary Activity:

a) Any *amateur radio configuration* in the Residential and Rural Residential Zones that does not comply with Rule 4H.2.4 Amateur Radio Configurations in the Residential and Rural Residential Zones.

4H.2.5.1 Restricted Discretionary Activity – Standards and Terms – Amateur Radio Configurations in the Residential and Rural Residential Zones

a) No *amateur radio configuration* within any identified Viewshaft Protection Area shall exceed the maximum height identified within the Plan Maps (Part B).

Note: Any Activity that does not comply with Rule 4H.2.5.1 will result in the activity being considered a Discretionary Activity in accordance with the Objectives and Policies for the zone in which it is located and the relevant Natural Features and Landscapes Objectives and Policies.

Note: The provisions of 4I relating to Specified Airport Slopes and Surfaces also apply and if not met shall prevail over this rule.

4H.2.5.2 Restricted Discretionary Activity – Matters of Discretion and Conditions – Amateur Radio Configurations in the Residential and Rural Residential Zones

In considering whether to grant consent and what conditions, if any, to impose Council shall have regard to:

a) The bulk, form and scale, location and number of aerials, antennas or associated supporting structures and the extent to which the proposal would lead to a visual dominance and loss of visual amenity as viewed by adjoining and adjacent properties and the surrounding neighbourhood;

b) The extent to which the proposal would reduce adverse visual and amenity impacts through design measures including location on site, materials used, and finish of materials including colour;

c) The extent to which the proposal would reduce the ability to maintain access for maintenance, including for buildings on adjoining sites; and

b) In the case of pedestal antenna not complying with overshadowing standards the extent to which the proposal would result in the loss of sunlight and daylight to surrounding sites, particularly in relation to outdoor living areas or the main indoor living area windows of surrounding residential or rural residential properties.

4H.2.6 Discretionary Activity Rules

The following are Discretionary Activities:

a) Any Restricted Discretionary Activity that does not comply with *4H.2.5.1 Restricted Discretionary Activity – Standards and Terms* – **Amateur Radio Configurations** *in the Residential and Rural Residential Zones*; and

b) Any Activity which is not a Permitted, Controlled, Restricted Discretionary, or Non-Complying Activity.

Annexure B

Additional amendments to the Proposed Tauranga City Plan sought by appellants

4H.2.4

Aerials

c) i) Aerial elements up to 80mm in diameter and up to 14.9 m long provided that the aerial does not overhang a site boundary.

ii) Aerial wires provided that they do not overhang the boundary.

iii) Aerial vertical compromising tubular elements up to 13.5 m high

f) One support structure per site of a dimension of greater than 115mm provided that:

i) The maximum height of the support structure is 20m. The supporting structure may be one of the following:

(a) A guyed pole. The diameter of the pole being 115mm or less.

(b) A guyed lattice mast. The mast width being 300mm or less. The mast may be of constant width or tapering.

(c) A self-supporting lattice mast. The mast must fit within a tapering envelope 420mm wide at 20m and 660mm at 9m.

(d) A self-supporting tubular pole. The mast must fit within a tapering envelope 115mm at 20m and 230mm at 9m.

ii) Local enlargement of support structure to accommodate a rotator mechanism is permitted.

iii) The maximum height of the supporting structure and attached antennas and/or aerials must not exceed 26m.

iv) Supporting structure using tilt-over mechanism shall not exceed the above dimensions above 9m.

v) The supporting structure is located in accordance with the streetscape and setback standards applying to buildings in the zone in which they are located. For the purpose of this rule the overshadowing standards shall not apply to the supporting structure; and

vi) Where guy wires are used these must not exceed 12 mm in diameter; and

vii) At no point must any guy wire overhang the boundary

BEFORE THE ENVIRONMENT COURT

Decision No. [2012] NZEnvC 193

IN THE MATTER	of an appeal pursuant to Clause 14 of the First Schedule of the Resource Management Act 1991 (**the Act**)
BETWEEN	TAURANGA EMERGENCY COMMUNICATIONS GROUP INCORPORATED
	NEW ZEALAND ASSOCIATION OF RADIO TRANSMITTERS INCORPORATED
	(ENV-2011-AKL-000074)
	Appellants
AND	TAURANGA CITY COUNCIL
	Respondent

Hearing on the papers under section 279 of the Act

Environment Judge J A Smith

FINAL DECISION

A. **The Tauranga City Plan is amended in accordance with Annexure A, Annexure B and Annexure C to this decision.**

B. **There is no order as to costs.**

REASONS

Introduction

[1] This matter relates to the Tauranga City Plan. The Council, in considering the provisions for utilities in Tauranga, imposed controls over private radio communications. This effectively required them to comply with the building envelope (building height in each zone) together with a maximum intrusion for aerials and the like of a further 2m. These provisions were submitted on by the appellants and the Council considered these as part of its hearing process on the Proposed Tauranga City Plan. The appellants' submissions were refused, and they brought this appeal.

[2] The matter was heard at Tauranga on 14-15 May 2012, which resulted in the Court issuing interim decision [2012] NZEnvC 107.

[3] The decision recorded that the parties had co-operated and generated a set of agreed amendments to the Tauranga City Plan which were attached to the decision as Annexure A. The Court agreed with the parties that the changes properly recognised many of the activities of the amateur radio community in relation to activities that do not involve particularly high elements and directed that the amendments set out in Annexure A be incorporated into the City Plan.

[4] The decision also included Annexure B which set out the additional amendments sought by the appellants to the proposed Tauranga City Plan.

[5] The Court directed the Council to provide its proposed amendments to the provisions in Annexure B within 20 working days from the date of the decision. A joint memorandum setting out the agreed terms or the areas where there was still disagreement were to be filed within 20 working days thereafter.

[6] The parties generally reached agreement, however, in discussing the draft provisions an issue arose for which further guidance was requested from the Court. The issue related to the activity status of amateur radio configurations in the Wairakei and City Living Zones. In response the Court convened a Judicial Telephone

Conference which was held on 26 July 2012. Following the telephone conference the parties were directed to file a further joint memorandum.

[7] In accordance with this direction and those set out in decision [2012] NZEnvC 107 the parties have filed a joint memorandum setting out the agreed amendments. These amendments include the proposed wording for the rules relating to aerials (Rule 4H.2.4(c) and support structures (Rule 4H.2.4(f) (Annexure B), the amendments sought to Annexure A in order to provide clarity in terms of the maximum dimensions of the supporting structures, and for consistency with the wording proposed for Annexure B and the resulting consequential amendments to the Plan (Annexure C).

[8] The Court has considered the proposed amendments to Annexure A, the agreed version of Annexure B and the consequential amendments identified in Annexure C, and is satisfied that they reflect the Court's interim decision and provide for an appropriate outcome.

[9] Accordingly, the plan in amended in accordance with the attachments to this decision, being the revised version of Annexure A **("A")**, the agreed version of Annexure B **("B")** and the consequential amendments set out in Annexure C ("C").

[10] There is no order as to costs.

DATED at AUCKLAND this 7th day of September 2012

J A Smith
Environment Judge

"A"

REPLACEMENT ANNEXURE "A"
AGREED AMENDMENTS TO THE PROPOSED TAURANGA CITY PLAN

3 Definitions

amateur radio configuration
The antennas, aerials (including rods, wires and tubes) and associated supporting structures which are owned and used by licensed amateur radio operators.

network utility (network utilities)
Any activity relating to;
a)...

m) The operation and maintenance of *network utility* service
But excludes;
n) *amateur radio configurations.*

4H Purpose of the Permitted Intrusion Rules

Generally building bulk and scale is determined by the height, setback and overshadowing provisions of the relevant underlying zone. There will, however be instances where it is appropriate for design features or building components that are integral to the function of that building (e.g., chimneys, balustrades, plant rooms, etc.) to breach these provisions where their dimensions are not considered to create adverse effects on the amenity of adjoining properties.

In addition there is also a need for the Plan to recognise the Port of Tauranga and Tauranga City Airport and ensure that the day-to-day operation of both these activities can continue as safely and efficiently as possible.

Where an intruding building component cannot comply with the dimensions specified in these provisions then its potential adverse effects will need to be assessed against the relevant provision of the underlying zone.

Amateur radio configurations do not come within the definition of Network Utilities and are not subject to the same rules. For clarity the provisions relating to *amateur radio configurations* in the Residential and Rural Residential Zones are set out as part of the permitted intrusions provisions of this Chapter.

4H.1 Objectives and Policies for Permitted Intrusions

4H.1.1 Objective – Permitted Intrusions
Design features and building components are able to breach height and setback requirements where their dimensions are not considered to have an adverse effect on amenity values.

4H.1.1.1 Policy – Permitted Intrusions
By enabling design features and building components to intrude into height, setback and overshadowing requirements to an extent where they are not considered to generate adverse effects on the amenity of adjoining properties or the surrounding neighbourhood.

4H.1.2 Objective – Amateur Radio Configurations
Amateur radio configurations are provided for where they do not have an adverse effect on existing and anticipated residential or rural residential amenity and character.

4H.1.2.1 Policy – Amateur Radio Configurations
By enabling *amateur radio configurations* to intrude into the zone based permitted activity standards for height, overshadowing, streetscape and setback requirements for the Residential or Rural Residential Zone in which they are located to the extent they are not considered to generate adverse effects on the existing and anticipated residential or rural residential character and amenity of adjoining properties or the surrounding neighbourhood.

4H.2 Permitted Activity Rules
Note: For radio and telecommunication masts, aerials, antenna dishes, antenna panels and electric lines meeting the definition of a "Network Utility (Network Utilities)" refer to Chapter 10 – Network Utilities and Designations.

Note: For amateur radio configurations refer to Rule 4H.2.4 Permitted Activities – Permitted Intrusions for Amateur Radio Configurations in the Residential and Rural Residential Zones.

Note: Where an activity does not comply with a Permitted Activity Rule for Permitted Intrusions, it shall be assessed under the Activity Status of the relevant Chapter Rule with the exception of Amateur Radio Configurations which shall be assessed under the activity status contained within Chapter 4H.

Note: Permitted Intrusions in the Transmission Plan Area shall comply with the New Zealand Electrical Code of Practice 2001:34.

Note: The height of crop protection structures shall comply with Rule 16A.8.2 – Building Height.

4H.2.3 Permitted Height and Viewshaft Protection Area Intrusions

...

b) In all other zones:

i) A *design feature* or *building component*, which does not exceed the maximum permitted *height* by more than 2 metres and/or an external dimension of 2 metres in any other direction (excluding diagonal measurements);

ii) Satellite and microwave dishes, radio and telecommunication *aerials* and *antenna* which comply with the provisions of *Chapter 10 – Network Utilities and Designations*; or

iii) Private (for residential and recreational purposes) radio and telecommunication *antennas* (being no greater than $2m^2$ in area) and *aerials* (being no greater than 80mm in diameter) excluding *amateur radio configurations;*

...

4H.2.4 Permitted Activities – Permitted Intrusions for Amateur Radio Configurations in the Residential and Rural Residential Zones

Note: Where an activity does not comply with the Permitted Activity Intrusion Rule it shall be considered a Restricted Discretionary Activity, unless stated otherwise.

The following *amateur radio configurations* are permitted activities under this Rule, unless:

a) the provisions of 4I (Specified Airport Slopes and Surfaces) applies; and/or
b) they are proposed to be located within or on one or more of the following Plan Areas: Special Ecological Plan Area; Outstanding Natural Features and Landscapes Plan Area, Important Amenity Plan Area; Coastal Hazard Erosion Plan Area, Coastal Protection Plan Area, Flood Hazard Plan Area; High Voltage Transmission Plan Area; and/or
c) they are proposed to be located within or on the site of an Item listed in Appendix 7A: Register of Built Heritage or Appendix 7B: Register of Significant Maori Items, or an archaeological site identified on Council's GIS database.

in which case the provisions of 4I, the relevant Plan Area(s) and/or heritage provisions shall prevail:

Antennas

a) Where attached to a building or other structure (including a mast) radio and telecommunications antenna up to and including 2m in diameter for an antenna dish and not exceeding $2m^2$ in area or 2m in any dimension for a panel antenna; provided the antenna does not overhang a site boundary; and

b) One pedestal mounted antenna per site provided that:
   i) The antenna is pivoted less than 4m above the ground with a maximum diameter of 5m; and
   ii) The pedestal and/or the antenna are located in accordance with the streetscape, setback and overshadowing standards applying to buildings in the zone in which they are located.

Supporting Structures

d) No more than six support poles for wire aerials of less than 115mm in outside diameter per site provided:

   i) The maximum height of the support poles is the maximum building height applying in the zone in which they are located;

   ii) The streetscape, setback and overshadowing standards shall not apply to these support poles;

iii) Where guy wires are used these must not exceed 12mm in diameter; and

iv) At no point must any guy wire overhang the boundary.

e) One pole support structure (excluding support poles for wire aerials) or lattice support structure per site provided that:

i) The maximum height of the pole support structure is 9m and the maximum inscribed circle of the pole and any lowering mechanism shall be 600mm below 4m in height and 115mm above 4m; or

ii) The maximum height of the lattice support structure is 9m and the maximum inscribed circle of the lattice support structure and any lowering mechanism shall be 900mm below 8m in height and 660mm above 8m; and

iii) The pole or lattice structure is located in accordance with the streetscape and setback standards applying to buildings in the zone in which they are located. For the purpose of this rule the overshadowing standards shall not apply to the pole or lattice support structure; and

iv) Where guy wires are used these must not exceed 12mm in diameter; and

v) At no point must any guy wire overhang the boundary.

Note: The provisions of 4I relating to Specified Airport Slopes and Surfaces also apply and if not met shall prevail over this rule.

4H.2.5 Restricted Discretionary Activity Rules – Amateur Radio Configurations in the Residential and Rural Residential Zones

The following is a Restricted Discretionary Activity:

a) Any *amateur radio configuration* in the Residential and Rural Residential Zones that does not comply with Rule 4H.2.4 Amateur Radio Configurations in the Residential and Rural Residential Zones.

4H.2.5.1 Restricted Discretionary Activity – Standards and Terms – Amateur Radio Configurations in the Residential and Rural Residential Zones

a) No *amateur radio configuration* within any identified Viewshaft Protection Area shall exceed the maximum height identified within the Plan Maps (Part B).

Note: Any Activity that does not comply with Rule 4H.2.5.1 will result in the activity being considered a Discretionary Activity in accordance with the Objectives and Policies for the zone in which it is located and the relevant Natural Features and Landscapes Objectives and Policies.

Note: The provisions of 4I relating to Specified Airport Slopes and Surfaces also apply and if not met shall prevail over this rule.

4H.2.5.2 Restricted Discretionary Activity – Matters of Discretion and Conditions – Amateur Radio Configurations in the Residential and Rural Residential Zones

In considering whether to grant consent and what conditions, if any, to impose Council shall have regard to:

a) The bulk, form and scale, location and number of aerials, antennas or associated supporting structures and the extent to which the proposal would lead to a visual dominance and loss of visual amenity as viewed by adjoining and adjacent properties and the surrounding neighbourhood;

b) The extent to which the proposal would reduce adverse visual and amenity impacts through design measures including location on site, materials used, and finish of materials including colour;

c) The extent to which the proposal would reduce the ability to maintain access for maintenance, including for buildings on adjoining sites; and

b) In the case of pedestal antenna not complying with overshadowing standards the extent to which the proposal would result in the loss of sunlight and daylight to surrounding sites, particularly in relation to outdoor living areas or the main indoor living area windows of surrounding residential or rural residential properties.

4H.2.6 Discretionary Activity Rules

The following are Discretionary Activities:

a) Any Restricted Discretionary Activity that does not comply with *4H.2.5.1 Restricted Discretionary Activity – Standards and Terms –* **Amateur Radio Configurations** *in the Residential and Rural Residential Zones*; and

b) Any Activity which is not a Permitted, Controlled, Restricted Discretionary, or Non-Complying Activity.

"B"

Amend Rule 4H.2.4 by inserting the following:

Aerials

c) *Aerials* that comply with the following:

(i) Any of the elements making up the *aerial* do not exceed 80mm in diameter;

(ii) For horizontal HF yagi *aerials*, the maximum element length does not exceed 14.9m, and the boom length does not exceed 13m;

(iii) No part of the *aerial* (including aerial wires) overhangs a site boundary;

(iv) The streetscape and setback standards applying to buildings in the applicable Residential Zone or Rural Residential Zone (except that aerial wires are not required to comply with the streetscape and setback standards);

(v) No part of the *aerial* exceeds the maximum stated height applying to buildings in the applicable Residential Zone or Rural Residential Zone by more than 2m (except for vertical aerials as provided for under (vi) below); and

(vi) For vertical aerials, one vertical aerial to a maximum height of 20m, provided there is only one vertical aerial or one supporting structure (and attached aerial(s) or antenna(s)) under (f) below per site that exceeds the maximum stated height applying to buildings in the applicable Residential Zone or Rural Residential Zone by more than 2m.

Supporting Structures

d)..

e)..

f) For each site, one support structure (in addition to support structures permitted under 4H.2.4 d) and e)) that exceeds the maximum stated height applying to buildings in the applicable

Residential Zone or Rural Residential Zone by more than 2m, provided that:

(i) Any attached *antenna* complies with 4H.2.4 a) and any attached *aerial* complies with 4H.2.4 c) (excluding c)(v)).

(ii) The maximum height of the support structure and any attached *aerials* or *antennas* is 20m.

(iii) There is no vertical *aerial* on the site permitted under 4H.2.4 c)(vi) that exceeds the stated height applying to buildings in the applicable Residential Zone or Rural Residential Zone by more than 2m.

(iv) The supporting structure may be one of the following:

(a) A guyed mast. The maximum inscribed circle of the mast below 9m shall be 1000mm, and above 9m shall be 115mm; or

(b) A guyed lattice mast. The maximum inscribed circle of the mast below 9m shall be 1000mm, and above 9m shall be 300mm. The mast may be of constant width or tapering; or

(c) A self-supporting lattice mast. The maximum inscribed circle of the mast below 9m shall be 1000mm, and above 9m must fit within a tapering envelope with a maximum inscribed circle of 660mm at 9m and 420mm at 20m; or

(d) A self-supporting tubular mast. The maximum inscribed circle of the mast below 9m shall be 1000mm, and above 9m must fit within a tapering envelope with a maximum inscribed circle of 230mm at 9m and 115mm at 20m.

(v) There may be local enlargement of support structure to accommodate a rotator mechanism.

(vi) There may be a lowering mechanism on a support structure provided that the diameter of the support structure and lowering mechanism does not exceed the dimensions specified in (iv)(a)-(d) above.

(vii) The supporting structure is located in accordance with the streetscape and setback standards applying to buildings in the applicable Residential Zone or Rural Residential Zone. For the purpose of this rule the overshadowing standards shall not apply to the supporting structure.

(viii) Where guy wires are used these must not exceed 12 mm in diameter.

(ix) At no point must any guy wire overhang the boundary.

"C"

Consequential amendments as follows (additions shown underlined, deletions strikethrough):

14B: Suburban Residential, Wairakei Residential and Large Lot Residential Zones

14B.2 Activity Status Rules

14B.2.1 Activities in Suburban Residential, Wairakei Residential and Large Lot Residential Zones

Table 14B.1: Suburban Residential, Wairakei Residential and Large Lot Residential Zone Activity Status

Use/Activity	Relevant Rule	Suburban Residential	Large Lot Residential	Wairakei Residential
Accessory buildings, structures and activities		P *(Refer Rule 14B.3)*	P *(Refer Rule 14B.3)*	RD (P) *(Refer Rule 14B.6)* *With the exception of permitted* *Amateur Radio Configurations (refer relevant Rule 4H.2.4)*

Note: (P) in this table in relation to the Wairakei Residential Zone means an activity is a permitted activity (excluding Amateur Radio Configurations permitted under Rule 4H.2.4) provided that the proposed development has been designed and constructed in accordance with a comprehensive development consent granted under Rule 14B.6 g) – Restricted Discretionary Activity Rules and provided under Rule 14B.3.15 - Wairakei Residential Zone – Permitted Activities and Rule 14B.6.10 – comprehensive development consent.

14B.3 Permitted Activity Rules

14B.3.2 Building Height - Suburban Residential, Large Lot Residential

a) The maximum *height* of any *building*, with the exception of the permitted intrusions either under ~~in~~ *Rule 4H.2.3 or 4H.2.4*, on a *site* shall be:

14B.3.4 Setbacks - Suburban Residential, Large Lot Residential

a) All *buildings*, excluding any *setback* intrusions permitted under either *Rule 4H.2.1 or 4H.2.4*, shall provide the following *setbacks* from a side or rear *boundary*:

14B.3.6 Overshadowing - Suburban Residential, Large Lot Residential

a) All *buildings*, excluding any overshadowing intrusions permitted under either *Rule 4H.2.2 or 4H.2.4*, shall be within a *building* envelope calculated in accordance with *Appendix 14C: Overshadowing*;

14B.3.15 Wairakei Residential Zone – Permitted Activities

No activity within the Wairakei Residential Zone shall be considered a Permitted Activity (other than Amateur Radio Configurations permitted under Rule 4H.2.4) unless in accordance with a *comprehensive development consent* granted under *Rule 14B.6 g) – Restricted Discretionary Activity Rules* and provided for under *Rule 14B.6.10 – comprehensive development consent*

Note: Any Activity that does not comply with Rule 14B.3.15 – Wairakei Residential Zone – Permitted Activities shall be considered a Non-Complying Activity.

14C: Urban Marae Community Zone and the Ngati Kahu Papakainga Zone

14C.5 Permitted Activity Rules

14C.5.2 Building Height

a) The maximum height of any building, with the exception of the permitted intrusions under either ~~in~~ *Rule 4H.2.3* *or 4H.2.4,* shall be:

14C.5.5 Setbacks

All *buildings,* excluding any setback intrusions permitted under either *Rule 4H.2.1* *or 4H.2.4* shall provide the following *setbacks* from a side or rear *boundary*:

14C.5.7 Overshadowing

a) All *buildings*, excluding any overshadowing intrusions permitted under either *Rule 4H.2.2* *or 4H.2.4* shall be within a *building* envelope calculated in accordance with *Appendix 14C: Overshadowing*;

14D: City Living Zone

14D.2 Activity Status Rules

Use/Activity	Relevant Rule	City Living Residential	City Living Mixed Use
Accessory buildings, structures and activities	*14D.4*	RD *With the exception of permitted* *Amateur Radio Configurations (refer relevant Rule 4H.2.4)*	RD *With the exception of permitted* *Amateur Radio Configurations (refer relevant Rule 4H.2.4)*

Table 14D.1: City Living Zone Activity Status

14D.4 Restricted Discretionary Activity Rules

14D.4.2.4 Building Height
a) The maximum *height* of any *building* or *structure* (Refer to *Appendix 14D: City Living Zone Building Heights*); with the exception of the Permitted Intrusions under either ~~in~~ *Rule 4H.2.3* or *4H.2.4*, shall be:

14D.4.2.7 Overshadowing
a) All *buildings*, excluding any overshadowing intrusions permitted under either *Rule 4H.2.2* or *4H.2.4*, on a *site* shall be within a *building* envelope in accordance with *Appendix 14C: Overshadowing;*

14E: High Density Residential Zone

14E.3 Permitted Activity Rules

14E.3.2 Building Height

a) The maximum *height* of any *building* with the exception of the Permitted Intrusions under either ~~in~~ *Rule 4H.2.3* *or 4H.2.4* on a *site* shall be 9 metres.

14E.3.4 Setbacks

All *buildings,* excluding any *setback* intrusions permitted under either *Rule 4H.2.1* *or 4H.2.4* shall provide the following *setbacks* from a side or rear *boundary*:

14E.3.6 Overshadowing

a) All *buildings*, excluding any overshadowing intrusions permitted under either *Rule 4H.2.2* *or 4H.2.4* and excluding *buildings* in the High Rise Plan Area, shall be within a *building* envelope calculated in accordance with *Appendix 14C: Overshadowing.*

15A: Rural Residential Zone

15A.2 Activity Status Rules

15A.2.1 Activities in the Rural Residential Zone

Table 15A.1: Rural Residential Zone Activity Status

Use/Activity	Relevant Rule	Rural Residential	Tara Road Urban Growth Plan Area
Accessory buildings, structures and activities	*15A.3*	P	C *With the exception of permitted* *Amateur Radio Configurations (refer relevant Rule 4H.2.4)*

15A.2 Permitted Activity Rules

15A.3.2 Building Height

a) The maximum *height* of any *building*, with the exception of the permitted intrusions under either ~~in~~ *Rule 4H.2.3* *or 4H.2.4* shall be 9 metres;

15A.3.4 Setbacks

All *buildings*, excluding any *setback* intrusions permitted under either *Rule 4H.2.1* *or 4H.2.4* shall provide the following *setbacks* from a side or rear *boundary*:

15A.3.5 Overshadowing

All *buildings*, excluding any overshadowing intrusions permitted under either *Rule 4H.2.2* *or 4H.2.4*, shall be within a *building* envelope calculated in accordance with *Appendix 14C: Overshadowing.*

Antenna Height and Communications Effectiveness

Second Edition

A Guide for City Planners and Amateur Radio Operators

By R. Dean Straw, N6BV, and Gerald L. Hall, K1TD
Senior Assistant Technical Editor and Retired Associate Technical Editor

The American Radio Relay League, Inc.
225 Main Street
Newington, CT 06111

Executive Summary

Amateur radio operators, or "hams" as they are called, communicate with stations located all over the world. Some contacts may be local in nature, while others may be literally halfway around the world. Hams use a variety of internationally alloeated frequencies to aceomplish their communications.

Except for local contacts, whieh are primarily made on Very High and Ultra High Frequencies (VHF and UHF), communicating between any two points on the earth rely primarily on high-frequency (HF) signals propagating through the ionosphere. The earth's ionosphere acts much like a mirror at heights of about 150 miles. The vertical angle of radiation of a signal launched from an antenna is one of the key factors determining effective communication distances. The ability to communicate over long distances generally requires a low radiation angle, meaning that an antenna must be placed high above the ground in terms of the wavelength of the radio wave being transmitted.

A beam type of antenna at a height of 70 feet or more will provide greatly superior performance over the same antenna at 35 feet, all other factors being equal. A height of 120 feet or even higher will provide even more advantages for long-distance eommunications. To a distant receiving station, a transmitting antenna at 120 feet will provide the effect of approximately 8 to 10 times more transmitting power than the same antenna at 35 feet. Depending on the level of noise and interference, this performanee disparity is often enough to mean the difference between making distant radio contact with fairly reliable signals, and being unable to make distant contact at all.

Radio Amateurs have a well-deserved reputation for providing vital communications in emergency situations, such as in the aftermath of a severe icestorm, a hurricane or an earthquake. Short-range communications at VHF or UHF frequencies also require sufficient antenna heights above the loeal terrain to ensure that the antenna has a clear horizon.

In terms of safety and aesthetic considerations, it might seem intuitively reasonable for a planning board to want to restrict antenna installations to low heights. However, such height restrictions often prove very counterproductive and frustrating to all parties involved. If an amateur is restricted to low antenna heights, say 35 feet, he will suffer from poor transmission of his own signals as well as poor reception of distant signals. In an attempt to compensate on the transmitting side (he can't do anything about the poor reception problem), he might boost his transmitted power, say from 150 watts to 1,500 watts, the maximum legal limit. This ten-fold increase in power will very signifieantly increase the *potential* for interference to telephones, televisions, VCRs and audio equipment in his neighborhood.

Instead, if the antenna can be moved farther away from neighboring eleetronic devices—putting it higher, in other words—this will greatly reduee the likelihood of interference, which decreases at the inverse square of the distance. For example, doubling the distance reduces thc potential for interference by 75%. As a further benefit, a large antenna doesn't look anywhere near as large at 120 feet as it does close-up at 35 feet.

As a not-so-inconsequential side benefit, moving an antenna higher will also greatly reduce the potential of exposure to electromagnetic fields for neighboring human and animals. Interference and RF exposure standards have been thoroughly covered in recently enacted Federal Regulations.

Antenna Height and Communications Effectiveness

By R. Dean Straw, N6BV, and Gerald L. Hall, K1TD
Senior Assistant Technical Editor and Retired Associate Technical Editor

The purpose of this paper is to provide general information about communications effectiveness as related to the physical height of antennas. The intended audience is amateur radio operators and the city and town Planning Boards before which a radio amateur must sometimes appear to obtain building permits for radio towers and antennas.

The performance of horizontally polarized antennas at heights of 35, 70 and 120 feet is examined in detail. Vertically polarized arrays are not considered here because at short-wave frequencies, over average terrain and at low radiation angles, they are usually less effective than horizontal antennas.

Ionospheric Propagation

Frequencies between 3 and 30 megahertz (abbreviated MHz) are often called the "short-wave" bands. In engineering terms this range of frequencies is defined as the *high-frequency* or *HF* portion of the radio spectrum. HF radio communications between two points that are separated by more than about 15 to 25 miles depend almost solely on propagation of radio signals through the *ionosphere*. The ionosphere is a region of the Earth's upper atmosphere that is ionized primarily by ultraviolet rays from the Sun.

The Earth's ionosphere has the property that it will refract or bend radio waves passing through it. The ionosphere is not a single "blanket" of ionization. Instead, for a number of complex reasons, a few discrete layers are formed at different heights above the earth. From the standpoint of radio propagation, each ionized layer has distinctive characteristics, related primarily to different amounts of ionization in the various layers. The ionized layer that is most useful for HF radio communication is called the *F layer*.

The F layer exists at heights varying from approximately 130 to 260 miles above the earth's surface. Both the layer height and the amount of ionization depend on the latitude from the equator, the time of day, the season of the year, and on the level of sunspot activity. Sunspot activity varies generally in cycles that are approximately 11 years in duration, although short-term bursts of activity may create changes in propagation conditions that last anywhere from a few minutes to several days. The ionosphere is not homogeneous, and is undergoing continual change. In fact, the exact state of the ionosphere at any one time is so variable that is best described in statistical terms.

The F layer disappears at night in periods of low and medium solar activity, as the ultraviolet energy required to sustain ionization is no longer received from the Sun. The amount that a passing radio wave will bend in an ionospheric layer is directly related to the intensity of ionization in that layer, and to the frequency of the radio wave.

A triangle may be used to portray the cross-sectional path of ionospheric radio-wave travel, as shown in **Fig 1**, a highly simplified picture of what happens in propagation of radio waves. The base of the triangle is the surface of the Earth between two distant points, and the apex of the triangle is the point representing refraction in the ionosphere. If all the necessary conditions are met, the radio wave will travel from the first point on the Earth's surface to the ionosphere, where it will be bent (*refracted*) sufficiently to travel to the second point on the earth, many hundreds of miles away.

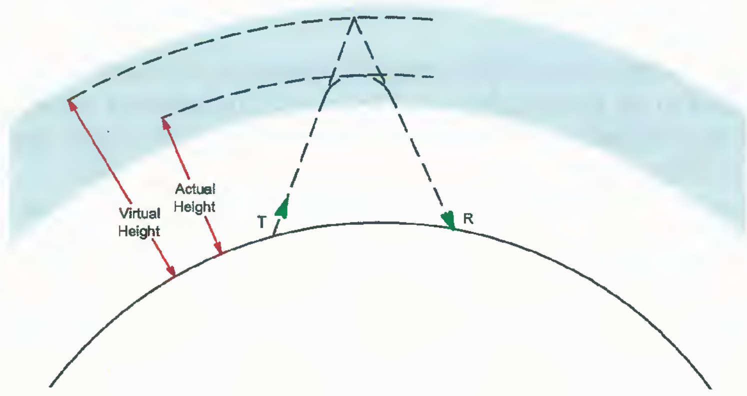

Fig 1—A simplified cross-sectional representation of ionospheric propagation. The simple triangle goes from the Transmitter T up to the virtual height and then back down to the Receiver R. Typically the F layer exists at a height of 150 miles above the Earth at mid-latitudes. The distance between T and R may range from a few miles to 2500 miles under normal propagation conditions.

Of course the Earth's surface is not a flat plane, but instead is curved. High-frequency radio waves behave in essentially the same manner as light waves—they tend to travel in straight lines, but with a slight amount of downward bending caused by refraction in the air. For this reason it is not possible to communicate by a direct path over distances greater than about 15 to 25 miles in this frequency range, slightly farther than the optical horizon. The curvature of the earth causes the surface to "fall away" from the path of the radio wave with greater distances. Therefore, it is the ionosphere that permits HF radio communications to be made between points separated by hundreds or even thousands of miles. The range of frequencies from 3 to 30 MHz is unique in this respect, as ionospheric propagation is not consistently supported for any frequencies outside this range.

One of the necessary conditions for ionospheric communications is that the radio wave must encounter the ionosphere at the correct angle. This is illustrated in **Fig 2**, another very simplified drawing of the geometry involved. Radio waves leaving the earth at high elevation angles above the horizon may receive only very slight bending due to refraction, and are then lost to outer space. For the same fixed frequency of operation, as the elevation angle is lowered toward the horizon, a point is reached where the bending of the wave is sufficient to return the wave to the Earth. At successively lower angles, the wave returns to the Earth at increasing distances.

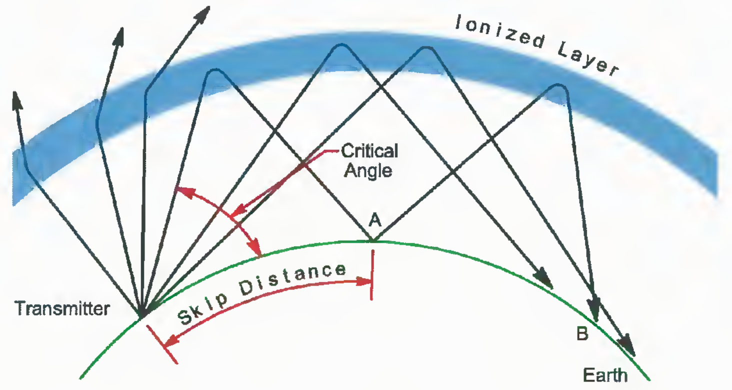

Fig 2—Behavior of radio waves encountering the ionosphere. Rays entering the ionized region at angles above the critical angle are not bent enough to return to Earth and are lost to space. Waves entering at angles below the critical angle reach the Earth at increasingly greater distances as the angle approaches the horizontal. The maximum distance that may normally be covered in a single hop is 2500 miles. Greater distances may be covered with multiple hops.

If the radio wave leaves the earth at an *elevation angle* of zero degrees, just toward the horizon (or just tangent to the earth's surface), the maximum distance that may be reached under usual ionospheric conditions is approximately 2,500 miles (4,000 kilometers). However, the Earth itself also acts as a reflector of radio waves coming down from the ionosphere. Quite often a radio signal will be reflected from the reception point on the Earth back into the ionosphere again, reaching the Earth a second time at a still more distant point.

As in the case of light waves, the angle of reflection is the same as the angle of incidence, so a wave striking the surface of the Earth at an angle of, say, 15° is reflected upward from the surface at the same angle. Thus, the distance to the second point of reception will be approximately twice the distance of the first. This effect is also illustrated in Fig 2, where the signal travels from the transmitter at the left of the drawing via the ionosphere to Point A, in the center of the drawing. From Point A the signal travels via the ionosphere again to Point B, at the right. A signal traveling from the Earth through the ionosphere and back to the Earth is called a *hop*. Under some conditions it is possible for as many as four or five signal hops to occur over a radio path, but no more than two or three hops is the norm. In this way, HF communications can be conducted over thousands of miles.

With regard to signal hopping, two important points should be recognized. First, a significant loss of signal occurs with each hop. Lower layers of the ionosphere absorb energy from the signals as they pass through, and the ionosphere tends to scatter the radio energy in various directions, rather than confining it to a tight bundle. The earth also scatters the energy at a reflection point. Thus, only a small fraction of the transmitted energy actually reaches a distant receiving point.

Again refer to Fig 2. Two radio paths are shown from the transmitter to Point B, a one-hop path and a two-hop path. Measurements indicate that although there can be great variation in the ratio of the two signal strengths in a situation such as this, the signal power received at Point B will generally be from five to ten times greater for the one-hop wave than for the two-hop wave. (The terrain at the mid-path reflection point for the two-hop wave, the angle at which the wave is reflected from the earth, and the condition of the ionosphere in the vicinity of all the refraction points are the primary factors in determining the signal-strength ratio.) Signal levels are generally compared in decibels, abbreviated dB. The decibel is a logarithmic unit. Three decibels difference in signal strengths is equivalent to a power ratio of 2:1; a difference of 10 dB equates to a power ratio of 10:1. Thus the signal loss for an additional hop is about 7 to 10 dB.

The additional loss per hop becomes significant at greater distances. For a simplified example, a distance of 4,000 miles can be covered in two hops of 2,000 miles each or in four hops of 1,000 miles each. For illustration, assume the loss for additional hops is 10 dB, or a 1/10 power ratio. Under such conditions, the four-hop signal will be received with only 1/100 the power or 20 dB below that received in two hops. The reason for this is that only 1/10 of the two-hop signal is received for the first additional (3^{rd}) hop, and only 1/10 of that 1/10 for the second additional (4^{th}) hop. It is for this reason that no more than four or five propagation hops are useful; the received signal eventually becomes too weak to be heard.

The second important point to be recognized in multihop propagation is that the geometry of the first hop establishes the geometry for all succeeding hops. And it is the elevation angle at the transmitter that sets up the geometry for the first hop.

It should be obvious from the preceding discussion that one needs a detailed knowledge of the range of elevation angles for effective communication in order to do a scientific evaluation of a possible communications circuit. The range of angles should be statistically valid over the full 11-year solar sunspot cycle, since the behavior of the Sun determines the changes in the nature of the Earth's ionosphere. ARRL did a very detailed computer study in the early 1990s to determine the angles needed for propagation throughout the world. The results of this study will be examined later, after we introduce the relationship between antenna height and the elevation pattern for an antenna.

Horizontal Antennas Over Flat Ground

A simple antenna that is commonly used for HF communications is the horizontal half-wave *dipole*. The dipole is a straight length of wire (or tubing) into which radio-frequency energy is fed at the center. Because of its simplicity, the dipole may be easily subjected to theoretical performance analyses. Further, the results of proper analyses are well borne out in practice. For these reasons, the half-wave dipole is a convenient performance standard against which other antenna systems can be compared.

Because the earth acts as a reflector for HF radio waves, the directive properties of any antenna are modified considerably by the ground underneath it. If a dipole antenna is placed horizontally above the ground, most of the energy radiated downward from the dipole is reflected upward. The reflected waves combine with the direct waves (those radiated at angles above the horizontal) in various ways, depending on the height of the antenna, the frequency, and the electrical characteristics of the ground under and around the antenna.

At some vertical angles above the horizon, the direct and reflected waves may be exactly in phase—that is, the maximum signal or field strengths of both waves are reached at the same instant at some distant point. In this case the resultant field strength is equal to the sum of the two components. At other vertical angles the two waves may be completely out of phase at some distant point—that is, the fields are maximum at the same instant but the phase directions are opposite. The resultant field strength in this case is the difference between the two. At still other angles the resultant field will have intermediate values. Thus, the effect of the ground is to increase the intensity of radiation at some vertical angles and to decrease it at others. The elevation angles at which the maxima and minima occur depend primarily on the antenna height above ground. (The electrical characteristics of the ground have some slight effect too.)

For simplicity here, we consider the ground to be a perfectly conducting, perfectly flat reflector, so that straightforward trigonometric calculations can be made to determine the relative amount of radiation intensity at any vertical angle for any dipole height. Graphs from such calculations are often plotted on rectangular axes to show best resolution over particularly useful ranges of elevation angles, although they are also shown on polar plots so that both the front and back of the response can be examined easily. **Fig 3** shows an overlay of the polar elevation-pattern responses of two dipoles at different heights over perfectly conducting flat ground. The lower dipole is located a half wavelength above ground, while the higher dipole is located one wavelength above ground. The pattern of the lower antenna peaks at an elevation angle of about 30°, while the higher antenna has two main lobes, one peaking at 15° and the other at about 50° elevation angle.

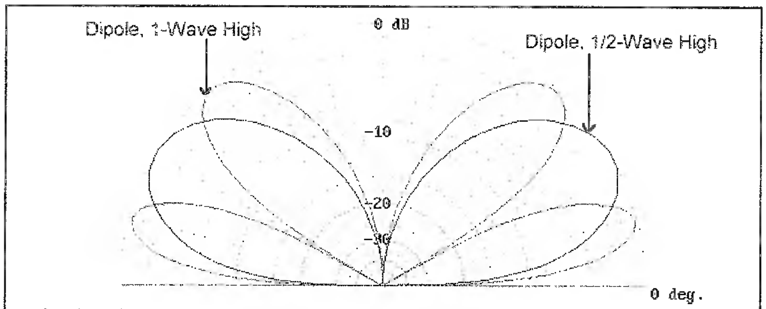

Fig 3–Comparison of elevation responses for two dipoles: one ½-wavelength high, and the other 1-wavelength high.

In the plots shown in Fig 3, the elevation angle above the horizon is represented in the same fashion that angles are measured on a protractor. The concentric circles are calibrated to represent ratios of field strengths, referenced to the strength represented by the outer circle. The circles are calibrated in decibels. Diminishing strengths are plotted toward the center.

You may have noted that antenna heights are often discussed in terms of *wavelengths*. The reason for this is that the length of a radio wave is inversely proportional to its frequency. Therefore a fixed physical height will represent different electrical heights at different radio frequencies. For example, a height of 70 feet represents one wavelength at a frequency of 14 MHz. But the same 70-foot height represents a half wavelength for a frequency of 7 MHz and only a quarter wavelength at 3.5 MHz. On the other hand, 70 feet is 2 wavelengths high at 28 MHz.

The lobes and nulls of the patterns shown in Fig 3 illustrate what was described earlier, that the effect of the ground beneath an antenna is to increase the intensity of radiation at some vertical elevation angles and to decrease it at others. At a height of a half wavelength, the radiated energy is strongest at a rather high elevation angle of 30°. This would represent the situation for a 14-MHz dipole 35 feet off the ground.

As the horizontal antenna is raised to greater heights, additional lobes are formed, and the lower ones move closer to the horizon. The maximum amplitude of each of the lobes is roughly equal. As may be seen in Fig 3, for an antenna height of one wavelength, the energy in the lowest lobe is strongest at 15°. This would represent the situation for a 14-MHz dipole 70 feet high.

The elevation angle of the lowest lobe for a horizontal antenna above perfectly condueting ground may be determined mathematically:

$$\theta = \sin^{-1}\left(\frac{0.25}{h}\right)$$

Where

θ = the wave or elevation angle
h = the antenna height above ground in wavelengths

In short, the higher the horizontal antenna, the lower is the lowest lobe of the pattern. As a very general rule of thumb, the higher an HF antenna can be placed above ground, the farther it will provide effective communications beeause of the resulting lower radiation angle. This is true for any horizontal antenna over real as well as theoretically perfect ground.

You should note that the *nulls* in the elevation pattern can play an important role in communications—or lack of communieation. If a signal arrives at an angle where the antenna system exhibits a deep null, communication effectiveness will be greatly reduced. It is thus quite possible that an antenna can be *too high* for good communications efficiency on a particular frequency. Although this rarely arises as a significant problem on the amateur bands below 14 MHz, we'll discuss the subjeet of optimal height in more detail later.

Actual earth does not reflect all the radio-frequency energy striking it; some absorption takes place. Over real earth, therefore, the patterns will be slightly different than those shown in Fig 3, however the differences between theoretical and perfect earth ground are not significant for the range of elevation angles necessary for good HF communication. Modern computer programs can do accurate evaluations, taking all the significant ground-related factors into account.

Beam Antennas

For point-to-point communications, it is beneficial to concentrate the radiated energy into a beam that ean be aimed toward a distant point. An analogy can be made by comparing the light from a bare electric bulb to that from an automobile headlight, which incorporates a built-in focusing lens. For illuminating a distant point, the headlight is far more effective.

Antennas designed to concentrate the radiated energy into a beam are called, naturally enough, *beam antennas*. For a fixed amount of transmitter power fed to the transmitting antenna, beam antennas provide increased signal strength at a distant receiver. In radio communications, the use of a beam antenna is also beneficial during reception, because the antenna pattern for transmission is the same for reception. A beam antenna helps to reject signals from unwanted directions, and in effect boosts the strength of signals received from the desired direction.

The increase in signal or field strength a beam antenna offers is frequently referenced to a dipole antenna in free space (or to another theoretical antenna in free space called an *isotropic antenna*) by a term called *gain*. Gain is commonly expressed in decibels. The isotropic antenna is defined as being one that radiates equally well in all directions, much like the way a bare lightbulb radiates essentially equally in all directions.

One particularly well known type of beam antenna is called a *Yagi*, named after one of its Japanese inventors. Different varieties of Yagi antennas exist, each having somewhat different characteristics. Many television antennas are forms of multi-element Yagi beam antennas. In the next section of this paper, we will refer to a four-element Yagi, with a gain of 8.5 dBi in free space, exclusive of any influence due to ground.

This antenna has 8.5 dB more gain than an isotropic antenna in free space and it achieves that gain by squeezing the pattern in certain desired directions. Think of a normally round balloon and imagine squeezing that balloon to elongate it in one direction. The increased length in one direction comes at the expense of length in other directions. This is analogous to how an antenna achieves more signal strength in one direction, at the expense of signal strength in other directions.

The elevation pattern for a Yagi over flat ground will vary with the electrical height over ground in exactly the same manner as for a simpler dipole antenna. The Yagi is one of the most common antennas employed by radio amateurs, second in popularity only to the dipole.

Putting the Pieces Together

In **Fig 4**, the elevation angles necessary for communication from a particular transmitting site, in Boston, Massachusetts, to the continent of Europe using the 14-MHz amateur band are shown in the form of a bargraph. For each elevation angle from 1° to 30°, Fig 4 shows the percentage of time when the 14-MHz band is open at each elevation angle. For example, 5° is the elevation angle that occurs just over 12% of the time when the band is available for communication, while 11° occurs about 10% of the time when the band is open. The useful range of elevation angles that must accommodated by an amateur station wishing to talk to Europe from Boston is from 1° to 28°.

In addition to the bar-graph elevation-angle statistics shown in Fig 4, the elevation pattern responses for three Yagi antennas, located at three different heights above flat ground, are overlaid on the same graph. You can easily see that the 120-foot antenna is the best antenna to cover the most likely angles for this particular frequency, although it suffers at the higher elevation angles on this particular propagation path, beyond about 12°. If, however, you can accept somewhat lower gain at the lowest angles, the 70-foot antenna would arguably be the best overall choice to cover all the elevation angles.

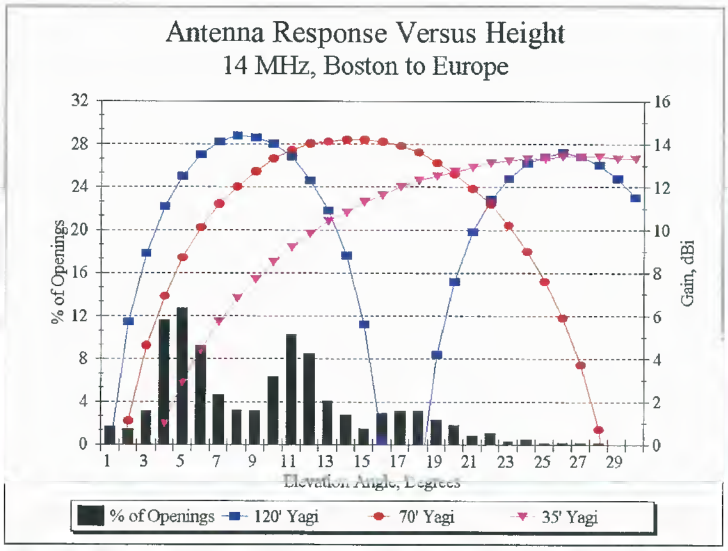

Fig 4—Elevation response patterns of three Yagis at 120, 70 and 35 feet, at 14 MHz over flat ground. The patterns are overlaid with the statistical elevation-angles for the path from Boston to continental Europe over the entire 11-year solar sunspot cycle. Clearly, the 120-foot antenna is the best choice to cover the low angles needed, but it suffers some at higher angles.

Other graphs are needed to show other target receiving areas around the world. For comparison, **Fig 5** is also for the 14-MHz band, but this time from Boston to Sydney, Australia. The peak angle for this very long path is about 2°, occurring 19% of the time when the band is actually open for communication. Here, even the 120-foot high antenna is not ideal. Nonetheless, at a moderate 5° elevation angle, the 120-foot antenna is still 10 dB better than the one at 35 feet.

Fig 4 and Fig 5 have portrayed the situation for the 14-MHz amateur band, the most popular and heavily utilized HF band used by radio amateurs. During medium to high levels of solar sunspot activity, the 21 and 28-MHz amateur bands are open during the daytime for long-distance communication. **Fig 6** illustrates the 28-MHz elevation-angle statistics, compared to the elevation patterns for the same three antenna heights shown in Fig 5. Clearly, the elevation response for the 120-foot antenna has a severe (and undesirable) null at 8°. The 120-foot antenna is almost 3.4 wavelengths high on 28 MHz (whereas it is 1.7 wavelengths high on 14 MHz.) For many launch angles, the 120-foot high Yagi on 28 MHz would simply be too high.

The radio amateur who must operate on a variety of frequencies might require two or more towers at different heights to maintain essential elevation coverage on all the authorized bands. Antennas can sometimes be mounted at different heights on a single supporting tower, although it is more difficult to rotate antennas that are "vertically stacked" around the tower to point in all the needed directions. Further, closely spaced antennas tuned to different frequencies usually interact electrically with each other, often causing severe performance degradation.

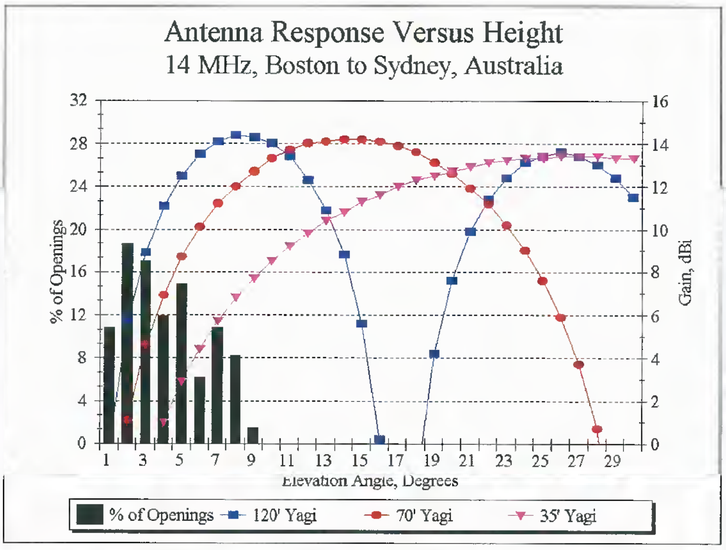

Fig 5—Elevation responses for same antennas as Fig 4, but for a longer-range path from Boston to Sydney, Australia. Note that the prevailing elevation angles are very low.

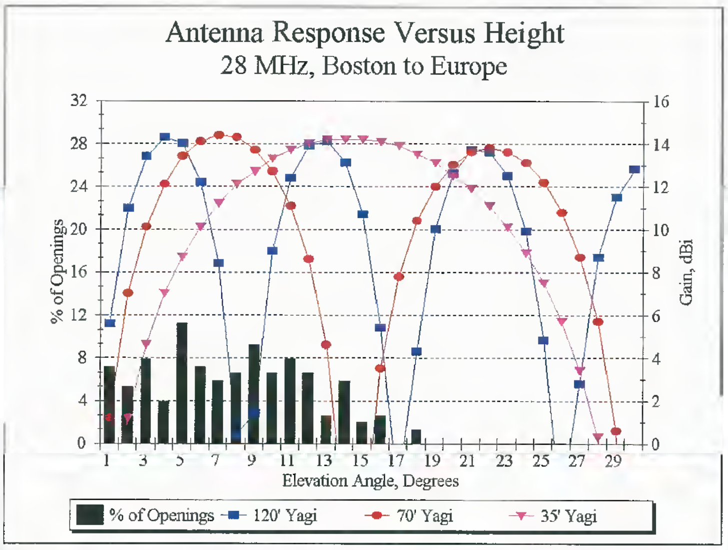

Fig 6—Elevation angles compared to antenna responses for 28-MHz path from Boston to Europe. The 70-foot antenna is probably the best overall choice on this path.

During periods of low to moderate sunspot activity (about 50% of the 11-year solar cycle), the 14-MHz band closes down for propagation in the early evening. A radio amateur wishing to continue communication must shift to a lower frequency band. The next most highly used band below the 14-MHz band is the 7-MHz amateur band. **Fig 7** portrays a 7-MHz case for another transmitting site, this time from San Francisco, California, to the European continent. Now, the range of necessary elevation angles is from about 1° to 16°, with a peak statistical likelihood of about 16% occurring at an elevation of 3°. At this low elevation angle, a 7-MHz antenna must be *very* high in the air to be effective. Even the 120-foot antenna is hardly optimal for the peak angle of 3°. The 200-foot antenna shown would be far better than a 120-foot antenna. Further, the 35-foot high antenna is *greatly* inferior to the other antennas on this path and would provide far less capabilities, on both receiving and transmitting.

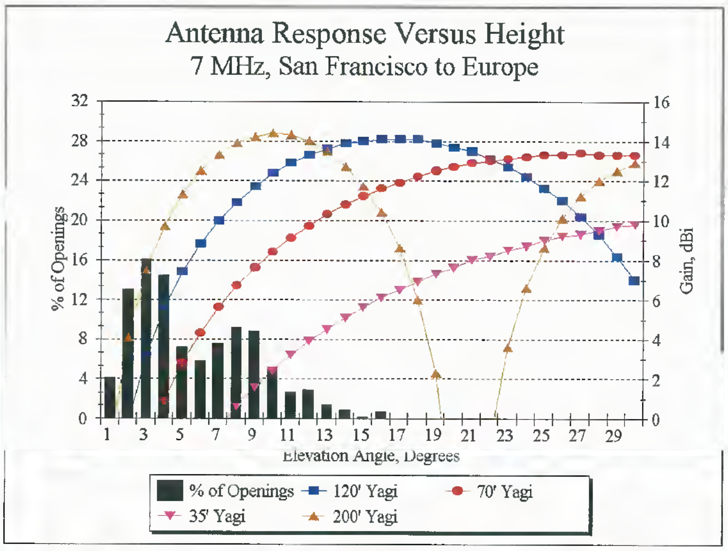

Fig 7—Comparison of antenna responses for another propagation path: from San Francisco to Europe on 7 MHz. Here, even a 120-foot high antenna is hardly optimal for the very low elevation angles required on this very long path. In fact, the 200-foot high antenna is far better suited for this path.

What If the Ground Isn't Flat?

In the preceding discussion, antenna radiation patterns were computed for antennas located over *flat ground*. Things get much more complicated when the exact local terrain surrounding a tower and antenna are taken into account. In the last few years, sophisticated ray-tracing computer models have become available that can calculate the effect that local terrain has on the elevation patterns for real-world HF installations—and *each* real-world situation is indeed different.

For simplicity, first consider an antenna on the top of a hill with a constant slope downward. The general effect is to lower the effective elevation angle by an amount equal to the downslope of the hill. For example, if the downslope is –3° for a long distance away from the tower and the flat-ground peak elevation angle is 10° (due to the height of the antenna), then the net result will be 10° – 3° = 7° peak angle. However, if the local terrain is rough, with many bumps and valleys in the desired direction, the response can be modified considerably. **Fig 8** shows the fairly complicated terrain profile for Jan Carman, K5MA, in the direction of Japan. Jan is located on one of the tallest hills in West Falmouth, Massachusetts. Within 500 feet of his tower is a small hill with a water tower on the top, and then the ground quickly falls away, so that at a distance of about 3000 feet from the tower base, the elevation has fallen to sea level, at 0 feet.

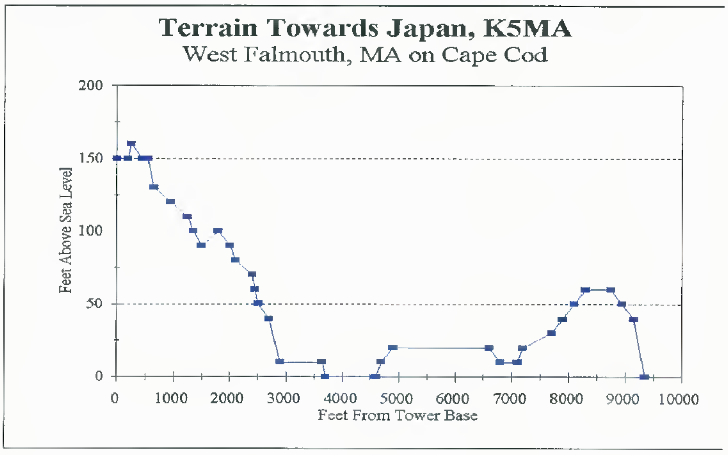

Fig 8—Terrain profile from location of K5MA, Jan Carman, in West Falmouth, MA, towards Japan. This is a moderately complicated real-world terrain on one of the highest hills on Cape Cod.

The computed responses toward Japan from this location, using a 120- and a 70-foot high Yagi, are shown in **Fig 9**, overlaid for comparison with the response for a 120-foot Yagi over flat ground. Over this particular terrain, the elevation pattern for the 70-foot antenna is actually better than that of the 120-foot antenna for angles below about 3°, but not for medium angles! The responses for each height oscillate around the pattern for flat ground — all due to the complex reflections and diffractions occurring off the terrain.

At an elevation angle of 5°, the situation reverses itself and the gain is now higher for the 120-foot-high antenna than for the 70-foot antenna. A pair of antennas on one tower would be required to cover all the angles properly. To avoid any electrical interactions between similar antennas on one tower, two towers would be much better. Compared to the flat-ground situation, the responses of real-world antenna can be very complicated due to the interactions with the local terrain.

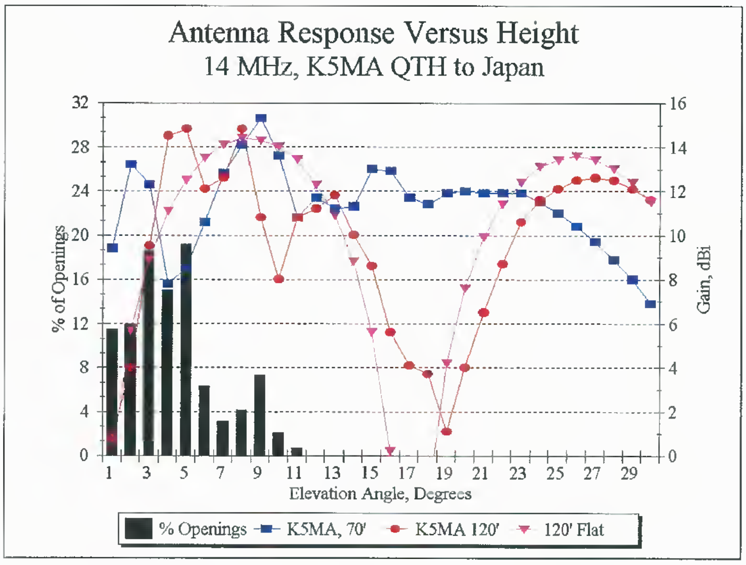

Fig 9—Computed elevation responses of 120- and 70-foot high Yagis, at the K5MA location on Cape Cod, in the direction of Japan and over flat ground, for comparison. The elevation response of the real-world antenna has been significantly modified by the local terrain.

Fig 10 shows the situation for the same Cape Cod location, but now for 7 MHz. Again, it is clear that the 120-foot high Yagi is superior by at least 3 dB (equivalent to twice the power) to the 70-foot high antenna at the statistical elevation angle of 6°. However, the response of the real-world 120-foot high antenna is still up some 2 dB from the response for an identical antenna over flat ground at this angle. On this frequency, the local terrain has helped boost the gain at the medium angles more than a similar antenna 120 feet over flat ground. The gain is even greater at lower angles, say at 1° elevation, where most signals take off, statistically speaking. Putting the antenna up higher, say 150 feet, will help the situation at this location, as would adding an additional Yagi at the 70-foot level and feeding both antennas in phase as a vertical stack.

Although the preceding discussion has been in terms of the transmitting antenna, the same principles apply when the antenna is used for reception. A high antenna will receive low-angle signals more effectively than will a low antenna. Indeed, amateur operators know very well that "If you can't hear them, you can't talk to them." Stations with tall towers can usually hear far better than their counterparts with low installations.

The situation becomes even more difficult for the next lowest amateur band at 3.5 MHz, where optimal antenna heights for effective long-range communication become truly heroic! Towers that exceed 120 feet are commonplace among amateurs wishing to do serious 3.5-MHz long-distance work.

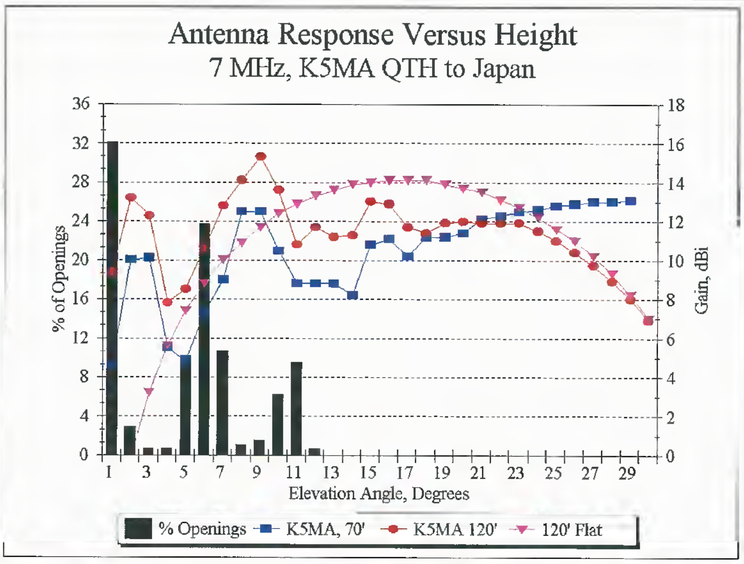

Fig 10—Elevation response on 7 MHz from K5MA location towards Japan on 7 MHz. The 120-foot high Yagi is definitely superior to the one only 70-feet high.

The 3.5 and 7-MHz amateur bands are, however, not always used strictly for long-range work. Both bands are crucial for providing communications throughout a local area, such as might be necessary in times of a local emergency. For example, earthquakes, tornadoes and hurricanes have often disrupted local communications—because telephone and power lines are down and because local police and fire-department VHF/UHF repeaters are thus knocked out of action. Radio amateurs often will use the 3.5 and 7-MHz bands to provide communications out beyond the local area affected by the disaster, perhaps into the next county or the next metropolitan area. For example, an earthquake in San Francisco might see amateurs using emergency power providing communications through amateurs in Oakland across the San Francisco Bay, or even as far away as Los Angeles or Sacramento. These places are where commercial power and telephone lines are still intact, while most power and telephones might be down in San Francisco itself. Similarly, a hurricane that selectively destroys certain towns on Cape Cod might find amateurs in these towns using 3.5 or 7.0 MHz to contact their counterparts in Boston or New York.

However, in order to get the emergency messages through, amateurs must have effective antennas. Most such relatively local emergency situations require towers of moderate height, less than about 100 feet tall typically.

Antenna Height and Interference

Extensive Federal Regulations cover the subject of interference to home electronic devices. It is an unfortunate fact of life, however, that many home electronic devices (such as stereos, TVs, telephones and VCRs) do not meet the Federal standards. They are simply inadequately designed to be resistant to RF energy in their vicinity. Thus, a perfectly legal amateur-radio transmitter may cause interference to a neighbor's VCR or TV because cost-saving shortcuts were taken in the design and manufacture of these home entertainment devices. Unfortunately, it is difficult to explain to an irate neighbor why his brand-new $1000 stereo is receiving the perfectly legitimate transmissions by a nearby radio operator.

The potential for interference to any receiving device is a function of the transmitter power, transmitter frequency, receiver frequency, and most important of all, the proximity of the transmitter to the potential receiver. The transmitted field intensity decreases as the inverse square of the distance. This means that doubling the height of an antenna from 35 to 70 feet will reduce the potential for interference by 75%. Doubling the height again to 140 feet high would reduce the potential another 75%. Higher is better to prevent interference in the first place!

Recently enacted Federal Regulations address the potential for harm to humans because of exposure to electromagnetic fields. Amateur-radio stations rarely have problems in this area, because they use relatively low transmitting power levels and intermittent duty cycles compared to commercial operations, such as TV or FM broadcast stations. Nevertheless, the potential for RF exposure is again directly related to the distance separating the transmitting antenna and the human beings around it. Again, doubling the height will reduce potential exposure by 75%. The higher the antenna, the less there will any potential for significant RF exposure.

THE WORLD IS A VERY COMPLICATED PLACE

It should be pretty clear by now that designing scientifically valid communication systems is an enormously complex subject. The main complications come from the vagaries of the medium itself, the Earth's ionosphere. However, local terrain can considerably complicate the analysis also.

The main points of this paper may be summarized briefly:

> **The radiation elevation angle is the key factor determining effective communication distances beyond line-of-sight. Antenna height is the primary variable under control of the station builder, since antenna height affects the angle of radiation.**
>
> **In general, placing an amateur antenna system higher in the air enhances communication capabilities and also reduces chances for electromagnetic interference with neighbors.**

Kazimierz "Kai" Siwiak, KE4PT
10988 NW 14th St, Coral Springs, FL 33071; ke4pt@amsat.org

An Optimum Height for an Elevated HF Antenna

What is the best height for your antenna? The author considers factors that can help you decide.

There are two ways to think abont antenna and propagation problems in linear media: in transmit mode and in receive mode. By the reciprocity theorem both methods will predict the same performance. We will view the problem of finding an optimum height for HF antennas in receive mode rather than in transmit mode, because this reveals very interesting insights. For example, the field-strength at the receiving location is the result of an interference pattern between waves that arrive by a direct path added to the wave reflected from the earth's surface. The addition of these two waves results in a standing wave versus height for the field strength at the receiving location. Because this vertical standing wave has peaks and can have deep nulls, there is an optimum placement for an antenna. In the equivalent transmit mode point of view, far-field transmit patterns are calculated as an interference pattern between the direct wave and a ground reflected wave, but as *The ARRL Antenna Book* explains, that point of view obscures the physical meaning of "take-off" angle, so we can't directly appreciate what happens when an antenna is elevated.[1] By viewing the problem in receive mode, however, we see, among other things, that waves arriving from the lowest arrival angle do not always result in the best link margin to a DX station. We can also see that low antennas can work surprisingly well for DX, and that the best height for vertically polarized antennas is not the same as for horizontally polarized antennas.

With this analysis it is easy show that the optimum antenna height depends on frequency, polarization, properties of the earth at the reflection point, and on the arrival angle from the wave source in the ionosphere. While surface roughness is considered, there is also a terrain dependence, which for simplicity will not be considered here; see Dean Straw's terrain analysis program HFTA in the 21st edition of *The ARRL Antenna Book*. Furthermore, since the apparent wave earth reflection point is usually distant from the antenna, it is not important what the earth looks like directly under an elevated antenna. What is important is the earth's properties at the reflection point — typically hundreds to thousands of meters distant from the tower. This is an idealized problem where we allow for surface ronghness, but we assume an earth that is smooth enough so that we can apply spherical earth geometry.

We begin by laying a foundation based on a spherical earth geometry for the propagation of waves to the receiving location. The reflection properties of ground and sea water are shown to affect how the reflected wave combines in constructive and destructive interference with the direct wave. Optimum heights are found for desired ranges of arrival angles and for multiple bands. Finally, path link margins are estimated for multi-hop propagation. We discover that a range of "take-off" angles must be accommodated for optimum performance.

[1]Notes appear on page 38.

Spherical Earth Geometry

Because we are dealing with distances that approach the earth's horizon, we calculate the direct and earth-reflected paths using spherical-earth reflection geometry. The solution to the spherical earth geometry given in Chapter 2 of M. I. Skolnik's *Radar Handbook* involves a cubic eqnation to find the arc distance G_b to the reflection point.[2]

$$2G_b^3 - 3GG_b^2 + \left[G^2 - 2a_e\left(h_{ant} + h_i\right)\right]G_b + 2a_e h_{ant} G = 0 \quad \text{[Eq 1]}$$

where:
h_{ant} is the height at the receiving antenna,
a_e is the earth's radius,

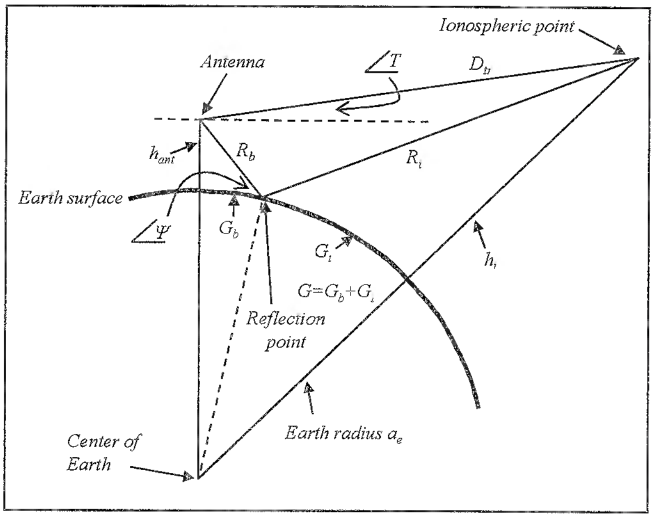

Figure 1 — Spherical earth geometry, shown with an exaggerated height dimension. Source: based on information from *Radar Handbook* (see Note 2).