## 2.14 Atmospheric Attenuation Conceptual Model Specification

As radar energy passes through the atmosphere, it is attenuated by the quantum-mechanical effects of oxygen and water vapor molecules. This absorption of electromagnetic energy occurs within the troposphere, which extends to an altitude of approximately 100,000 ft., and varies as a function of frequency, refractive range, altitude, and atmospheric conditions.

Van Vleck [A.2-20] has shown that for specific values of temperature, pressure, water vapor density, and frequency the absorption of a wave traveling from point $r_1$ to point $r_2$ is:

$$A = \int_{r_1}^{r_2} \gamma(r)\,dr \qquad (2.14\text{-}1)$$

where the coefficient of absorption ($\gamma$) varies as a function of absolute temperature, atmospheric pressure, and the water vapor density. Coefficients of absorption have been empirically derived and published for standard atmospheric conditions categorized as: Tropical, Mid-Latitude Summer, Arctic Summer, Standard Day, Mid-Latitude Winter, and Arctic Winter.

For frequencies less than 2 GHz, the effects of atmospheric attenuation and scattering is small. Attenuation becomes increasingly significant as the frequency increases above 2 GHz and becomes severe at frequencies greater than 20 GHz.

Additional attenuation can also be attributed to scattering or diffraction caused by particles suspended in the atmosphere such as raindrops, hail, snowflakes, and dust. This type of attenuation can be substantial but is very difficult to model accurately due to the variability of the particle density along the radar path.

Because of the uncertainty of the atmospheric conditions for any particular scenario, the atmospheric attenuation is typically modeled as that for a "Standard Day." This can lead to significant errors in the prediction of radar detection in scenarios having other than the Standard Day atmospheric conditions. For example, at microwave frequencies on the order of 15.0 GHz, the differences in absorption loss between the extremes in atmospheric conditions, at typical radar detection ranges, can be on the order of 12 dB, resulting in a three to one difference in target detection range.

In ALARM, the modeled atmospheric attenuation is a function of the radar frequency, range to the target, and the target elevation angle for a single set of atmospheric conditions categorized as "Standard Day."

### 2.14.1 Functional Element Design Requirements

This section contains the design requirements necessary to fully implement simulation of atmospheric attenuation in ALARM 3.0.

1. ALARM shall calculate signal losses due to absorption and scattering by oxygen and water vapor in the atmosphere for a representative set of common radar frequencies, radar antenna boresight elevation angles, and radar-to-target ranges.

2. ALARM shall use estimates for atmospheric absorption for “Standard Day” atmospheric conditions, as defined in prevailing radar literature.

### 2.14.2 Functional Element Design Approach

The approach for implementing the design requirements outlined in the previous section is described below in terms of design elements. A design element is an algorithm that represents a specific component of the FE design.

### Design Element 14-1: Provision of Atmospheric Attenuation Values for Common Radar/Target Scenarios

Atmospheric attenuation is calculated in ALARM 3.0 by a table look-up, followed by interpolation. There are seven different two-dimensional tables of attenuation values, one for each of the radar antenna boresight elevation angles 0, 1, 2, 5, 10, 30, and 90 degrees. Each table is indexed by frequency (row) and range (column). The frequencies and ranges provided in each table are displayed below.

Table 2.14-1 Available Radar Frequencies for Calculation of Atmospheric Attenuation

| Frequencies (MHz) |
|---|
| 0 |
| 10 |
| 100, 200, 300, ..., 1000 |
| 2000, 3000, 4000, ..., 10000 |
| 12000 |
| 16000 |
| 20000 |
| 22000 |
| 30000 |

Table 2.14-2 Available Radar-to-Target Ranges for Calculation of Atmospheric Attenuation

| Ranges (NM) |
|---|
| 0 |
| 25 |
| 50 |
| 75 |
| 100 |
| 150 |
| 200 |
| 350 |

The tables provided in ALARM for calculation of atmospheric attenuation satisfy design requirement 1.

## Design Element 14-2: Estimation of Atmospheric Attenuation Values for Standard Day Conditions

The values in the ALARM tables are taken from tables defined in Skolnik [A.1-18], pages 2.48 through 2.51, and Blake [A.1-25], pages 210 through 216, for atmospheric attenuation for a standard, clear day. ALARM uses interpolation to estimate atmospheric attenuation values not explicitly given in the tables. The interpolation method that is employed depends upon the antenna boresight elevation angle input to the attenuation subroutine.

For elevation angles less than or equal to $0^0$, the attenuation table for $0^0$ elevation is consulted. For elevation angles greater than or equal to $90^0$, the attenuation table for $90^0$ elevation is consulted. Equations 2.14-2 through 2.14-4 below describe the interpolation algorithm used for either of these two cases:

$$\text{Left} = (\text{Factor}_F \quad \text{Table}_{\text{R1, F2}}) + ((1 - \text{Factor}_F) \quad \text{Table}_{\text{R1, F1}}) \tag{2.14-2}$$

$$\text{Right} = (\text{Factor}_F \quad \text{Table}_{\text{R2, F2}}) + ((1 - \text{Factor}_F) \quad \text{Table}_{\text{R2, F1}}) \tag{2.14-3}$$

$$\text{ATTDB} = (\text{Factor}_R \quad \text{Right}) + ((1 - \text{Factor}_R) \quad \text{Left}) \tag{2.14-4}$$

where

| | | |
|---|---|---|
| Left | = | attenuation value for interpolated frequency at low end of range interval |
| Right | = | attenuation value for interpolated frequency at high end of range interval |
| $\text{Factor}_F$ | = | fraction of the distance across the interval [F1, F2] where the input frequency lies |
| $\text{Factor}_R$ | = | fraction of the distance across the interval [R1, R2] where the input range lies |
| F1, F2 | = | attenuation table frequencies that bound the input frequency |
| R1, R2 | = | attenuation table ranges that bound the input range |
| ATTDB | = | two-way attenuation value, in dB, obtained by interpolating across the range interval |

For elevation angles between $0^0$ and $90^0$, the attenuation value must also be interpolated across the elevation interval. This is accomplished by:

1. using the attenuation table for the elevation angle at the low end of the elevation angle interval to execute equations (2.14-2) through (2.14-4);

2. using the attenuation table for the elevation angle at the high end of the elevation angle interval to execute equations (2.14-2) through (2.14-4);

3. combining the values obtained in the previous two steps while interpolating across the elevation angle interval, using equation (2.14-5).

$$ATTDB = (Factor_E \quad ATTDB_{Right}) + ((1 - Factor_E) \quad ATTDB_{Left}) \qquad (2.14\text{-}5)$$

where $ATTDB_{Left}$ = interpolated attenuation value for low end of elevation angle interval, obtained in step (1.) above

$ATTDB_{Right}$ = interpolated attenuation value for high end of elevation angle interval, obtained in step (2.) above

$Factor_E$ = fraction of the distance across the interval where the input antenna boresight elevation angle lies

### 2.14.3 Functional Element Software Design

This section contains the software design necessary to implement the functional element requirements outlined in Section 2.14.1 and the design approach outlined in Section 2.14.2. Section 2.14.3 is organized as follows: the first part describes the subroutine hierarchy and gives descriptions of the relevant subroutines; the next portion consists of a flow chart of the software logic and describes all important operations represented by each block in the chart; the last part contains a description of all input and output data for the functional element as a whole and for each subroutine which implements atmospheric attenuation.

#### Atmospheric Attenuation Subroutine Design

The FORTRAN call tree that implements the Atmospheric Attenuation Functional Element in the ALARM 3.0 source code is shown in Figure 2.14. The diagram depicts the entire model's structure for this functional element, from ALARM (the main program) through the least significant subroutine in the atmospheric attenuation functional element. Subroutines which directly implement the atmospheric attenuation functional element appear as shaded blocks. Subroutines which use the functional element results appear with bands at the ends. Each of these subroutines is briefly described in Table 2.14-3.

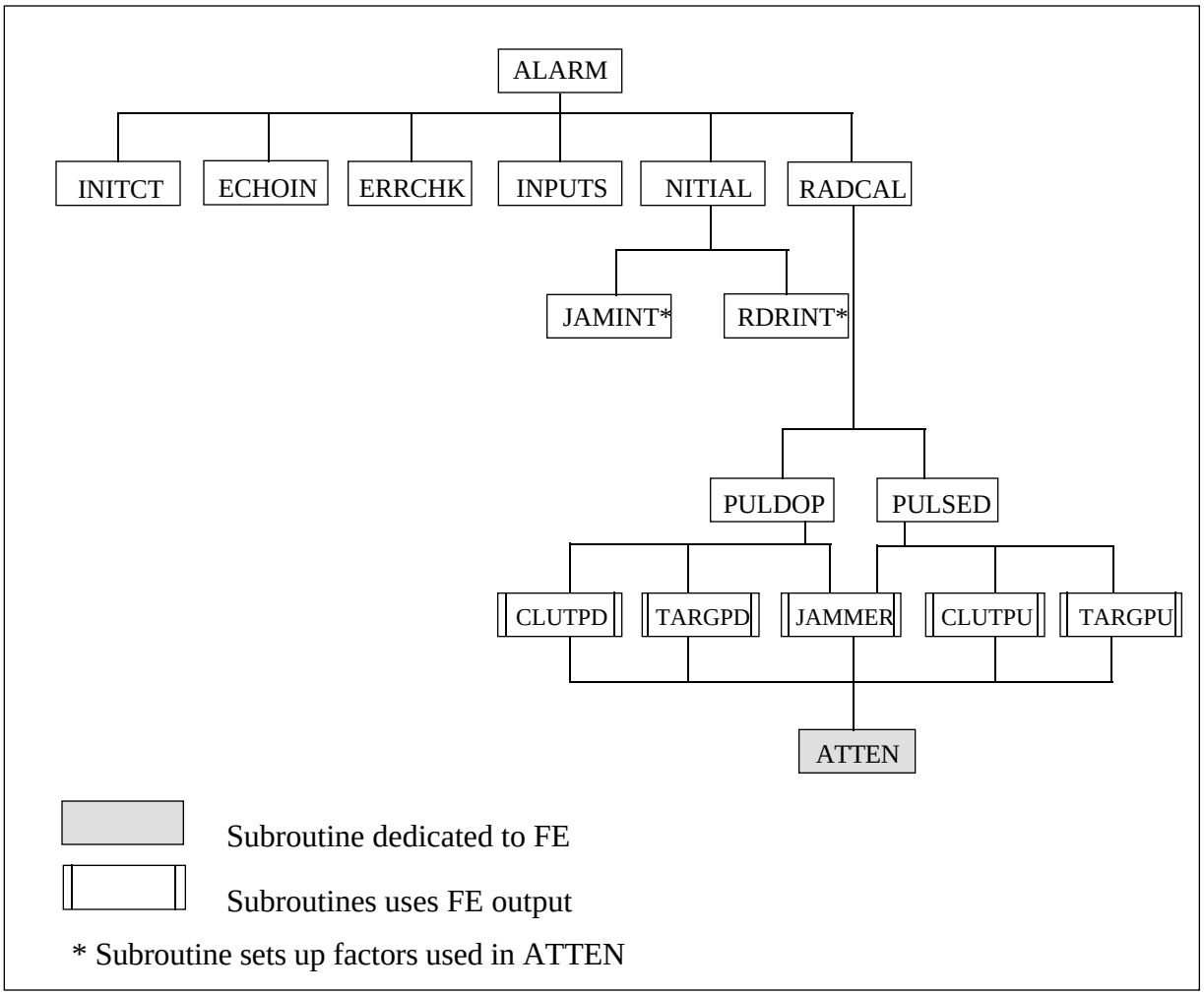


Figure 2.14-1 Call Hierarchy for Atmospheric Attenuation

Table 2.14-3 Subroutine Descriptions

| Module Name | Description |
|---|---|
| **ATTEN** | Calculates one-way attenuation of radar energy by the atmosphere due to the presence of oxygen and water vapor. |
| CLUTPD | Determines clutter signal power for a pulse doppler radar. |
| CLUTPU | Determines clutter signal power for a pulsed radar. |
| JAMINT | Called if data black DATAJAMR was supplied in input stream; initializes both onboard and stand-off jammer data. |
| JAMMER | Computes jamming signal power for an onboard deception jammer, onboard self-screening noise jammer, and a stand-off noise jammer. |
| RDRINT | Initializes engineering-level radar data input in data block DATARADR. |
| TARGPD | Determines target body signal power for a pulse doppler radar. |
| TARGPU | Determines the target body signal power for a pulsed radar. |
| Note: Modules implementing the atmospheric attenuation functional element are identified in **bold** letters. | |

## Logical Flow for Atmospheric Attenuation

Figure 2 shows the flow of logic in the source code implementation of the atmospheric attenuation functional element. The numbered blocks are discussed after the diagram.

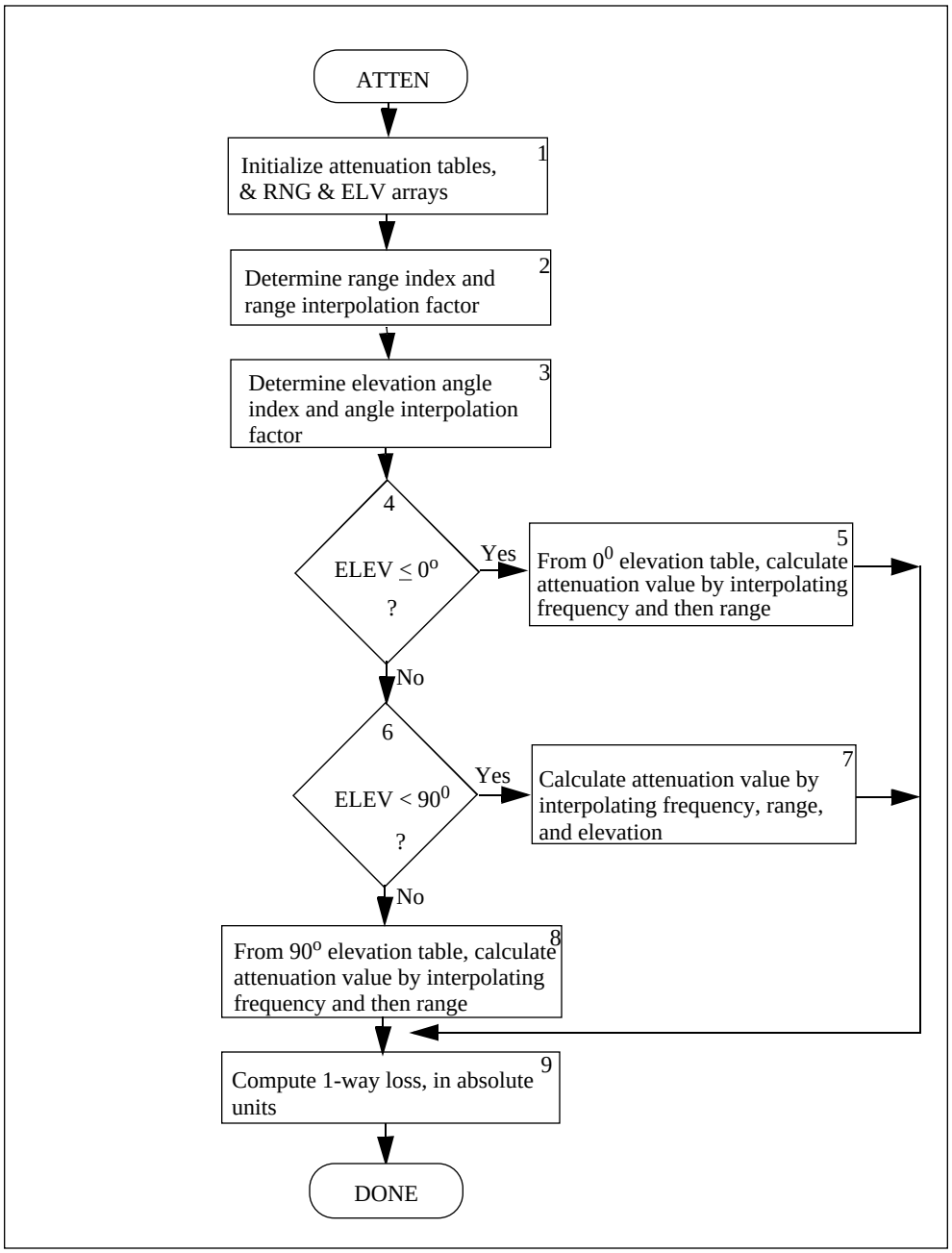


Figure 2.14-2 Flow of Logic, Atmospheric Attenuation

**Block 1:** The atmospheric attenuation tables are loaded with values from the tables cited in 2.14-2, Functional Element Design Approach. The RNG array is loaded with values in kilometers that correspond to the ranges used in the attenuation tables (0, 25, 50, 75, 100, 150, 200, and 350 nautical miles). The ELV array is loaded with values in radians that correspond to the elevation angles used in the attenuation tables (0, 1, 2, 5, 10, 30, and 90 degrees).

**Block 2:** ATTEN calculates the range indices and range interpolation factor (i.e., fraction of the distance across the interval [RNG(IRNG), RNG(IRP1)] where the input range to target is located). The range indices (IRNG and IRP1) are used to select the correct column within an attenuation table.

**Block 3:** ATTEN calculates the elevation angle indices and angle interpolation factor (i.e., fraction of the distance across the interval [ELV(IELV), ELV(IEP1)] where the input elevation angle of the antenna boresight is located). The angle indices (IELV and IEP1) are used to select the correct attenuation table.

**Blocks 4 through 8:** Table look-ups and interpolation are performed to find the correct two-way atmospheric attenuation value, in decibels, for the input elevation angle, range, and frequency. There are three cases to consider:

**Blocks 4 and 5:** If the elevation angle is less than or equal to $0^0$, the table for $0^0$ elevation angle only is searched. For the range at the lower end of the range interval, the attenuation value is calculated by two look-ups in the table, one for each end of the frequency interval. The final value is then calculated by combining the two table values while interpolating across the frequency interval. The same procedure is performed for the range at the upper end of the range interval. The final two-way atmospheric attenuation value is computed by combining the two values while interpolating across the range interval.

**Blocks 6 and 7:** If the elevation angle is between $0^0$ and $90^0$, the elevation will need to be interpolated, in addition to the range and frequency. This is accomplished by first searching only the table that corresponds to the lower end of the elevation angle interval, and interpolating as above for range and frequency. Next, the table corresponding to the upper end of the elevation angle interval is searched, with interpolation for range and frequency being performed as described above. The final two-way atmospheric attenuation value is found by combining the two values derived from the two different tables while interpolating across the elevation angle interval.

**Block 8:** If the elevation angle is greater than or equal to $90^0$, the table for $90^0$ elevation angle only is consulted. For the range at the lower end of the range interval, the attenuation loss is calculated by two look-ups in the table, one for each end of the frequency interval. The final value is then calculated by combining the two table values while interpolating across the frequency interval. The same procedure is performed for the range at the upper end of the range interval. The final two-way atmospheric attenuation value is computed by combining the two values while interpolating across the range interval.

**Block 9:** The subroutine output, ATTABS, is computed. It is the one-way loss, in absolute units.

## Atmospheric Attenuation Inputs and Outputs

Data output by the atmospheric attenuation functional element consists of a single value, the one-way atmospheric attenuation, in absolute units, for the specified antenna boresight elevation angle, radar frequency, and range from the radar to the target. The single user input which affects atmospheric attenuation is the frequency of the radar transmitter. The inputs passed by ALARM to the atmospheric attenuation subroutine ATTEN, as well as the constant data used in calculating the attenuation, are described in Table 2.14-6.

Table 2.14-4 Atmospheric Attenuation Output

| Variable Name | Description |
|---|---|
| ATTABS | Absolute one-way atmospheric attenuation. |

Table 2.14-5 User Inputs for Atmospheric Attenuation

| Datablock Name | Variable Name | Description |
|---|---|---|
| DATARADR | FREQIN | Radar transmit frequency, in MHz. |
| DATAJAMR | CFREQJ(I) | Center frequency of the jammer spectrum (up to 1 onboard and 5 stand-off jammers are allowed). |

Table 2.14-6 Subroutine ATTEN Inputs

| Name | Type | Description |
|---|---|---|
| ELEV | Argument | Elevation angle of the radar antenna boresight above the local horizontal plane (radians). |
| RANGE | Argument | Range from the radar antenna to the target (meters). |
| IFREQ | Argument | Radar frequency index, computed in subroutine RDRINT or JAMINT. |
| FRQFAC | Argument | Radar frequency interpolation factor (i.e., fraction of the distance across the interval [frq(ifreq), frq(ifreq+1)] where radar or jammer transmit frequency is located). Note: frq is an array containing common radar transmit frequencies modeled in ALARM. FRQFAC is computed in subroutine RDRINT or JAMINT. |
| RNG | Constant Array | Ranges, in meters, for which attenuation values are given. |
| ATTDB | Constant Array | Two-way atmospheric attenuation (dB) for RNG(I) and FRQ(J). Array consists of seven distinct arrays, one for each of the elevation angles 0, 1, 2, 5, 10, 30, and 90 degrees. |
| DEGRAD | Common CONSTR | Conversion factor for degrees to radians. |
| HALFPI | Common CONSTR | Constant, $\pi/2$. |

### 2.14.4 Assumptions and Limitations

The tables from which the atmospheric attenuation value is determined are based on a clear, standard day. The standard day values assume a constant oxygen content and a constant absorption coefficient for water vapor density of 7.5 g/m$^3$.

The range from the radar transmitter to the target is limited to 350 NM. This is not a problem since detection ranges affected by atmospheric attenuation are typically less than 350 NM.

The range of elevation angles are effectively limited to $0^0$ to $90^0$. This is a reasonable range for considering the effects of atmospheric attenuation.