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# SENSITIVITY TIME CONTROL LOSS

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Research, Development, and Engineering Center

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This report determines the loss associated with the use of sensitivity time control in a receiver. The receiver consists of three stages, the second stage of which incorporates the STC signal level control function. An example receiver is considered to illustrate the degree of STC loss that might be expected in a typical receiver. The loss is expressed in terms of the receiver's various noise figures, gains of each stage, and the range ratio.

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# 1. INTRODUCTION

The power received by a radar receiver is inversely proportional to the fourth power of the range between the radar and the target ignoring propagation factors such as multipath, atmospheric attenuation, antenna patterns, etc. At short ranges, small moving objects (birds or insects) or vehicular traffic not completely removed by an MTI may be detected resulting in an excessive number of targets which exceed the radar's target handling capability. Furthermore, the signal levels returned from ground clutter often exceed the receiver's dynamic range.

Pulsed radar receivers are often protected against these conditions by altering the dynamic range through the use of a technique called sensitivity time control (STC). This programmed control of the receiver's gain is used to maintain a more or less constant signal level as a function of range for a fixed-sized scatterer. If the primary purpose of the STC is to protect against large discrete clutter (buildings, mountains, etc.), then the receiver power gain is caused to vary by the fourth power of range (or of time). If the goal is to maintain a constant power level received from some specified distributed ground clutter, then a third power of range is used as the STC function since the area of the cell of ground clutter varies linearly with range.

The effects of STC on low radar cross section targets can be both beneficial and detrimental. In the case of unwanted targets such as birds at close ranges, it tends to reduce the detectability of these targets. At the same time, it can also hinder the detection of certain desired low radar cross section targets (such as cruise missiles and hovering helicopters) at these same close ranges.

At long ranges, the echo signal strength from low radar cross section targets is too small to be detected. As the target approaches the radar, the signal strength increases until it is strong enough for detection to occur. If STC is used in the receiver, the gain of the receiver is reduced inside a specified range, $R_{stc}$. At ranges less than $R_{stc}$, the signal level of the low cross section target is reduced along with the clutter signals and those of unwanted targets thereby reducing the probability of detection of the desired target. Consequently, as the target of interest is reaching the range where detection could occur, the STC function is reducing the gain which counteracts the increased signal strength of these small targets.

This adverse effect of STC on target detection can be described by a loss factor which is a function of the range relative to $R_{stc}$ and the various noise figures and gains of the devices in the receiver which precede and follow the actual STC stage. A common method of implementation for STC is to control the gain of one or more amplification stages. An alternate approach is the use of a variable attenuator such as a pin diode attenuator. These attenuators are normally located in the IF stage following RF and IF amplification, but they have been used in the RF stage prior to amplification. For this latter case (attenuation prior to RF amplification), the effect of the STC attenuator is equivalent to increasing the receive loss by the amount of the STC attenuation loss and using this increased value of loss in the calculation of the system input noise temperature.

In this report, we will determine the loss associated with the use of STC implemented in the IF stage by finding the ratio of the output signal-to-noise power without STC, $(S_0/N_0)$, to the output signal-to-noise power ratio with STC, $(S_0/N_0)_{stc}$ for equal input signal and noise conditions.

## 2. DERIVATION OF FORMULAS

The receiver to be analyzed in determining the STC loss factor consists of a first stage of RF/IF amplification, the STC stage (a variable gain amplifier or an attenuator), and a third stage of further amplification. Each stage of a receiver will generally consist of several sections (isolators, mixers, pads, etc.) of which each section is characterized by a noise factor and a gain. A receiver can be reduced to a three stage problem for analysis of the STC loss by considering (1) a first stage having a noise factor and gain determined by all of the devices in the receiver which precede the STC device, (2) the second stage as the STC device with its own noise factor and gain, and (3) a third stage having a noise factor and gain determined by all devices following the STC stage. The analysis which follows will make use of this simplified three stage receiver.

Consider the radar receiving system shown in Figure 2.1 consisting of an antenna, a transmission line with RF losses $L_r$, three stages, each described by its effective noise factor (F) and gain (G) characteristic, and terminated in a matched resistive load (R).

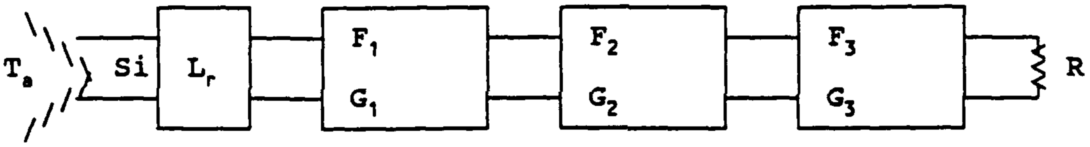

Figure 2.1

Although the RF receive losses could be incorporated into the characteristics of the first stage, the radar engineer will recognize this conventional representation as that given by Blake [1]. Each stage is a four-terminal network having both input and output terminals matched correctly; i.e., the internal impedance of any one of the networks is matched to the output impedance of the previous stage. The second stage (STC device) will first be considered as an amplifier having a noise factor and a gain which is variable with time inside of the STC enable range, $R_{stc}$. Expressions will be developed for determining the STC loss with and without jamming energy present. An attenuator will then be considered as the STC device with the development of the corresponding equations for STC loss.

### 2.1 Variable Gain Amplifier as STC Stage

The first method to be analyzed for accomplishing the STC function is that of varying the gain of an amplification stage in a receiver. A technique that is commonly used to control the gain is to apply a voltage ramp to the normal gain control terminals of an IF amplifier or a series of amplifiers in cascade. The noise figure of the variable gain stage should remain relatively constant with the change in gain and will be assumed to do so in this analysis. This is not strictly true especially when several variable gain amplifiers are cascaded in series to achieve the overall STC effect.

By varying the gain of this stage during the receiving interval between pulses, the receiver can be made to compensate for the changes in signal strength with range. For the condition when the receiving time corresponds to a range R that is less than the selected STC range, the gain of the second stage is reduced by a factor K where

$$K = (R_{stc}/R)^n \qquad (2.1.1)$$

The value of the exponent 'n' is normally chosen to be between the values of three and four. The choice of the actual value depends on whether the concern is primarily that of preventing distributed clutter (n=3) or large discrete clutter (n=4) from saturating the receiver. The value four would also be used if prevention of detection of small unwanted targets at short ranges was a consideration. The gain of the second stage is then expressed by

$$G_2' = G_2/K \qquad (2.1.2)$$

The loss incurred by using STC will be determined by calculating the reduction in S/N through the receiver of Figure (2.1) as a function of K as determined by the target range. What will be termed STC loss will be defined as the ratio of the output S/N without STC to the output S/N with STC.

$$L_{stc} = (S_o/N_o)/(S_o/N_o)_{stc} \qquad (2.1.3)$$

Various noise sources, both external and internal to the antenna, contribute to the noise power delivered by the antenna. These sources include galactic (or sky) noise, contributions from the ground, and ohmic losses inside the antenna. The antenna noise effect can be represented by a resister at the antenna output terminal having a temperature $T_a$ where $T_a$ is given by Blake [1] as

$$T_a = (0.876T_a'-254)/L_a + 290 \qquad (2.1.4)$$

Here, $T_a'$ is the apparent sky noise temperature and $L_a$ is the ohmic losses within the antenna.

In keeping with the method reported by Blake for expressing the effective system noise power at the antenna output terminal as that of a resistor having a temperature of $T_s$ degrees Kelvin,

$$T_s = T_a + T_r + L_rT_o(F_r-1) \tag{2.1.5}$$

where

$T_s$ = System input noise temperature
$T_a$ = Antenna temperature at the output terminals
$T_r$ = $T_o(L_r-1)$
$L_r$ = Receiving transmission line loss
$F_r$ = Total noise factor of receiver components following transmission line
$T_o$ = Reference temperature of 290 K

The total receiver noise factor $F_r$ for the receiver of Figure 2.1 without STC enabled is given in terms of the noise factor and gain of each stage by

$$F_r = F_1 + (F_2-1)/G_1 + (F_3-1)/G_1G_2 \tag{2.1.6}$$

The output signal-to-noise ratio without STC expressed in terms of the input signal power ($S_i$) and effective system noise power at the antenna output terminals is

$$S_o/N_o = \frac{S_iG_1G_2G_3/L_r}{kT_oB(G_1G_2G_3/L_r)[T_a/T_o+(L_r-1)+L_r(F_r-1)]}$$

$$= \frac{S_i}{kT_sB} \tag{2.1.7}$$

where k is Boltzmann's constant and B is the receiver bandwidth.

For the ranges where STC is implemented ($R<R_{stc}$), the second stage gain will have a value less than $G_2$, the normal gain without STC enabled. The signal-to-noise ratio out of the receiver when the second stage gain is reduced by $K = (R_{stc}/R)^n$ is then

$$(S_o/N_o)_{stc} = \frac{S_iG_1G_2G_3/L_rK}{kT_oB(G_1G_2G_3/L_rK)[T_s'/T_o]}$$

$$= \frac{S_i}{kT_s'B} \tag{2.1.8}$$

where

$$T_s' = T_a + T_r + L_rT_o[F_1+(F_2-1)/G_1+K(F_3-1)/G_1G_2-1] \tag{2.1.9}$$

From (2.1.9), the noise factor of the receiver within the range $R_{stc}$ is observed to be

$$F_{rstc} = F_1 + (F_2-1)/G_1 + K(F_3-1)/G_1G_2) \qquad (2.1.10)$$

The STC loss can now be expressed in terms of the system input noise temperatures derived above through substitution of (2.1.7) and (2.1.8) into (2.1.3)

$$L_{stc} = T_s'/T_s \qquad (2.1.11)$$

The final equation for the STC loss in terms of K and the characteristics of each stage is

NO JAMMING

$$L_{stc} = \frac{T_a+T_r+L_rT_o[F_1+(F_2-1)/G_1+K(F_3-1)/G_1G_2-1]}{T_a+T_r+L_rT_o[F_1+(F_2-1)/G_1+(F_3-1)/G_1G_2-1]} \qquad (2.1.12)$$

or, in terms of the system input noise temperature,

$$L_{stc} = \frac{T_a+T_r+L_rT_o[F_1+(F_2-1)/G_1+K(F_3-1)/G_1G_2-1]}{T_s} \qquad (2.1.13)$$

The effect of noise jamming energy present at the antenna output terminals can be expressed as an additive noise temperature $T_j$. The total input noise temperature ($T_i$) is then

$$T_i = T_s + T_j \qquad \text{(without STC)} \qquad (2.1.14)$$

or $$T_i = T_s' + T_j \qquad \text{(with STC)} \qquad (2.1.15)$$

The jamming noise temperature is given by

$$T_j = J_o/k \qquad (2.1.16)$$

where $J_o$ is the received jamming power spectral density as defined by Barton [2] in watts/Hz.

The STC loss with noise jamming present can then be expressed as

$$L_{stc} = \frac{T_s' + T_j}{T_s + T_j}$$

$$= \frac{T_s'/T_s + T_j/T_s}{1 + T_j/T_s} \qquad (2.1.17)$$

The ratio of $T_j/T_s$ is simply the jamming-to-noise ratio, J/N, at the antenna output terminal. Thus, with the inclusion of noise jamming, the equation for STC loss becomes

WITH JAMMING

$$L_{stc} = \frac{\dfrac{T_a+T_r+L_rT_o(F_{rstc}-1)}{T_s} + J/N}{1 + J/N} \qquad (2.1.18)$$

where $F_{rstc}$ is the noise factor defined in (2.1.10) when STC is enabled. The first term in the numerator of (2.1.18) is easily recognized as the equation for the STC loss without jamming energy present.

## 2.2. Attenuator as STC Stage

As was noted earlier, the STC fuction can be achieved through the use of a variable attenuator such as a pin diode attenuator. As shown in Appendix B, an attenuator is considered as a passive four-terminal device having a noise factor equal to the attenuation factor and a gain equal to the reciprocal of the attenuation factor. The loss attributed to the use of STC when an attenuator is used as the second stage in Figure 2.1 is arrived at by equating that stage's noise factor to K of (2.1.1) and its gain to the reciprocal of K. Without STC (beyond ranges of $R_{stc}$), the second stage noise factor and gain are equal to unity.

The noise factor without STC of (2.1.6) with $F_2 = G_2 = 1$ reduces to

$$F_r = F_1 + (F_3-1)/G_1 \qquad (2.2.1)$$

with the corresponding system input noise temperature of

$$T_s = T_a + T_r + L_rT_o[F_1+(F_3-1)/G_1-1] \qquad (2.2.2)$$

Likewise, the noise factor with STC becomes

$$\begin{aligned} F_{rstc} &= F_1 + (K-1)/G_1 + K(F_3-1)/G_1 \\ &= F_1 + (KF_3-1)/G_1 \end{aligned} \tag{2.2.3}$$

with the substitution of $F_2 = K$ and $G_2 = 1/K$. The equation for $T_s'$ for the case of the attenuator is then

$$T_s' = T_a + T_r + L_r T_o[F_1+(KF_3-1)/G_1-1] \tag{2.2.4}$$

Incorporating (2.2.2) and (2.2.4) into (2.1.11) produces the STC loss equation for the attenuator case

**NO JAMMING**

$$L_{stc} = \frac{T_a+T_r+L_rT_o[F_1+(KF_3-1)/G_1-1]}{T_a+T_r+L_rT_o[F_1+(F_3-1)/G_1-1]} \tag{2.2.5}$$

or, in terms of the system input noise temperature,

$$L_{stc} = \frac{T_a+T_r+L_rT_o[F_1+(KF_3-1)/G_1-1]}{T_s} \tag{2.2.6}$$

When jamming energy is present, the expression for $L_{stc}$ takes on the form similar to that of (17)

**WITH JAMMING**

$$L_{stc} = \frac{\dfrac{T_a+T_r+L_rT_o[F_1+(KF_3-1)/G_1-1]}{T_s} + J/N}{1 + J/N} \tag{2.2.7}$$

In both of the cases (an amplifier or an attenuator) that have been examined for providing the required gain control in the second stage, the loss attributed to STC is of the form

$$L_{stc} = \frac{T_s'/T_s + J/N}{1 + J/N} \tag{2.2.8}$$

However, the particular formula for evaluating $T_s$ and $T_s'$ depends on the actual STC implementation.

It is easy to ascertain from the examination of (2.1.18) and (2.2.8) that the presence of jamming energy in the receiver produces the interesting result of a reduced STC loss, all other factors being equal. This is because the jamming noise has the same effect as a higher receiver front-end, or pre-STC, noise figure which masks the adverse consequences of reducing receiver gain in the STC circuits. Thus, the STC loss should be reexamined when making performance calculations in an ECM environment.

## 3. SIMPLIFIED FORMULAS

For the case where noise from the receiver dominates (as is generally the condition when STC is used), it is convenient to make the approximation that

$$(T_a + T_r)/L_r = T_o \tag{3.1}$$

This is equivalent to using the value of $T_o$ for not only the temperature of the transmission line but for the antenna temperature as well. Making this substitution into (2.1.12), (2.1.18), (2.2.5), and (2.2.7) results in a set of simplified equations for the STC loss as follows:

VARIABLE AMPLIFIER

NO JAMMING

$$L_{stc} = \frac{1 + \dfrac{F_2-1}{F_1G_1} + \dfrac{K(F_3-1)}{F_1G_1G_2}}{1 + \dfrac{F_2-1}{F_1G_1} + \dfrac{F_3-1}{F_1G_1G_2}} \tag{3.2}$$

WITH JAMMING

$$L_{stc} = \frac{\dfrac{1 + (F_2-1)/F_1G_1 + K(F_3-1)/F_1G_1G_2}{1 + (F_2-1)/F_1G_1 + (F_3-1)/F_1G_1G_2} + J/N}{1 + J/N} \tag{3.3}$$

ATTENUATOR

NO JAMMING

$$L_{stc} = \frac{1 + \dfrac{(KF_3-1)}{F_1G_1}}{1 + \dfrac{F_3-1}{F_1G_1}} \tag{3.4}$$

**WITH JAMMING**

$$L_{stc} = \frac{\dfrac{1 + (KF_3-1)/F_1G_1}{1 + (F_3-1)/F_1G_1} + J/N}{1 + J/N} \qquad (3.5)$$

# 4. EXAMPLE RECEIVER

An example receiver is considered to illustrate the degree of STC loss that might be expected in a typical receiver. The STC loss as a function of the range normalized to $R_{stc}$ has been calculated for a radar receiver having the parameters shown in Table 4.1. In this example, a variable attenuator is used as the STC device to control the receiver's signal level as a function of range. The receiver's signal level is assumed to be adjusted to follow the third power of range in order to prevent receiver saturation by distributed ground clutter returns. Equation (2.2.5) has been used in producing the results shown in the figures in this section.

| Receiver Parameters: | | | |
|---|---|---|---|
| $T_a$ | - | Antenna noise temperature (deg K) | 150 |
| $L_r$ | - | Receiving transmission line loss (dB) | 1.5 |
| $F_1$ | - | Noise figure of pre-STC stage (dB) | 3.0 |
| $G_1$ | - | Pre-STC Gain (dB) | 25-45 |
| $F_3$ | - | Post-STC noise figure (dB) | 20 |
| K | - | STC attenuation factor | $R^3$ |

Table 4.1 Example Receiver

Five curves are presented in Figure 4.1 which demonstrate the effect of different pre-STC receiver gain levels on the STC loss as a function of range. The post-STC noise figure of 20 dB is considered to be representative of receivers where the first significant component following the STC attenuator is a device such as a mixer or fixed attenuator rather than an amplifier. A typical pre-STC gain would be about 30 dB.

The effect of a lower post-STC noise figure is demonstrated in Figure 4.2 by reducing the noise figure $F_3$ by 5 dB (a 15 dB noise figure rather than the 20 dB used in Figure 4.1). The improvement (reduction in loss) is seen to approach the difference in noise figure (5 dB in this case) as range decreases.

The STC loss can be maintained at a quite modest level if the receiver design can accomodate a high pre-STC gain and a low post-STC noise figure. Figure 4.3 illustrates the dependency of STC loss upon the pre-STC gain and the post-STC noise figure for a value of $R/R_{stc}$ of 0.1. The nearly horizontal lines connect points having the same value of $G_1/F_3$ (ratio of pre-STC gain to post-STC noise factor) indicating that the STC loss remains approximately fixed as long as this ratio's value is maintained.

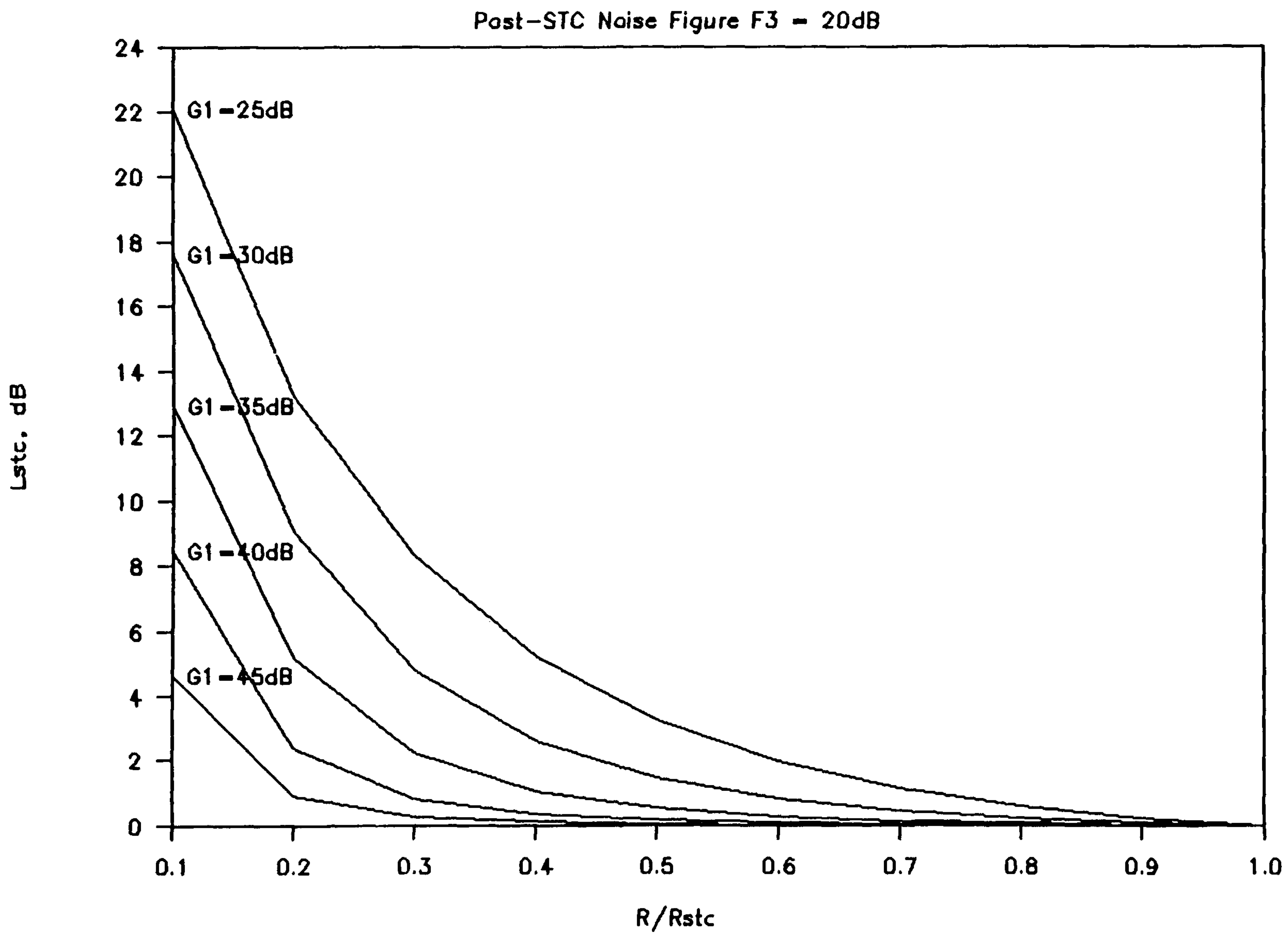

Figure 4.1. STC loss versus $R/R_{stc}$ for attenuator, $F_3$ = 20 dB.

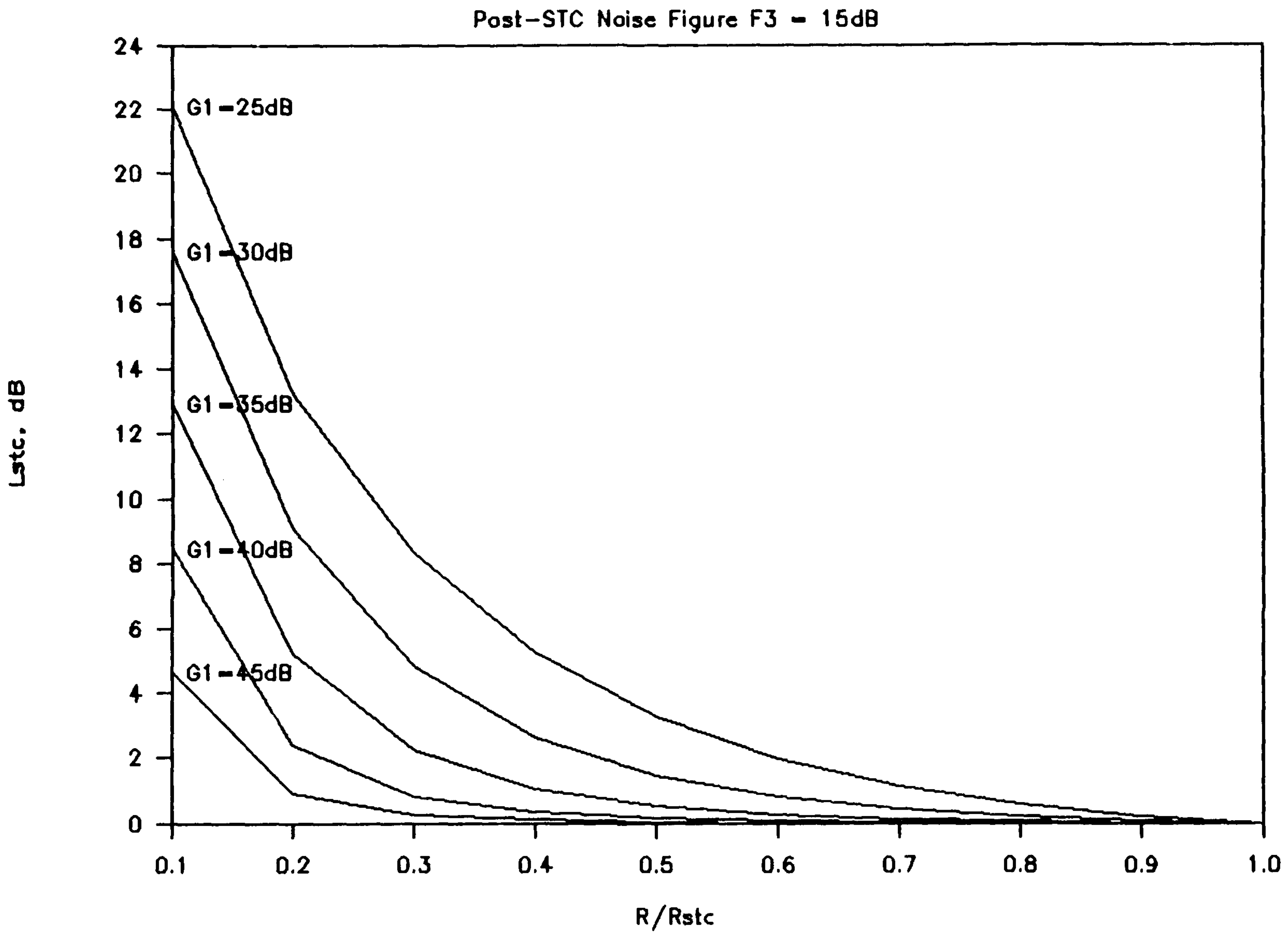

Figure 4.2. STC loss versus $R/R_{stc}$ for Attenuator, $F_3$ = 15 dB.

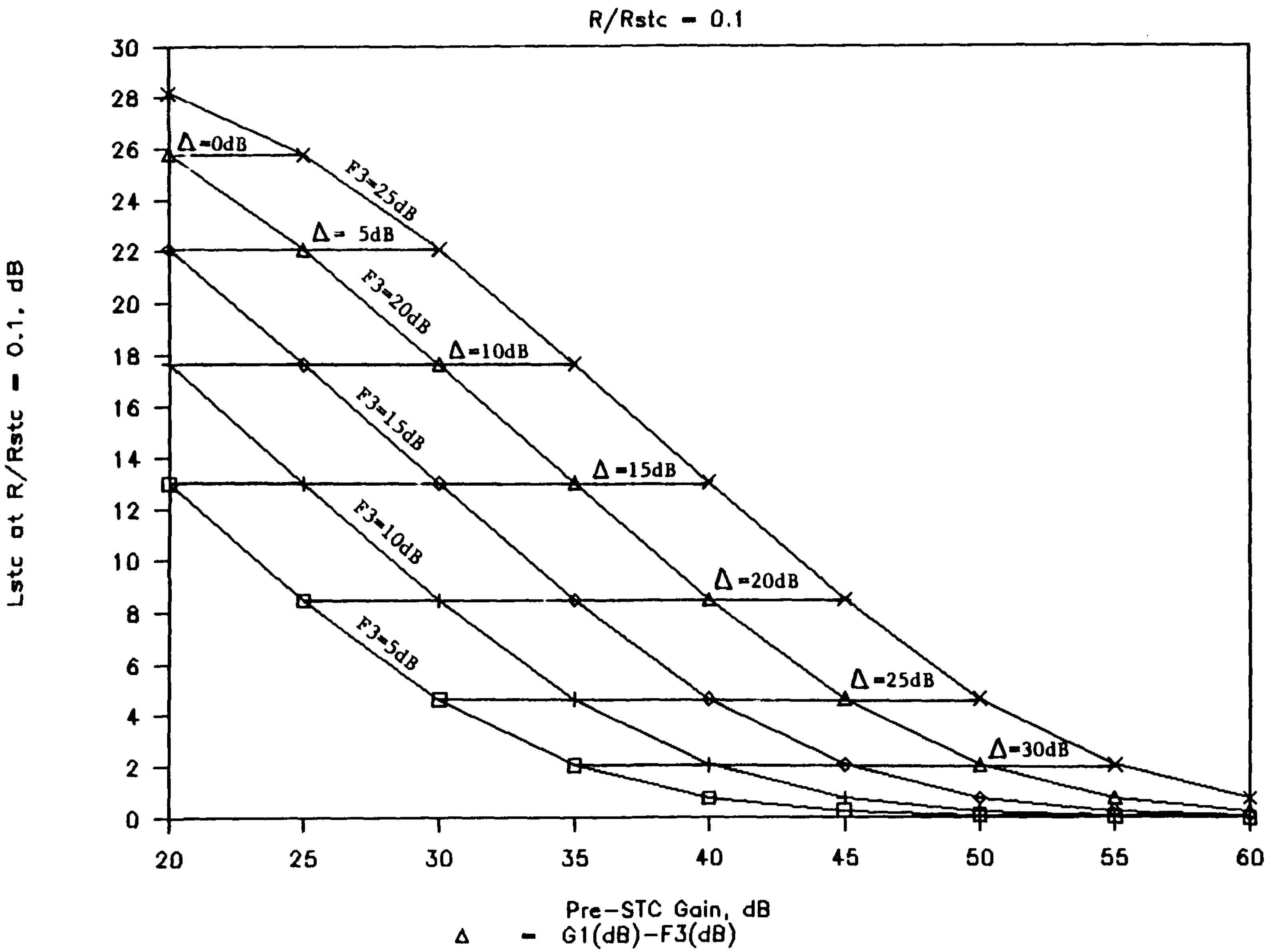

Figure 4.3. STC loss versus pre-STC gain, $R/R_{stc} = 0.1$.

## 5. CONCLUSIONS

The amount of loss that can be expected due to the inclusion of STC in a radar's receiver depends on a number of factors. The two major factors are (1) the available receiver gain prior to any gain reduction by whatever means (attenuators or variable gain stages), and (2) the post-STC noise factor (noise factor of those components which follow the STC stage). A receiver using a gain reduction factor of $R^3$ will have a lower STC loss than one using $R^4$.

Generally, there is not a significant difference between the variable gain amplifier approach to implementing STC and that of using variable attenuators to control the signal level. In the example receiver of Section 4, the use of (2.1.12) for the variable gain amplifier would have yielded almost the same STC loss as the attenuator (the STC loss for the attenuator was less than 0.05 dB greater at $R/R_{stc} = 0.1$). If a low value (5 dB for example) had been used for the post-STC noise figure $F_3$, this difference in loss would have increased to 1.0 dB or more at $R/R_{stc} = 0.1$.

Finally, the amount of loss attributed to the inclusion of STC in a radar's receiver should be examined separately for benign and jamming envionments. The adverse effect of STC on signal-to-noise is reduced when jamming energy is present since the received signal-to-interference ratio is not changed as much by the reduction in gain due to the action of the STC. This effect is equivalent to a higher pre-STC noise figure.

# REFERENCES

1. Blake, L. V., Radar Range Performance Analysis, Artech House, 1986, pp. 150-172.

2. Barton, D. K., Modern Radar System Analysis, Artech House, 1988, pp. 33-34.

# LIST OF SYMBOLS

| | |
|---|---|
| $B$ | Bandwidth of receiver |
| $E_n$ | RMS open circuit voltage across resistor |
| $E_o$ | RMS output voltage |
| $F_a$ | Noise factor of attenuator |
| $F_1$ | Noise factor of first stage (pre-STC noise factor) |
| $F_2$ | Noise factor of second (STC) stage |
| $F_3$ | Noise factor of third stage (post-STC noise factor) |
| $F_r$ | Total noise factor of receiver components following transmission line |
| $F_{rstc}$ | Noise factor of receiver within the range $R_{stc}$ |
| $G_1$ | Gain of first stage (pre-STC gain) |
| $G_2$ | Gain of second stage without STC enabled |
| $G_2'$ | Gain of second stage with STC enabled |
| $G_3$ | Gain of third stage |
| $J_o$ | Received jamming spectral density |
| $J/N$ | Jamming-to-noise ratio at antenna output terminals |
| $K$ | Gain reduction factor or attenuation factor |
| $k$ | Boltzmann's constant |
| $L_a$ | Antenna ohmic losses |
| $L_r$ | Receiving transmission line loss |
| $L_{stc}$ | Loss due to STC |
| $N_a$ | Additional noise power delivered from passive network |
| $N_i$ | Input noise power |
| $N_1$ | Attenuated input noise power delivered to output |
| $n$ | Exponent in K determined by STC time constant |
| $P_o$ | Power dissipated in load resistor |
| $R$ | Resistance or range |
| $R_L$ | Resistance of load |
| $R_{stc}$ | Range inside of which STC is enabled |
| $S_i$ | Input Signal power |
| $S_o/N_o$ | Output signal-to-noise ratio without STC enabled |
| $(S_o/N_o)_{stc}$ | Output signal-to-noise ratio with STC enabled |
| $T_a$ | Temperature at output terminal of antenna |
| $T_a'$ | Apparent sky noise temperature |
| $T_i$ | Total input noise temperature with jamming |
| $T_j$ | Jamming noise temperature |
| $T_o$ | Reference temperature of 290 K |
| $T_r$ | Receiving transmission line temperature |
| $T_s$ | System input noise temperature without STC enabled |
| $T_s'$ | System input noise temperature when STC enabled |

# APPENDIX A

# NOISE TEMPERATURE FROM A RESISTOR

# APPENDIX A

## NOISE TEMPERATURE FROM A RESISTOR

The term $kT_oB$ is used for the input thermal noise source so often that its origin has perhaps been forgotten. This appendix is included as background information if this is the case for the reader.

A resistance behaves as a noise source (Johnson-noise) and develops an instantaneous voltage between the terminals, the rms open circuit value of which is given by

$$E_n = (4kT_oBR)^{1/2} \tag{A-1}$$

The resistance may then be represented by a Thevenin's equivalent circuit having $E_n$ as its voltage source and the resistance R as the internal impedance. To realize maximum power transfer from this circuit, a resistor of value R is placed at the output as the load impedance.

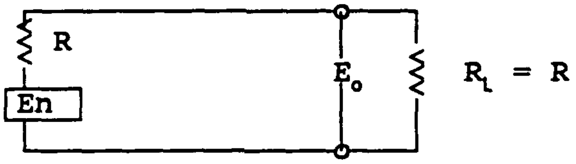

Figure A-1

The output voltage across the load resistor $R_L$ is

$$\begin{aligned} E_o &= E_n[R_L/(R_L+R)] \\ &= E_n/2 \\ &= (kT_oBR_L)^{1/2} \end{aligned} \tag{A-2}$$

The power dissipated in the load is then

$$\begin{aligned} P_o &= E_o^2/R_L \\ &= kT_oB \end{aligned} \tag{A-3}$$

Thus, when the input of a network is terminated with a resistance matched to that network's impedance, the noise power available at the input to the network is equal to $kT_oB$.

# APPENDIX B

# NOISE FACTOR OF AN ATTENUATOR

# APPENDIX B

## NOISE FACTOR OF AN ATTENUATOR

The attenuator shown in Figure B-1 is considered as a passive four-terminal network having an attenuation factor of K.

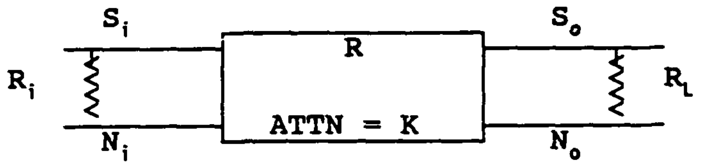

Figure B-1

By definition, the gain of the device is

$$G = S_o/S_i$$

$$= 1/K \qquad \text{(B-1)}$$

For a matched four-terminal network, the input and load impedances ($R_i$ and $R_L$) are terminated with a resistance equal to the internal resistance (R) of the network.

A thermal noise source at a temperature T delivers an available noise power of kTB watts. Assuming that all components are at the same temperature $T_o$, the noise power $N_i$ available at the input of the attenuator due to $R_i$ is

$$N_i = kT_oB \qquad \text{(B-2)}$$

The noise power furnished to $R_L$ by the device due to the internal resistance is also

$$N_o = kT_oB \qquad \text{(B-3)}$$

This power furnished to the output resistor is due in part to the attenuated input power and to an additional amount from the passive network. The portion due to the attenuated input power is

$$N_1 = kT_oB/K \qquad \text{(B-4)}$$

The additional noise power added by the network's internal resistance must be equal to $kT_oB(1-1/K)$, or

$$N_a = kT_oB(1-1/K) \qquad \text{(B-5)}$$

in order for the power dissipated in the load resistance to be equal to that shown in (B-3). This additive power can be related to the noise factor of the attenuator by setting it equal to the familiar relation for the noise added by a network having a noise factor $F_a$ and a gain of 1/K.

$$N_a = kT_oB(F_a-1)/K \tag{B-6}$$

The noise out of the attenuator is then the combination of the two parts

$$\begin{aligned} N_o &= N_1 + N_a \\ &= kT_oBF_a/K \end{aligned} \tag{B-7}$$

Since we know that the noise out is equal to $kT_oB$, then the noise factor for the attenuator must equal the attenuation factor, or

$$F_a = K \tag{B-8}$$

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